The Potential Financial Costs of Climate Change on Health of Urban and Rural Citizens: A Case Study of *Vibrio cholerae* Infections at Bukavu Town, South Kivu Province, Eastern of Democratic Republic of Congo

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Abstract

Background: Cholera epidemics have a recorded history in eastern Congo dating to 1971. A study was conducted to find out the linkage between climate variability/change and cholera outbreak and to assess the related economic cost in the management of cholera in Congo.

Methods: This study integrates historical data (20 years) on temperature and rainfall with the burden of disease from cholera in South-Kivu province, eastern Congo.

Results: Analyses of precipitation and temperatures characteristics in South-Kivu provinces showed that cholera epidemics are closely associated with climatic factors variability. Peaks in Cholera new cases were in synchrony with peaks in rainfalls. Cholera infection cases declined significantly ($P<0.05$) with the rise in the average temperature. The monthly number of new Cholera cases oscillated between 5 and 450. For every rise of the average temperature by 0.35 °C to 0.75 °C degree Celsius, and for every change in the rainfall variability by 10-19%, it is likely cholera infection risks will increase by 17 to 25%. The medical cost of treatment of Cholera case infection was found to be of US$50 to 250 per capita. The total costs of Cholera attributable to climate change were found to fall in the range of 4 to 8% of the per capita in annual income in Bukavu town.

Conclusion: It is likely that high rainfall favor multiplication of the bacteria and contamination of water sources by the bacteria (*Vibrio cholerae*).The consumption of polluted water, promiscuity, population density and lack of hygiene are determinants favoring spread and infection of the bacteria among human beings living in over-crowded environments.

Keywords: Climate change, Citizens health, Cholera burden, Medical treatment, Health systems adaptation, Congo

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Introuduction

In East and central Africa, a cholera epidemic was first reported in 1836 along the Indian Ocean coast, killing as many as 20 000 people in Zanzibar alone. Thereafter, the trend in cholera cases in Africa appears to have been on the decline; between 1870 and 1970 there were no reported cases of cholera in Africa. Major outbreaks began spreading across the continent in 1970, with epidemics reported in West Africa (Guinea) and the Horn of Africa (Ethiopia, Somalia, and Sudan) and reaching Kenya in 1971. The most severe cholera outbreak on the African continent was in 1998, accounting for more than 72% of the global total number of cholera cases (1-3). *Vibrio cholerae* prefers to attach itself to chitinaceous zooplankton and shellfish (4) Zooplankton and shellfish increase in numbers, following large bursts of phytoplankton associated with warm sea surface temperatures (5). Specific social risk factors for cholera in eastern and central Africa region include drinking water (6) from the lake or a stream, sharing food with a person with watery diarrhea, and attending funeral feasts (2).

Several categories of ill health important (including Cholera) at the global level are likely to be affected by climate change (7) although there is limited available evidence of the relationships between climate exposure and on chronic non-communicable diseases (8). Climate change may have negative impacts of climatic factors and climate change on some physiological functions and on cardio-vascular and kidney diseases (8). Endemic and chronic disease risks are likely to increase with climate change and related increase in air pollution, malnutrition, and extreme weather events (8). The vulnerability of a community or its capacity to adapt to a health risk is determined by the local climatic environment, socioeconomic status, efficacy of governance and civil institutions, quality of public health infrastructure, and access to relevant local information on extreme weather events and disease (3). Studies in which *V. cholerae* are related spatially and temporally to El Nino, or its proxies and predictors, may be an effective way

to prevent exposure to cholera. Understanding which demographic or geographical subpopulations may be most vulnerable is necessary to reduce potentially adverse health effects driven by climate variability and change (9). The direct risk factors for cholera transmission world (10) are those facilitating the presence of faeces in the environment and its contamination of water, food, and hands, as documented by an extensive literature. Additionally, *V. cholerae* is known to be a regular resident of the aquatic environment, able to exist as a free-living aquatic organism (3, 6, 9). Cholera in many accounts is representative for other diarrheal diseases (6, 10). However, it differs from many other forms of diarrhea in that it can cause high numbers of cases and deaths over a very short period. For example, extreme cholera outbreaks took place in a Rwandan refugee camp at Goma in 1994 where over a matter of weeks there were 70,000 cholera cases and an estimated 12,000 deaths, giving a case fatality rate of 17.1%. Cholera risk assessment in program in DRC is recent initiative aiming at gathering evidence for a range of indicators of cholera risk (11).

Despite significant advances in preventing death from cholera, and recognition of broad scale patterns in cholera incidence, there remains unpredictable cholera risk in Congo. This may be indicative for much of Africa given that epidemics have occurred in an irregular pattern in several parts of the continent. Gaps have remained in understanding the implications for interventions of changes occurring in the ecology and epidemiology of *V. cholerae*, its virulence and opportunism in both aquatic reservoirs and people. There is an aquatic reservoir for endemic cholera in Congo Lakes and a seasonal pattern to cholera because of rainfall, although cholera is low or non-existent in some years. Risk factors vary spatially over time. Awareness of cholera risks is high among the people of Bukavu, reflecting education efforts by local health authorities. Yet actions to remove risk remain incomplete. Improving conditions that enable the population

to act on existing knowledge about prevention is likely to prove the most desirable intervention over the longer term

There is increasing emphasis on quantifying the health impacts from climate change (WHO 2008). Recent studies have associated temperatures and rainfall anomalies with diarrhea and cholera, and stress the role of climate variability in cholera transmission in Africa. Higher ambient temperatures lead to higher water temperatures in shallow bodies of water, such as ponds and rivers and shallow coastal waters, and a recent study has shown that both an increase in local temperature and the occurrence of floods caused by heavy monsoons can contaminate drinking water and influence the prevalence of the disease (12-15).

The World Health Organization (WHO) has examined the global burden of disease attributable to climate change up to 2000, concluding against this background that planning health adaptation to climate-change impacts will require detailed assessments of national vulnerabilities to specific health risks. Additionally, the WHO projected the health burden for Sub-Saharan Africa in 2030. The projections are based on case studies from Peru and Fiji, where the data from Peru showed an increase of 8% for every 1°C increase in temperature, while the study from Fiji showed an increase of 3% per degree of temperature increase. Since then, the WHO has used an average of 5% to predict the increase in the relative number of diarrheal incidences for 2050, taking into account socio-economic development and increased coverage of water and sanitation (12-13).

This vulnerability to current climate variability and future climate change can be reduced by means of adaptation (16- 17) in most Sub-Sahara Africa countries including Congo. Adaptation, broadly defined, would include all current and future activities or interventions that reduce or prevent additional cases of disease or deaths attributable to climate change. Adaptation would include measures to reduce the acute and chronic health impacts of extreme events (heat waves, floods and droughts).

There is a need to increase access to clean, affordable and safe water and sanitation and to reduce vulnerability from environmental risks (4,

12, 13, 17, 18) as general development objective. There exist several reviews and studies of the costs of health intervention programs, which address the prevention of climate-related diarrhea and cholera worldwide. These studies present measures to reduce vulnerability to current events. Other recent studies have turned to focusing specifically on adaptation costs, including those related to reducing the impacts of future climate change. However, there is very little information in the literature on the costs of health adaptation, especially for developing countries and on a country level. This could be attributed to adaptation being a relatively new field and the difficulties in quantifying costs, especially in developing countries, due to a lack of data and long-term reporting on disease and climate variables.

The aim of this paper was to provide preliminary evidences for the potential impacts of climate change on the prevalence and burden of diseases attributable to diarrheal diseases (including cholera).

Materials and Methods

Study area, study design, Health data

The study was conducted at Bukavu town and at Katana health zone (45 km far ways from Bukavu Town). Historical data on deaths and cases of cholera infection were acquired from the South-Kivu provincial inspection at Bukavu town (Fig. 1).

Fig.1: Map of Democratic Republic of Congo showing where Bukavu town (study area) is located

The main source of secondary health data in this study was obtained from the weekly epidemiological review as supplied by local hospitals to the provincial health inspection of South-Kivu Province that has reliable patients' health records. Two data sets were available. One data set covering cholera cases throughout Bukavu town on a monthly basis between 1992 and 2011, while a second data set for cholera cases were available on a monthly basis for Katana rural health zone (1992 to 2011), death data was not used since across years, there were rare cases of death due to Cholera infection.

Climate data and socio-economic surveys

The climate variables were acquired from Lwiro research center meteorological station. Temperature and precipitation data were collected from Lwiro meteorological research station. Daily minimum and maximum temperatures and monthly precipitation values were available for the period of 1992 to 2011. Practically, the data include rainfall (monthly totals in millimeters) and temperatures (monthly mean of daily minimum and maximum temperatures). In addition to climate and health variables, socioeconomic data (net revenue per capita, population density, etc) were gathered for the datasets containing data per month and per year at town and provincial level.

Socio-economic data

Community interviews were also conducted and aimed at assessing household perceptions of environmental and diseases–related to climate change and variability. An integrated approach using both quantitative and qualitative techniques was employed in assessing the vulnerability of communities. Using a semi-structured questionnaire, a household survey of >1000 people was conducted at three cholera sites in the 3 different municipalities of Bukavu town (Fig.1a). These primary data were complemented with key informant interviews and participatory stakeholder meetings. The survey sample was stratified to ensure that communities living at various distances (0.5, 1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 km) from Lake Kivu edge (50 km) to deep inside the country are included in the study. Thereafter, households in

each of these strata were further stratified by gender, profession, age, and socio-economic status. The survey sought to establish the health (prevalence of cholera and related diarrheal diseases), demographic (sex and age mostly affected) and socio-economic (type of activity, tribe, religion, low to high income earners, employed to non employed people) characteristics of the affected communities living in urban, peri-urban and rural areas. The key issues identified by the household survey regarding vulnerability and adaptability to cholera were probed in greater depth in the focus group discussions.

Data analysis

Assessing the relationship between climate variability and cholera cases: analysis of the health impact of climate change

Datasets were created for the purpose of the analysis. There were dataset-containing data aggregated at the monthly level allowed the observation of any seasonal trend in cholera cases and climate variables that cannot be observed with the annual data. Stability in climatic data was calculated in this study using the CV (coefficient of variation) index. CV is an appropriate, and widely used, to measure (investigate) of variability because it is standardized to the mean, accounting for the tendency of variability to increase with the mean. Note that in the primary literature, authors report either temporal variability (CV) or temporal stability (1/CV). The inverse of the coefficient of variation $1/CV =$ (mean / standard deviation) $*100$ is a convenient measure of stability because it is dimensionless and scale invariant, and accounts for non-linear dynamics. Stability is the inverse of variability. Temporal and spatial stability of rainfall were considered here as low variation over time (days within year or the season) and space (within site variation) respectively.

In order to investigate trends in the seasonal pattern and analyze the magnitude of the burden of cholera attributable to climate change, a multiple regression model was applied with monthly number of new cases of Cholera as response variable and monthly rainfall, average and maximum/-

minimum temperature and years as predictor variables (covariates). The estimates are based on past correlations between increased growth trends for *Cholera* new cases and climatic factors variability. Regression analyses were conducted using Minitab version 16 for Windows. A time-trend variable was used to predict future trends in cholera case based.

Financial costs of Cholera attributable to climate change

In the context of assessing the total costs of health impacts attributable to climate change, several measures are needed to be taken into account. Here, only the financial costs were estimated; the total costs were not estimated in this study given the fact that death data was not used. To estimate the economic costs due to Cholera infection (burden of disease attributable to climate change), a questionnaire was addressed to affected people (family members) and they were asked to report on their annual net income, their costs for treatment of Cholera (including drugs, bed, hospitalization) infection cases. Households were also requested to indicate climate-related diseases during interviews about major environmental problems in Bukavu town. In addition, the population density (as a proxy of promiscuity) was used. The assumption is that it is expected that areas that are over-populated will face problem of accessing safe water drinking; and this situation can lead people to use artesian water sources that are potentially full of *V. cholerae* especially during the rainy seasons.

Results

Climatic patterns

Climatic trends over Bukavu town region largely reflect that of the South-Kivu provinces as a whole, with two wet and relatively warm seasons in March, April, and May and October, November, and December , and two dry seasons in January and February (hot and dry) and June, July, and August (cold and dry). The largest portion of the inter-annual variability in rainfall is accounted for by the short rains season of October, November and December. Rainfall in eastern DRC is quasi-

periodic, with a dominant timescale of variability of 5 to 6 that is particularly influenced by El Nino Southern oscillation induced changes in the short rains period (October-November).

The mean annual rainfall in the region varies from 1300 ± 256 mm to more than 2031 ± 449 mm. About 80-90% of the annual rainfall is received during the first and second rainy seasons. The high inter-annual variability in rainfall is reflected in its high degree of coefficient of variation, ranging from 20% during rainy months to 78% during dry seasons. This variability in annual rainfall is the most important factor, influencing occurrence and emergence of new cholera cases in the region. The impact of projected climate change by the end of 21st century (IPCC, 2007) is more likely in lowland zones of South-Kivu province than in mountainous zones. There is a decal trends in annual rainfall the region showing no significant change during 1992 to 2003 in the max/mini temperature but significant change (increase) from 2003 to 2011. Long-term annual rainfall (24 years) showed an overall increasing trend at the rate of 12.45 mm / year despite high variation observation during drought year's months. The temporal stability (measured as reciprocal of the coefficient of variation (1/CV) was calculated for rainfall and temperature data from 1992 to 2012 and it was found that there was a high variability and lack of temporal stability in rainfall (Fig.2). Across years, there was a monthly variability in rainfall. The variability was high between May and September of each year. Across months, there was an annual variability in rainfall (Fig. 2A, C). Similar trends (annual and monthly instability) are observed for the maximum and the minimum temperature. Across years, there was a monthly instability in the rainfall. The instability was high between January and March and between October and December. Across months, there was an annual instability in rainfall (Fig. 3B, D). Similar trends (annual and monthly instability) are observed for the maximum and the minimum temperature (Fig. 3).

Cholera outbreaks were linked to various factors. These are closely related to regional climatic factors. For example, they tend to match the most important months in the year that have the

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climatological characteristics to precipitate a cholera outbreak. Peaks in Cholera outbreak may be affected by promiscuity and poor hygiene. However, peaks related to poor hygiene and sanitation/promiscuity may be localized and sporadic. Thus, cholera epidemics (high disease prevalence in eastern Congo and in Bukavu appeared to be closely associated with rainfall oscillations mainly associated with the short rains season (September October and November-December) than during the long rainy season of February-May. Cholera peaks coincide with high flow peaks during rainfall in the months of September, October, November and December (1993-1994, 1996-1997,1998-1999, 2001-2003, 2007-2008, 2010-2011). During other months of the year, the data (cholera occurrences) are offset, indicating that there is no correlation between the two, and hence cholera outbreaks during such months of the years may be attributed to non-climatic causes.
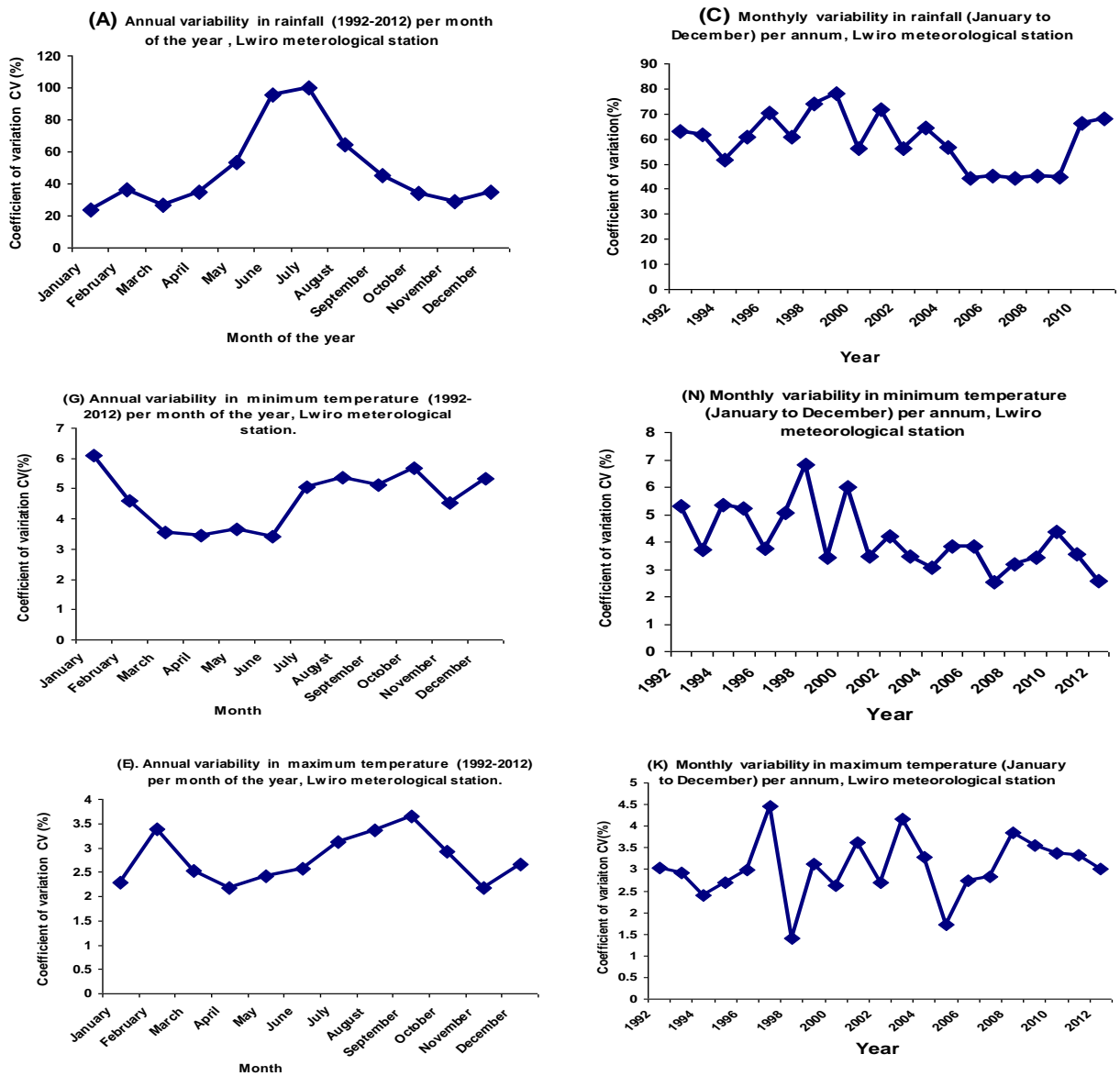

Fig. 2: Spatial and temporal variability in rainfall (A,C) , in minimum temperature (G,N) and in maximum temperature (E,K) ; data from Lwiro meteorological station from 1992-2012
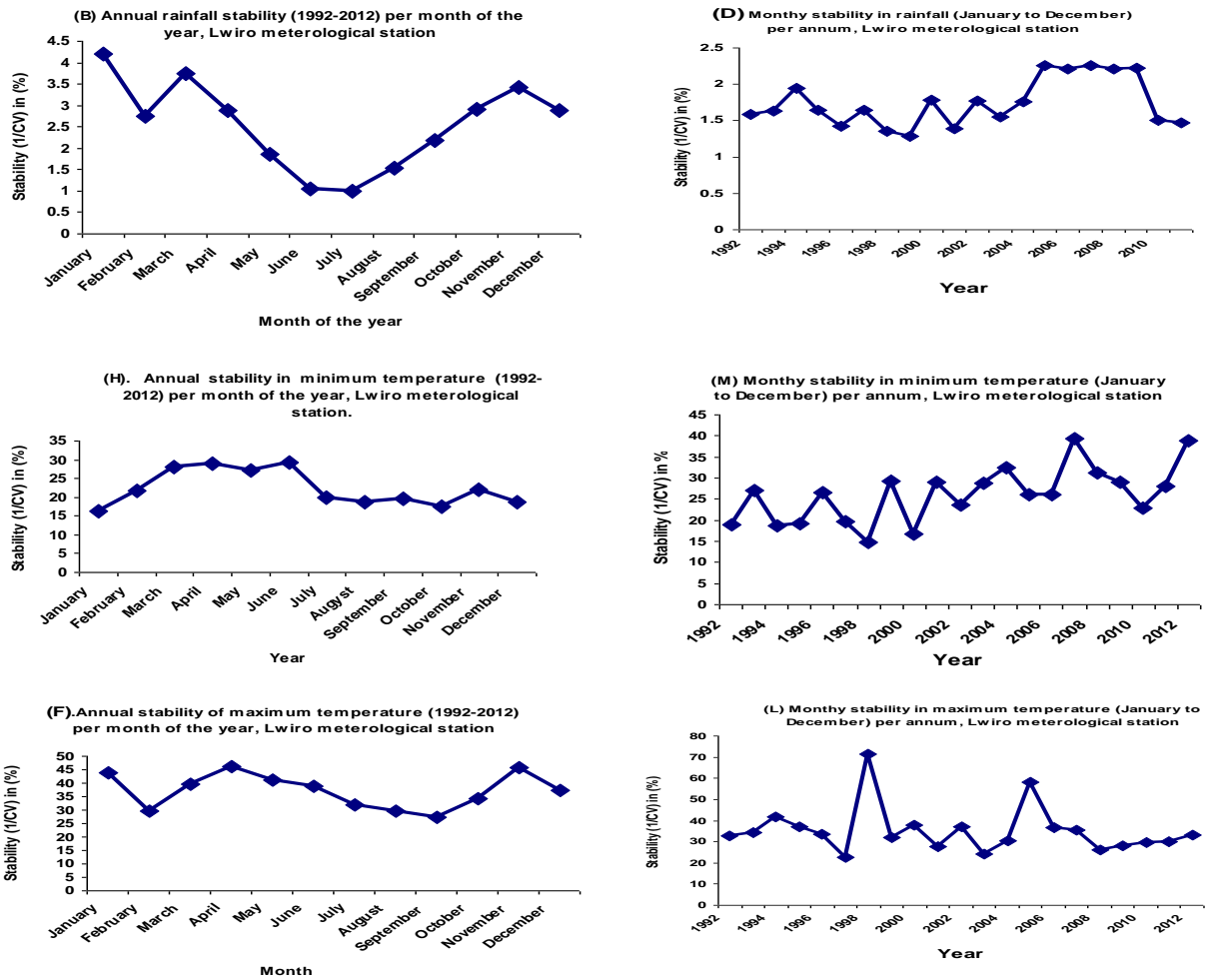
Fig. 3: Spatial and temporal stability in rainfall (B,D), in minimum temperature (H,M) and in maximum temperature (F,L) data from Lwiro meteorological station from 1992 to 2012

Average temperature maximum appears to play a role in the cholera epidemics as well, because during the years that the epidemics occurred (2010-2011), temperatures high above normal were recorded in this study region. It appears that the temperature trigger is a sustained temperature high above normal for 3 month in the early part of the year (January-February-March) followed by a gradual cooling (Fig.4) in super ceding months (Fig. 4-5). Even when precipitation are high above normal are recorded, cholera outbreaks are rare if the average temperature is relatively cool. Thus, cholera epidemics in south-Kivu provinces are associated with the anomalously warm and wet months of the years, such as in 2011. More locally at Bukavu town,

the cholera epidemics/ outbreaks tend to occur anytime in the year from April to December following periods of mainly sustained anomalous high temperatures in the months of January-February-March and heavy rains. Therefore, cholera outbreaks (not epidemics) are associated with the long rains season or with the short rains season when there is above-normal rainfall and temperatures. Abiotic factors (e.g., sunlight, pH, nutrients) that drive aquatic primary productivity in Lake Kivu also likely play a significant role in enhancing the possibility of cholera outbreaks, but this aspect was not assessed in this study. High-positive anomalies in average temperature are required therefore, to drive cholera epidemics in South-Kivu provinces.

In addition, high rainfall and consequent floods (soil/water erosion) are needed to disperse the cholera pathogen in the lake basin area including in some artesian water sources. The climatic thresholds that are required to precipitate a cholera epidemic are therefore as follows: sustained warm monthly temperatures in the months of January-February-March (exceeding, by at least one standard deviation, the mean annual temperature for the period 1992 to 2012) coupled with landslides, sufficient rainfall to produce at least a 2-years flood event in rivers and streams flowing from mountains and hills of Bukavu town around the lake Kivu during the September-October-November-December rainy season. This climatic effect can be exacerbated and prolonged by similarly anomalous temperatures and rainfall in the September-October-November-December, with its effects being reflected in the January-February hot and dry seasons. When the above climatic factors are met, human vulnerability to cholera epidemics is dramatically increased in eastern Congo.

Relationships between Cholera cases and climatic factors

Different climate related problems (Table-1) were identified by respondents during the survey.

Table 1: Perception of respondents about major climate related problems faced by human communities in Bukavu town, South-Kivu province, eastern Congo, 2011

	Number of respondents (indicating / identifying) the problem as climate related threat				
	\multicolumn{4}{c}{Males}	\multicolumn{4}{c}{Females}
	Yes	No	Not sure	χ^2	Yes	No	Not Sure	χ^2
Heat/increases temperature	109	12	3	456.78***	3	5	12	1.98 ns
Mosquitoes	3	45	12	104044***	43	32	0	234.56 ***
Diseases	45	12	5	234.56***	23	17	10	3.89 ns
Shortage of water	33	12	6	160.07***	23	12	0	387.26 **
Environmental pollution	25	5	7	156.89***	23	2	0	1385.09 ***
Bad smell in the area	19	45	8	18.60**	4	2	1	0.348 ns
Crude garbage disposal	17	7	9	221.45 **	2	0	5	2.40 ns
Drought	12	34	12	1.063 ns	8	2	0	4.121 *
Dirty unsafe water	23	34	45	165.95***	1	9	3	6.43 **
Off-plot sludge disposal	10	8	12	10.57***	4	5	4	6.43 **
Noise	7	0	4	0.46 ns	9	2	7	5.76 * *
Poor infrastructure	8	5	7	12.71***	1	5	8	5.92 **
Poor social services	7	4	3	0.67 ns	12	6	0	26.71 ***
Promiscuity	8	5	6	0.475 ns	1	0	5	6.204 **
Lack of public toilets	34	5	7	148.89***	1	2	0	0.073 ns
Noises	9	2	0	7.92**	9	0	1	7.92 ***
Anarchic constructions	23	12	5	37.59***	8	0	2	4.98 *
Lack of roads	4	7	0	12.71**	6	1	2	262.71 **
Dusts	12	3	0	36.54***	5	0	1	6.24 **
Mud	45	9	0	21.88***	2	6	1	0.073 ns
Hunger	12	2	7	10.67***	3	6	2	7.92 **
Increased flies	2	1	3	0.087 ns	1	3	0	3.11 ns
Increased mosquitoes	6	1	5	4.23***	5	0	1	6.24 **
Inflation	24	3	0	269.37***	4	3	0	0.77 ns
Military unrest/Insecurity	21	4	2	51.84**	1	2	6	0.13 ns
Landslides,	5	23	9	18.76***	8	6	5	0.67 ns
Earth quakes	14	4	0	133.47***	4	1	0	1.046 ns
Soil erosion	5	23	9	18.76***	8	6	5	3.02 ns
Poor sanitation and floods	34	4	3	128.53***	1	2	5	4.47 *
Smelling garbage	3	5	0	4.47*	3	2	0	3.11 ns
Smelling domestic wastes	3	9	1	3.45*	2	6	4	3.23 ns

N=1346 is the total interviewed people(female and males) during household surveys conducted in 2011/ Levels of significance of the Chi-square test value: *** = significant at P≤0.001 ; ** = significant at *P*≤0.01; /* = significant at *P*≤0.05; ns = not significant

Males and females have different perceptions. For example, while most male respondents significantly ($P<0.05$) perceived that common diseases affecting the community were climate related, there was no significant($P>0.05$) differences in the number of female respondents who answered "Yes", "No" "Not Sure" when asked if diseases were climate related problems (Table-1). A number of diseases (including Cholera) are suspected to be exacerbated by climate change and climate variability by the provincial health inspection of South-Kivu (Table-2). However, communities have different perspectives about the most frequent climate induced diseases in Bukavu town. These include diarrheas, cholera and malaria (Table-3). The multiple pair-wise correlation analysis showed that cholera cases are positively correlated with minimum temperature ($r=-0.28$, $P=0.041$), maximum temperature ($r=-0.32$, $P=0.032$), urban population growth rate ($r=0.25$, $P=0.047$). Although linear correlation between cholera cases and maximum/minimum temperatures were significant, multiple regression models indicated that the number of new cholera cases was significantly ($P<0.05$) and positively related to total rainfall and to the number of years. On the contrast, cholera cases were negatively and significantly ($P<0.05$) related to the average temperature. Across years (from 1992 to 2011), Cholera cases was not related ($P>0.05$) to maxim-um temperature and to minimum temperature but was found to be significantly negatively related to mean temperature ($P<0.05$) and positively related to rainfall ($P<0.001$; Table 4).

Table 2: Diseases that are prevalent by municipality in Bukavu town from different age category of people (above 5 years and under 1-5 years people) and that are suspected to have been driven by climatic factors from 2009 to 2011 according to the health inspection registers of South Kivu province, eastern Congo

Areas	Rank no of (%)	Kadutu		Ibanda		Bagira	
		Above 5 years	**Under 1-5 years**	**Above 5 years**	**Under 1-5 years**	**Above 5 years**	**Under 1-5 years**
Residential /administrative areas	1 (35)	Malaria	Malaria	Malaria	Malaria	Malaria	Malaria
	2 (30)	Acute respiratory infection	Acute respiratory infection	Acute respiratory infection	Pneumonia	Urinary tract infection	Acute respiratory infection
	3 (15)	Skin infections	Skin infections	Diarrhea	Gastroenteritis	Acute respiratory infection	Diarrhea
	4 (10)	Anemia	Anemia	Nutritional disorders	Acute respiratory infection	Pneumonia	Urinary tract infection
	5 (7)	Diarrhea	Pneumonia	Pneumonia	Skin infections	Pneumonia	Skin infections
	6 (3)	Dysentery	Cholera	Cholera	Amibia	Cholera	Acute respiratory infection
Communal over-crowded areas	1 (30)	Malaria	Malaria	Malaria	Malaria	Malaria	Malaria
	2 (25)	Urinary tract infection	Diarrhea	Urinary tract infection	Urinary tract infection	Skin infections	Urinary tract infection
	3 (13)	Pneumonia	Protein energy malnutrition	Skin infection	Anemia	Ear infections	Protein energy malnutrition
	4 (12)	Non-infectious gastro	Eye infections	Skin infection, non fungal	Worms	Ear infections	Diarrhea
	5 (10)	Skin infection, non fungal	Skin infection, non fungal	Tuberculosis	Minor surgery	Dysentery	Nutritional deficiencies
	6 (7)	Cholera	Amibia	Cholera	Amibia	Cholera	Amibia
	7 (3)	Intestinal worms	Nutritional deficiencies	Anemia	Diarrhea	Diarrhea	Anemia

Diseases are ranked in order of importance (frequency: 1= highly prevalent, 7= less prevalent) in each municipality of Bukavu town; %= the percentage of prevalence of the disease in the area

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Table 3: Community perception of illnesses and diseases suffered by residents of Bukavu from 2010 to 2011

	Frequency of households indicating the disease among those interviewed during the study period								
	Diseases								
Households opinion	Diarrhea	Typhoid	Inter worms	Cholera	Bilharziose	Hepatitis	Filariasis	Dysentery	Malaria
Rarely	345	121	267	45	33	17	11	19	167
Often	45	16	123	12	12	8	7	23	156
Frequent	12	23	56	8	7	11	18	45	87
Very Frequent	24	6	45	24	19	9	21	28	67
	Statistics								
DF	1	1	1	2	1	1	1	1	2
χ^2-test	4566.34	179070	8.25843	73.5324	8.28938	0.9345	5.40822	3.82941	2211.88
P	<0.0001	<0.0001	<0.0001	<0.0001	0.004	0.345	0.020	0.050	<0.0001

Table 4: Mutiple regression to estimate the relationships between the number of new *Cholera* cases and climatic factors (maximum temperature, minimum temperature, average temperature, monthly rainfall) from 1992 to 2011,Bukavu ,South-Kivu province, eastern Congo

Terms	Un-standarized coefficients		Full model	
	Regression Coefficient	SE coefficient	*T*-statistic	*P-value*
Constant	-16573.1	6381.87	-2.5969	0.010
Years (1992-2011)	8.7	3.23	2.69796	0.007
Rainfall (mm) Lwiro	0.5	0.10	4.74386	0.000
Maximum temperature	5.2	6.17	0.83794	0.403
Minimum temperature	-4.1	6.04	-0.67651	0.499
Mean temperature	-43.6	20.21	-2.15795	0.032
Whole model: Model $F_{(5,246)}$=22.678; Model $P<0.0001$; Multiple R^2= 25.33%				

These results suggested over years, increase in rainfall indirectly induced an increase in new cholera cases. However, increase in average temperature induced a reduction in rainfall and this in turn had a significant effect in the reduction in Cholera cases. In other words, Cholera burdens in also related to variability in climatic factors (rainfall and temperature) such as the rise in temperature reduces Cholera cases while increase in rainfall increases Cholera cases. Looking at the data, it was observed that a seasonal pattern seemed to exist during the rainy season when lower minimum/maximum temperatures and lower total rainfall coincided with lower cases of cholera (Figs.4-8). From 1992 to 2002, *V.cholerae* infections tend to peak during September to March periods during or immediately after rainfall peaks (Fig.4). Interestingly, from 2003 to 20011, the number of New cases of Cholera increased significantly ($P<0.01$) in Bukavu town (Figure-5). Similarly trends were observed in a rural health zone (that is located at 45 Km far from Bukavu town) of South-Kivu province (Fig. 6). The trends in minimum temperature and in maximum temper-ature were not in synchrony with cholera cases (Fig.7) from 1992 to 2011 although there was a tendency for the maximum temperature to increase from 2002 to 2011 (Fig. 8). This result suggests that cholera cases in South-Kivu provinces might be better explained by average temperatures and total rainfall than by rainfall minimum and maximum temperature. Cholera cases were significantly ($P<0.05$) related to total rainfall and to rainfall observed in the previous month of the cholera occurrence. The fact that the dataset gathered per month showed a positive and significant association between cholera cases and rainfall, and a negative and significant association between cholera cases and the average temperatures reflected that observed reduction of cholera cases during dry and semi-dry seasons (May–September). The signs of the estimated coefficients for all explanatory variables (years, rainfall and average temperature) were not as expected since the period (months: dry and semi-dry months) of less rainfall (droughts periods during which the atmospheric temperature is high) are observed being associated with less Cholera cases a and high number of cholera cases are frequently being observed during and 1 to 3 months after the start of the rainy season or during rainy months.
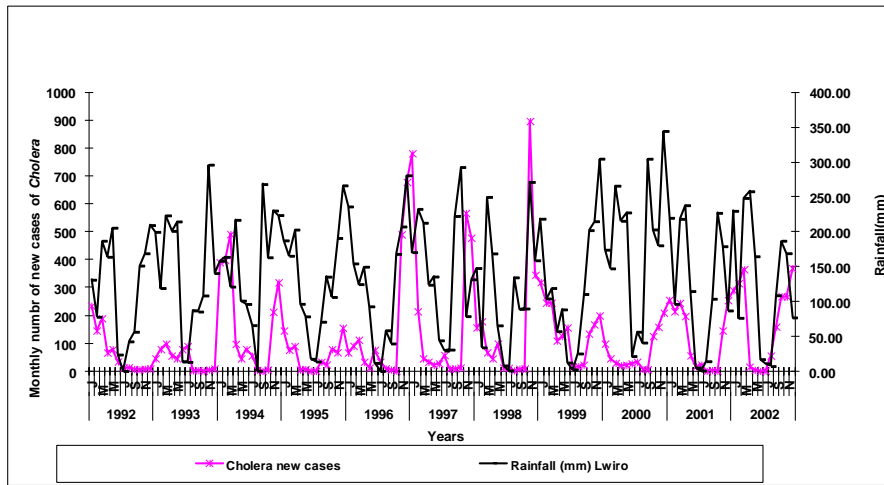
Fig. 4: Mean monthly rainfall at Lwiro meteorological station and cases of *Vibrio cholerae* infection by month along the period (1992-2002)
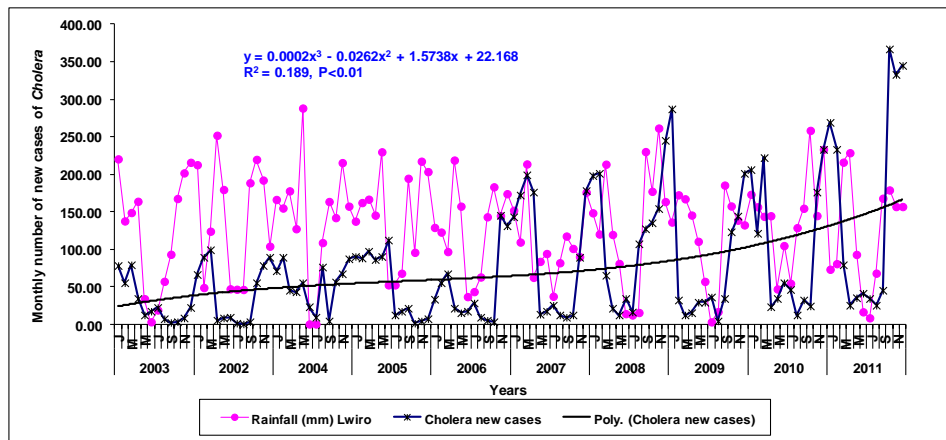

Fig. 5: Mean monthly rainfall at Lwiro meteorological station and cases of *Vibrio cholerae* infection by month along the period (2003-2011)
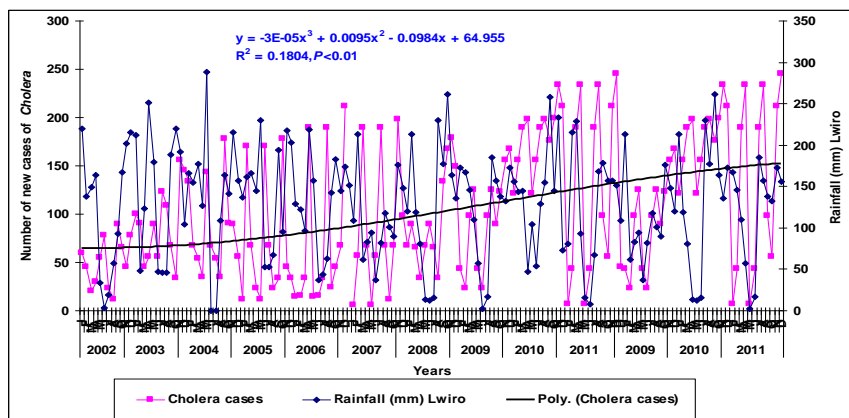

Fig. 6: *Vibrio cholerae* infection cases in Katana rural health zonal area and monthly rainfall at Lwiro meteorological stations along the period from 2002 to 2011

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The negative sign of the coefficient of variable average temperature (indirectly "drought") confirms that cholera cases decrease in months with less rainfall, as expected. Using the coefficient in the regression models, Cholera risk ratio was estimated to be equal to 1.17 using the monthly data set. In other words, an increase in temperature equal to 1 degree Celsius would increase the relative risk for cholera cases in South-Kivu province of by 17%. Since average temperature explained better cholera cases, the regression model indicated that an increase in temperature equal to 1 degree Celsius would increase the relative risk for cholera cases in Katana rural health zone by 25%.

Costs of Cholera attributable to climate change
There was a significant ($P<0.05$) and consistent variability in the number of new cases of *Cholera* infections across localities from different municipalities of Bukavu Town. The increase in new number of Cholera cases tended to follow the population density that was taken as proxy for promiscuity. It is likely that the consumption of water from artesian water sources may favor Cholera outbreak increase in Bukavu town since it was observed that the number of *V. cholera* increased in groundwater sources during the rainy season than during the dry season. Highest numbers of Cholera were registered at Kadutu-Nyamugo, Muhungu followed by Cimpunda, Bagira and Nguba-Keredi, Cidasa, Muhungu, and Chai. The results of the financial cost estimates show that the annual costs of treatment of cholera cases range from 50 to 250$ per capital (Fig. 9).

However, the full health costs of climate change may be much larger if other health variables affected by climate change, such as other water-borne diseases besides cholera (e.g., diarrhea, typhoid), malnutrition, food-borne (e.g., Salmonella) and vector-borne diseases (e.g., malaria), were taken into account. Over years, higher mean expenditure for *Cholera* case treatments were registered at Labote-Nyawere followed by Muhungu; areas where affected people reported higher annual income per capita. The rest of the localities had almost similar costs (Fig.9).The financial loss as a percentage of the total annual revenue per capita varied from an area to other ones. However, affected people from Cimpunda and Keredi-Nguba had higher financial losses (6-8% due to Cholera treatment although this loss was not significant across localities.

Socio-economic status
The socio-economic characteristics suggest certain poverty indices that reflect the vulnerability of communities (living in some municipalities of Bukavu) to cholera epidemics. Most of these communities are poor, relying predominantly on either farm incomes, self-employment (small-business). Formal employment that is a source of steady income is the privilege of only a few, with 8% to 34% relying on this source of income in Kadutu and Bagira municipalities. The daily income disparities in total monthly incomes are also large, which is symptomatic of inequity in these communities. These vary between US$ 0.5, 1.5. 2.5 Kadutu, Bagira and Ibanda respectively.
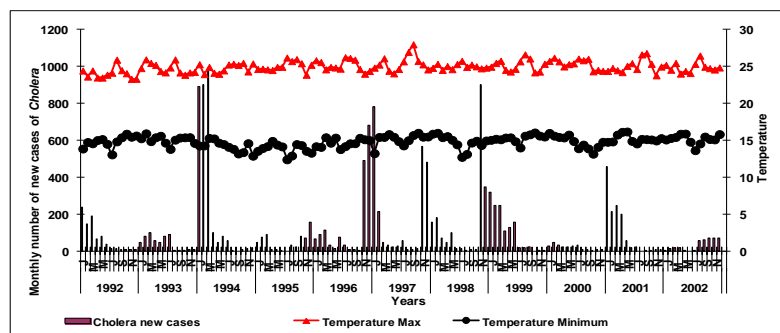

Fig. 7: *Vibrio cholerae* infection cases and the daily (min/maxim) temperature values at Lwiro meteorological stations along the period from 1992 to 2002
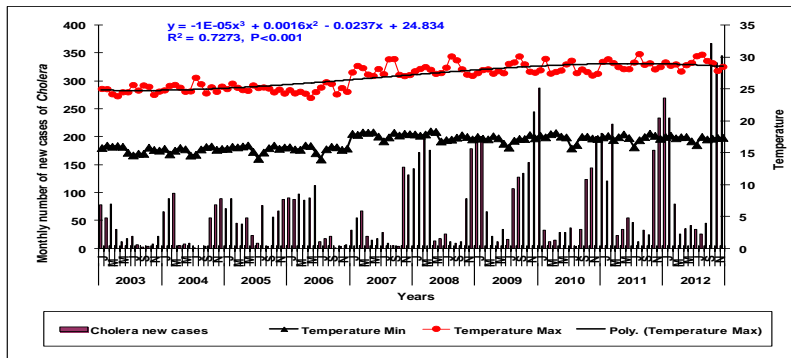
Fig. 8: *Vibrio cholerae* infection cases and the daily (min/maxim) temperature values at Lwiro meteorological stations along the period from 1992 to 2002
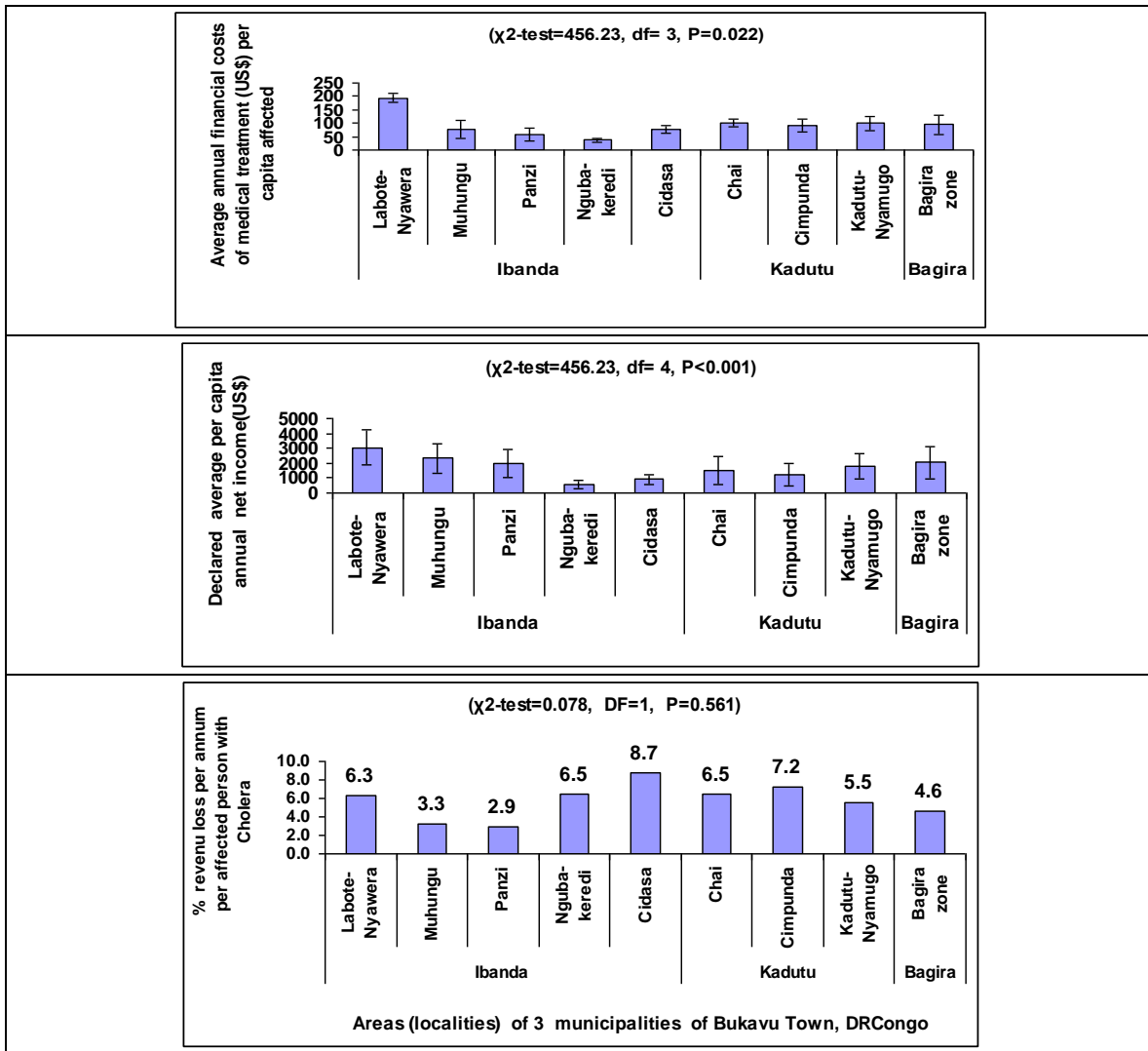

Fig.9: Average financial cost of medical treatments (a), average per capita annual net income (b) and percent of the revenue loss per annum per affected person (c) with *Cholera* in different localities of Ibanda, Kadutu and Bagira municipalities of Bukavu Town, Eastern Congo

The type of food and frequency of meals that a household has is a good measure of household food security. Although most of the households reported having a fairly well balanced diet of proteins and carbohydrates, a significant proportion of the households in the study areas indicated days of household food shortages. The highest proportion (70%) was reported in Kadutu followed by Bagira and Ibanda crops grown (urban agriculture) may also be used to indirectly measure the level of communities' involvement in the monetary economy and thereby challenge their ability to afford medical care during cholera epidemics. Inhabitants of Bagira grow sell all their agricultural produces. Most residential houses in the survey areas are semi permanent (iron roofs and mud walls, such as a greater density of permanent houses: stone/brick walls and tiled roofs), accounting for 34 to 78% of the respondents' houses in Kadutu, Bagira and Ibanda. Coupled with other factors, such as income levels, promiscuity, population density and food insecurity, this is an indication of the low socio-economic status inherent in these communities.

Discussion

Trends in climatic (temperature and rainfall) factors and its impacts of health systems and livelihoods

There is a noticeable rise in temperature from 2003 to 2007 in the province. A local warming rate of about 0.27-45 °C per decade between 1992 and 2012 that is significantly higher than global averaged warming. .The mean daily temperatures in DRC will rise by 1.5 °C throughout the country (19), but particularly in eastern DRC. The increase in temperature will be more during the cool months of June, July and August than during the warm months of December- January and February. The deference between the two periods was predicted to be about 1.2°C on average. The increase in annual temperature over the whole country is predicted to be between 1.6 5 °C and 2.78 °C in the warmest months of December and February and between 1.55 °C to 4.24 °C in the coolest months of June to August.

A preliminary study of temperature from some stations in eastern DRC representing different zones show predominantly increasing annual temperatures suggesting that temperature is bound to increase throughout the eastern part of the country (19). Such temperature trends coupled with variations in rainfall are likely to be forceful in designing mitigation and adaptation measures, as they will have different impacts on different ecosystems and production and on health systems. These changes are therefore expected to vary across the province but will mostly have negative impacts on agriculture and food security, livestock production and health, water resources, energy, human health, forest ecosystems and biodiversity, wetlands integrity, and above all the attainment of the millennium development goals.

The impact of climate change and climate variability in eastern DRC is therefore increasingly threatening the livelihoods of especially rural population with low income, food insecurity, inadequate health services, unstable energy supplies, and fragile natural ecosystems. As such, agriculture, water, energy, health and forestry are the most vulnerable sectors of the economy under climate change impacts in eastern Congo (19). Congo is not homogeneous from a climatic point of view. Some areas have bi-modal rains i.e. have two distinct rainfall seasons comprised of the long rains between March-May and short rains between October-December. This pattern of rainfall is typical of most eastern provinces of DRC including South-Kivu province. Elsewhere in the country, especially in the southern (Katanga province) rainfall is mainly unimodal, starting from November and running until End April. There will be increased rainfall in some parts of country while other parts will experience decreased rainfall by 2050. The areas with two rainfall seasons, eastern provinces would experience increase in rainfall for both seasons ranging from 2 to 26% (19). The other areas receiving uni-modal rainfall pattern, Southern part of the country may experience a decrease in annual rainfall by a range of between 0.5 to 17%. These precipitation predictions do offer greater regional specificity, however, the results should be interpreted with caution as they do

not include an uncertainty analysis and rely on preliminary analysis (19). There is an increasing frequency of erratic rainfall pattern throughout the country, particularly in eastern. For example, in the past decade, South-Kivu province had been receiving delayed rainfalls (starting in November instead of September), making the rainy season to become shorter. The annual precipitation is decreasing at a lapse rate of 5 to 12mm/year between about1992 to 2011. Overall annualized rainfall values are on decreasing trend in the province although there may be a great variability in trend of rainfall across territories. Some territories (Mwenga) show increasing rainfall trends in both long and short rain seasons.

On the other hand, rainfalls for other territories (Kabare, Walungu and Uvira) there is a slight increasing trend during October to December (short rain season) and significant increase during March to May (long rains). Territories locates near water bodies and forest (Idjwi) do not show any change in rainfall while Kalehe plain shows increasing rainfall trends. Uvira (Ruzizi plain) did show decreasing trends for both seasons. These few examples show the variability in weather patterns as influenced by climate variability, which may not justify the same adaptation and mitigation measures for the public health. This may therefore call for specific health adaptation and mitigation measures in different areas (territories) depending on the observed variability.

Impact of the variability in climatic factors on Cholera burden and on health of communities

Disease vectors have climatic thresholds (20) that govern their abundance and potential for disease transmission. Therefore, an increase in temperatures would cause worldwide net increase in the geographical distribution of vector organisms, with impacts on the timing and severity of infection disease epidemics in many areas of the world. There are few detailed studies on climate related costs in the health sector in Sub-Sahara Africa and in Uganda. This is the first tempting to link cases of cholera to environmental and socio-economic factors in predicting climate change impacts to cholera in Congo and assessing the related costs.

The results of the regression model predicted a future disease burden with average temperature increase. It was also predicted that a reduction in the incidence rates of cholera in case of normal rainfall. The increase in the incidence of Cholera may be partially and or primarily attributed to change in the rainfall and in temperature. It is likely that increase in the variability in rainfall and temperature will would undergo increase in cholera cases in the future.

Although accurate costs were not estimated given the lack of consistent long-term socio-economic datasets in the province, the reliability of regressions analyses is to some extent limited. It is likely that, with more time-specific data available on health and climate variables, the results could show even stronger impacts. In addition, the impacts of climate variability on the burden of disease in the form of cholera are complex and dependent on a number of risk factors from local socio-environmental conditions. For a waterborne disease, the results presented in this paper may seem high, with a 17-25% percent increase in the relative risk per degree Celsius, in comparison to the 5% increase as predicted by WHO (1998) for Sub-Saharan Africa (21) predict an increase in diarrheal incidences of 0.6% point for a 1 degree Celsius increase in temperatures for South Africa. The estimates presented in this paper seem high, considering that cholera is included as a diarrheal disease in the study by (21). The results in this study conform to what would be expected given previous evidence on linkages between environmental risk factors and cholera in central Africa adding to the existing evidence of the implications of climate change for cholera.

Costs of Cholera attributable to climate change

The reported costs for treating cholera cases (US$ 50 to 250) were high compared to the treatment (US$10 to 100) of diarrhea cases (other climate related diseases) in province. This is normal since diarrheal patients can be treated as outpatients, while treatment of cholera has to include hospitalization for an average of five to six days per case, as well as the cost of surveillance of other people than the patient. In Zambia, average

inpatient costs for diarrhea are estimated to by US$78 per bed day, while for Congo, inpatient costs are estimated in the range of USD 1 to15 dollars per day.

Overall, cholera is an acute intestinal disease caused by infection of the *V. cholerae bacterium*. Often manifested as a constant diarrhoeal disease, cholera is associated with significant mortality as well as economic loss due to the strain on health care. Cholera often affects nations with lower economic status. Cholera is often associated with low-income nations where it can cause significant mortality and economic loss during outbreaks and even be endemic to a certain region. Severe dehydration and electrolyte imbalance may occur due to constant diarrhoea and lead to death in 50% of cases when it is left untreated. *V.cholerae*, the bacterium which is the etiologic agent of cholera, is transmitted through fecal-contaminated water and food. Cholera is considered endemic to a region when the bacterium inhabits the native environment and outbreaks are independent of imported cases.

Cholera may become endemic to a region through various routes, which are dependent on the local environmental conditions. Commonly, the collapse of water sanitization and water routing infrastructure is the main cause of cholera outbreaks. Recently, multiple-drug-resistant *V. cholerae* species have been reported. Furthermore, the interaction between this waterborne bacterium, the human host, and the environment (4) needs significant consideration when building strategies for cholera management and eradication. The World Health Organization (WHO) requires all cholera cases to be reported to the organization. Importantly, due to the overburden of many health-care systems, frequently cholera cases go underreported. Cholera outbreaks are currently being reported in the Democratic Republic of Congo, specifically, in locations in proximity to the Congo River and major Lakes. The WHO has reported 3,896 cases with 265 associated deaths attributed to this cholera outbreak as of 20 July 2011 in western Congo (1).

There is a need to put in places adaptation and preventives measures to reduce the burden of Cholera cases. Promiscuity, demographic explosion and consumption of artesian water sources and consumption of crude water from Lake Kivu may favor the Cholera transmission among human beings. It is believed that improved sanitation and hygiene facilities should be vital components of the planning and provision of water supply services by the REGIDESO (the national water corporation company to prevent Cholera Outbreaks.

In brief, there is a need to reduce vulnerability to cholera from improved water access and sources, as well as medical treatment in cases of illness. The lack of introduction of adequate preventive adaptation measures will continue increasing the burden of disease and the related financial costs will increase considerably. Access to urban and rural water supply services increased in South-Kivu provinces vary from 24 to 54% in 2011. Thus, the need to initiate new key structural developments in the water and sanitation sectors in Bukavu town.

Information of safe way of handling cholera cases is lacking. Public perception and awareness of extreme weather events and disease are among the critical factors determining the prevention and adaptive capacity of individuals and communities to the impact (s) of such climate-sensitive diseases as cholera. Generally, a significant proportion of the respondents (50-89%) across the three municipalities tend to think that the health of household members is associated with weather conditions. Based on experiential rather than scientific underpinnings, the respondents indicate that cholera occurs mostly during wet weather conditions and during periods of low water supply associated with dry seasons. The explanation provided by health workers was that it is because of the sandy/clay nature of the soil that pit latrines often collapse and are contaminated easily during rainy seasons than during dry season in rural areas and in Bukavu. Similarly, awareness of the causes and prevention of cholera is equally high. Most households are knowledgeable about the necessary medical treatment, such as the use of antibiotics and oral rehydration salts. However, they indicated that they rarely used such medical treatment

because of the costs involved and instead relied on those that were distributed during such epidemics.

It has been found that cholera is significantly underreported, which can possibly be expanded further to other regions. The main reason for this situation is the limitations of disease surveillance. As well as monitoring disease outbreaks (13) and tracking individual cholera infections and mortalities, it is also imperative to have vigilant testing for antibiotic resistance as several multiple-drug-resistant *V. cholerae* species have been identified. Inadequate and poorly monitored water treatment and supply systems are often responsible for cholera outbreaks (6, 7). The transfer of water supply has been suggested as a precipitating factor in the major outbreak of cholera in western Congo. Water supply-and-demand infrastructure issues can cause local people to use self-maintained shallow wells that can easily become contaminated with bacterium that cause cholera. As well, poor water sanitation and open drains allowing easy contamination of *V. cholerae* to water supplies have been identified as issues perpetuating the cholera struggles in Congo. Furthermore, access to adequate sanitized water also played a significant role in the 2012 cholera outbreak in Bukavu town, where less than 16% of the population received treated water across all municipalities. Environmental factors have significant influence on the outbreak potential and pathogenesis of *V. cholerae* as well as other pathogens. It is obvious that the fecal-oral transmission route relies heavily on the ecology of the native water supply. Furthermore, the seasonal water cycles have been shown to affect the emergence and re-emergence of *V. cholerae* and the health of local populations, particularly in eastern Congo. These issues are important in defining coping mechanisms (11). The poverty indicators undermine the coping mechanisms (11) that could help the susceptible urban and rural communities reduce their vulnerability to cholera epidemics in South-Kivu province. This is because of lack of economic resources to invest in health coping mechanisms that can offset the costs of adaptation. Measures employed at the household level include washing hands before meals, treating drinking water, and constructing pit latrines. The communities were also able to distinguish between the different levels of responsibility in the control of cholera. The strategies at the village level do not require as much economic resources as those at the municipality district level, a reflection of the communities' awareness of this limitation.

Conclusion

Cholera is a devastating disease that affects hundreds of thousands of people per year. Over 200,000 cases were reported to the WHO in 2009 but case estimates exceed 500,000 worldwide (11). It is clear that management of this disease requires consideration of many aspects including molecular biology, the environment, local governmental water treatment programs, and improved local, national and international case reporting (11). Overall, cholera outbreaks and epidemics can be linked to natural, socio-economic, and health systems. The climate data used in this study showed that the onset of cholera at Bukavu town starts earliest in the month of April within any given year following a sustained 1 to 3 months period of average, maximum and minimum temperature in January-February-March, in combination with above-normal rains from April through December. There may be some epidemics in January that are related to sustained average temperatures in September-October-November and December season.

Persistent levels of poverty, civil wars and in security may have contributed to make human communities to be more vulnerable to cholera epidemics in eastern of Congo. Future adaptation programs should take into account the diversity of factors that influence a society's capacity to cope with the changes (22, 23). Persistent levels of poverty, civil wars and in security may have contributed to make human communities to be more vulnerable to cholera epidemics in eastern of Congo. Such programs should take into consideration the demographic trends, ecological and socio-economic and education factors. Similarly, the public health infrastructure and the institutions

of governance need to be improved. Climate variability and change no doubt play an important role in the people's health and productivity and their responsiveness to extreme weather events. The management of cholera outbreaks and epidemics must factor in climate considerations if it is to reduce vulnerability and increase the adaptive capacity of the lake basin communities.

Ethical considerations

Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc) have been completely ob served by the authors.

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