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Climate Change

Cholera Dynamics: The Influence of Climatic Variability (Temperature and Rainfall) in Sumbawanga District, Tanzania

Felex Kibona[1]*, Josephat Saria[1], Brown Gwambene[2], Honest Emmanuel[3]

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Author Affiliation:
[1]Department of Physical and Environmental Sciences, the Open University of Tanzania, P.O. Box 23409, Dar es Salaam, Tanzania
[2]Faculty of science and education, P.O. BOX 200, University of Iringa, Tanzania
[3]Ministry of Health, P.O. Box 743, Dodoma, Tanzania

***Corresponding author:**
Felex Kibona, Department of Physical and Environmental Sciences, the Open University of Tanzania, P.O. Box 23409, Dar es Salaam, Tanzania; Email: felix.kibona@yahoo.com

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ABSTRACT

Cholera is a waterborne disease mainly caused by the bacterium Vibrio cholerae. It has a significant impact on humans, leading to fatalities, especially in third-world countries with poor sanitation and inadequate water supplies. Variations in climatic conditions influence the development and survival of Vibrio cholerae, increasing the risk of cholera outbreaks. This study aims to assess the influence of climate variability on cholera dynamics in Sumbawanga District, Tanzania. It utilizes multiple sources of secondary data, including climatological data (rainfall, maximum and minimum temperatures) from 1994 to 2023, obtained from the Tanzania Meteorological Authority, and cholera cases from 2010 to 2024, obtained from the Ministry of Health, Tanzania. The trends and amount of climatological data were identified by using the Mann-Kendall trend test and the Sens slope estimator, where the significant fluctuation with a decreasing trend in yearly average total rainfall and statistical significance with increasing trends were indicated in both minimum and maximum temperature. Moderate negative correlation (-0.39) was revealed between rainfall and maximum temperature, while a strong negative correlation (-0.64) was revealed between rainfall and minimum temperature. The result indicated a very weak negative relationship between rainfall and cholera incidence in Sumbawanga District, with a correlation coefficient of -0.08. The relationship between maximum temperature and cholera incidence showed a very weak negative correlation of -0.05, while the correlation between minimum temperature and cholera incidence revealed a strong positive correlation of 0.82. According to these findings, immediate actions are required to miminize the effects of cholera related to climate variability. Therefore, policymakers, local authorities, and development stakeholders should collaborate to alleviate adverse effects and enhance resilience in vulnerable communities.

Keywords: Cholera, temperature, rainfall, Climatic variability, and correlation

1. INTRODUCTION

Health is influenced at every stage of life by complex interactions among various elements, including social and economic circumstances, biology and genetics, health services, education, culture, the physical environment, as well as personal health, habits, and coping abilities. Climate constitutes one of several factors that can impact health, and specific analyses are necessary to understand the pathways through which climate and climate change can exert such effects (Kangalawe and Lyimo, 2013). The rise in temperature and rainfall variability patterns influences the survival and development of the pathogen, triggering cholera outbreaks (Bastin et al., 2024). In the region experiencing a shortage of rainfall, it results in a scarcity of water supply for domestic purposes, and the few accessible sources of water become contaminated. Due to the shortage of water sources, communities are at risk of contracting cholera because they consume the available contaminated water (Ishaya and Farida, 2023). The temperature increases the convection process, especially in tropical regions, resulting in heavy rainfall, which is often accompanied by flooding, destruction of sanitation infrastructure, and contamination of water for domestic use, thus increasing the risk of cholera outbreaks (Jutla et al., 2013). Flooding promotes the development and spreading of Vibrio cholerae (Idoga et al., 2019). A study on cholera cases in Qom, Iran, found that lower rainfall is significantly associated with an increase in cholera infections, especially during the warmer months Asadgol et al., 2019). Climate change increases the occurrence and magnitude of waterborne diseases, including cholera (Christak et al., 2020). Cholera epidemics are now associated with climate and climatic events like El Nino. In Africa, there has been a rise in cholera cases, marked by several epidemics in regions affected by El Nino, including Tanzania, which experienced its most extensive outbreak since the 1997–1998 El Nino (Moore et al., 2017). Cholera is a waterborne disease affecting the intestinal caused by the bacterium Vibrio cholerae that exists in surface and well water, seafood, raw fruits and vegetables (Mukherjee, 2021). The bacterium enters the body of a human being through eating tainted food or drinking contaminated water (Onitilo et al., 2023). Communities with low incomes are most vulnerable to cholera outbreaks due to inadequate basic requirements for disease prevention, such as proper sanitation (Mora et al., 2022). The poverty hinders the community from having access to safe water and proper sanitation, where in some parts open defecation is more practised because of being a part of traditional culture, increasing the chance of cholera prevalence (Charnley et al., 2022). Changes in behaviour and attitude, such as discouraging open defecation, use of well-treated or boiled drinking water, and good personal hygiene at the family level, minimize the likelihood of cholera epidemics (Ali et al., 2021; Davies et al., 2017).

Despite the efforts made by national and International organizations to reduce the significant impacts of climate change globally, a gap exists in the influence of climate variables on cholera dynamics at the local levels, including the Sumbawanga District, Tanzania. The study will enable both regional and national policymakers to create a sustainable environment by advising the government and related stakeholders on increasing the number of health centers and providing proper adaptation methods to minimize the risks of cholera at the local level.

2. MATERIALS AND METHODS

2.1. Area of a study

This study conducted in the Sumbawanga district of the Rukwa region in Tanzania, found in the southwestern highland zone of the country (08.40˚S; 31.70˚E) (see Figure 1). Sumbawanga District, located at an elevation of 1,700 meters above sea level, covers a total area of 8,871 square kilometers, of which 668 square kilometers are water and 8,203 square kilometers are land (Lupia et al., 2024). Most residents in Sumbawanga District rely on agricultural activities, particularly cereal crops, as their primary source of income. Those living along the shores of Lake Rukwa depend on both fishing and crop production. According to the 2022 census of housing and population, the Sumbawanga District Council has a total population of 494,330, including 238,600 males and 255,730 females (Mosha and Seko, 2024). Households were selected through simple random sampling to gather primary data on climatic parameters (temperature and rainfall) related to cholera incidence using a well-prepared structured questionnaire. Key informants specialized in health, meteorology, and water quality were involved in data collection in order to share their comprehensive insights related to climate variables and cholera outbreaks. The study included a sample size of 391 respondents, with data collected from four specific wards (Kilangawana, Ilemba, Mtowisa, and Muze) out of the twenty-seven wards in the district.

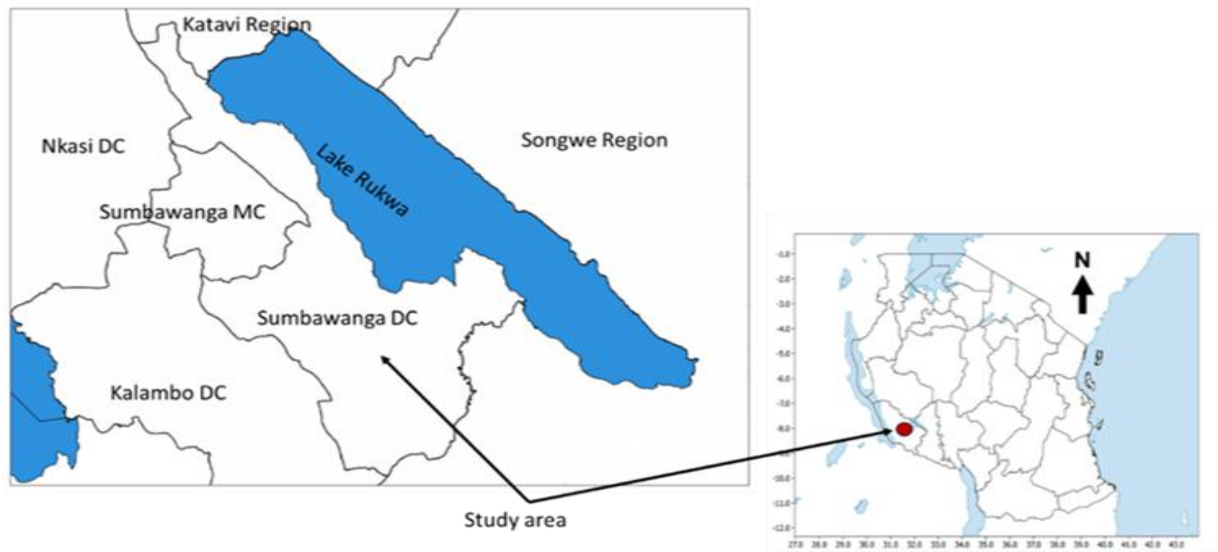

Figure 1. Shows the location of the Study Area

2.2 Data collection methods

The primary data was gathered using a well-prepared questionnaire distributed to households, a key informant interview guide for healthcare providers, and community leaders to collect qualitative data on local perceptions of the relationship between climatic data (temperature and rainfall) and cholera outbreaks. Focus Group Discussions involved community members to gain in-depth insights into local adaptation strategies and community resilience concerning climate change and its impacts (Kabir, 2016). The 30 years of historical climatic data obtained from the Tanzania Meteorological Authority from 1994 to 2023 included total mean monthly rainfall, annual mean maximum temperature, and annual mean minimum temperature. A period of at least 30 years is considered standard for recognizing climate change by the World Meteorological Organization (WMO) (Arguez and Vose, 2011).

2.3. Methodology

In this study, some of the calculations used to calculate climatological parameters, such as anomaly, standardized anomaly, Pearson correlation analysis, as well as trend and significance testing using Mann-Kendall and Sens slope estimator.

2.3.1. Calculations for climatological parameters

To describe clearly the trends of rainfall patterns in the Sumbawanga region, the annual cycle diagram is used. The annual rainfall cycle is a fundamental aspect of regional climate, playing a vital role in both natural and human systems. The following equation is used to calculate the yearly mean rainfall

$$\bar{R}_m = \frac{1}{N}\sum_{i=1}^{N} R_{m,i} \qquad (1)$$

Where: $\bar{R}_m$ = rainfall in month,

$R_{m,i}$ = rainfall in month m of year i

N= number of years.

2.3.2. Anomaly and Standardized Rainfall Anomaly (Z-Score)

The Z-score method was applied to assess the trends and fluctuations in climatic patterns in the Sumbawanga District. The Z-score describes how much wetter or drier the current period is compared to the historical norm. Its importance also lies in detecting droughts and flooding, whereby negative anomalies indicate drier-than-normal conditions (potential drought) while positive anomalies indicate wetter-than-normal conditions (possible flooding). The calculation of the standardized anomaly used the following equation:

$$Z_t = \frac{R_t - \bar{R}}{\sigma} \quad (2)$$

Where:
Z_t = standardized anomaly
σ =standard deviation,
$\bar{R}$ = long-term average rainfall for that period.

2.3.3. Correlation Analysis

The Pearson correlation coefficient is used to assess the linear relationship between rainfall and temperature over the Sumbawanga District. As a statistical measure, it allows us to find the strength and direction of the relationship between climatic data (rainfall and temperature) and cholera cases. Its values range from -1 to +1. The value r = +1 indicates a perfect positive linear correlation, r = −1 indicates a perfect negative linear correlation, while r = 0 signifies no linear correlation at all.
Therefore

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \quad (3)$$

Where X_i, Y_i represent individual data points, $\bar{X}$, $\bar{Y}$ represent the mean of X and Y, respectively, and n represents the number of data points. In this formula, X is rainfall, while Y is temperature.

Furthermore, the Sens slope estimator and the Mann-Kendall trend test were performed to identify trends and magnitude in the time series of climatological parameters (Abegaz and Abera, 2020). Mann-Kendall test statistics (S) is given by the following formula for a given series Xi, i=1, 2, …, n

$$S = \sum_{i=1}^{n-1} \sum_{j=i\_+1}^{n} sign(X_J - X_I) \quad (4)$$

Where Xi and Xj are the values of sequence i, j; n is the length of the time series, and if

θ = Xj - Xi
Therefore

$$sgn(\theta) = \begin{Bmatrix} 1 & if & \theta > 0 \\ 0 & if & \theta = 0 \\ -1 & if & \theta < 0 \end{Bmatrix} \quad (5)$$

For n>10, the test statistic z approximately follows a standard distribution;

$$Z = \begin{cases} \frac{s-1}{\sqrt{var(s)}} \; if \; s > 0 \\ 0 \; if \; s = 0 \\ \frac{s+1}{\sqrt{var(s)}} \; if \; s < 0 \end{cases} \quad (6)$$

s>0= Increasing trend
s=0 No trend
s<0=Decreasing trend

Also, the value of Z obtained from the significance level of 5% in the standard distribution table; the null hypothesis, H0, that there is no trend in the records, is either accepted or rejected (Shifteh Somee et al., 2013). A very high value of S indicates an increasing trend, and a negative value signifies a decrease (Rhavse et al., 2015).

2.3.4. Analysis of survey data

Lastly, the qualitative data from the survey were analyzed using IBM SPSS version 20 to generate descriptive statistics and frequency distributions. Frequencies and percentages in tables and figures using Excel and Pearson correlation were used to present the results of this study.

3. RESULTS AND DISCUSSION

3.1. Demographic Characteristics of Respondents

The demographic characteristics of the respondents reflect the backgrounds of those who directly collected primary data.

Table 1. The Demographic Distribution of Respondents

Variables		Kilangawana (n= 59)		Ilemba (n = 88)		Mtowisa (n = 121)		Muze (n = 123)	
		frequency	percentage	frequency	Percentage	frequency	percentage	frequency	Percentage
Sex	Male	20	33.9	48	54.5	54	44.6	56	45.5
	Female	39	66.1	40	45.5	67	55.4	67	54.5
Age	15-24	8	13.6	6	6.8	3	2.5	16	13.0
	25-34	15	25.4	26	29.5	18	14.9	19	15.4
	35-44	12	20.3	18	20.5	40	33.1	34	27.6
	45-54	19	32.2	23	26.1	44	36.4	38	30.9
	55-64	5	8.5	15	17.0	16	13.2	16	13.0
Marital Status	Single	10	16.9	8	9.1	16	13.2	28	22.8
	Married	23	39.0	41	46.6	75	62.0	65	52.8
	Separated	7	11.9	13	14.8	16	13.2	14	11.4
	Divorced	12	20.3	16	18.2	5	4.1	6	4.9
	widower	7	11.9	10	11.4	9	7.4	10	8.1
Education level	No formal education	5	8.5	12	13.6	23	19.0	29	23.6
	Primary	16	27.1	32	36.4	41	33.9	46	37.4
	O level	16	27.1	23	26.1	38	31.4	33	26.8
	A level	13	22.0	7	8.0	2	1.7	3	2.4
	college/university	9	15.3	14	15.9	17	14.0	12	9.8

3.1.1. The age group of respondents

Table 1 describes the age categories of respondents selected from each ward. The majority age group was 45-54, with 19 (32.2%), 23 (26.1%), 44 (36.4%), and 38 (30.9%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. The age group was 35-44 years, with 12 (20.3%), 18 (20.5%), 40 (33.1%), and 34 (27.6%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. The age group 25-34 years, with 15 (25.4%), 26 (29.5%), 18 (14.9%), and 19 (15.4%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze, respectively. The age group with the lowest number was 15-24 years, with 8 (13.6%), 6 (6.8%), 3 (2.5%), and 16 (13.0%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively.

The study by Hughes et al., (2016) highlighted the importance of including the age groups of respondents in research. It stresses that describing demographic characteristics, such as age, is essential for assessing the maturity levels of participants. This enabled a comprehensive sharing of understanding, experiences, attitudes, and behaviors among respondents of different ages regarding their perceptions of cholera incidence linked to climatic factors in their local environment (Orimbo et al., 2020). It is important to consider the age group of respondents involved in data collection, as mature age groups tend to have sufficient experience related to environmental changes (Gamble et al., 2013).

3.1.2. Marital status of the respondents

Table 1 shows that the most participants were married, with 23 (39%), 41 (46.6%), 75 (62%), and 65 (52.8%) respondents in Kilangawana, Ilemba, Mtowisa and Muze wards, respectively. The single respondents with 16 (16.9%), 8 (9.1%), 16 (13.2%), and 28 (22.8%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. The separated category, with 12 (20.3%), 13 (14.8%), 5 (4.1%), and 14 (11.4% respondents in Kilangawana. Ilemba, Mtowisa, and Muze wards, respectively. The divorced category, with 12 (20.3%), 16 (18.2%), 5 (4.1%), and 6 (4.9%) respondents in Kilangawana. Ilemba, Mtowisa, and Muze wards, respectively. The widower category, with 7 (11.9%), 16 (18.2%), 9 (7.4%), and 6 (4.9%) respondents in Kilangawana. Ilemba, Mtowisa, and Muze wards, respectively.

The marital status of respondents involved in data collection was also considered in this study, where the majority of respondents were married across the selected four wards. The study by Porter and Whitcomb, (2005) emphasized the significance of incorporating demographic information, particularly marital status, in research. Researchers expected that having the majority of married couples would allow them to share living conditions, joint decision-making, and household resilience that shape the health impacts based on climate change (Caspi et al., 1992).

3.1.3. Sex of the respondents

The study examined the sex of the respondents, with each ward having both male and female participants. The majority of respondents were female, with 39 (66.1%), 40 (45.5%), 67 (55.4%), and 67 (54.5%) in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. Male respondents, with 20 (33.9%), 48 (54.5%), 54 (44.6%), and 56 (45.5%) in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively, as shown in Table 1.

The research considered both sexes in data collection, and the results revealed that most of the respondents were female. The study by Tabassum and Nayak, (2021) noted that most women are available and accessible at home for taking care of children and other related domestic activities, while most men are not at home and are busy with other economic activities during the day. Women are willing to express themselves emotionally in everything related to health and social behaviour (Al-Manasra, 2013). Furthermore, women are more frequently engaged with healthcare, education, and social welfare services, increasing their likelihood of being reached and recruited in such settings, including clinics, schools, and community centers.

3.1.4. Education levels of the respondents

The study aimed to explore the education levels of respondents from each ward. Most respondents had a primary education, as indicated in Table 1. The results showed that the majority of the participants had primary education, 16 (27.1%), 32 (36.4%), 41 (33.9%), and 46 (37.4%) at Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. The secondary level of education was the second-highest category, with 16 (27.1%), 23 (26.1%), 38 (31.4%), and 33 (26.8%) respondents from Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. No formal education was the third category, with 5 (8.5%), 12 (13.6%), 23 (19%), and 29 (23.6%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards. The Advanced level of education was the fourth category of education level, with 13 (22%), 7 (8%), 2 (1.7%), and 3 (2.4% respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. Additionally, the College/University Category was the fifth category, with 9 (15.3%), 14 (15.9%), 17 (14%), and 12 (9.8%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively.

The study conducted by Porter and Whitcomb, (2005) highlighted the significance of demographic information during data collection. Participants with higher education levels tend to contribute more knowledge and expertise on the subject matter. Hammer, (2011) emphasized the importance of collecting demographic information from respondents, including their educational levels. The study by Wolf and Moser, (2011) revealed the importance of identifying the educational background of respondents at an early stage, as different levels of education provide a wider range of knowledge due to variations in understanding and experience. The study by Kabir et al., (2016) also explained the importance of involving individuals with both lower and higher levels of education in data collection. An individual with higher education can provide the required knowledge about climate change than those with lower levels of education.

3.2. The temporal trends and variability in rainfall and temperature

3.2.1. Annual rainfall trends

The annual rainfall trend from 1994 to 2023 was analyzed and presented in Figure 2. The results show that the maximum yearly total rainfall of 1,161.7 mm was recorded in 2009, while the minimum yearly total rainfall of 563.9 mm was recorded in 2021.

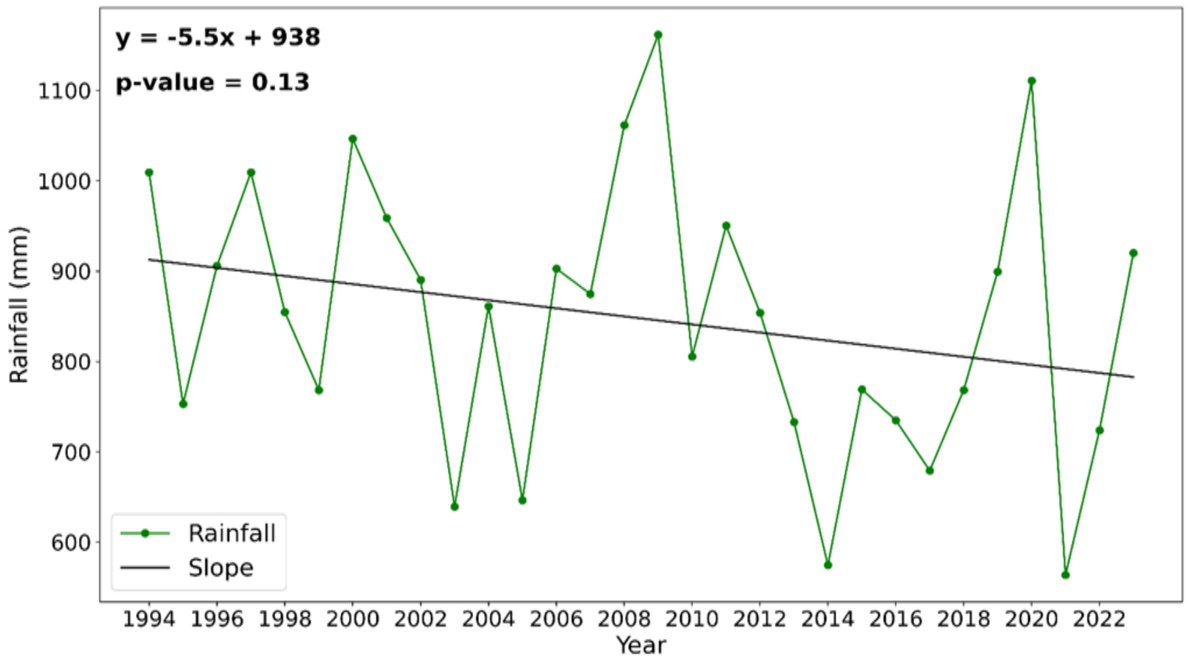

Figure 2. Annual rainfall showing decreasing trends (1994 – 2023)

The study shows that the Sumbawanga District experiences a temporal rainfall variability with a decreasing trend. The study by Owusu and Waylen, (2009) on the coast of Guinea in West Africa shows both temporal and spatial fluctuations in rainfall patterns with a declining trend. Moreover, Gebrechorkos et al., (2019) revealed that the rainfall variability in East Africa is influenced by the El Nino Southern Oscillation and the Indian Ocean Dipole, causing both upward and downward trends in different regions. The study findings by Ongoma et al., (2018) noted a decline in rainfall distribution, observing that both very heavy and severe rainfall have decreased from 1961 to 2010. However, the rate of this decrease is statistically insignificant.

3.2.2. Annual mean maximum temperature trends

The results in Figure 3 show the annual mean maximum temperature, with the highest of 29.9°C recorded in 2021 and the lowest of 22.6°C recorded in 2003.

Figure 3 indicates an increasing trend of annual average maximum temperature, revealing 0.6°C per decade, which is statistically significant. Hansen et al., (2006) in their study revealed that in the last 30 years, the global temperature has been rising by 0.2°C every ten years. Collins, (2011) revealed a significant increase in temperature trends from 1979 to 2010 across most African regions, including Northern and Southern Hemisphere Africa, tropical Africa, and subtropical Africa. Moreover, Changa et al., (2021) revealed that over the last two decades, temperatures have been observed to show an increasing trend in some regions in Tanzania, consistent with an overall rise in global temperature. Also, the study findings by Arellano et al., (2025) noted a positive temperature trend in Spain and future extreme temperature events are predicted to rise as a result of this trend, extending across a wider area.

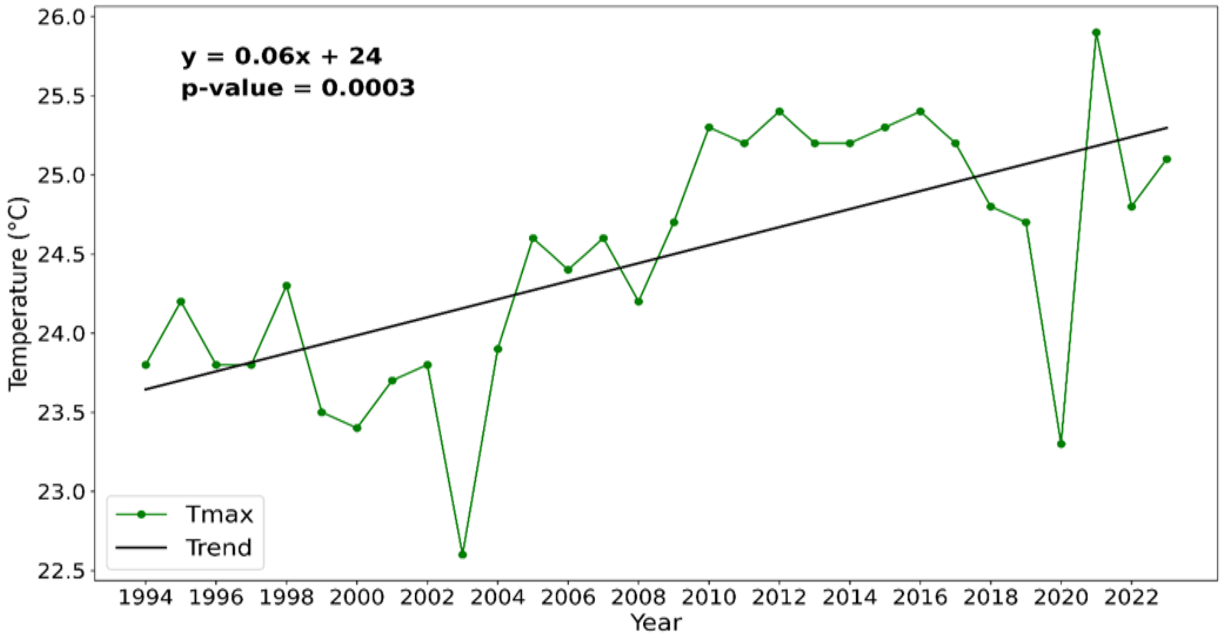

Figure 3. The 30-year annual average maximum temperature trends (1994-2023)

3.2.3. Annual minimum temperature trends

Figure 4 revealed that the highest minimum temperature recorded was 15.4°C in 2014, while the lowest minimum temperature was 11.2°C recorded in 2009.

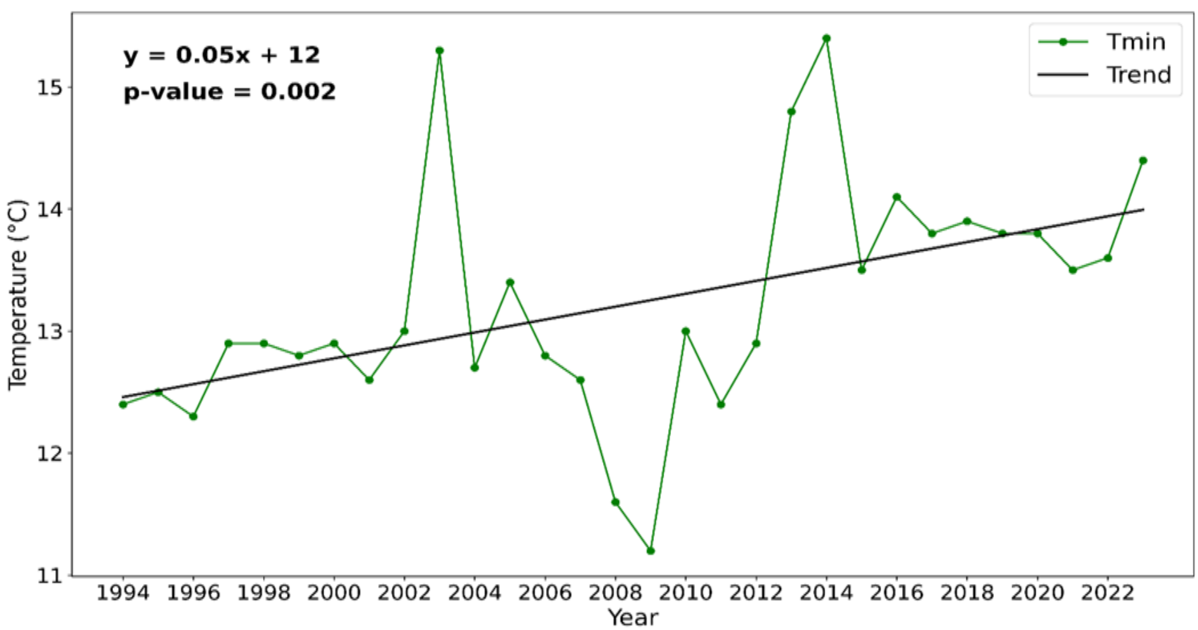

Figure 4. Annual average minimum temperature trends (1994 –2023)

Figure 4 indicates that there is a statistically significant trend, indicating a positive trend over the period. Sun et al., (2019) in their study indicated that the decrease in diurnal temperature range, suggesting that night temperatures increased, and implying a greater increase in minimum temperature than maximum temperature. Changa et al., (2017) noted that in Tanzania, the percentage of cold nights has decreased by 10%, indicating that there is a rise in minimum temperature from 1961 to 2015. Lindsey and Dahlman, (2020) in their study revealed that the global increase in minimum temperature is uniform across all regions. Msomba et al., (2025) noted a positive trend in meteorological parameters that distress crop productions by creating favorable conditions for the survival and development of pests as well as influencing human diseases.

3.3. Cholera dynamics

3.3.1. Correlation between maximum temperature and cholera

Figure 5 indicates the relationship between the monthly average maximum temperature and the monthly cholera cases, which suggests a very weak negative correlation (r=-0.05).

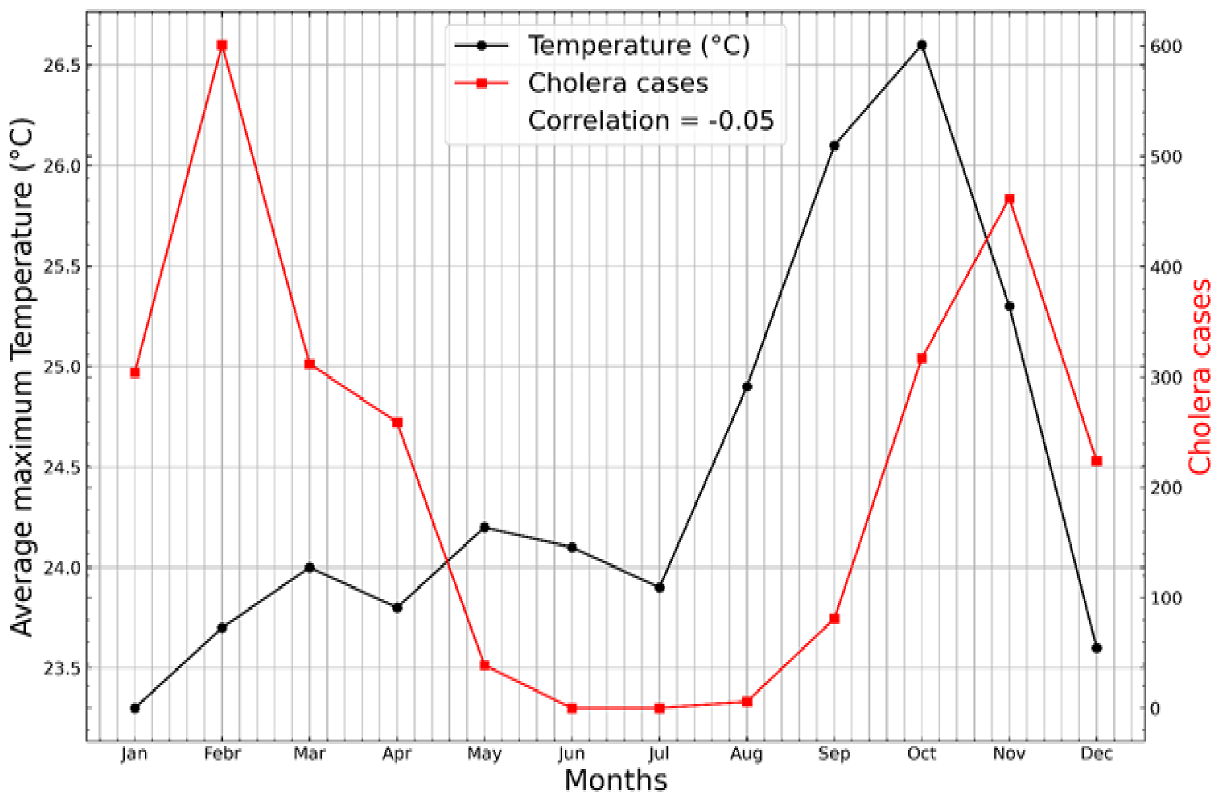

Figure 5. Relationship of monthly average maximum temperature and cholera outbreaks (2010-2024).

The results indicate that the increase in temperature does not correlate with the cholera outbreaks. The study by Ishaya and Farida, (2023) in Nigeria revealed no correlation between meteorological parameters (temperature and rainfall) and cholera cases.

3.3.2. The relationship between minimum temperature and cholera outbreaks

Figure 6 revealed the relationship between minimum temperature and cholera outbreaks in the Sumbawanga District from 2010 to 2024, indicating a strong positive correlation of 0.82.

Figure 6 shows that the increase in minimum temperature influences the cholera cases. Hashizume et al., (2010) demonstrated that the change in temperature significantly influences cholera dynamics. Charnley et al., (2021) noted that the temperature rise modifies the intensity of evaporation, consequential in the drying up of many sources of water. The remaining few sources of water inspire Vibrio cholerae to concentrate and develop in a small area, leading to more cholera prevalence. The study by Asagdol et al., (2010) revealed that extreme weather events such as floods enable the movement of Vibrio cholerae from one place to another, spreading cholera within the community.

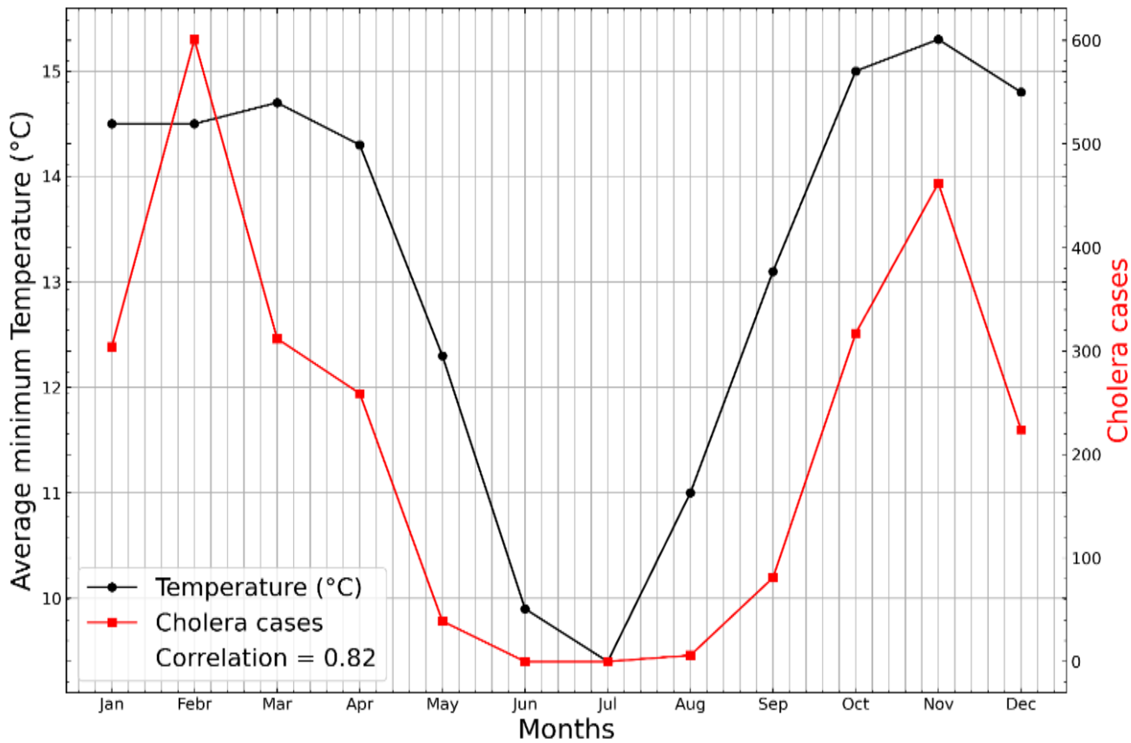

Figure 6. Annual relationship between minimum temperature and cholera outbreaks.

3.3.3. Correlation of rainfall patterns and cholera

Figure 7 shows a correlation coefficient of 0.61, suggesting a moderate positive relationship between rainfall and cholera cases in the Sumbawanga District.

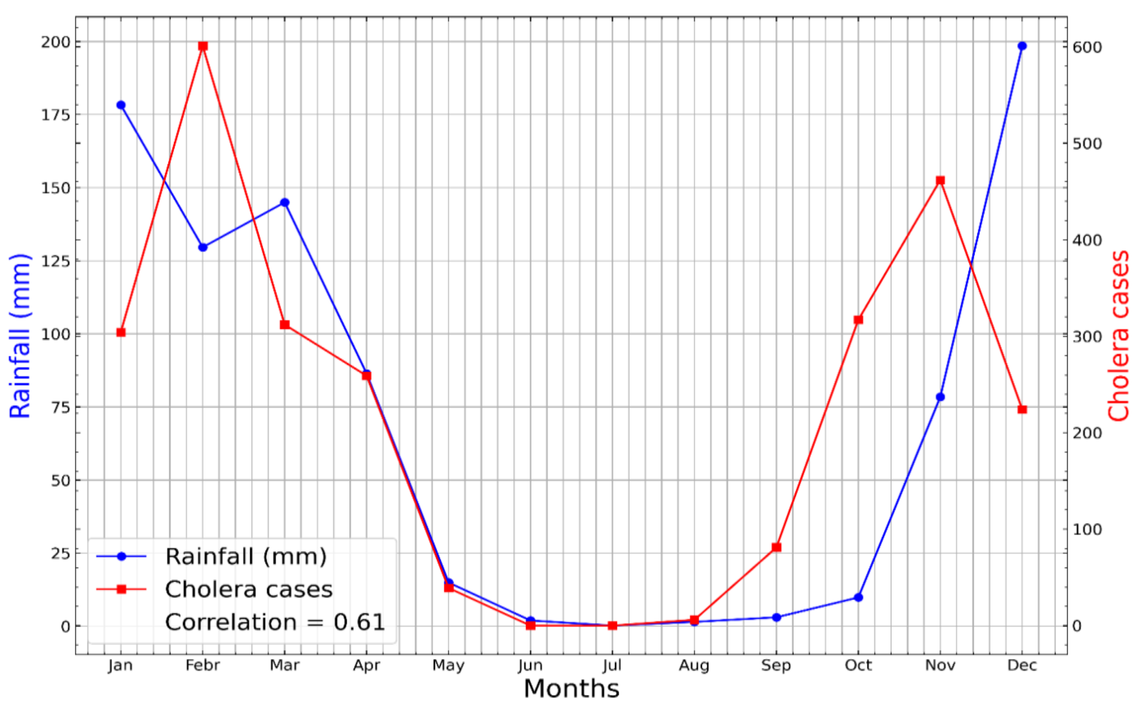

Figure 7. The monthly relationship between rainfall and cholera cases (2010-2024).

Figure 7 indicates a correlation coefficient of 0.61, suggesting a moderate positive relationship. Floods destroy sanitation infrastructures and expose Vibrio cholera to the surface, contaminating domestic water (Morris, 2011). The study by Charnley et al., (2022) observed more cholera cases during the rainy season or just after the rainy season, depending on the stability and nature of the infrastructure. The study by Ganesan et al., (2020) noted the increase in the frequency and intensity of cholera outbreaks when the drought persists for a long time.

3.4. Perceived climatic variables and cholera dynamics

3.4.1. Perceived rainfall patterns and cholera

Figure 8 indicates the observed and perceived impacts of rainfall on cholera outbreaks. The majority of respondents replied to an increase in floods, with 7 (11.9%), 21 (23.9%), 55 (45.5%), and 49 (39.8%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze, respectively. Respondents replied not sure with the changes in flood, with 17 (28.8%), 26 (29.5%), 52 (43%), and 48 (39%) in Kilangawana, Ilemba, Mtowisa, and Muze, respectively. A decrease in flood was reported, with 29 (49.2%), 31 (35.2%), 8 (6.6%), and 14 (11.4%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze, respectively. Flood remains the same, with 6 (10.2%), 10 (11.4%), 6 (5%), and 12 (9.8%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively.

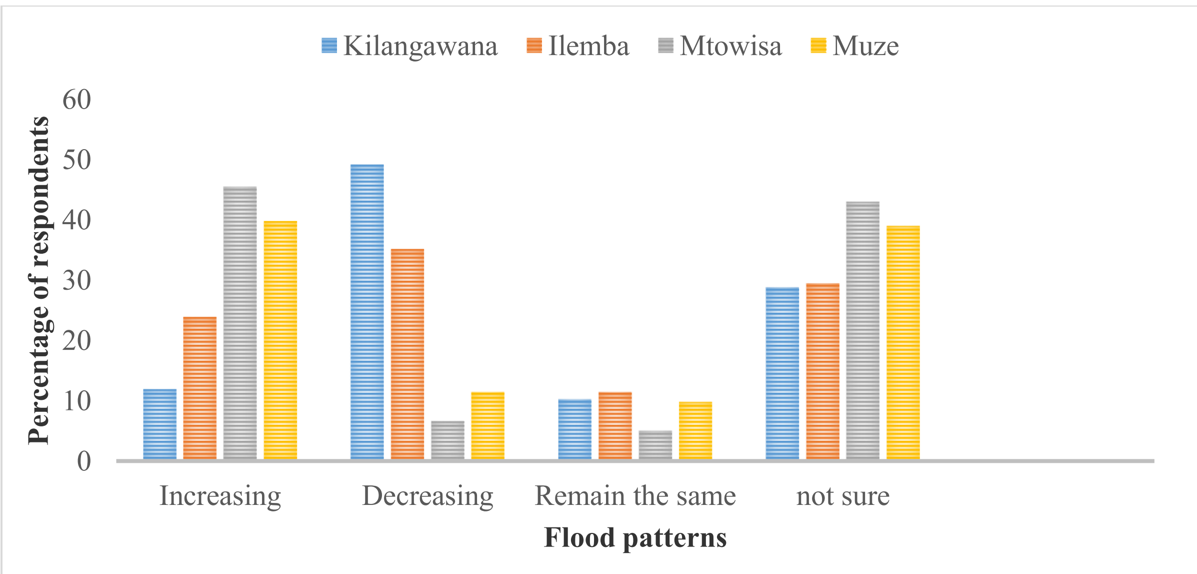

Figure 8. The perception effect of rainfall on cholera outbreaks

The study by Bastin et al., (2024) revealed that floods can transport Vibrio cholera from one point to another, contaminating water used for domestic purposes. Idoga et al., (2019) noted that the floods can lead to an increase in water levels that favours the development and spread of Vibrio cholera, which is the main causative of cholerae. Charnley et al., (2021) noted that during the drought, limited water bodies encourage the concentration of Vibrio cholerae, resulting in cholera epidemics. Floods from heavy rainfall expose Vibrio cholera to the surface, creating interaction with human beings, resulting in cholera transmission (Carrel et al., 2010). Heavy rain in areas with poor infrastructure leads to the contamination of domestic water, increasing the intensity and frequency of cholera outbreaks (Anthonj et al., 2022).

3.4.2. The effects of temperature on cholera outbreaks

Figure 9 indicates community perceptions regarding the temperature effect on water quality and storage. The majority of respondents replied to moderate impacts, with 28 (47.5%), 28 (31.8%), 73 (59.3%), and 73 (59.3%) in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. High impact, with 28 (47.5%), 55 (62.5%), 45 (37.2%), and 42 (34.1%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze, respectively. The low impact was reported with 3 (5.1%), 4 (4.5%), 8 (6.5%), and 8 (6.5%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze, respectively.

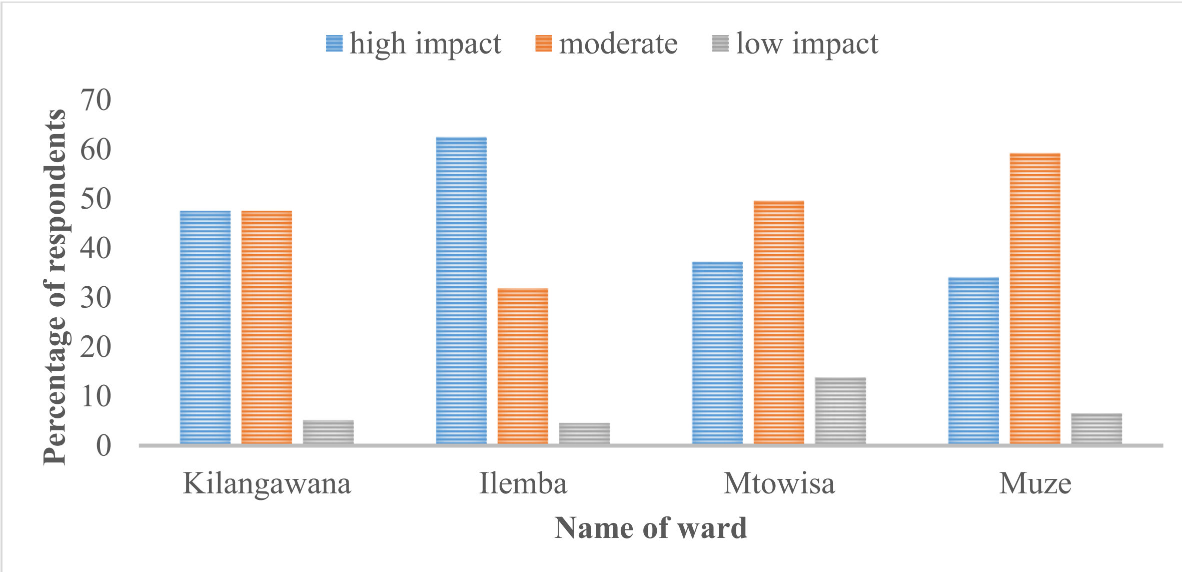

Figure 9. The local community perceived effects of temperature on water quality

Asadgol et al., (2019) demonstrated that surface temperatures (20°C to 30°C) create conducive environmental conditions for the development and survival of Vibrio cholerae, posing a significant cholera epidemic. Chernley et al., (2021) in their study noted that rising temperatures during droughts lead to higher concentrations of Vibrio cholerae, as access to clean drinking water becomes limited. The survey conducted by Ishaya and Farida, (2023) indicated that the frequency of cholera is higher during the dry season compared to the rainy season. This relationship is due to limited water for domestic purposes, encouraging the existence and development of pathogens.

3.4.3. The perceived temperature trends

Figure 10 shows various perceptions regarding the temperature trend. The majority of respondents replied to an increase in temperature, with 35 (59.3%), 68 (77.3%), 85 (70.2%), and 76 (60.2%) in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. No change in temperature was reported, with 13 (22%), 10 (11.4%), 21 (17.4%), and 26 (21.1%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. A decrease in temperature was reported, with 11 (18.6%), 10 (11.4%), 15 (12.4%), and 23 (18.7%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively.

Most respondents believe that temperatures in the Sumbawanga District are rising. According to Changa et al., (2021), there has been an increase in temperature trends over the past two decades, which aligns with the global temperature patterns highlighted in recent Intergovernmental Panel on Climate Change (IPCC) reports regarding the State of Climate in Africa report. According to the research conducted in South Africa (1960 to 2003), 23 meteorological stations out of 26 stations showed a statistically significant increasing trend in maximum temperature (Kruger and Shongwe, 2004).

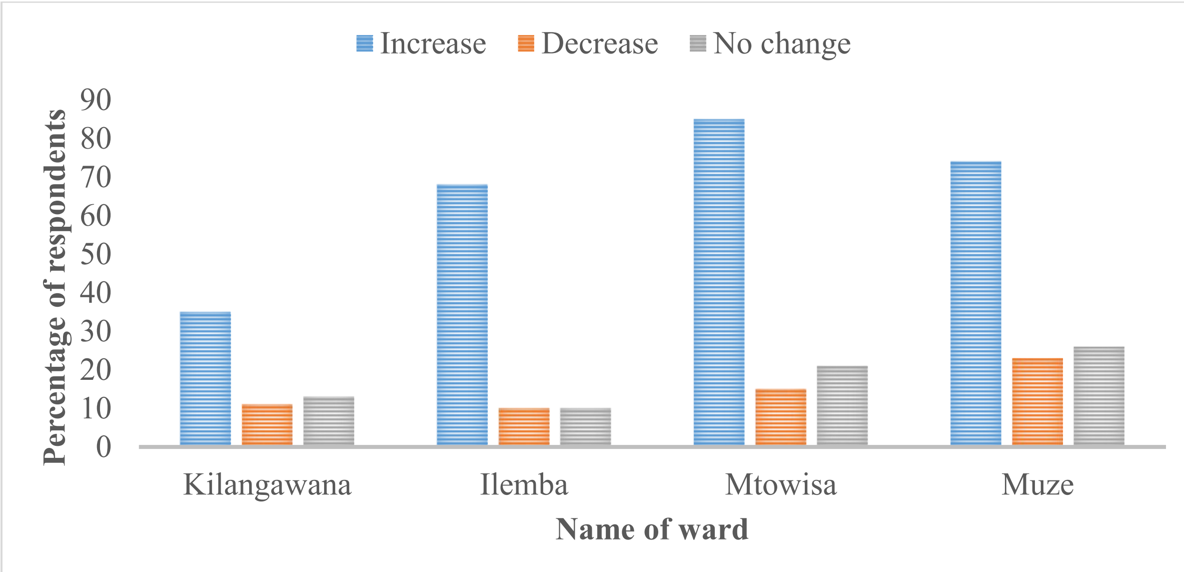

Figure 10. Local community perceived temperature trends in Sumbawanga District

3.4.4. The perceived rainfall patterns and distribution

Figure 11 shows the perceptions of respondents from all wards about the patterns and distribution. The majority of respondents replied to slightly less rainfall, with 17 (28.8%), 38 (43.3%), 41 (33.9%), and 56 (45.5%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. Much more rainfall with 10 (16.9%), 4 (4.5%), 48 (39.7%), and 28 (22.8%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. Much less rainfall, with 14 (23.7%), 27 (30.7%), 14 (11.6%), and 12 (9.8%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. No change, with 9 (15.3%), 7 (8%), 11 (9.1%), and 14 (11.4%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively. Also, slightly more rainfall, with 9 (15.3%), 12 (13.6%), 7 (5.8%), and 13 (10.6%) respondents in Kilangawana, Ilemba, Mtowisa, and Muze wards, respectively.

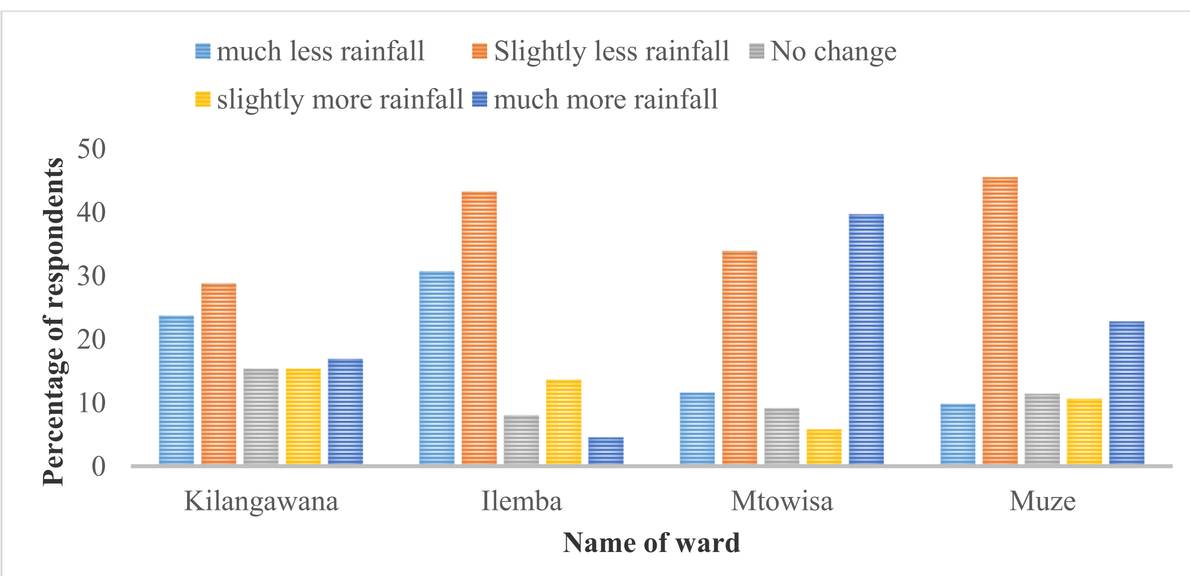

Figure 11. Local community perceived rainfall trends in Sumbawanga District

The study by Christaki et al., (2020) noted that the rainfall variability influences the water quality by creating a conducive environment and fostering the proliferation of Vibrio cholera, increasing cholera prevalence. Heavy rainfall creates floods that enable the contamination of Vibrio cholera with domestic water, favoring the transmission (Idoga et al., 2019).

4. CONCLUSION AND RECOMMENDATIONS

The study confirmed that both increases and decreases in rainfall could heighten the risk of cholera, reflecting a non-linear relationship between climate and disease. Findings revealed that rising minimum and maximum temperatures, alongside variations in rainfall patterns, contribute to creating favourable conditions for cholera transmission. Flooding from heavy rainfall often overwhelms sanitation infrastructure, contaminating water sources and increasing cholera epidemics. Conversely, prolonged dry periods push communities to rely on unsafe water sources, further amplifying outbreak potential.

The study recommends that national, local, and regional policymakers should prioritize the strengthening of the network of meteorological stations, strengthening of health centres, improving climate-resilient WASH infrastructure, enhancing early warning and disease surveillance systems, promoting community-based education and engagement, encouraging household-level adaptation strategies, and supporting policy integration and multi-sector collaboration.

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Authors contributions

Felex Kibona; Writing original draft, Validation, Software, Investigation, Methodology, Data curation, Conceptualization, Formal analysis. Josphate Saria; Visualization, Validation, Supervision, Methodology, Conceptualization, Data curation, Formal analysis. Brown Gwambene; Writing, Review and Editing, Methodology, Formal analysis. Honest Emmanuel: Writing, Review and Editing, Methodology, Formal analysis. All authors reviewed and approved the final manuscript.

Informed consent

Oral informed consent was obtained from individual participants included in the study.

Ethical approval

The study was done in conformity with ethical guidelines. Participation was entirely voluntary, and all respondents provided informed consent. The participants' anonymity and confidentiality were ensured, and the data obtained were utilized purely for the study. The ethical guidelines for Human Subjects are followed in the study.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

Data can be provided upon request by contacting the Tanzania Meteorological Authority and the Ministry of Health, Tanzania.

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