

Assessment of Environmental Factors Associated with Endemic Cholera in Lukanga Swamps of Kapiri Mposhi District in Central Province of Zambia

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Abstract Cholera, an acute diarrheal disease, is caused by the bacterium *Vibrio cholerae* and is usually transmitted through contaminated water or food. This study assessed the environmental factors associated with endemic cholera in Lukanga Swamps from January 2010 to January, 2018. This was a Time Series Correlational Study. Air temperature and precipitation data were collected from 19 lagoons using satellite remote sensing from 2010 to 2016. Water samples were also collected for analysis. Data were analyzed in Stata Version 14. Results from the standard Poisson regression (PR) model were compared with those from the Zero-Inflated negative binomial regression (ZINBR) to determine the best-fit model. The study reported 133 cholera cases during the study period. It found that increased rainfall was associated with decreased risk of cholera cases (IRR = 0.992, 95% CI: 0.988 – 0.997, $P=0.002$). We also found that a 1-degree increase in temperature increased the risk of cholera cases by 27%, which was statistically significant (IRR = 1.265, 95% CI: 1.142–1.402, $P = 0.0001$). Water quality monitoring tests from 19 lagoons revealed that 19/36 (53%) of water samples had faecal coliforms. The study further revealed a pH range of 7.1 to 8.5 or higher. *V. cholerae* was not isolated from 164 water samples. In conclusion, air temperature was strongly associated with cholera outbreaks in the Lukanga Swamps. Increased rainfall was also associated with a decreased risk of cholera cases. Therefore, a multifaceted approach should be used to prevent and control cholera in Lukanga Swamps.

Keywords Endemic Cholera, Environmental Factors, Lukanga SWAMPS.

Background

Cholera, an acute diarrheal disease caused by the bacterium *Vibrio cholerae*, is usually transmitted through water or food contaminated with faecal matter [1]. About 1.4- 4.3 million annual global cholera cases are reported, and deaths range from 28,000 to 142,000. Cholera has become endemic in Africa, with large epidemics occurring in different parts of the continent. Over the course of 2007 to 2011, more than 100,000 cases of cholera were reported to WHO annually from at least 20 African countries, with case fatality rates reaching about 3% [2]. In Zambia, cholera has been endemic since its first occurrence in 1977/1978, just like in other areas of Africa [3]. Recent studies have established that cholera occurs in three forms: epidemic (a sudden outbreak in a previously relatively disease-free region and primarily inland), endemic (recurring essentially annually and predominantly along coastal regions), and mixed-mode (a combination of epidemic and endemic disease occurrence) [4].

According to Jutla in 2015 [4], air temperature, precipitation, humidity, water pH, water quality, and sanitation were associated with cholera outbreaks. In Kapiri Mposhi district, there has been a problem of cholera for many years emanating from the Lukanga Swamps. Lukanga Swamps recorded 42 cases in 2012, 47 cases in 2014, 6 cases in 2015, and 30 cases in 2016, respectively [5]. There is little information available for Lukanga Swamps on environmental factors associated with endemic cholera. The main objective of this study was to assess environmental factors associated with endemic cholera in Lukanga Swamps from 2010 to 2018. It specifically also sought to assess the association between environmental conditions (temperature and

precipitation) and cholera cases in Lukanga Swamps from January, 2010 to December, 2016.

Methods

Study Area

This study was conducted in Lukanga Swamps in Central Province of Zambia as indicated in Figure 1. The catchment area of the wetland is 13,520 km². The Lukanga Swamp is located approximately 50 km west of Kapiri Mposhi District, in the Central Province of Zambia, within the catchment of the Kafue River. It is estimated that about 60,000 people live in, or close to, the wetland [6].

Study Type

A quantitative time-series correlational design was employed to examine the association between environmental factors and cholera epidemics in the Lukanga Swamps. The design allowed the examination of temporal patterns and statistical relationships between environmental variables and cholera incidence without manipulating any study variable. A time-series design involves the collection and analysis of observations measured at successive points in time, enabling the identification of temporal patterns, seasonal variations, and long-term trends in disease occurrence and environmental conditions.

Sampling Procedure

This study employed total sampling, including all 19 accessible lagoons in the Lukanga Swamps through Kapiri Mposhi district, from which cholera had previously broken out.

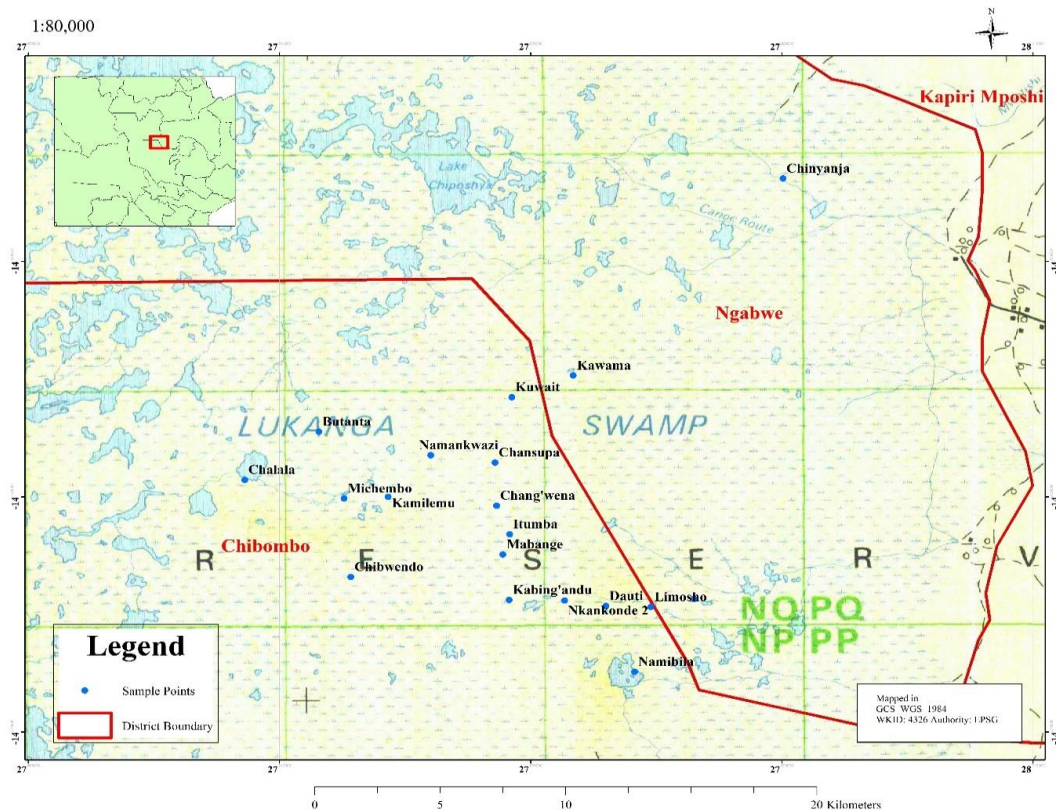


Figure 1. Study Site Map with Water Sample Collection Points Dotted in Blue

Data Collection Techniques and Tools

Satellite remote sensing was used to obtain information for environmental variables including: air temperature and precipitation for the period of 2010 to 2016. Water quality monitoring and pH were also determined from September, 2017 to January 2018 through water sample collection and analysis. In addition, the sanitation condition of the Lukanga Swamps was also assessed through observations.

Study Variables

The following variables were considered in this study: Cholera cases were the outcome variable, while Air temperature, Rainfall, sanitation, Potential Hydrogen, and Water quality were predictor variables.

Data for Cholera Cases

Information for cholera cases was obtained from the Kapiri Mposhi District Health Office Information System database and from the

Provincial Health Office line listing database from January, 2010 to December, 2016.

Environmental Data (Air Temperature and Precipitation)

Historic data for Environmental factors such as air temperature and precipitation were collected from all 19 lagoons using satellite remote sensing. Due to a lack of weather information in the study area, rainfall and temperature estimates were collected from Tropical Applications of Meteorology using Satellite and ground-based observations [8]. TAMSAT was developed by the University of Reading in 1977 and has an archive of data from 1983 to the present [8]. TAMSAT is derived from a combination of geostationary Meteosat data and gauge observations using a calibration approach that exploits both data sets [9]. The primary objective has been to render historic and near real-time precipitation estimates for drought monitoring in sub-Saharan Africa where there is a lack or complete absence of in situ observations [10].

TAMSAT provides decadal (10-day) rainfall data at 4 kilometres spatial resolution across the whole African continent.

Rainfall and temperature data were collected in the ArcMap protocol of ArcGIS, where decadal data within each month were summed to derive a monthly value. Within ArcMap, monthly rainfall and temperature values from January, 2010 to December 2016 were extracted at each of the 19 sample points using the *Extract Multi Values to Points* tool in the Spatial Analyst toolbox, resulting in a table.

Water Sampling

Water samples were collected from all lagoons under study for five months from September, 2017 to January, 2018 to assess the presence of faecal coliforms and *Vibrio cholerae*. The total number of water samples planned to be collected was 190 from the 19 lagoons under study. However, we managed to collect 164 water samples due to logistical challenges. For quality control purposes, water samples were delivered to two different laboratories: 90 samples to the Food and Drugs Control Laboratory and 74 samples to the Centre for Infectious Diseases and Research in Zambia (CIDRZ) Laboratory, both in Lusaka, for analysis. Sampling techniques were upheld to maintain the efficacy of the samples. Water samples were collected using sterilized 500 mL bottles for bacteriological analysis to the Food and Drugs Control Laboratory, while Whatman 903 filter papers were used to collect and store water samples for CIDRZ Laboratory for isolation of *V. cholerae*.

Procedure taken at Food and Drugs Lab: Water samples were enriched in alkaline peptone broth (1% peptone, 1% Sodium Chloride (NaCl, pH 8.4), using a concentration of broth relative to sample volume. Enriched cultures were incubated for 6 to 8 hours at 35 degrees Celsius, then a loopful of the enrichment broth was streaked onto

thiosulfate-citrate-bile salts-sucrose (TCBS) agar, and the plates were incubated at 35 degrees for 18 to 24 hours. Suspected *V. cholerae* colonies appear yellow, a result of sucrose fermentation.

Procedure taken at Centre for Infectious Diseases and Research in Zambia (CIDRZ): Water samples stored on Whatman 903 filter papers and kept at room temperature were delivered to CIDRZ every month for the detection of *Vibrio cholerae* 01/0139 by Polymerase chain reaction (PCR). In order to perform PCR, deoxyribonucleic acid (DNA) had to be extracted from the bacterial cells. Thermal shock was used to lyse the bacterial cells that were present on the filter papers and release the DNA. The Chelex matrix was used to absorb cell lysis products that interfere with the PCR amplification process. Then, a multiplex PCR assay for rapid detection of toxigenic *Vibrio cholerae* 01 and 0139 was comprehensively done.

Potential Hydrogen Levels

The pH level, which is important in creating a conducive environment for the growth of microorganisms including *V. cholerae*, was measured on a monthly basis from each lagoon. Water samples from each study lagoon were collected for five months in a one-litre container and were submitted to Mahatma Gandhi Memorial Clinic in Kabwe for pH analysis in a Porter Lab. The readings were recorded on the checklist formulated for that purpose. However, the instrument used to measure pH was calibrated from 0 to 8.5, and above 8.5, it was giving a greater than sign, making it difficult to know the exact pH readings for all those that indicated the greater than sign.

Assessment of Sanitation Status in 19 Lagoons of Lukanga Swamps

The evaluation of sanitation status in all 19 sampled lagoons was conducted through observations, as initially designed, and by

asking where people answered the call of nature within the swamps.

Data Processing and Analysis

Data on temperature and precipitation were collected for 84 months from January 2010 to December 2016, and average monthly temperatures and precipitation were reported. A total of 164 water samples for water quality monitoring were collected from 19 lagoons for five months from September, 2017 to January, 2018. Data were entered in Microsoft Excel and then exported to Stata version 14 for analysis.

To assess the association between cholera cases and air temperature and precipitation, Poisson Regression and Zero-inflated negative binomial regression Models were used and compared to choose the best fit model. Zero-inflated negative binomial regression was the best fit model with (AIC 92.7, BIC 107.3) compared to the Poisson regression model with (AIC 296.5, BIC 303.8). The level of significance was set at less than 0.05 with a 95% confidence interval. Results were

presented as frequencies in tables, percentages, and graphs. Data were restricted, and only the research team had access.

Ethical Considerations

The ethical approval of this research was obtained from the University of Zambia Biomedical Research Ethics Committee (UNZABREC). The researcher sought permission from Kapiri Mposhi District Local Authority and the District Health Office, which partly covers the Lukanga swamps where the study was conducted. The Fishing Committees in the Lukanga swamps were also informed of the study.

Results

Cholera Cases from 2010 to 2016 in Lukanga Swamps

The study revealed that there were 133 cholera cases in the period under study. It was observed that 2014 had the highest number of Cholera cases, whilst the lowest was in 2015, when 6 cases were recorded Figure 2.

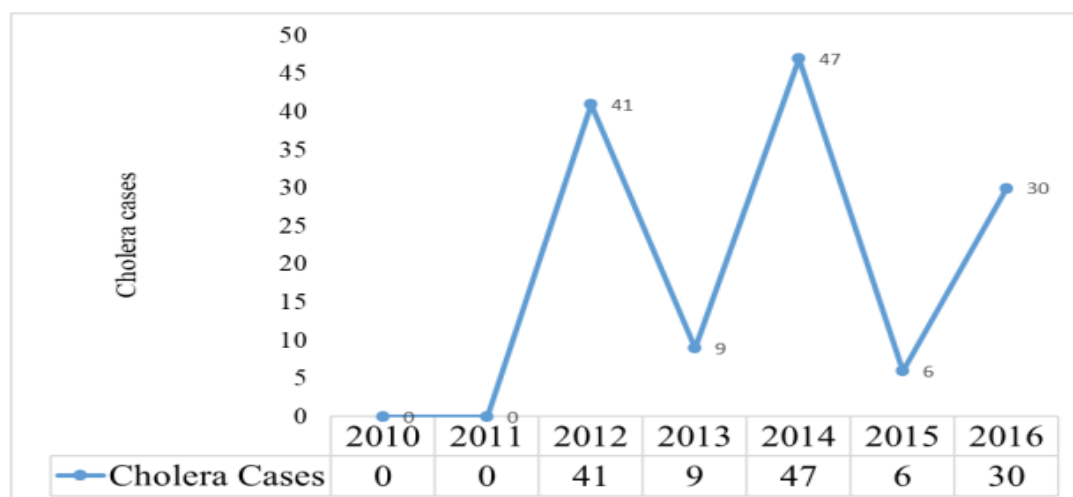


Figure 2. Cholera Cases in Lukanga Swamps from January 2010 to December 2016

Environmental Conditions (Precipitation and Temperature) in Lukanga Swamps from 2010 to 2016

The study revealed that air temperatures in the Lukanga Swamps ranged between 16°C and 28°C from January 2010 to December

2016, with the lowest temperature in June 2010 and the highest in October 2016. Monthly precipitation over the seven-year period showed high variability, spanning from 0.05 mm in April 2016 to 248 mm in December 2013 (Figure 3).

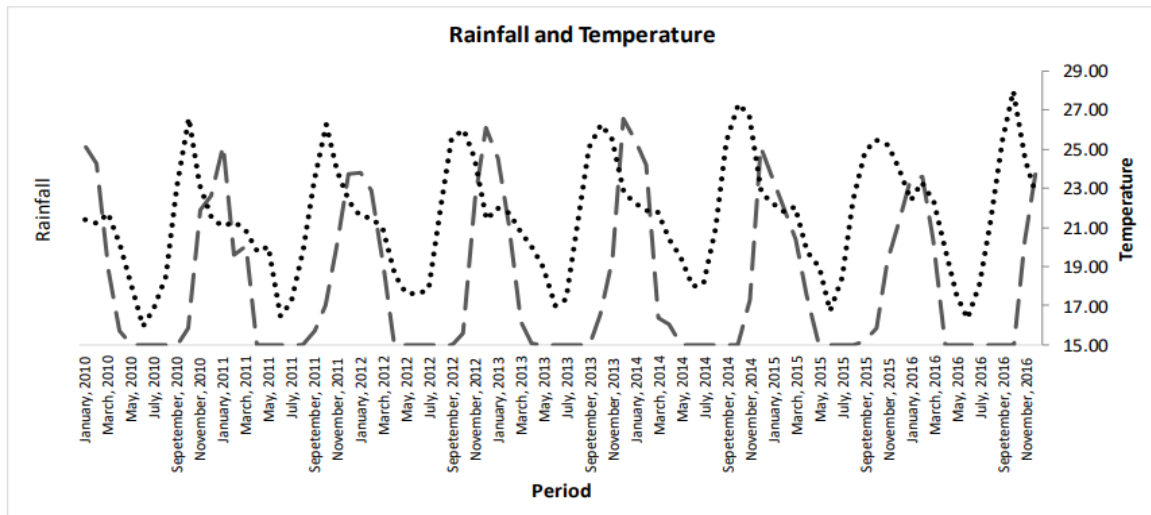


Figure 3. Rainfall (Dashed) and Temperature (Dotted) from 201 to 2016

Association between Environmental Conditions and Cholera Cases in Lukanga Swamps from 2010 to 2016

A significant association was found between increased temperatures and cholera cases ($p = 0.001$), while higher rainfall

correlated with a reduced risk of cholera ($IRR = 0.992$, 95% CI: 0.988–0.997, $p = 0.002$). Additionally, cholera cases in the Lukanga Swamps occurred primarily during the dry season (Figure 4).

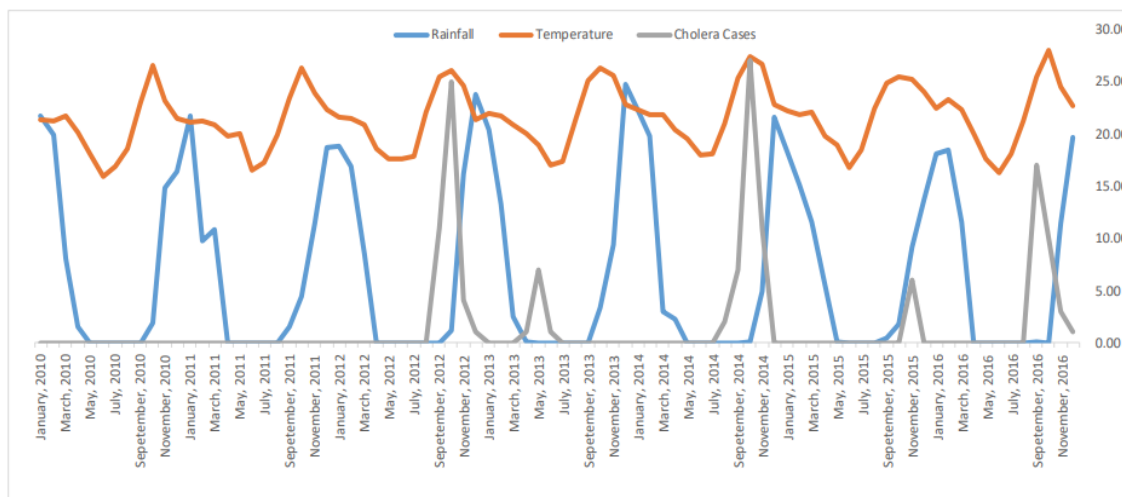


Figure 1. Association between Environmental Conditions (Rainfall and Temperature) and Cholera Cases in Lukanga Swamps from 2010 to 2016

Zero-Inflated Negative Binomial Regression Analysis of the Association between Temperature, Precipitation and Cholera Cases in Lukanga Swamps

The air temperature and rainfall data were collected over 84 months, and the study revealed that increased rainfall was associated

with a decreased risk of cholera cases (Incidence RR = 0.992, 95% CI: 0.988–0.997, $p = 0.002$). The results also revealed that a 1-degree increase in temperature increased the risk of cholera cases by 27% and was statistically significant ($IRR = 1.265$, 95% CI: 1.142–1.402, p -value = 0.0001) (Table 1).

Table 1. Association between Rainfall, Temperature and Cholera Cases using Zero Inflated Negative Binomial Regression Analysis

Predictor Variable	Incidence Rate Ratio (IRR)	P-Value	[95 % CI]
Temperature	1.265	0.0001	1.142 -1.402
Rainfall	0.992	0.002	0.988- 0.997
IRR = Incidence Rate Ratio, CI = Confidence Interval (N = 84 months)			

Sanitation Situation in 19 Lagoons of Lukanga Swamps from September 2017 to January 2018.

The study revealed that in Lukanga Swamps, there is no land that provides for digging and construction of sanitary facilities. That illustrates the impossibility of having a sanitary facility in that aquatic environment.

The study further revealed that people within the Swamps camps live on strong floating surfaces that had been naturally established, though reinforced with grass and reeds to strengthen the base. The study has also shown that both Fishermen and Fish Traders have specific areas designated for sanitation and also for drawing water for drinking, washing cooking utensils, and cooking within the same body of water.

Water Quality Monitoring from the 19 lagoons in Lukanga swamps

The water quality monitoring was conducted over two months, December 2017 and January 2018, to isolate faecal coliforms. The results of the monitoring showed that 19/36 (53%) of water samples were contaminated with faecal coliforms. In December 2017, 12/19 (63%) of the lagoons were contaminated, and the faecal coliform contamination level per 100 ml of water sample ranged from 1-200 Colony Forming Units (CFU). In January 2018, 7/19 (37%) of the lagoons were contaminated, and the faecal coliform contamination level ranged from 2-200 CFU, as indicated in Figure 5.

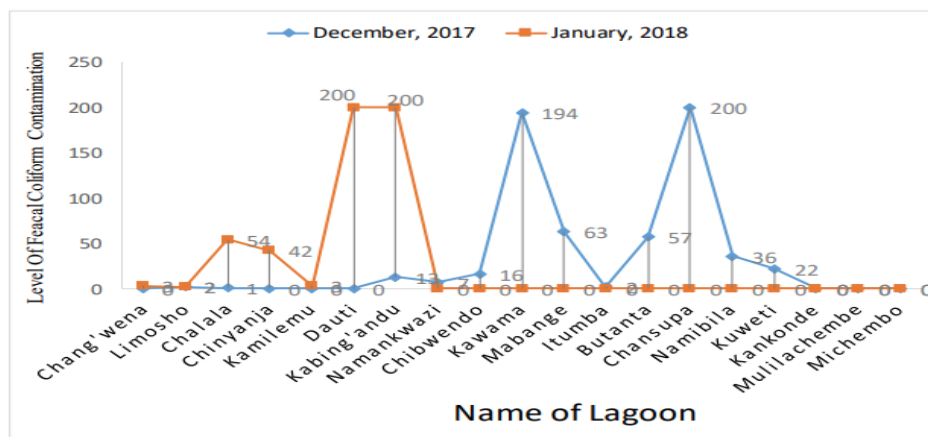


Figure 5. Faecal Coliform (FCU/200ml water) for December 2017 and January, 2018 per Lagoon

Microhabitat Condition (Water pH) of the 19 Lagoons in Lukanga Swamps

A total of 89 water samples were collected and tested for pH from 19 Lagoons monthly from September, 2017 to January, 2018. The pH in the lagoons under study ranged from 7.1 to 8.5. The study indicates that 2/19 lagoons

(Chansupa and Chang'wena) gave pH readings more than 8.5 in all the months beyond the pH testing machine calibration range of 6.5–8.5, while other lagoons had some months with readings beyond the capacity of the testing machine. The study shows variants in pH readings from all 19 lagoons for the period of five months, Figure 6.

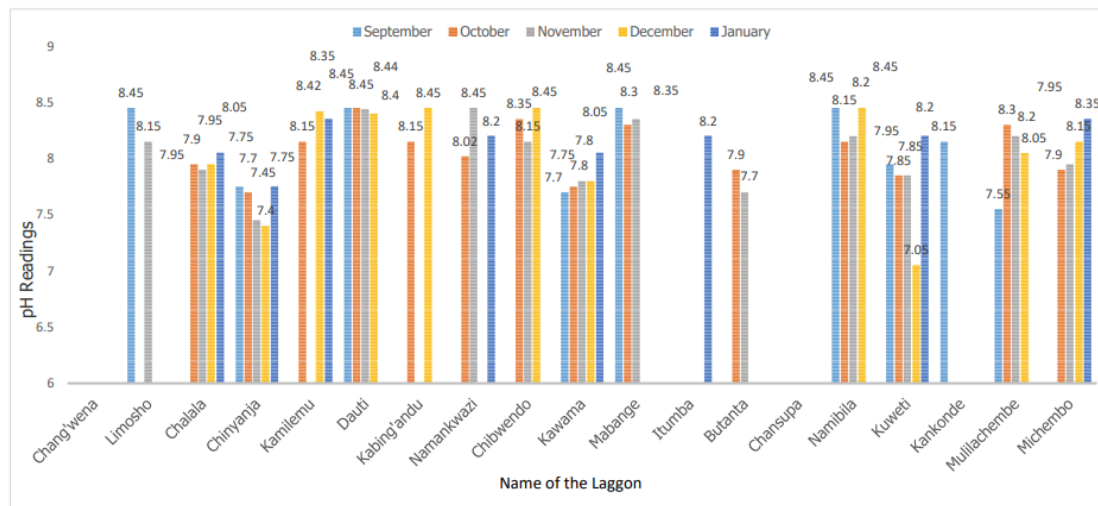


Figure 6. Monthly pH Levels in Water Per Lagoon from September 2017 to January 2018

Water Sample Analysis

A total of 164 water samples were analysed by two different Laboratories to isolate *Vibrio cholerae*. The study revealed that 90/90 (100%) water samples submitted to the Food and Drugs Control Laboratory to isolate *Vibrio* were all non-reactive. It further shows that of the 74/74 (100%) water samples submitted to the Centre for Infectious Diseases and Research in Zambia (CIDRZ) to isolate *Vibrio* were also non-reactive.

Discussion

A total of 133 cholera cases were recorded during the study period. The study indicates that precipitation and temperature are significantly associated with recurring cholera outbreaks in Lukanga Swamps. Environmental and microhabitat conditions provide a supportive environment for *Vibrio* to thrive and trigger cholera outbreaks within Lukanga Swamps. Water quality monitoring showed heavy contamination with faecal coliforms, ranging from 1-200 cfu/100 mL in water samples. The study also showed that all 164 water samples submitted to the Food and Drugs Control Laboratory (90) and the Centre for Infectious Disease and Research in Zambia (CIDRZ) (74), respectively, from September 2017 to January 2018 for *Vibrio* isolation were non-reactive.

This study revealed that cholera outbreaks mainly occurred during the dry season. This agrees with a study in Ghana on cholera outbreak response in two districts in 2016, which found that most cases occurred before the rainy season [11]. This contrasts with a study in Tanzania on co-variation of cholera with climatic and environmental parameters in coastal regions, which found that cholera cases occurred every month between 2004 and 2010 [12].

The study also found that one-degree increase in temperature increases the risk of cholera cases by 27%, and that was statistically significant. This agrees with the study done in Tanzania, which concluded that temperature was significantly associated with cholera, i.e., a 1- degree Celsius increase in air temperature increased the relative risk of cholera by 15–29% [13]. Water temperature, in particular, has been shown to be an important factor governing the seasonal and geographical variation in *Vibrio cholerae* [14]. Another study done in Tanzania shows a significant relationship between cholera cases and temperature and predicts an increase in the initial risk ratio for cholera in Tanzania in the range of 23-51% for a 1-degree Celsius increase in annual mean temperature [15]. The significant relationship between temperature and cholera cases could be because increased

temperature is supportive of growth and multiplication of *Vibrio cholerae*. A study conducted in China in 2012 shows that *Vibrio* is able to grow within the temperature range of 20°C and 45°C and that it cannot survive at 4°C for extended periods [16]. This finding is similar to the study of Gaudart and others, which revealed that about 50% or more cholera outbreaks occurred when the air temperature was $> 31^{\circ}\text{C}$, approximately one standard deviation from average air temperature over the previous 2 months (solid line) [17].

On the other hand, according to a study done in India using a time series statistical model, the incidence of cholera has not been correlated with air temperature [18]. However, according to a time series analytical study done in Bangladesh, Ali and others hypothesised that an increase in Surface Sea Temperature (SST) results in replication of phytoplankton populations, which are directly associated with the increase in *V. cholerae* bacteria and are linked spatially and temporally to zooplankton populations [19].

This study has shown that increased rainfall was associated with decreased risk of cholera cases and was statistically significant. This may be linked to the occurrence of cholera outbreaks mostly during the dry seasons, with high peaks between August and October in Lukanga Swamps, and reduced cholera outbreaks during rainy seasons. This finding was consistent with a time series model study done in India for 11 years from 2000 to 2010, which showed initially that from 2000 to 2004, there was a significant association between rainfall and cholera cases, but from 2005 to 2010 the study indicated a significant negative association between rainfall and cholera cases [20]. On the other hand, a study done in Bangladesh showed an association between cholera and rainfall [21], and this finding was similar to a study done in Zambia by Mudenda in 2014 that heavy rainfall and flooding were

associated with triggering outbreaks of diarrhoea.

In this study, an assessment of sanitation status revealed that there was no land where to dig and construct sanitary facilities. A further assessment indicated that there was open defecation within the aquatic environment.

According to Juliana, the cholera organism can survive in almost all kinds of aquatic environments, including fresh water sources such as lakes, ponds, rivers and tanks. Cholera bacteria can also survive in non-aquatic environments such as refuse dump sites, fruits, fresh vegetables, meat, cooked food, human and animal faecal waste, untreated or inadequately treated waste [22]. The implication of open defecation in an aquatic environment would be a great contribution to the reservoir of *V. cholerae*. The challenge is that carriers could be asymptomatic and shed pathogenic clones in their stools, further enriching the water sources with virulent bacteria and facilitating the initiation of an epidemic [23]. A study undertaken in Ghana in two districts, Akatsi District in Volta Region and Komenda-Edina-Eguafo-Abirem (KEEA) Municipal in Central Region during the 2012 cholera epidemic provided a warning that Cholera remains a threat to areas where access to safe drinking water and adequate sanitation cannot be assured [11].

This study revealed that water sources in the Lukanga swamps were heavily contaminated. A water quality monitoring done in December, 2017 and January, 2018 indicated heavy water contamination with faecal coliforms ranging from 1 – 200 Colony Forming Units (cfu) /100ml of water samples, and that could be due to a cracked safe excreta disposal system and hygiene practices in the aquatic environment of Lukanga Swamps. These results have been substantiated by other studies, and a study conducted in the USA in 2011 indicated that substantial populations of fecal coliforms and *E. coli* are harbored in freshwater bottom sediments, bank soils, and

beach sands [24]. Another study in the USA revealed similar findings on assessment of the available wastewater treatment plant. Treated effluent data and in-stream sampling data indicated that water quality criteria for faecal coliform in recreational waters exceeded 800 cfu/100ml water samples at all locations of the Santa Cruz River [25].

The assessment of microhabitat condition, i.e., potential hydrogen (pH), showed variation across all 19 sampled lagoons over five months. The pH in 89 water samples collected and analysed to assess whether it was within the range that supported the thriving of *V. cholerae* ranged from 7.1 to above 8.5. These results align with previous studies, which have shown that a pH of ~ 8.0 and warm water temperatures between 19 and 28°C were associated with increased concentrations of cholera bacteria [17]. Another study conducted in Haiti to monitor water sources for environmental reservoirs of Toxigenic *Vibrio cholerae* O1 found that, because the sites varied from mountains to floodplains to estuaries, there was relatively wide variability in salinity (0–21.6 g/L), pH (6.4–8.6), and temperature (24.3–33.7°C) [26].

In this study, the analysis of water samples to isolate *Vibrio cholerae* from 19 sampled lagoons of the Lukanga Swamps from September, 2017 to January, 2018 did not yield positive results. A similar study revealed that in most cases *Vibrio cholerae* has been found to persist in its natural environment mainly in two forms: viable but not culturable (VBNC) and conditionally viable environmental cells (CVEC). VBNC is a dormant state that *Vibrio cholerae* enters in response to nutrient deprivation and other environmental conditions [23]. This could probably be one of the reasons isolation of *Vibrio cholerae* during the study period was not achieved. On the other hand, in a study done in Haiti, they managed to isolate *Vibrio cholerae* O1 (toxigenic and nontoxigenic), and all isolations occurred at water temperatures of

>31°C. The study further indicated that there was evidence that *Vibrio cholerae* O1 isolation was more common in the environment preceding epidemic peaks of disease among humans [26]. Water samples were collected for analysis to isolate *Vibrio cholerae* during a non-epidemic period, making it relatively difficult to isolate the organism, as elucidated by Alam and others in their study.

Conclusion

The study revealed that there were 133 cholera cases in the period under study, with the highest number of cases recorded in 2014, with 47 cases, and no cases in 2010 and 2011, respectively. Air temperature was found to be the main predictor associated with cholera outbreaks in the Lukanga Swamps, and it shows the ability to predict these outbreaks with a lag time of two months prior to temperature rise. This implies that if temperature is monitored regularly and when it rises to levels that are supportive of a cholera outbreak, then disease preventive measures could be implemented to prevent the outbreak. The study also revealed that increased amount of rainfall was associated with decreased risk of cholera cases. In Lukanga Swamps, therefore, increased amount of rainfall plays a preventive role against cholera outbreaks, and the risk of cholera outbreaks increases when there is reduced amount of rainfall. This is very important for policy makers and implementers to note when it comes to the application of interventions to prevent disease outbreaks in Lukanga Swamps. Microhabitat condition (pH) showed a supportive environment for growth of *Vibrio cholerae* within the Lukanga Swamps, and coupled with poor sanitation, the risk of cholera outbreak increases. Environmental factors therefore provide early warning systems of cholera outbreaks for impactful implementation of identified interventions in that aquatic environment. Environmental factor-based interventions, coupled with disease

surveillance and individual vaccination, should be fundamental elements for preventing and controlling cholera outbreaks in the Lukanga Swamps.

Recommendations

- To develop an Environmental Management policy that will address environmental factors associated with cholera outbreaks in Fishing Camps of Lukanga Swamps.
- Establishment of a robust surveillance system to detect trend variations in environmental factors and conditions that trigger cholera outbreaks in Lukanga Swamps.
- Development of an individual cholera vaccination programme in Fishing Camps for cholera-prone areas.
- Promote safe water and hygiene within the Lukanga Swamps.
- Strengthen and conduct regular monitoring of environmental factors associated with cholera outbreaks in that aquatic environment.
- Develop and implement an epidemic preparedness plan for mounting a timely and appropriate response.

Limitations of the Study

Humidity could not be extracted through remote sensing, which was supposed to be assessed alongside temperature and precipitation, because it required more time to process.

Water quality monitoring to isolate fecal coliforms was conducted for only two months, December 2017 and January 2018, due to inadequate funds for analysis. Some potential confounding variables that were not identified or considered during the study, and that future studies should consider, include: population movement, water use behavior, vaccination, and socioeconomic status.

What is already known about this Topic?

- Cholera is an epidemic and endemic disease in certain areas
- That Environmental Factors can be associated to cholera endemicity in Lukanga Swamps

What this study adds

- This study shows that air temperature was the main predictor associated with cholera outbreaks in the Lukanga Swamps, and it demonstrates the ability to predict these outbreaks with a lag time of two months prior to a temperature rise.
- This implies that with regular temperature monitoring, preventive measures could be implemented to prevent the outbreak at the right time.
- The study also revealed that an increased amount of rainfall was associated with decreased risk of cholera cases. In Lukanga Swamps, therefore, increased amount of rainfall plays a preventive role against cholera outbreaks, and the risk of cholera outbreaks increases when there is reduced amount of rainfall.

Competing Interests

The authors declare no competing interests.

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Authors' Contributions

- **Simeon Sikwiya:** Conception and design, acquisition of data, analysis and data interpretation, critical revision and manuscript writing.
- **Meki Deborah Chisala, Roma Chilengi:** Conception and design, supervision, critical revision, funding acquisition, and manuscript writing reviews and final approval.

Data Availability

The data supporting this study are not publicly available due to privacy restrictions and ethical concerns. Still, they are available

from the corresponding author upon reasonable request and with permission from the National Remote Sensing Centre of Zambia, which provided technical support to extract the climatological data through the Remote Sensing System.

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