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SPATIAL ANALYSIS OF CHOLERA CASES AND RELATED SOCIO-ECONOMIC FACTORS IN FLOOD PRONE AREAS OF BUDIRIRO AND GLEN-VIEW, HARARE

BY

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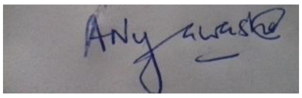
Abstract

Cholera remains a significant public health challenge in urban areas, particularly in regions prone to flooding. This study investigated the spatial distribution of cholera cases and the associated socio-economic and environmental factors in Budiriro and Glen View, Harare, Zimbabwe. A household survey was conducted using a questionnaire to obtain household level data on sanitation hygiene behaviours and practices and related socio-economic factors. Additional data was obtained through key informant interviews using an interview guide while historical data was obtained from City of Harare. Using spatial analysis techniques within a GIS framework, cholera hotspots were identified and correlated. Chi square was used to test for association. Results showed that proximity to sewer chokes significantly increases cholera risk (p-value ≤ 0.001). Distance from boreholes also significantly correlates with cholera cases ($p \leq 0.001$), with intermediate distances (101–300m) showing higher cholera risk, likely due to cross-contamination. There is no statistically significant relationship found between water source types and cholera cases ($p = 0.410$). This implies that cholera risk may depend more on secondary factors rather than the type of source. Socio-economic factors also had varied influence on cholera cases. In terms of gender, males were significantly more affected than females ($p = 0.002$). This implies that gender-sensitive cholera prevention strategies are essential. Cholera risk also significantly varied across age groups ($p \leq 0.001$), with individuals aged 15+ years most affected. Younger children had lower cases, possibly due to protective caregiving practices. Meanwhile, no significant relationship was found between education level and cholera risk ($p = 0.433$). Cholera cases were evenly distributed across education levels. This implies that knowledge alone may not reduce cholera risk. Knowledge levels showed no significant association with cholera risk ($p = 0.350$). This suggests a gap between knowledge and practice. Handwashing with soap is globally considered the most cost-effective way of preventing and controlling cholera. Handwashing practices were significantly associated with cholera risk ($p \leq 0.001$). Regular handwashing reduced risk but did not eliminate it completely. This underscores the need for complementary interventions. While water treatment is expected to result in high protection, water treatment practices were not significantly associated with cholera risk ($p = 0.343$). This was counterintuitive and highlighted gaps in water treatment practice. Treated water could become re-contaminated due to improper storage, emphasising the need for consistent water quality monitoring. By addressing hotspots, environmental and socio-economic risk factors, these recommendations provide a holistic strategy to reduce cholera incidence in flood-prone urban areas.

Key words: Spatial Analysis; Cholera Cases; Flood-Prone Area; Socio-economic Factor.

Declaration Page

I declare that this dissertation is my original work except where sources have been cited and acknowledged. The work has never been submitted elsewhere and will not be submitted to any other university for the award of a degree.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Copyright

Dedication

This research is dedicated to my wife Agness Nyawasha and my family, for standing with me when things were tough and challenging, when I struggled to balance work, study and social life. They offered me assurance, comfort and strength to endure.

List of Acronyms and Abbreviations

Africa CDC	Africa Centres for Disease Control and Prevention
CATIs	Case Area Targeted Interventions
CTX	cholera toxin
ECHO	European Commission for Humanitarian Assistance
E. coli	Escherichia coli
FGD	Focus Group Discussions
GIS	Geographical Information System
GPS	Global Positioning System
GTFCC	Global Task Force on Cholera Control
KII	Key Informant Interviews
MoHCC	Ministry of Health and Child Care
MSD	Meteorological Service Department
MSD	Meteorological Service Department
NGO	Non-Governmental Organisation
OCVs	Oral cholera vaccines
ORS	Oral Rehydration Salts
SADC	Southern Africa Development Community
SDG	Sustainable Development Goal
SEM	Socio-Ecological Model
SitRep	Situational Report
USD	United States Dollars
WASH	Water Sanitation and Hygiene
WHO	World Health Organisation
ZINWA	Zimbabwe National Water Authority

Table of Contents

CHAPTER 1: INRODUCTION

1.1 Introduction

This chapter provides an overview of the research topic, establishing the context and significance of the study. It begins by introducing the central theme and key concepts related to the subject area. The chapter articulates the specific problem being addressed, highlighting its importance and the need for investigation. The purpose of the study is outlined, detailing the main objectives and research questions it aims to answer. Relevant background information about the study's context such as geographic, social, or historical aspects is presented to situate the research within a broader framework. The significance of the study is emphasized, showcasing its potential contributions to the field and benefits to specific populations or communities. Additionally, the chapter discusses anticipated limitations and defines the scope of the research, clarifying what will and will not be covered. Finally, the chapter concludes with a brief overview of the structure of the study, providing a roadmap for the reader on how each subsequent chapter will build upon the previous one to address the research objectives.

1.2 Background to the study

Cholera remains a significant public health threat globally, with an estimated 1.3 to 4 million cases and 21,000 to 143,000 deaths recorded annually, affecting community health and labour availability, reducing productivity, and increasing household and government expenditure on health (WHO, 2024). It is most prevalent in low-income countries with limited access to clean water, sanitation, and healthcare, particularly in regions of Africa, South Asia, and the Caribbean. Zimbabwe is ranked among the top 20 countries targeted for cholera eradication under the Global Roadmap to 2030 developed by the Global Task Force on Cholera Control (GTFCC). The GTFCC's "Ending Cholera: A Global Roadmap to 2030" initiative classifies Zimbabwe as a priority country due to its history of recurrent cholera outbreaks, high-risk populations in urban and rural areas, and challenges related to water, sanitation, and healthcare infrastructure.

This roadmap aims to reduce cholera deaths by 90% and ultimately eliminate the disease in targeted regions through enhanced vaccination efforts, water and sanitation improvements, and rapid response to outbreaks. Countries like Zimbabwe are prioritized due to their vulnerability to cholera and the potential impact that coordinated efforts can have on reducing disease incidence in these high-burden region. Climate change is recognised as one of the most critical threats that increases vulnerability to cholera outbreak among the at-risk population in urban areas. Major impacts on the environment and society have been in the form of droughts, and floods. Flooding in one part and drought (dry season) in the other parts increase the complexity of the outbreak response. The Africa Centre for Disease Control and Prevention, the continent's chief health advisory body, has also tied the worst outbreak of cholera in three years to climate change, saying adverse weather is raising the risk of this disease faster than in the rest of the world (Africa CDC, 2018). Data from the World Health and national governments, also show that cholera cases surge whenever cholera hotspot areas experience flooding Organization (WHO, 2019). Between 2022 and 2023, cholera cases surged more than four-fold in the region following Cyclone Freddy. The number of cases jumped to about 95,300 from about 26,250 including over 1,600 deaths in the three countries of Zimbabwe, Zambia and Mozambique, making it one of the worst cholera outbreaks in decades (ibid).

Cholera is a waterborne disease often associated with poor sanitation and contaminated water sources, especially in areas prone to flooding. In Harare, the suburbs of Budiriro and Glen-View have been hotspots for cholera outbreaks, partly due to poor sanitation infrastructure, high population density, and frequent flooding. Floods can exacerbate the spread of cholera by contaminating drinking water sources with sewage. Spatial analysis using GIS can help understand the geographic distribution of cholera cases, identify environmental factors contributing to the outbreaks, and assist in planning effective public health interventions. Previous studies and epidemiological data have identified specific areas within Harare that consistently exhibit high incidences of cholera cases, indicating the presence of hotspot areas associated with flooding (Ayling, et al, 2023). Statistical modelling by Luque-Fernández et al. (2012) showed that for every 100 m increase in elevation, cholera risk dropped by about 30%, underscoring that low-lying, flood-prone suburbs (particularly southwest) were persistent hotspots. Furthermore, spatial analyses have demonstrated how cases can cluster among close contacts and therefore be more prevalent in dense living conditions where safely managed water supply is not readily available for drinking and domestic use (White et al, 2022). Understanding the dynamics of contamination pathways in these hotspot areas is therefore crucial for cholera anticipation, targeted intervention and developing early action strategies for risk mitigation and elimination. This research thus stems from the urgent need to understand patterns of cholera outbreaks with a view to effectively anticipate cholera risk and develop effective early actions and response strategies aimed at cholera risk mitigation and elimination in the country in line with the Global Cholera Elimination Plan, or the "Global Roadmap to

2030,". Traditional approaches to cholera control have not sufficiently addressed the key transmission pathways and risk factors driving transmission within these localized hotspots. Advances in Geographic Information Systems (GIS) and spatial analysis techniques have provided researchers with powerful tools and opportunities to generate evidence required to analyse the spatial disease transmission dynamics, and inform evidence-based interventions. Given the persistent nature of cholera outbreaks in Harare, particularly in the Western district, there is a pressing need for evidence-based interventions tailored to the specific characteristics and trends of hotspot areas, to effectively mitigate and eliminate the epidemic. This research thus seeks to carry out a spatial analysis of the key cholera risk factors in hotspot areas of Harare Western district, to understand their trends, relationships and how they reinforce each other in influencing cholera outbreak. This will help improve early warning, prediction of cholera outbreak and recommend early action for cholera risk elimination and mitigation.

1.3 Problem statement

Cholera continues to recur in Zimbabwe, with Budiriro and Glen View repeatably being the major hotspot areas, resulting in deaths, suffering and huge burden on the national fiscus and the health delivery system. If not addressed, the risk is likely to continue in the context of recurring climate-change and cyclone-related flooding in the target areas which amplifies the risk factors and increases vulnerability of local communities. While the general determinants and drivers of the epidemic are known, Ayling et al, (2023) reiterate that there is still a lack of understanding of cholera risk factors and how they interact and reinforce each other at local level to drive cholera outbreak and hotspot formation. This is undermining effective cholera risk mitigation and elimination in Zimbabwe as outlined in the National Cholera Elimination Plan of 2018-2028 and the achievement of Zimbabwe's vision of becoming an Upper Middle-Income country by 2030. The research sought to deepen understanding of the spatial patterns of cholera and related risk factors, to provide evidence-based insights that guide development of early warning systems and triggers, better prediction, early action, and the design of targeted interventions for effective cholera risk mitigation, elimination, and resilience building in urban settings. The study sought to do so by conducting a rigorous spatial analysis of cholera and related risk factors in hotspot areas of Harare, utilizing Geographic Information System (GIS) and advanced statistical techniques, based on the February 2023 to 30 June 2024 cholera outbreak. This was done through analysing historical epidemiological data, integrating it with socio-economic, infrastructural, environmental, and demographic variables.

Definition of terms

Key terms used in this study are defined. These definitions were adapted from WHO (2023) and OCHA (2022), with contextual modifications.

Cholera	It is an acute, infectious diarrheal disease caused by the bacterium Vibrio cholerae (WHO, 2023)
Cholera case	refers to an instance where a person is diagnosed with cholera, an acute diarrheal disease caused by the bacterium Vibrio cholerae (WHO, 2023).
Cholera hotspot	is a specific geographic area where cholera cases are consistently reported, indicating persistent or recurrent outbreaks. These areas are typically characterized by conditions that facilitate the transmission and spread of the disease, such as poor sanitation, unsafe water sources, and high population density (WHO, 2023).
Flood	This is the overflow of water onto areas of land that are normally dry. It happens when water levels in rivers or lakes rise above their banks, or when heavy rainfall, poor drainage, or other factors cause water to accumulate on land (Midgley et al, 2022).
Flood prone	refers to areas that are susceptible to flooding due to specific geographic, climatic, or human-made factors. These locations are at a higher risk of experiencing floods either regularly or during extreme weather events (Midgley et al, 2022).
Geographic Information System (GIS)	Is a powerful tool used to capture, store, manipulate, analyze, manage, and visualize spatial and geographic data. It enables users to map and analyze the relationships between different features or phenomena in a specific geographic area (Luque Fernández et al, 2012).
Risk	Is the potential for a negative outcome or loss due to exposure to a hazard, uncertainty, or vulnerability (GTFCC, 2017).
Spatial analysis	Refers to a set of techniques and methods used to examine the spatial relationships, patterns, and distributions of features or phenomena on Earth's surface (Mpofu, 2020).

1.4 Research objectives

1.4.1 Main objective

The broad objective of the research is:

To determine the spatial patterns of cholera cases and the related environmental and socio-economic risk factors in flood prone areas in Budiriro and Glen View.

1.4.2 Specific objectives

The specific research objectives of this study include:

1. To identify cholera hotspots and related factors in flood prone urban areas.
2. To determine the environmental factors related to distribution of cholera cases in flood prone urban areas zones, water points, and sanitation facilities.
3. To understand current practices and gaps in cholera preparedness, management and control

1.5 Research questions

1.5.1 Main research question

1. How does the interaction of environmental and related socio-economic risk factors in flood prone urban areas enhance prediction, preparedness, control and management of cholera outbreaks in Harare?

1.5.2 Specific research questions

The specific research questions are:

i. Which specific areas are the most at-risk of cholera outbreak in Budiriro and Glen-View?
ii. What are the most significant risk factors that trigger cholera outbreaks in hotspot areas of Budiriro and Glen View?
iii. How can cholera outbreak be effectively prevented, managed and controlled in Glen View and Budiriro?
iv. What early actions can be taken to mitigate and prevent, control and manage cholera outbreaks

1.6 Significance of the Research

This research has the potential to significantly impact on the design and development of sustainable cholera prevention and control strategies, urban planning, and policy in Zimbabwe and beyond in the context of climate change related flooding. By identifying specific spatial patterns of cholera outbreak in Harare, the research will help inform early warning systems and triggers, predicting cholera outbreak, and early actions for cholera risk mitigation and elimination at the local level. This could assist public health authorities in Zimbabwe and beyond to improve policy and design of cholera prevention and control interventions during emergency times. Findings from this research will also build on past similar researches, highlighting areas where improvements are needed. This will guide investments and policy decisions that will reduce the risk of future outbreaks and build resilience to cholera and flooding. In particular, the spatial analysis aspect of the research will inform urban planning efforts by identifying how urban growth and land use patterns may be contributing to the spread of cholera.

The research will also add to the existing body of knowledge on urban flooding, cholera and its determinants and understanding strategies for eradication of the disease particularly in an urban setting. It will be a reference for future studies and can be used to compare cholera dynamics in different regions. Finally, the research will provide evidence that will inform climate policy and programming that address both immediate cholera outbreaks and long-term public health challenges in Zimbabwe and beyond.

1.7 Summary

The chapter provides an overview of the cholera problem in urban areas, focusing on its impact in Harare, Zimbabwe. It highlights cholera as a recurring public health challenge, particularly in high-density suburbs like Budiriro and Glen View, where inadequate sanitation, poor infrastructure, and socio-economic disadvantages create favourable conditions for outbreaks. The chapter underscores the urgency of understanding the factors that contribute to cholera vulnerability to improve prevention and response measures. It sets the context for the research, justifies the need for a spatial and socio-economic analysis of cholera vulnerability, and lays out the framework for exploring how environmental and infrastructural factors interact with socio-economic conditions to influence the risk of cholera outbreaks. The study is positioned as a critical step toward data-driven, targeted public health interventions to reduce cholera transmission in urban Zimbabwe.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter provides an in-depth exploration of existing research, theories, and frameworks related to the study's topic. It aims to establish a foundation for the research by analysing and synthesising relevant scholarly work, identifying key themes, concepts, and findings that have shaped understanding in this area. The literature review highlights previous studies' strengths and limitations, noting gaps or inconsistencies that the current research intends to address. By examining the work of leading researchers, this chapter situates the study within the broader academic conversation and contextualizes its relevance. This background analysis will ultimately justify the research focus, laying the groundwork for the study's objectives, methodology, and anticipated contributions.

2.2 Background

Cholera, remains a significant global public health challenge, particularly in developing countries with inadequate water and sanitation infrastructure. According to the World Health Organization (WHO, 2023), cholera continues to affect millions of people annually, with recurring outbreaks in Africa, Asia, and the Americas. The persistence of cholera in urban areas, especially in densely populated and underserved communities, underscores the need for comprehensive epidemiological studies that incorporate spatial analyses to better understand the dynamics of cholera transmission.

2.3 Spatial Distribution and Clustering of Cholera Cases

Spatial analysis, which examines how disease cases are distributed across space and time, has become a critical tool in modern epidemiology (Manyangadze et al, 2015). Studies by Ali et al. (2012) and others highlight the role of environmental and geographic variables in cholera transmission, underscoring the importance of localized studies. Geographic Information Systems (GIS) and spatial mapping are often employed to visualize and analyze cholera clusters, as seen in research on cholera hotspots across sub-Saharan Africa (Rebaudet et al., 2013). These studies emphasize that spatial clustering often correlates with densely populated and low-income urban settlements, where sanitation and clean water access are limited.

This approach allows researchers to identify patterns and trends in disease outbreaks, facilitating targeted interventions. In the context of cholera, spatial analysis has been used to map hotspots, understand the role of environmental factors, and anticipate or predict future outbreaks. Studies held in Dhaka, Bangladesh, and Accra, Ghana, have demonstrated how GIS and remote sensing can be employed to monitor cholera incidence in relation to environmental and demographic variables (Sasaki et al., 2009; Ahmed et al., 2019).

2.4 The Epidemiology of cholera

Cholera is an infectious disease caused by the bacterium *Vibrio cholerae* (WHO, 2015). It is characterized by acute onset of profuse watery diarrhoea, often described as "rice-water stool," vomiting, and rapid dehydration. The symptoms are due to the cholera toxin (CTX), a potent enterotoxin that disrupts the normal ion transport in the intestines, leading to massive water loss. There are several different types of cholera, primarily distinguished by the specific strain of *Vibrio cholerae* involved and the severity of the disease. The major serogroups that cause epidemic cholera are the O1 and O139 strain (Tamason et al, 2016). The O1 serogroup is historically significant because it has been responsible for almost all of the major cholera pandemics recorded. Other non-O1, non-O139 strains of *Vibrio cholerae* can occasionally cause gastrointestinal illness. However, these are generally associated with sporadic cases rather than large outbreaks and typically cause milder forms of diarrhoea. They are less likely to produce cholera toxin, and therefore, severe watery diarrhoea is less common.

Without prompt rehydration, severe cases can lead to shock and death (WHO, 2016). Transmission occurs primarily through the ingestion of contaminated water or food. Human carriers can spread the bacteria to water sources, perpetuating the cycle of infection. Treatment focuses on rapid rehydration using oral rehydration salts (ORS) or intravenous fluids for severe cases (ibid). Antibiotics like doxycycline or azithromycin can reduce the duration of symptoms and bacterial shedding. Preventive measures include improving water supply and sanitation, promoting good hygiene practices, and educating communities about cholera transmission. Vaccination is another key preventive strategy. Oral cholera vaccines (OCVs) are effective against both O1 and O139 serogroups and are used in high-risk areas and during outbreaks (WHO, 2016).

2.5 Cholera trends

Cholera is an acute diarrheal illness caused by ingestion of food or water contaminated with the bacterium *Vibrio cholerae*. The disease is endemic in many parts of the world, with periodic outbreaks leading to high morbidity and mortality, especially in vulnerable populations. Cholera is primarily found in regions of Africa, Southeast Asia, and Haiti, where inadequate access to clean water and sanitation facilities creates ideal conditions for the spread of *Vibrio cholerae*. The World Health Organization (WHO, 2024) reports that cholera affects between 1.3 million and 4 million people annually, resulting in approximately 21,000 to 143,000 deaths globally. Following the devastating earthquake in Haiti in January 2010, a cholera outbreak occurred, attributed to contamination of the Artibonite River. This outbreak led to over 820,000 cases and nearly 10,000 deaths, making it one of the most significant in recent history (WHO, 2015). Amid ongoing conflict from 2016 to date, Yemen experienced one of the worst cholera outbreaks. During the Yemen civil war (October 2016 – November 2021), which is widely recognized as the worst cholera epidemic in recorded history, with over 2.5 million suspected cases and nearly 4,000 deaths reported. The collapse of water and sanitation infrastructure fuelled this crisis.

Sub-Saharan Africa is one of the regions most affected by cholera, with frequent outbreaks linked to poor sanitation, unsafe drinking water, and inadequate health infrastructure. In particular, cholera remains a significant public health challenge in the Southern Africa Development Community (SADC) region. The region has a significant history with cholera, marked by periodic outbreaks affecting multiple member states. The region's vulnerability is exacerbated by factors such as rapid urbanization, urban informality, population displacement due to conflict or natural disasters, and climate variability. Studies have shown that the risk of cholera increases in areas with heavy rainfall and flooding, which often lead to contamination of water sources (ibid). In 2013-2014, a notable outbreak, with more than 10,000 cases was reported in Angola (Rusvingo, 2014). Meanwhile, a significant flooding in 2015 led to a cholera outbreak in Malawi, affecting thousands of people (Msyamboza, 2016). In all situations, outbreaks were linked to poor sanitation and heavy rains, especially in Lusaka from 2017-2018. Another outbreak in 2018 affected thousands of people following the Cyclone Idai which affected mostly Zimbabwe, Malawi and Mozambique, highlighting the impact on health of climate-change related natural disasters (Deprez and Labattut, 2020). After cyclone Idai, between 2021-2022, Malawi continued to experience recurring outbreaks, with significant cases reported during the rainy season.

In Zimbabwe, a severe cholera outbreak occurred between 2000-2001, following Cyclone Eline, which affected over 160,000 people, (Chigudu, 2020). This was part of a series of recurring episodes, often linked to the rainy season when water sources were contaminated. The 2000 outbreak which had a case fatality of 4.1%, was triggered by heavy rains and subsequent flooding brought by cyclone Eline that affected water and sanitation systems. The historic and deadliest cholera outbreak was experienced in Zimbabwe between 2008-2009 where over 100,000 cases were reported and nearly 4,300 deaths recorded (Chigudu, 2020). This followed heavier than normal rainfall associated with La Nina resulted in floods in Southern Africa in 2008 which affected Zimbabwe, Malawi, Zambia and Mozambique (Mupedziswa, 2010). In Harare, the case fatality rate was 4.3%, the highest in the history of the epidemic. The epicentre was in the Western district covering Glen-View and Budiriro suburbs. The outbreak, which affected 63 districts countrywide, was linked to the collapse of the healthcare system and water infrastructure during an economic crisis. Many residents in Glen View and Budiriro relied on boreholes, wells, and other water sources that were contaminated due to poor infrastructure and inadequate waste management. On 6 September 2018, another cholera outbreak hit Harare. A total of 10,000 cases and around 60 deaths were reported with a case fatality of 2.2% (Winstead, 2020). Again, the outbreak started in the densely populated areas of Glen View and Budiriro in the capital city. The outbreak quickly spread, prompting the government to declare a state of emergency on September 11, 2018, in an effort to control and contain the disease (ibid).

On 12 February, 2023, another cholera outbreak hit Zimbabwe. It started in Chegutu, a town located about 110 Km away from the capital city. The outbreak started in the suburb of Pfupajena, a densely populated area within Chegutu. The index case was linked to contaminated water sources in Pfupajena where residents relied on boreholes, wells, or other local water sources, which were likely contaminated with *Vibrio cholerae* due to inadequate sanitation and waste management. The outbreak quickly spread to 62 districts of the country resulting in 34,550 suspected cases, 4221 confirmed cases and 719 confirmed deaths with a country case fatality of 2.1% (Ministry of Health and Child Care SitRep, 28 July 2024). In Harare, the first case was reported on 3 March 2023. Again, like previous outbreaks, it started in Glen View, the traditional hotspot suburb. Like in all other outbreaks, the index case was linked to drinking from a contaminated water source. Following concerted efforts to respond to the outbreak by government and its partners, the outbreak was declared over on 8 August 2024 after the last positive case was recorded on 30 June 2024.

According to the Global Task Force on Cholera Control (2017), Zimbabwe is ranked among the top 20 countries targeted for cholera eradication under the Global Roadmap to 2030 developed by the Global Task Force on Cholera Control (GTFCC). The GTFCC's "Ending Cholera: A Global Roadmap to 2030" initiative classifies Zimbabwe as a priority country due to its history of recurrent cholera outbreaks, high-risk populations in urban and rural areas, and challenges related to water, sanitation, and healthcare infrastructure.
This roadmap aims to reduce cholera deaths by 90% and ultimately eliminate the disease in targeted regions through enhanced vaccination efforts, water and sanitation improvements, and rapid response to outbreaks. Countries like Zimbabwe are prioritized due to their vulnerability to cholera and the potential impact that coordinated efforts can have on reducing disease incidence in these high-burden region (Global Task Force on Cholera Control, 2017).

2.6 Environmental and Socioeconomic Determinants of Cholera in Urban Areas

Socio-economic conditions such as poverty, education levels, and housing quality have been repeatedly associated with increased cholera vulnerability (Mengel et al., 2014). Research has consistently highlighted the role of environmental and socioeconomic factors in driving cholera outbreaks. Key environmental determinants include proximity to contaminated water bodies, sewer bursts, poor drainage systems, and inadequate solid waste management. In urban areas, the risk is heightened by high population density, poverty, urban landuse, food vending and limited access to clean water and sanitation facilities (Chirisa et al., 2015). A study in Lusaka, Zambia, identified slum areas with poor infrastructure as major cholera hotspots, underscoring the need for targeted public health interventions (Rainey & Watkins, 2010). The specific role of socio-economic variables, such as household income, education, and occupation, is documented as influencing hygiene practices and the ability to access treated water, factors crucial for cholera prevention (Kariuki et al., 2010). These conditions often lead to compromised water quality, which further increases infection risks, as highlighted by investigations in urban areas across Africa.

In Zimbabwe, cholera outbreaks are influenced by a combination of environmental and socio-economic factors, particularly in urban areas where population density is high, and infrastructure is often inadequate. In many urban areas of Zimbabwe, especially in high-density suburbs like those in Harare Western district, water sources are often contaminated due to poor sanitation infrastructure. The lack of well-maintained sewage systems leads to the contamination of drinking water with Vibrio cholerae, the bacterium responsible for cholera. During heavy rains, surface runoff carries contaminated materials into water supplies, exacerbating the problem (Chigudu, 2020). The collapse of sanitation infrastructure in cities like Harare Western district, partly due to economic challenges, has been a critical factor in cholera outbreaks. Burst sewage pipes and leaking toilets in residential areas contribute to the spread of the disease. The inability of Municipal systems to properly manage waste leads to the proliferation of cholera in densely populated areas (Chirisa et al., 2015).

Seasonal patterns, particularly the rainy season, have a significant impact on cholera outbreaks in Zimbabwe. The rainy season often leads to flooding, which often mixes human waste with drinking water sources. Additionally, high temperatures facilitate the growth of Vibrio cholerae in water bodies, increasing the risk of transmission (Luque Fernández et al., 2009). High levels of poverty in urban Zimbabwe are closely linked to inadequate housing and sanitation conditions. In informal settlements and high-density suburbs, residents often lack access to safe drinking water and proper sanitation facilities. These areas become hotspots for cholera due to overcrowded living conditions, which facilitate the rapid spread of the disease (Chigudu, 2020). Limited access to healthcare in urban areas further exacerbates the cholera situation. During outbreaks, healthcare facilities are often overwhelmed, and the lack of resources such as clean water, rehydration salts, and antibiotics makes it difficult to manage and contain the disease. Above all, the economic crisis in Zimbabwe has strained the health sector, reducing its capacity to respond effectively to cholera outbreaks (Rusvingo, 2014). As a result, the public health infrastructure in urban Zimbabwe has suffered from years of underfunding and neglect.

The lack of effective disease surveillance systems means that cholera outbreaks are often detected late, and response efforts are delayed. Additionally, public health education campaigns are limited, leading to poor awareness of cholera prevention measures among the population (Mugari et al., 2020). Lastly, rapid urbanization without corresponding improvements in infrastructure has led to the development of informal settlements that are particularly vulnerable to cholera. High population density in these areas, combined with inadequate sanitation and waste management systems, creates ideal conditions for cholera transmission (Chirisa et al., 2015).

2.7 The Role of Household Size and Population Density

Household size and population density have been found to affect disease transmission rates. Larger household sizes can facilitate quicker spread within a family, especially in overcrowded conditions where individuals share facilities. Research by Clemens et al. (2011) highlights how high population density and overcrowding increase direct and indirect contact with contaminated water sources, heightening exposure risk. Budiriro and Glen View, with their high population densities and limited household sanitation facilities, illustrate these conditions.

2.8 Water Supply, Sanitation, and Hygiene (WASH) in Cholera Prevention

WASH factors are central to cholera prevention, with inadequate infrastructure being a core driver of cholera persistence in urban slums. Poor WASH infrastructure is identified as a primary risk factor for waterborne diseases in many studies, including the World Health Organization’s reports on cholera risk factors (WHO, 2017). The relationship between water quality, sanitation access, and cholera is evident, with contamination in communal water sources posing a critical health risk. In Harare, studies have reported high levels of E. coli contamination in boreholes and public water points, particularly in Budiriro, emphasizing the need for improved water governance (Upper Manyame Sub-Catchment Council, 2024).

2.9 Influence of Environmental Factors and Flooding on Cholera

Environmental conditions, including flooding, exacerbate cholera risks by increasing water contamination and displacing populations. Urban micro, localized flash floods, that are common in Harare, specifically flood-prone areas like Budiriro and Glen View are especially vulnerable. Urban micro, localized flash floods are sudden, short-duration flooding events that occur in specific, small areas within urban environments, often with minimal warning. They are typically caused by intense, brief rainfall that overwhelm drainage systems, streets, and low-lying zones, leading to the rapid accumulation of water. These floods can occur even in areas that aren't typically prone to flooding, as they are influenced by the unique features of the urban landscape. Floods can disrupt sanitation systems, leading to the overflow of contaminated water into residential areas, as demonstrated in studies conducted in Bangladesh and Haiti following heavy rainfall events (Mukandavire et al., 2011). In such environments, pathogens like *Vibrio cholerae* thrive, with floodwaters aiding their spread across communities. Researchers also integrated environmental data, including rainfall patterns and temperature variations, with cholera incidence data. This integration showed that heavy rainfall, which led to flooding and the contamination of water sources, was a significant trigger for the outbreak. The analysis underscored the need for improved urban drainage and waste management systems. By integrating GIS, statistical models, remote sensing, and epidemiological techniques, researchers have been able to identify hotspots for epidemics, understand the role of environmental and socioeconomic factors, and predict future outbreaks (Mavhura and Manyangadze (2021).

2.10 Case Studies and Methodologies in Spatial Cholera Analysis

Several case studies have employed spatial analysis to understand cholera dynamics, utilising a combination of GIS, statistical models, remote sensing, and advanced spatial epidemiology techniques. GIS was used extensively by Ayling et al (2023), to map the spread of cholera in Harare hotspot areas. By overlaying cholera cases with environmental and infrastructure data, researchers identified hotspots and areas at risk. GIS mapping highlighted the causal relationship between cholera cases and the breakdown of water and sanitation infrastructure. In Harare, previous research has shown that cholera outbreaks are concentrated in certain high-density suburbs, where water and sanitation services are inadequate. For example, a study by Chigudu (2020) on the 2008-2009 cholera outbreak in Harare highlighted the critical role of infrastructural collapse in facilitating the spread of the disease. Mavhura and Manyangadze (2021) note that the use of GIS to map cholera cases has been instrumental in identifying these hotspots and guiding public health responses.

Similar study was conducted by Ayling et al (2023) in Harare to understand the factors associated with cholera outbreaks as an integral part of designing better approaches to mitigate their impact. The study focused on the 2018-209 cholera outbreak to understand how it unfolded and the factors associated with higher risk of being a reported case. Results of the study highlight a number of socio-demographic risk factors which suggest that there is a relationship between cholera risk and water infrastructure. The analysis shows that populations living close to sewer networks, with high access to piped water are associated with a higher risk of cholera outbreak. One possible explanation for this observation is that sewer bursts led to the contamination of the piped water network (ibid). This could have turned access to piped water, usually assumed to be associated with reduced cholera risk, into a risk factor for cholera outbreak. Such events highlight the importance of sewer infrastructure maintenance in the provision of Sustainable Development Goal (SDG) on improved water and sanitation infrastructure as a countermeasure against cholera outbreak. In the study by Ayling et al (2023), the researchers employed time-series analysis to track the daily and weekly incidence of cholera cases. This method allowed the researchers to identify peak periods of transmission, which were closely correlated with the rainy season and periods of water shortages.

2.11 Study gaps in the Literature

While there is considerable research on cholera in urban settings, there remains a gap in detailed spatial analyses that integrate environmental, infrastructural, and socioeconomic data in the context of Harare. Most existing studies have focused on descriptive epidemiology without fully exploring the complex interactions between these factors. There is also a need for more predictive models that can help in anticipating future outbreaks based on changing environmental conditions and urban growth patterns. This research aims to fill these gaps by providing a comprehensive spatial analysis of cholera in Harare, with a focus on identifying key determinants and informing public health strategies.

2.12 Research framework

This research is conducted guided by two frameworks, that is, the Geographic Information System (GIS)-Based Spatial Analysis and the Socio-economic and the Socio-ecological model. GIS is a tool for visualizing and analyzing spatial relationships in health studies. It allows for the integration of various data layers such as locations of cholera cases, flood-prone zones, population density, and water sources, which can reveal spatial patterns and hotspot areas of cholera risk. The major benefit is that GIS can conduct analyses like Kernel Density Estimation to identify cholera hotspots and Spatial Autocorrelation, for example, Moran's I, to assess clustering of cases. This model allows to visualize and quantify the interaction between cholera cases and environmental/socioeconomic factors, providing clear evidence for areas requiring urgent intervention. Data to be used include health records, flood risk maps, water source locations, and socioeconomic data on household characteristics which can all be layered to study interaction effects.

2.13 Socio-Ecological Model (SEM)

The Socio-Ecological Model (SEM) is a comprehensive framework for understanding the interplay between various factors that influence health behaviours and outcomes across multiple levels. This model, often used in public health, emphasizes that an individual's health is not determined solely by personal choices but also by the social and environmental contexts they are part of. SEM has five hierarchical levels that interact to shape health outcomes which are the individual level, interpersonal level, community level, organisational level and policy or societal level.

Individual Level

This level focuses on personal factors such as age, gender, knowledge, attitudes, beliefs, and health-related behaviours. For example, in a cholera study, individual knowledge about hygiene practices or clean water usage plays a role in disease prevention.

Interpersonal Level

This includes relationships with family, friends, and peers, which can impact health choices. Social networks influence behaviours such as hygiene practices and water sourcing. Household norms, values and peer influence, for example, household water treatment and handwashing with soap, can shape an individual's likelihood of adopting certain hygiene behaviours and practices.

Community Level

This level considers how relationships within a neighbourhood or community affect health. Community infrastructure, like access to safe water points or waste disposal facilities, affects disease spread, particularly in densely populated areas. Collective community norms, such as prioritizing clean water or community-based sanitation, play a critical role here.

Organizational Level

Institutions and organizations, such as schools, workplaces, healthcare facilities, and local governments, influence access to resources and health education. For instance, schools may provide health education on cholera prevention, while local government decisions on infrastructure impact water and sanitation availability.

Policy or Societal Level

This level includes local, national, and international policies, laws, and economic structures that shape health outcomes. Policy decisions on funding for water and sanitation or emergency response plans for cholera outbreaks are examples of how societal-level influences play a role. In Zimbabwe, policies around urban water management and sanitation infrastructure investment are crucial at this level.

Interaction Across Levels

The SEM emphasizes that these levels do not operate in isolation. Instead, they interact dynamically to influence health. For example, individual practices around water usage are influenced by household norms (interpersonal), community access to clean water (community), policies around water infrastructure (societal), and support from local organizations (organizational). These interconnected factors collectively determine health outcomes, making the SEM a useful model for designing targeted, multi-level interventions to address complex public health issues like cholera.

The SEM framework helps examine how individual, community, and environmental factors collectively influence cholera risk. It’s highly relevant in Budiriro, where factors like shared sanitation, community water sources, and neighbourhood flood patterns interact. SEM allows for a holistic analysis by incorporating individual and community-level factors (such as household size, hygiene practices, sanitation access) with broader environmental influences (like flooding and population density). This can help identify how these layered interactions reinforce vulnerability to cholera in specific areas, supporting a deeper understanding of hotspot formation. Household surveys, demographic data, and environmental risk maps provide a basis for analysis across SEM’s multiple levels. By combining GIS-based spatial analysis with the Socio-Ecological Model, the research will be able to capture both the spatial and multi-level interactions that drive cholera outbreaks in Budiriro and Glen View, allowing for a more comprehensive understanding and targeted intervention.

2.14 Summary

The chapter sets the foundation for understanding the complex interactions between spatial and socio-economic factors in cholera outbreaks, forming a basis for the subsequent analysis and findings of the study. The literature review provides an in-depth analysis of existing studies on cholera, focusing on the spatial distribution of cases, socio-economic factors influencing outbreaks, and vulnerabilities in urban settings, particularly in high-density areas. The literature underscores the importance of a holistic approach to cholera prevention, combining improvements in water and sanitation infrastructure with socio-economic support and public health education to reduce vulnerability in high-risk urban areas like Budiriro and Glen View

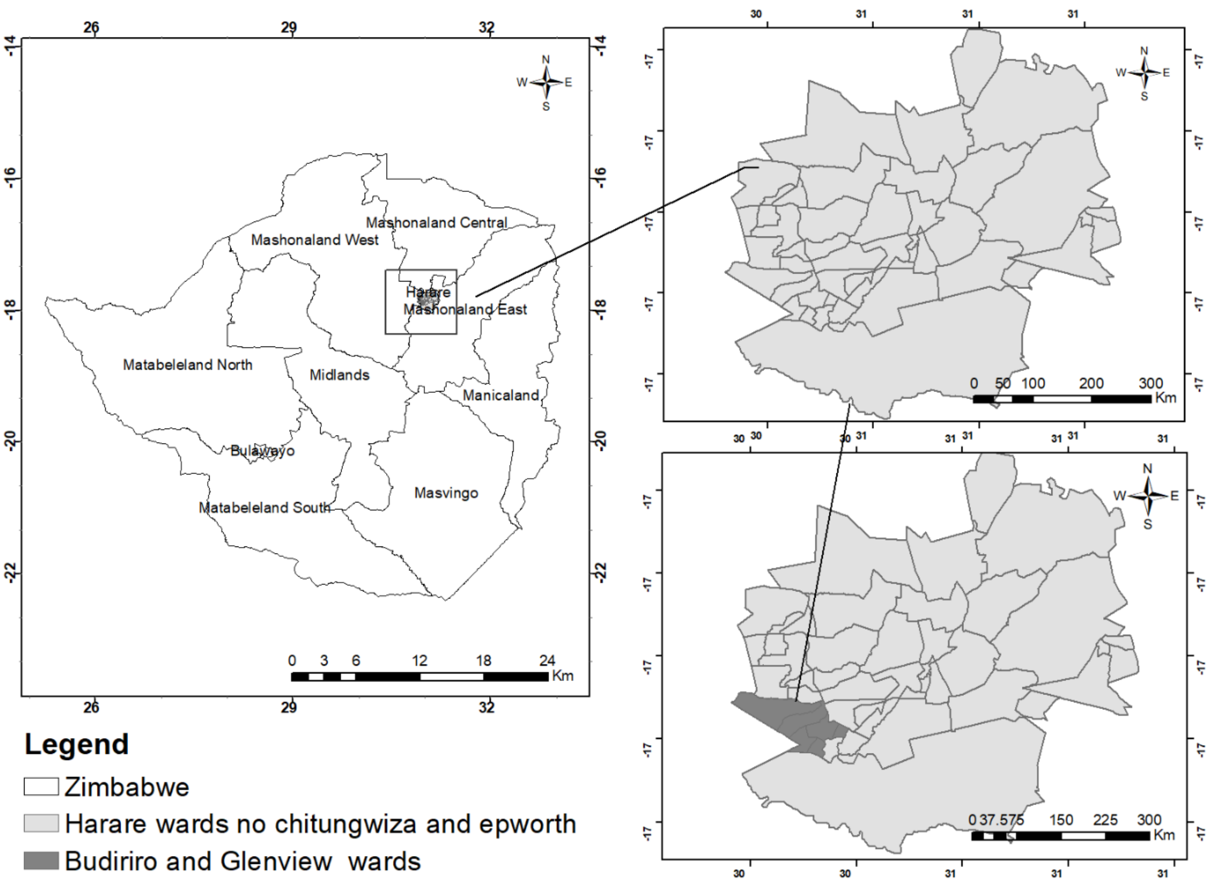
CHAPTER 3: METHODOLOGY

3.1 Introduction

The methodology will involve a mix of quantitative and qualitative approaches. The study will focus on collecting, analyzing, and interpreting data on cholera incidence and its related factors over time and across different locations in Harare utilising secondary (existing) and primary data from the field. Below is a detailed outline of the research methodology.

3.2 Study Area and Population

The study will focus on Harare, the capital city of Zimbabwe, particularly identifying cholera hotspot areas. These areas were selected based on historical data on cholera outbreaks and known vulnerabilities based on poverty, water and sanitation coverage, and population density among others.



3.3 Target Population

The total target population is about 150,185 being 60185 for Glen-View and 90,000 for Budiriro (Zimbabwe Census, 2022). This translates to about 25,030 households in the identified hotspot areas in Harare western district using an average household size of 6 family members. The study analysed the sample population by age, gender, socio-economic status, to understand differential effects.

3.4 Study Design

3.4.1 Spatial Analysis

The study employed a cross-sectional design with spatial components. The spatial component will map cholera cases across different areas of Harare based on line-list from the 2023/2024 cholera outbreak.

3.5 Sampling

A random sampling method was deployed to select a sample from the population. Random sampling minimized bias and ensures that the sample accurately represents the larger population affected by the cholera outbreak. In a cholera study, this sampling method is important because the disease affects various groups differently, for example, by age, gender, socioeconomic status, and by geographic location. A random sample captured this variation more accurately. This allowed for generalisation across the entire hotspot areas. Using an online sample calculator, a sample size of 384 people from the population of 150,185 was used. This provided results with a 95% confidence level and a 5% margin of error.

3.6 Data Collection

Both quantitative and qualitative data collection methods were used. Combining these approaches offers a more holistic view of cholera vulnerability in Budiriro and Glen View. Quantitative data provided the statistical evidence needed to identify patterns and correlations, while qualitative insights helped to explain these patterns by exploring community practices, perceptions, and challenges. Together, these methods provide a nuanced understanding that supports the design of targeted, culturally appropriate interventions and policies to reduce cholera risk.

3.6.1 Quantitative Data

Epidemiological Data

Data on cholera cases was collected from the Harare City Health Department, hospitals, clinics, and other health facilities. Data was also be obtained from national databases, such as the

Ministry of Health and Child Care (MoHCC) reports. Key variables considered when collecting data. These included flooding regime, sewer bursts, alternative water sources their distance from sewer lines, water quality, and water cuts. Data on cholera cases, including date of onset, location (GPS coordinates), patient demographics, clinical outcomes, and any known risk factors were collected. The following data were collected:

Environmental Data:
Environmental data was collected through a desk study. This included water and sanitation data on water quality, availability of sanitation facilities, and environmental conditions in the study areas. This also included surveys, water testing, and observational data. Weather and climate data were also gathered from the Meteorological Service Department (MSD) that included rainfall, temperature, and humidity levels, which may influence cholera outbreaks.

Socio-economic Data
A household survey was conducted using a household questionnaire to gather additional information on socio-economic factors, such as income levels, education, housing conditions, and hygiene practices. National Census data was also utilised to analyze population density and other demographic factors.

3.6.2 Qualitative Data:
Key Informant Interviews (KII) were conducted with public health officials, community leaders, and residents to understand local perceptions of cholera risk factors and control measures. In addition, Focus Group Discussions (FGD) were held in affected communities to gather insights into hygiene practices, water use, and community responses to cholera outbreaks.

3.7 Data Analysis
Data analysis involved the process of systematically examining, cleaning, transforming, and interpreting data to extract useful information, draw conclusions, and support decision-making. It also involved applying statistical, computational, and analytical techniques to make sense of data, uncover patterns, identify relationships, and generate insights relevant to a particular question or hypothesis. Various methods were used.

3.7.1 Spatial Analysis

Mapping was done using the Geographic Information System (GIS) tools to understand the distribution of cholera cases across Budiriro and Glen-View in Harare. In the process, clusters and hotspots of cholera incidence were identified. Hotspot analysis was done using statistical analysis that identified significant hotspots using methods such as Moran’s I. Moran’s I will be used to analyse spatial autocorrelation, helping to determine whether cholera cases were randomly distributed, clustered, or dispersed across these suburbs. By calculating Moran's I for the distribution of cholera cases, the study assessed if the cases exhibited a significant spatial pattern, which was crucial for identifying areas with heightened vulnerability. Once Moran’s I indicated clustering, the study further investigated which specific neighbourhoods within Budiriro and Glen View formed these clusters or hotspots. Other factors were overlayed to understand the association between clustering and socio-economic factors such as proximity to contaminated water sources or sewer chokes.

Further, a spatial autocorrelation by distance was used in spatial analysis to examine how related or similar values of a variable were, based on their spatial proximity or distance from each other. It measured the strength and pattern of relationships between data points at varying distances, helping to determine whether nearby locations tend to have similar or dissimilar values. This method reveals insights into spatial processes, patterns, and scales at which phenomena, such as disease spread or economic disparities, operate.

3.8 Ethical Considerations

The research process shall be guided by key ethical considerations that guide the conduct of researchers. They include the following:

Informed Consent. During field data collection, the researcher obtained informed consent from all participants involved in surveys, interviews, and focus group discussions. Confidentiality was observed to ensure that all personal data collected was anonymized and kept confidential to protect the identity of the respondents. Sensitive information was stored securely and used only for research purposes. The researcher ensured all participants fully understood the research purpose, methods, risks, benefits, and their right to withdraw at any time. Written consent forms were used or verbal consent where literacy was a concern. For vulnerable populations, like children or individuals with limited capacity to consent, consent was obtained from a guardian to ensure extra protections.

Respect for Privacy and Confidentiality. Researcher protected participants' privacy by anonymizing personal data and using codes or pseudonyms to identify respondents. Data was securely stored and managed, especially personal and sensitive information, to prevent unauthorized access or data breaches. Clear communication was given regarding how the data was used, who would have access, and how long it could be stored.

Minimizing Harm and Risk. Researcher identified and minimized potential risks to participants, whether physical, psychological, social, or economic. Researcher was sensitive to topics that could cause distress, especially in contexts involving trauma, illness, or social stigma and avoided pressuring participants and ensure they felt safe and comfortable during interactions. In case of discomfort, the researcher stopped data collection.

Avoiding Exploitation and Ensuring Fair Compensation. Measures were taken to refrain from exploiting participants, particularly in impoverished or marginalized communities. Fair compensation or incentives were provided, especially where data collection was time-intensive or involved travel. Compensation shall be proportional and does not coerce participation.

Respect for Local Culture and Norms. Communities were approached with cultural sensitivity, understanding local customs, values, and communication styles. Researcher worked with local facilitators or community leaders when necessary to foster trust and respect. Any actions or questions that were culturally insensitive or offensive were avoided.

Transparency and Honesty. Researcher was honest about the purpose and scope of the research. Deception or misleading of participants was avoided as could undermine trust. Realistic expectations about the outcomes of the study were set, especially where participants hoped for benefits from the findings.

Accountability to the Community. Findings of the research shall be shared with the local authority in an accessible and respectful way, through summary reports.

Ethical Approval and Compliance with Legal Standards. Researcher obtained ethical clearance from Harare City ethics committee, ensuring adherence to national and international ethical guidelines.

3.9 Validation and Reliability

To ensure data validity, reliability and enhanced accuracy, triangulation was done. This was done by cross-checking data from multiple sources, for example, epidemiological records, surveys, and interviews. Data collection tools and methods were pretested in a small area to allow for important adjustments to be made before the full study.\

3.10 Summary

The chapter outlined the study's design, data sources, data collection processes, and analytical techniques. It detailed the study design, which employed a spatial analysis approach to investigate cholera patterns and identify hotspots within Budiriro and Glen View. Both primary and secondary data sources were utilized. Primary data consisted of household surveys that collected socio-economic information, while secondary data included cholera case records, demographic data, and environmental information from local health authorities and municipal records.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1.1 Introduction

This chapter presents an in-depth analysis of the spatial patterns and socio-economic factors contributing to cholera vulnerability in Budiriro and Glen-View suburbs in Harare. Drawing on spatial mapping of cholera case concentrations, the chapter identifies clusters of high-risk areas at the neighbourhood level and specific streets, that correspond with specific environmental and socio-economic characteristics. This approach enables a comprehensive understanding of how spatial patterns of cholera overlap with socio-economic risk factors and vulnerabilities to create localized health risks. This granularity would help pinpoint precise areas for actionable insights and targeted interventions.

4.2 Spatial Distribution of Cholera Cases

The distribution map (Fig 1) highlights significant clustering of cholera cases along specific roads or regions in Budiriro and Glen View, suggesting localized outbreaks possibly linked to high-risk areas.

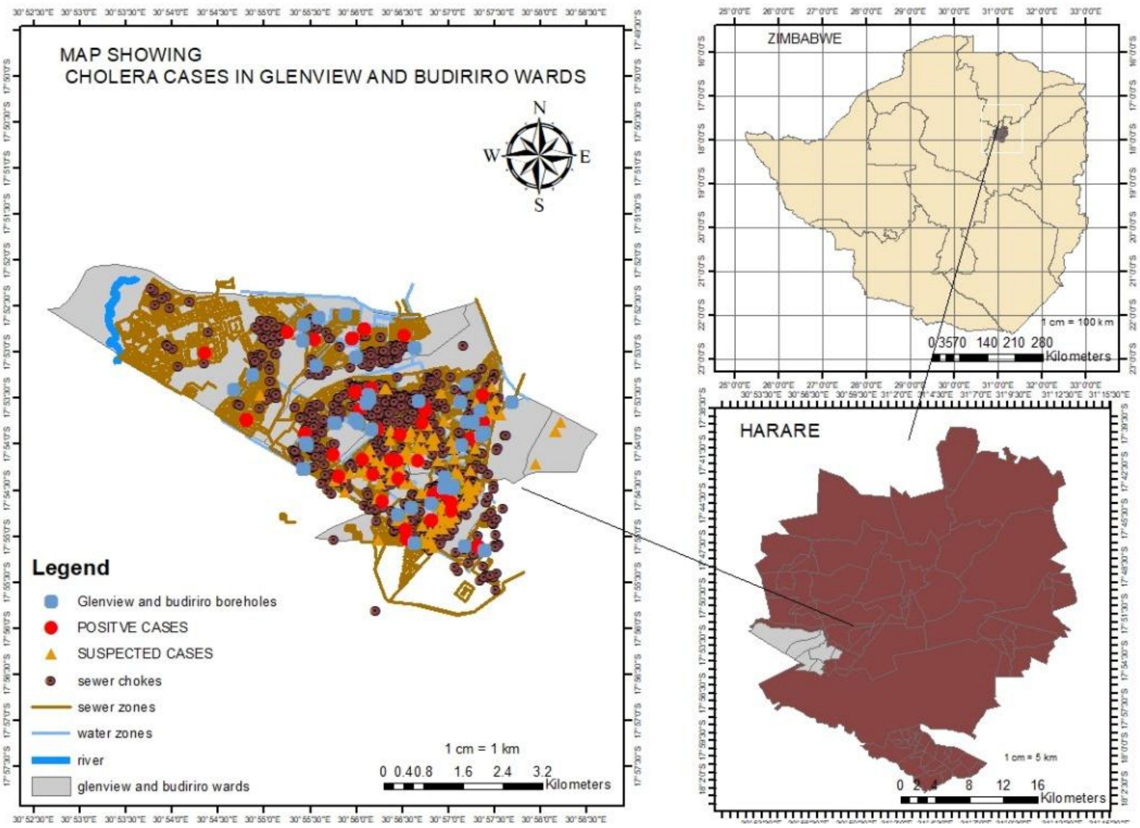


Figure 1: Spatial distribution of cholera cases

The map shows that cholera cases in Budiriro are concentrated around communal boreholes and wells especially those located near areas experiencing regular sewer chokes in densely populated areas, which may be potential contamination points due to their heavy use and reported E. Coli contamination. Cholera cases are densely clustered in low-lying, flood-prone sections of Budiriro and Glen View, where seasonal flooding likely exacerbates water contamination and disease spread. These areas are prone to micro and localised urban flash floods that overwhelm poor drainage system resulting in water flowing on roads and surrounding areas, increasing the risk of contamination of wells and shared boreholes. those located near areas experiencing regular sewer chokes in densely populated areas.

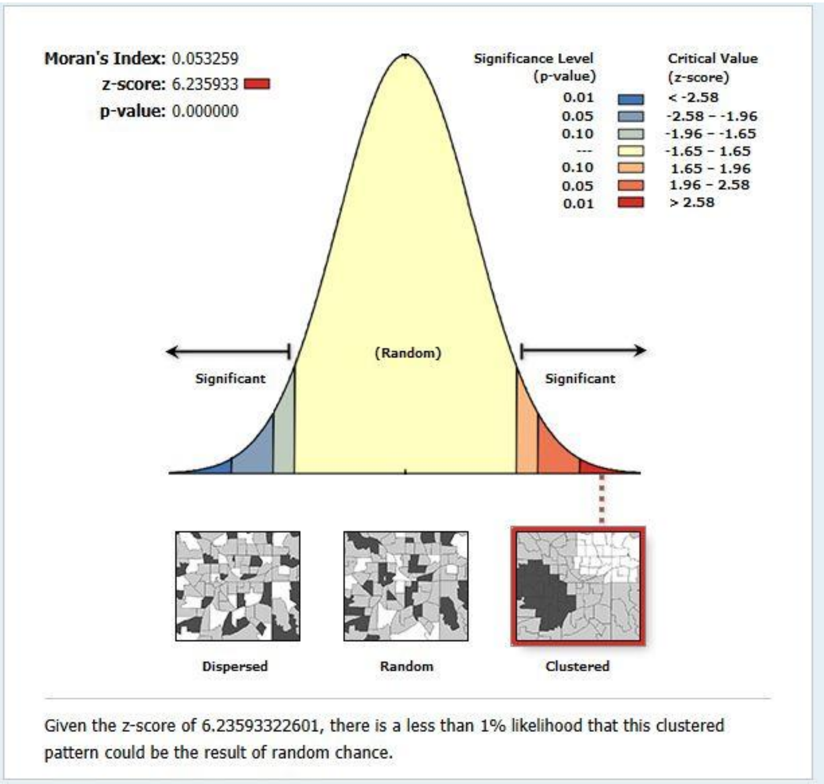
In Budiriro, cholera cases are more dispersed compared to Glen View, where cases are concentrated near major water points and high-density residential areas. The reliance on shared water points in Budiriro, increases the risk of cross-contamination, as many households share water resources. The risk is heightened in circumstances where households have compromised hand hygiene behaviours and practices. Similar to findings in Budiriro, several studies in Zimbabwe and other urban areas globally identify low-lying, flood-prone areas as hotspots for cholera transmission. Also consistent with findings in Budiriro, previous studies in Harare by Dunser et al. (2009), which analyzed the factors contributing to Zimbabwe's 2008-2009 cholera outbreak, found out that neighbourhoods in Harare relying on communal water points and boreholes, particularly in high-density areas, experienced higher cholera cases due to frequent contamination of these water sources. Limited maintenance of water infrastructure and the close proximity of boreholes to open defecation sites increased the risk of contamination, highlighting a critical link between the water source quality and cholera transmission in urban settings.

Globally, similar patterns have been observed. For example, a study by Sasaki et al (2009) in the slums of Kampala, Uganda, demonstrated that residents dependent on communal taps and boreholes were at significantly higher risk of cholera due to water contamination. Similarly, in Dhaka, Bangladesh, Talukder et al (2016) found that cholera incidence was elevated in densely populated areas where communal water sources were vulnerable to contamination from nearby sanitation facilities. These studies underscore the importance of protecting communal water sources and improving sanitation to prevent cholera in urban settings with high population density and limited infrastructure.

In summary, the spatial distribution map of cholera cases in Budiriro and Glen View reveals distinct clustering patterns, particularly in high-density residential zones and near communal water sources. Budiriro shows dispersed patterns with moderate clustering around boreholes, while Glen View exhibits more concentrated hotspots around sanitation-limited flood-prone areas. These findings underscore the role of environmental and infrastructural factors in cholera spread, highlighting areas requiring targeted interventions.

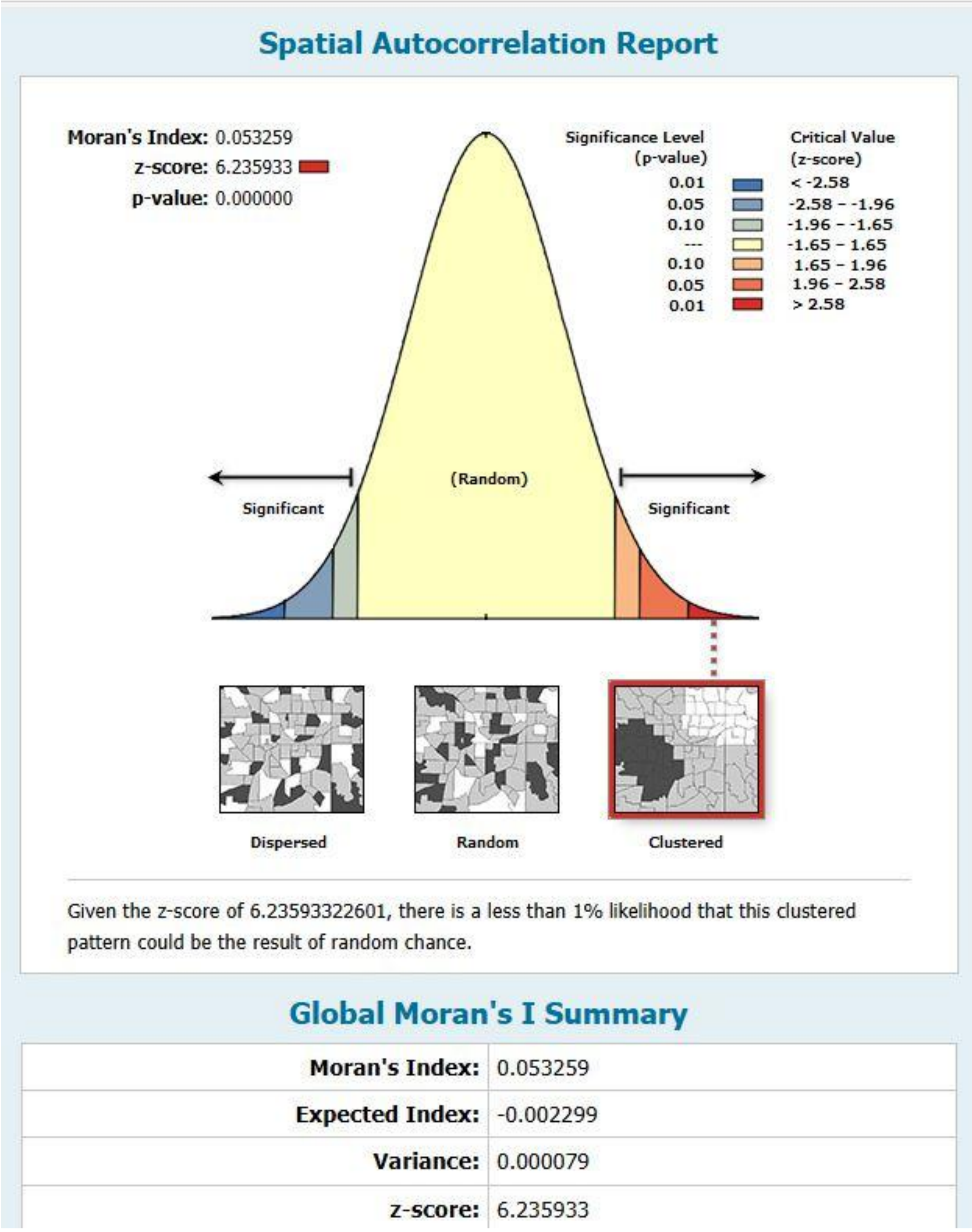
4.3 Hotspot and Cluster Analysis

Analysing cholera hotspots and clusters provides critical insight into the spatial dynamics of disease transmission, especially in high-density, low-resource settings like Budiriro and Glen View. Fig 1 illustrates a computation of the Moran's Index (or Moran's I) which is a statistical measure used in spatial analysis to assess the degree of spatial autocorrelation within the dataset.



Global Moran's I Summary

Moran's Index:	0.053259
Expected Index:	-0.002299
Variance:	0.000079
z-score:	6.235933
p-value:	0.000000



With a Moran's Index of 0.053259 and a high z-score of 6.235933, it suggests a meaningful clustering pattern in cholera cases across Budiriro and Glen View. These values provide strong evidence of positive spatial autocorrelation, where similar values, namely, high cholera case counts, tend to cluster in specific areas rather than being distributed randomly. A positive Moran's Index, though modest, combined with a high Z-score suggests a statistically significant pattern of spatial dependence, where cholera cases are concentrated in identifiable high-risk areas or "hotspots." Also, areas with higher housing density experience overcrowding, which overwhelms sanitation facilities and increases the use of shared water sources. The clustering of cholera cases in high-density zones suggests that crowded living conditions are a significant factor in cholera transmission, as the close proximity facilitates rapid spread of the disease through contaminated water and poor hygiene practices.

Further analysis is provided through spatial autocorrelation by distance as illustrated in fig 2.

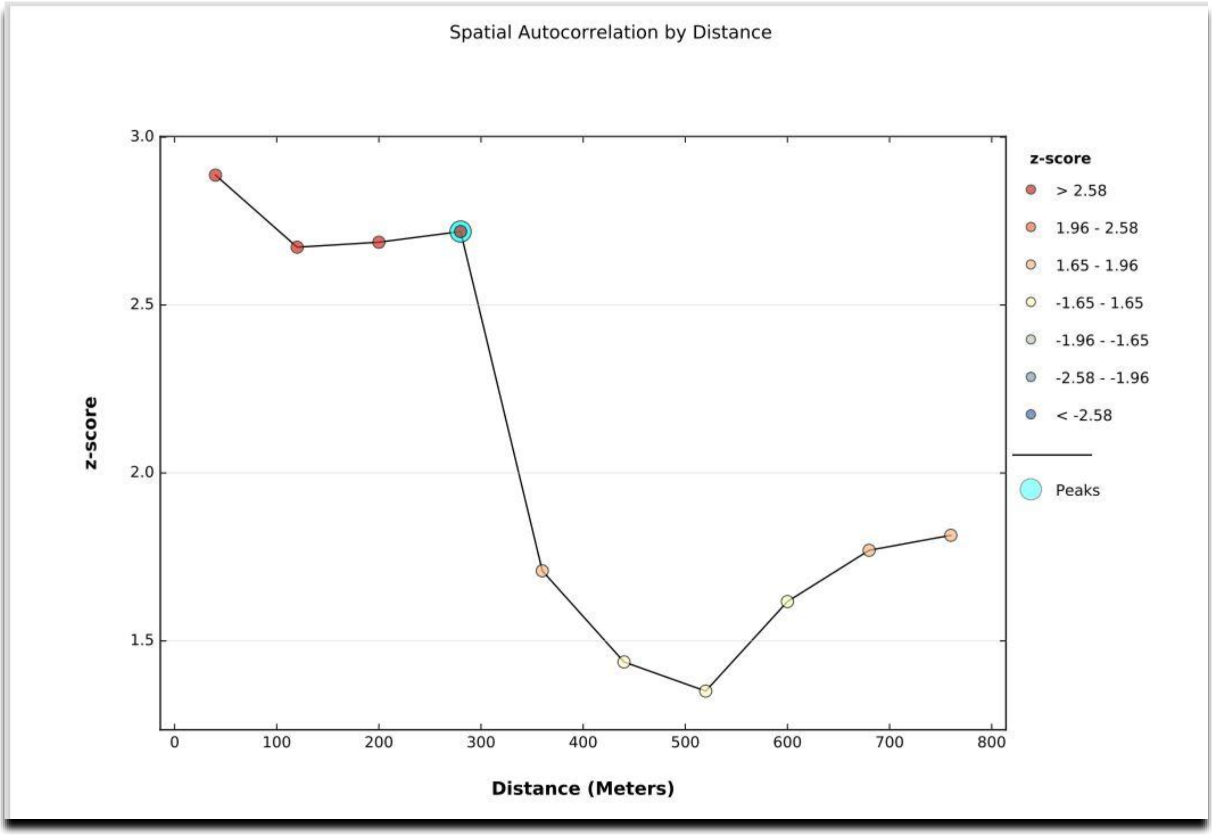


Figure 2: Spatial autocorrelation by distance

This graph displays the spatial autocorrelation of cholera cases as measured by the z-score of Moran's Index across different distance bands. A significant spatial autocorrelation with a Moran's Index of 0.053259 and a high z-score of 6.235933 suggests a meaningful clustering pattern in cholera cases across Budiriro and Glen View, where cholera cases are concentrated in identifiable high-risk areas or "hotspots" as illustrated in figure 3. These values provide strong evidence of positive spatial autocorrelation, where similar values, namely, high cholera case counts tend to cluster in specific areas rather than being distributed randomly.

The high z-scores above 2.58 for distances up to about 300 meters indicate statistically significant clustering of cholera cases within this range. This suggests that cholera cases are highly concentrated within short distances, likely pointing to localized factors, for example, communal boreholes, sewer chokes, or specific environmental conditions that drive clustering at this scale.

After reaching a peak near 300 meters, the z-score drops sharply, indicating a decrease in spatial autocorrelation. By around 500 meters, the z-scores are below 1.65, which suggests that the clustering effect weakens at greater distances.

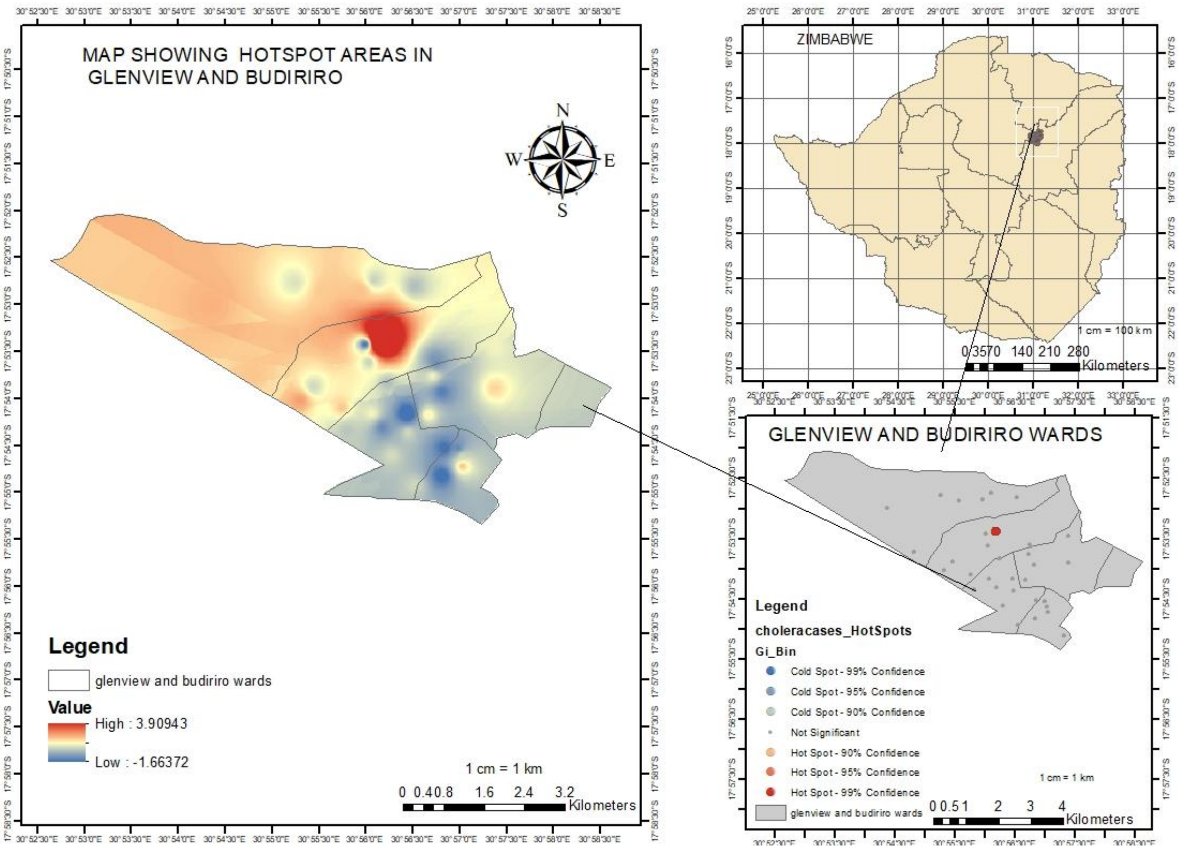


Figure 3: Hotspot areas

This pattern may imply that the influence of risk factors such as water contamination or human interaction diminishes as distance increases. There is a smaller increase in z-scores at around 700 meters, though the values do not reach the same level of significance as the initial peak. This secondary increase could suggest a weaker clustering effect at this distance, possibly due to broader, less intense risk factors affecting areas at this range, or it may reflect other spatial processes influencing case distribution beyond the immediate environment. The implications of this analysis are that the significant clustering within the first 300 meters suggests that localized transmission is occurring, potentially around specific points of exposure. This therefore demands that public health interventions should prioritize and target these high-risk zones within 300 meters, through Case Area Targeted Interventions (CATIs), focusing on Water Sanitation and Hygiene (WASH) improvements and education. The drop in autocorrelation beyond 300 meters suggests that cholera cases become less spatially dependent on one another as distance increases. This could indicate that cases beyond this range are more sporadic or influenced by different, less intense factors.

4.4 Spatial distribution of cholera cases and the location of sewer chokes and boreholes.

The map in Fig 4, shows that cholera cases are dispersed across Glen View and Budiriro, but there are notable clusters, particularly in areas where sewer chokes and water sources are concentrated. These sewer chokes are distributed throughout, and their proximity to cholera cases suggests a positive connection with contamination of local water supplies, increasing the risk of cholera.

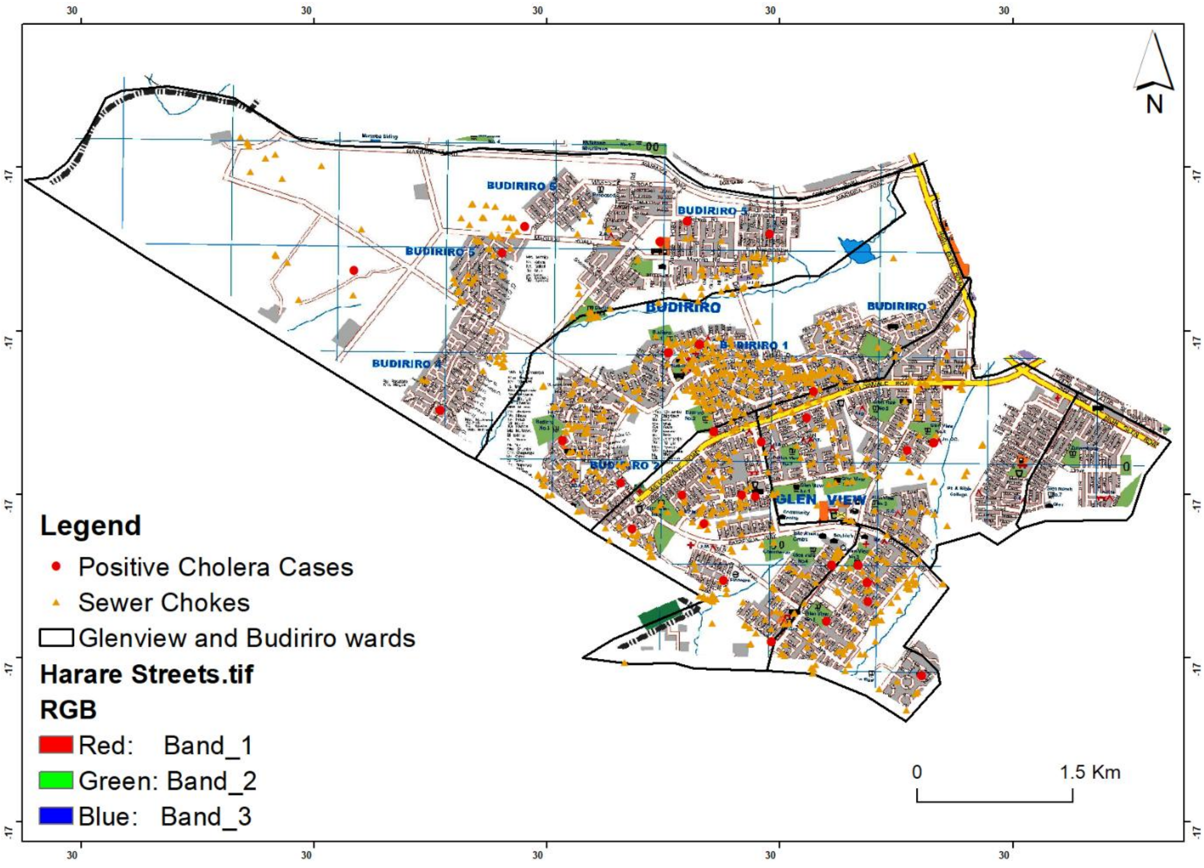


Figure 4: Cholera distribution in street map of Budiriro and Glen View

Major streets showing problem sewer chokes in Glen View include the following:

- sewer line number 10 which covers the following streets (58; 53; 56; 81; 78 and 73 crescent)
- sewer line number 1 which covers all of Glen 2
- sewer line number 2 covering Glen View High 2 school; 1st Drive to 21st street

In Budiriro, the problem sewer lines include the following:

- sewer line number 6 covering mainly house number 1055 along 46th street
- Jarawaza stand number 8216
- Budiriro 5B stand number 1700 and Southern Cross primary school
- Miti crescent covering Budiriro 4

Knowing these specific sites helps in carrying out targeted response to address the problem of sewer chokes. The City of Harare Superintendent for Budiriro and Glen-View, Mr Dicko reported that sewer chokes are mainly a result of deposition of oils, sand from scoring of pots at the household level as well as deposition of solids into the sewer lines such as rugs and baby diapers. He emphasised that the number of sewer chokes increases when Municipal water cuts are experienced leading to reduced water flow in the sewer lines. Also, he noted that the combination of high population density, limited sanitation, and poverty can create a self-reinforcing cycle. Outbreaks in vulnerable areas strain resources further, which can worsen sanitation and living conditions, leading to recurring health crises.

4.5 Elevation and flood risk

The elevation map shows the spread of cholera cases and provides valuable insights into how topography influences the distribution of cholera in Budiriro and Glen View as shown in figure 5. This elevation map of Glen View and Budiriro wards displays the distribution of cholera cases (marked by red dots) and boreholes (marked by blue dots) in relation to the area's topography. The colour gradient indicates varying elevations, with green representing lower elevations, transitioning through yellow and orange to brown, which indicates higher elevations.

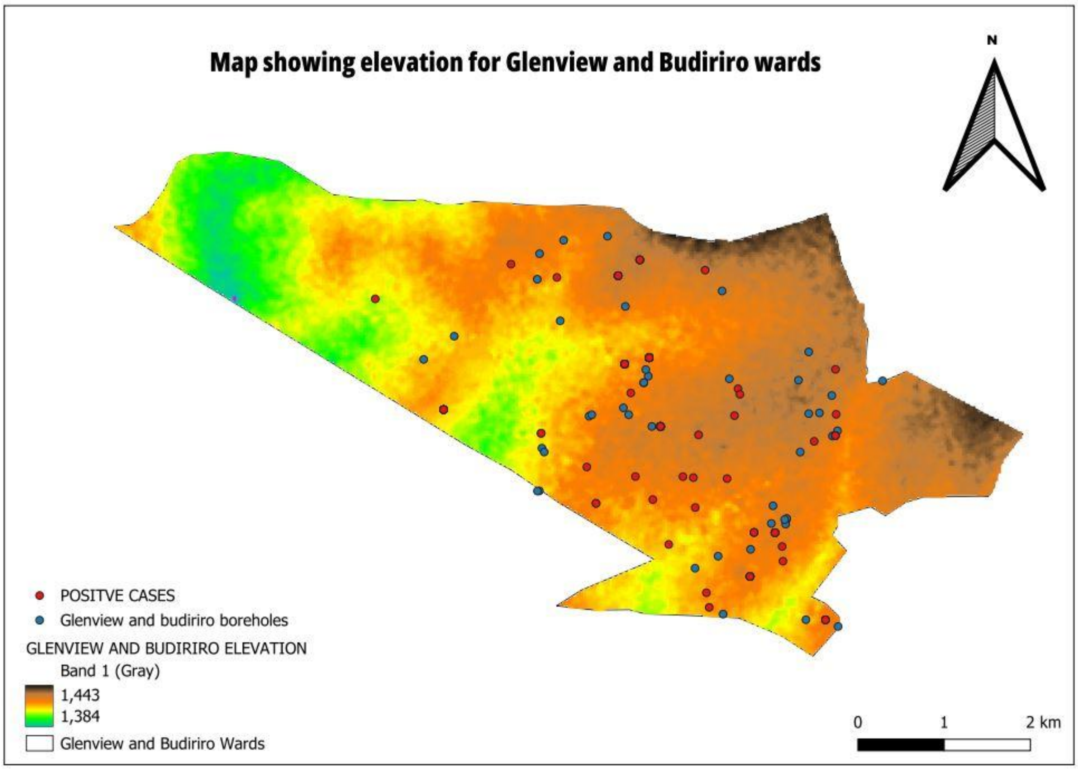


Figure 5: Elevation and spread of cholera cases

Cholera cases appear to be more concentrated in lower elevation areas, particularly in the green and yellow zones, which are likely to be low-lying and prone to urban flush flooding and water pooling or poor drainage. This clustering suggests that topography influences the spread of cholera, as these lower-lying areas are more susceptible to flooding and water contamination, due to accumulation of wastewater during extreme rain events.

The map also shows boreholes scattered across both low and high-elevation areas. In some instances, boreholes are located in or near zones with reported cholera cases, especially in lower elevations. This spatial relationship indicates a risk of borehole contamination, either from runoff or insufficient separation from contaminated surface water sources. Since boreholes are a primary water source, this proximity to cholera cases in low-elevation areas exacerbates the spread of cholera where the water is untreated.

The gradient from low (green) to high (brown) elevation indicates that cholera cases are more prevalent in lower areas. The City of Harare Water Engineer, Mr Charumbira highlights that this pattern is due to how water and contaminants flow across the landscape, as contaminants are more likely to collect in low-lying zones. Higher elevation areas (brown zones) show fewer cholera cases, due to better drainage and reduced water stagnation.

The clustering of cholera cases in low-lying areas, where water and contaminants accumulate, underscores the need for targeted interventions. Public health efforts should focus on improving sanitation and water quality through at-source chlorination in these vulnerable zones, especially in proximity to boreholes. This may include water treatment, borehole maintenance, and ensuring that boreholes are positioned at safer distances from potential contamination sources.

4.6 Spatial analysis of cholera cases and related environmental factors

In order to understand the significant influence of environmental factors to cholera cases in Budiriro and Glen view, Chi square tests were done on each of the factors. This would influence policy and programming decision making.

4.6.1 Relationship between occurrence of sewer chokes and cholera cases

Table 1 evaluates the relationship between distance from sewer chokes and cholera cases (positive or negative) using Chi square.

Table 1: Relationship between occurrence of sewer chokes and cholera cases

Variable	**Negative cholera cases (%)**	**Positive cholera cases**	**Chi square**	**p- value**
Distance from sewer chokes				
0-100m	19	4	**24.2**	**≤0.001***
101-200m	250	15		
201-300	129	22		
301-400	85	4		
401-500	40	2		
501+	85	0		

A p-value of ≤ 0.001 is highly significant, meaning there is less than a 0.1% chance that the observed relationship is due to random chance. Therefore, distance from sewer chokes is significantly associated with cholera cases. There is a relatively high percentage of positive cholera cases within closer distances compared to further distances. For intermediate distances (101–200m, 201–300m), cholera cases remain present but become less concentrated, suggesting a potential gradient of risk. This implies that proximity to sewer chokes increases the likelihood of contracting cholera, likely due to greater exposure to environmental contamination. Targeted interventions, for example, improved sewer maintenance and water treatment campaigns should prioritize communities living within 300m of sewer choke.

4.6.2 Proximity of boreholes and occurrence of cholera cases

Table 2 examines the relationship between distance from boreholes and cholera case status (positive or negative).

Table 2: Relationship between distance from boreholes and occurrence of cholera cases

Variable	**Negative cholera cases (%)**	**Positive cholera cases**	**Chi square**	**p- value**
Distance from boreholes				
0-100m	122	3	**22.3985**	**≤0.001***
101-200m	147	11		
201-300	214	32		
301-400	88	1		
401-500	36	1		
500+	0	0		

bold = statistically significant (p≤0.05)

The Chi-square statistic (22.3985) is relatively high, indicating a notable degree of association between distance from boreholes and cholera case status. A p-value of ≤ 0.001 indicates a statistically significant relationship between the distance from boreholes and the likelihood of cholera cases. The probability of observing this relationship by random chance is less than 0.1%. The proportion of positive cholera cases increases in the intermediate distances (101–300m). This indicates higher exposure or contamination risks in these zones. The significant Chi-square statistic and trends in the data suggest that distance from boreholes is a critical factor influencing cholera risk. Intermediate distances have higher exposure to contamination from boreholes due to cross-contamination between water sources and nearby sewage systems. This assists in targeting of water points for remedial work and calls for strengthening of water quality monitoring, treatment and safe handling practices in communities near communal boreholes.

4.6.3 Spatial relationship between water source type and cholera cases

This explores the relationship between type of water source and cholera case status (positive or negative).

Table 3: Relationship between water source type and cholera cases

Variable	Negative cholera cases (%)	Positive cholera cases	Chi square	p- value
Type of water source			**3.9996**	0.410
Borehole	246	25		
Protected well	133	22		
Unprotected well	27	3		
Municipal tap water	46	6		
River/stream	2	1		

A p-value of 0.410 is much higher than the conventional significance level of 0.05, suggesting that the observed differences in cholera cases among water source types are not statistically significant. This means there is no strong evidence that cholera risk varies systematically by water source type. While there is a large number of borehole users (246 negative cases, 25 positive cases), there is no significant deviation from expected values in terms of cholera risk. The lack of statistical significance (p-value > 0.05) suggests that the type of water source alone may not be a key determinant of cholera risk in this dataset. Investigating secondary factors like storage methods, contamination during transport, or usage patterns could provide additional insights for decision making and design of intervention.

4.7 Spatial distribution of cholera and related socio-economic factors

Further analysis was done to understand the significant influence of various socio-economic factors to the occurrence of cholera cases in Budiriro and Glen view.

4.7.1 Influence of gender on cholera cases

Table 4 examines the relationship between gender and cholera case status (positive or negative).

Table 4: Relationship between gender and cholera cases

Variable	Negative cholera cases (%)	Positive cholera cases	Chi square	p- value
Gender			9.88	**0.002**
Males	338	48		
Females	413	27		

There is a notable difference in cholera cases between males and females. The Chi-square statistic is moderately high. A p-value of 0.002 is highly significant, meaning there is a less than 0.2% probability that the observed difference between males and females is due to random chance. This suggests a statistically significant association between gender and cholera case status which means cholera risk is not evenly distributed across genders. Males appear to be more affected than females in this dataset. Males might have higher exposure to contaminated environments due to outdoor activities, occupations, or social roles. Gender-sensitive cholera prevention strategies tailored to the specific behaviours and vulnerabilities of each gender may be required. For example, targeting males with messaging about safe water and hygiene practices could help reduce their higher risk.

4.7.2 Association between age and cholera cases

Table 5 examines the relationship between age and cholera cases.

Table 5: Relationship between age and cholera risk

Variable	Negative cholera cases (%)	Positive cholera cases	Chi square	p- value
Age range (Years)				
Under 1 year	68	1	27.21	≤0.001
1 to 4 years	257	5		
5 to 14 years	136	10		
15+ years	290	40		

A high Chi-square statistic of 27.21 indicates substantial differences in cholera cases across the age groups. The p-value is highly significant (≤ 0.001), indicates that cholera risk varies significantly across age groups while suggesting that the observed differences in cholera cases among age groups are not due to random chance. The risk is particularly high among individuals aged 15+ years, suggesting age-related factors contribute to cholera susceptibility. One explanation could be that older individuals may have more direct exposure to contamination sources due to occupational activities or social roles. Children may have some protection due to caregiver practices or reduced exposure. This implies that interventions should focus on high-risk groups, particularly individuals aged 15+ years, including caregivers to reduce exposure and transmission.

4.7.3 Relationship between level of education and cholera cases

There is a relatively low Chi-square statistic between level of education and cholera case status.

Table 6: Relationship between education and cholera risk

Variable	Negative cholera cases (%)	Positive cholera cases	Chi square	p- value
Level of Education				
No school	40	4	2.744	0.433
Primary to secondary school	514	50		
Vocational training	29	3		
Tertiary school	63	11		

A p-value of 0.433 is much higher than the conventional significance level of 0.05, indicating that the relationship between level of education and cholera case status is not statistically significant in this setting. This indicates minimal differences in cholera cases across the education levels. Although there are some differences in positive cholera cases across education levels, these variations are likely due to chance. Cholera risk might be more influenced by other factors than by education level. Behavioural factors associated with education might not vary sufficiently in this population to show a strong effect on cholera risk. This means education alone may not be a determinant of cholera risk, so interventions should prioritize hybrid and integrated solutions to cholera prevention and control.

4.7.4 Relationship between knowledge on cholera prevention and control and cholera cases

Table 7 shows that the majority of residents fall into the category of high knowledge level, but the proportion of positive cases is not significantly different from the "low knowledge" group. A p-value of 0.350 is much higher than the conventional significance level of 0.05. This indicates that the observed relationship between cholera knowledge and case status is not statistically significant.

Table 7: Knowledge on cholera prevention and control and cholera risk

Variable	Negative cholera cases (%)	Positive cholera cases	Chi square	p- value
Knowledge on Cholera prevention & Control				
High	561	65	4.4526	0.350
low	86	3		

The chi-square statistic is relatively low, indicating minimal differences in cholera cases between individuals with high and low knowledge levels. This means that having knowledge about cholera prevention and control does not necessarily translate into protective behaviour. While knowledge is important, it may not be sufficient on its own to reduce cholera risk. Complementing knowledge campaigns with programs that enable communities to apply prevention practices to reduce cholera risk, for example, access to safe water, soap is critical.

4.7.5 Perception on harmfulness of baby faeces and cholera cases

Perception of the harmfulness of baby faeces is important among household members as it influences handling and disposal behaviours, which directly affect the risk of cholera transmission. Table 8 shows that the p-value is much greater than the standard significance threshold of 0.05 showing that the relationship between perception and cholera risk is not statistically significant.

Table 8: Perception on harmfulness of baby faeces and cholera risk

Variable	**Negative cholera cases (%)**	**Positive cholera cases**	**Chi square**	**p- value**
Perception on harmfulness of baby faeces				
Positive	472	56	2.8156	0.933
Negative	175	12		

The majority of participants fall into the group of those who perceive baby faeces as risky, but their cholera risk does not differ significantly from those with a negative perception. While perception is an important component of hygiene education, cholera transmission may be influenced more by other environmental and systemic socio-economic factors in this setting, rather than risk perceptions on baby faeces.

4.7.6 Knowledge about water treatment and cholera cases

Results show a low Chi-square statistic (1.2907) which indicates little difference in cholera cases between individuals with high and low knowledge of hand hygiene.

Table 9: Knowledge of hand hygiene and cholera risk

Variable	Negative cholera cases	Positive cholera cases	Chi square	p-value
Knowledge of hand hygiene				
High	619	67	1.2907	0.256
Low	28	1		

The p-value is greater than the standard significance level of 0.05, meaning the relationship between knowledge of hand hygiene and cholera case status is not statistically significant. Although hand hygiene knowledge is important, there is no strong evidence to suggest that knowledge of hand hygiene influences cholera risk in this setting. Individuals may have knowledge about hand hygiene but fail to consistently practice it, reducing its protective effect. It underscores the importance of bridging the gap between knowledge and practice, by emphasising hand hygiene messaging and consistent hand hygiene with soap practices.

4.7.7 Relationship between handwashing with soap practice and cholera risk

Table 10 shows the p-value is very small (≤ 0.001), indicating that the observed differences in cholera cases between different handwashing categories are statistically significant.

Table 10: Household handwashing practice and risk to cholera

Variable	Negative cholera cases (%)	Positive cholera cases	Chi square	p- value
Handwashing practice				
Always	212	42	22.27	**≤0.001**
Most of the time	187	8		
Occasionally	96	9		
Rarely	132	9		

This means there is strong evidence to suggest that handwashing practice is associated with cholera risk. The result is in line with conventional and global research which has singled out handwashing with soap as the most cost-effective way of preventing and controlling cholera. This highlights the need to strengthen campaigns that encourage frequent and thorough handwashing with soap, especially before eating and after using the toilet, as part of cholera prevention efforts. Regular handwashing (especially "Always" washing hands) appears to reduce the risk of cholera. The number of cases among those who rarely wash hands illustrates that the risk of cholera remains substantial, suggesting poor handwashing practices contribute to a higher risk of cholera transmission. However, those who wash hands always show that although this group is more likely to wash hands regularly, the proportion of positive cholera cases is still noticeable, indicating that handwashing alone does not provide complete protection. Other environmental and socio-economic factors, can better explain occurrence of cholera cases and the related interventions that provide more effective protection. This highlights the need to combine handwashing education with other interventions, such as improving water quality and access to sanitation facilities, to address multiple cholera transmission pathways.

4.7.8 Household (HH) water treatment and cholera case status

Table 11 illustrates the relationship between household water treatment and risk to cholera. The Chi-square statistic is relatively low, indicating limited evidence of differences in cholera cases between households that treat water and those that do not in Budiriro and Glen view. The p-value > 0.05 indicates that household water treatment is not significantly associated with cholera risk.

Table 11: Household water treatment and cholera risk

Variable	Negative cholera cases	Positive cholera cases	Chi square	p- value
HH Water treatment				
Treat water	153	24	4.4808	0.343
Do not treat water	494	44		

This means cholera risk does not appear to differ substantially between households that treat their water and those that do not treat water. The 24 positive cholera cases out of 177 households that treat water is slightly lower compared to households that do not treat. The group that is not treating water shows a lower cholera risk, which is counterintuitive but not statistically significant in this dataset. Results highlight challenges with treatment practice in Budiriro and Glen view. Households may not be using effective treatment methods or applying them consistently, resulting in similar cholera risks for both groups. Treated water might become re-contaminated due to improper storage or handling. Alternatively, cholera risk may be more strongly influenced by factors other than water treatment alone.

Emphasizing proper and consistent water treatment practices, along with safe water storage, may help reduce cholera risk. Households should be educated on effective water treatment methods that include boiling and chlorination and the importance of consistent use. It also underscores the need to ensure access to affordable water treatment solutions for households that lack resources.

4.8 Preparedness, Control and Management during flooding periods

Against a background of increased risk of environmental contamination and vulnerability to cholera infection, preparedness becomes apparent and critical to avert a potential outbreak. The following varied community-level preparedness, knowledge and practices on cholera control and management

4.8.1 Water treatment practice during summer season

Residents reported an increase in use of wells during the rainy season as the water table rises. However, not much hygiene behaviour changes were reported with the change in seasons.

Table 12:Water treatment practice during rainy seasons

Methods	Frequency	Percentage
None	462	66.28
Chlorination	157	22.53
Boiling	95	13.63
Other	19	2.73
Filtration	4	0.57
Solar Disinfection	1	0.14

Despite the heightened risk of environmental contamination during the rainy season, about 66% of residents from the cholera hotspot do not treat their water (table 1). This reflects the increased exposure to cholera infection. The Municipality of Harare confirmed the frequency of sewer chokes increases during the summer wet season due to increased water flow into the sewer lines. This increases risk of environmental contamination. Despite the increased risk of contamination of wells as the water tables rises, households perceive the water from wells as safer than that from the Municipality. Reports also indicate cholera cases and acute watery diarrhoea increase during summer seasons. No specific preparations are done by residents to minimise cholera risk during the rainy seasons. While boiling is the simplest water treatment methods, households indicated energy challenges to boil water.

4.8.2 Health-seeking behaviour

Fig 11 shows the distribution of multiple actions taken by households after identifying a suspected cholera case. While about 53% of the households used home-based oral rehydration solution (ORS) remedies, 49% visited the nearest health facility, indicating significant awareness of ORS and medication as lifesaving interventions. meanwhile, a significant 16% did nothing while others sought services from the traditional and faith healers. This increases health risks for individuals.

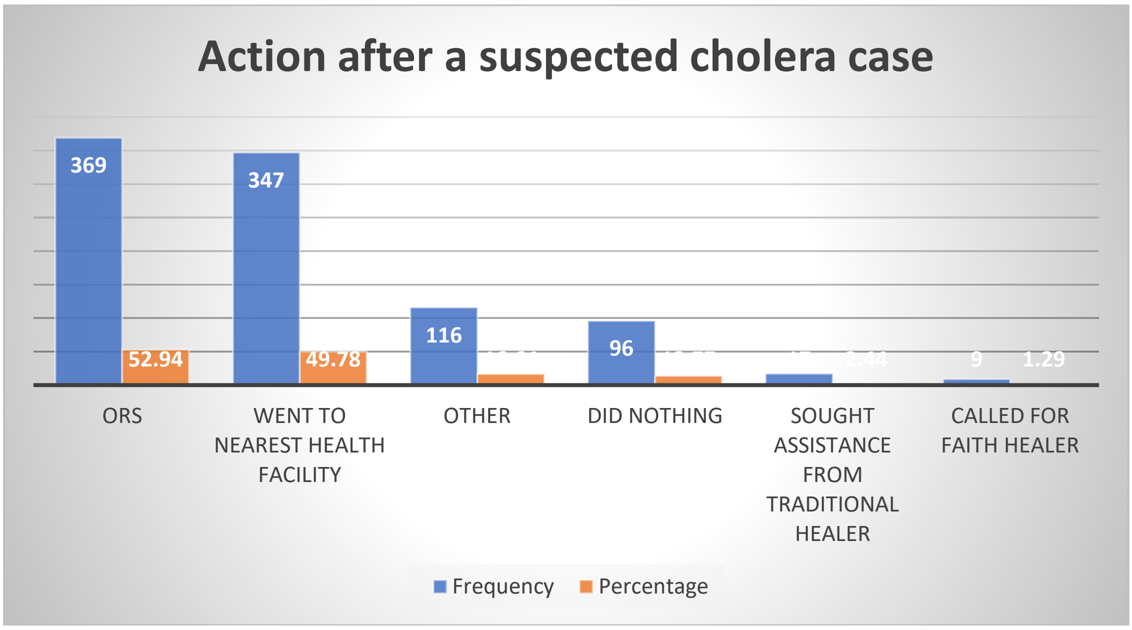


Figure 6: Action taken after suspected cholera case

This increases health risks for households and the communities, highlighting a critical gap in public health messaging and awareness. While results reflect a promising reliance on scientifically supported methods (ORS and health facilities), gaps still remain in addressing inaction and reliance on less effective practices. Targeted health education and messaging could raise awareness and reduce the proportion of those who "do nothing" and encourage consistent use of effective interventions. Majority of the suspected cholera cases were mainly among babies and young children. Giving explanation as to why some households sought assistance from traditional healers and faith healers, households indicated that there are cultural beliefs they their children will be suffering from fontanel (*chipande or nhava)* in vernacular, which have the same symptoms for acute watery diarrhoea and cholera. Those who "do nothing", believe their children would be experiencing teething (*kubuda mazino*) in vernacular. Such cultural belief systems and misconceptions are detrimental to cholera treatment and have implications to cholera preparedness, policy and planning as well as cholera elimination plans.

4.8.3 Waste collection

This section analyses solid waste management practices and behaviours of the surveyed households. The efficient and responsible management of waste is crucial for maintaining a clean and healthy living environment. This provides insights into how waste is handled, including waste disposal areas, methods of disposal, frequency of garbage collection, and the disposal of diapers. For households with young children, diaper disposal is a pertinent aspect of waste management. Key stakeholders have also expressed concerns with regards to diaper disposal and respondents indicated various methods of diaper disposal, including open dumpsites (55.38%), burning (27.55%), burying (14.78%), and flushing in toilets (2.58%). Some respondents (18.22%) provided additional methods, such as washing and burning or using specific containers. Results also show that solid waste collection in the study area is limited. The frequency of garbage collection varied among respondents, with the most common frequency being once every month (60.55%). Additionally, some households reported having garbage collected once a week (7.03%), once every two weeks (3.87%), or more than once a week (3.73%). Meanwhile, 24.82% of respondents reported that waste is never collected.

Most yards do not have space for burying garbage hence they burn the waste. When solid waste is not collected, households dump solid waste alongside roads, open spaces and in drains. About 66.67% of respondents mentioned evidence of open burning of waste. Garbage accumulation closes water drains contributing to flush floods and contamination of surroundings.

Respondents The District Environmental Health Technicians (DEHOs) for Budiriro and Glen-View offered a range of recommendations and desires for waste management improvements. These included calls for increased collection frequency, and better municipal waste collection. Many respondents expressed a desire for better management of waste, proper disposal facilities, and the reduction of waste-related health risks. The Municipality indicated intentions to clear garbage in preparation for the rainy season to minimise the negative impacts of solid waste to the environment. Efforts are underway to clear solid wastes following the declaration by government of solid waste state of disaster. It is yet to be known if the plan will be continued on a sustainable basis.

4.8.4 Cholera control

The Municipality of Harare treats cholera and other watery diarrhoea at their local clinics for free. Cholera is controlled through oral rehydration and application of intravenous fluids. Local Municipal health centres reported incapacity and lack of staff motivation due to poor remunerations. Clinics also lack stocks for essential products for cholera surveillance and treatment such as sampling and testing materials, oral rehydration solutions (ORS), ORP kits and personal protective equipment (PPE). Meanwhile, multilateral, local and international non-governmental organisations (NGOs) such as UNICEF, Oxfam, Welthungerhilfe and Zimbabwe Red cross Society (ZRCS), are assisting government the Municipality with non-food items (NFI) distributed to targeted households and providing hygiene education and messaging. This has implications on the need for government and the Municipality to step up cholera preparedness, prevention and control.

4.9 Discussion

The spatial distribution of cholera cases in the urban areas of Budiriro and Glen View reveals a complex interplay of factors that drive the spread of the disease, with a strong correlation between cholera incidence and the proximity to communal water sources, particularly in areas with poor sanitation and vulnerability to flooding. In Budiriro, cholera cases are more widely dispersed, but there is notable clustering around communal boreholes and wells. In contrast, Glen View shows more concentrated cholera hotspots, particularly in high-density residential zones and near major water points. These areas rely heavily on communal water sources, which increases the risk of cross-contamination, especially when hygiene practices are compromised. These findings reflect global trends seen in other urban areas with similar sanitation challenges, such as Kampala and Dhaka, where densely populated neighbourhoods with shared water points face elevated cholera transmission risks (Atuhaire et al; 2021). The seasonal flooding in this area exacerbates the contamination of these water sources, as poor drainage systems allow for the accumulation of wastewater, increasing the risk of contamination. This issue is further complicated by the dense population, where the likelihood of surface water contamination during heavy rains is high.

The study investigated multiple factors influencing cholera risk in Budiriro and Glen View, focusing on environmental, behavioural, and socio-economic variables. The significance of the factors in influencing occurrence of cholera cases varies. Environmental factors assessed included relationship between sewer chokes, proximity of boreholes and cholera cases. The study results show that proximity to sewer chokes significantly increases cholera risk (p-value ≤ 0.001), with the highest cases observed within 300m. This concurs with findings by Mpofu et al (2020) in their study on the geospatial clustering of cholera cases in Harare linked to environmental contamination from sewer chokes. This implies that environmental contamination from sewer chokes directly exposes nearby households to cholera pathogens. Intervention strategies should prioritize repairing sewer systems and improving sanitation infrastructure for communities within this radius. In terms of proximity of boreholes and cholera cases, evidence shows that distance from boreholes significantly correlates with cholera cases ($p \leq 0.001$). Intermediate distances (101–300m) show higher cholera risk, likely due to cross-contamination with nearby sewage systems. This highlights the need for improved water quality monitoring and enhanced borehole maintenance to reduce cross-contamination risks. There is no statistically significant relationship found between water source types and cholera cases ($p = 0.410$). This implies that cholera risk may depend more on secondary factors like storage and handling rather than the type of source. As such, policy and design of cholera prevention and control should go beyond water source type, emphasizing safe handling and storage practices to mitigate contamination risks.

Socio-economic factors also had varied influence on cholera cases. In terms of gender, males were significantly more affected than females ($p = 0.002$). Behavioural differences, such as outdoor exposure and occupational activities, likely explain this disparity. This implies that gender-sensitive cholera prevention strategies are essential, with targeted education for men about safe water and hygiene practices. Cholera risk also significantly varied across age groups ($p \leq 0.001$), with individuals aged 15+ years most affected. Younger children had lower cases, possibly due to protective caregiving practices. This implies that interventions should target high-risk groups, particularly adults, while maintaining protective measures for children. No significant relationship was found between education level and cholera risk ($p = 0.433$). Cholera cases were evenly distributed across education levels. This implies that knowledge alone may not reduce cholera risk. Integrated approaches combining education with practical interventions, such as water treatment and sanitation, are necessary.

Knowledge levels showed no significant association with cholera risk ($p = 0.350$). This suggests a gap between knowledge and practice. Policy and cholera mitigation efforts should focus on enabling communities to translate knowledge into consistent protective behaviours through access to safe water, soap, and improved infrastructure. While perception is important in determining hygiene behaviours, no significant association was observed between perceptions of baby faeces and cholera risk ($p = 0.933$). This implies that other systemic factors may outweigh perception in cholera transmission. Emphasis on proper disposal and hygiene practices remains critical. Handwashing with soap is globally considered the most cost-effective way of preventing and controlling cholera. The study results showed handwashing practices were significantly associated with cholera risk ($p \leq 0.001$). Regular handwashing reduced risk but did not eliminate it completely. This underscores the need for strengthening handwashing campaigns, but complementary interventions such as improved water quality and sanitation are necessary for comprehensive prevention. While water treatment is expected to result in high protection, the study showed that water treatment practices were not significantly associated with cholera risk ($p = 0.343$). This was counterintuitive and highlighted gaps in water treatment practice in Budiriro and Glen view. Treated water could become re-contaminated due to improper storage or inconsistent water treatment practices. Emphasis should be placed on educating households on consistent and effective treatment and safe water storage practices. Despite evidence of high contamination risk for cholera, most households (66%) do not treat water during rainy seasons. Limited energy resources and perceptions of well water safety exacerbate the problem. Enhancing preparedness through community education, accessible water treatment solutions, and addressing structural challenges including sewer maintenance, is critical during high-risk periods.

In conclusion, the findings suggest that the spread of cholera in Budiriro and Glen View is closely linked to inadequate sanitation, over-reliance on shared water sources, and the environmental challenges posed by flooding and poor drainage. These factors contribute to the clustering of cholera cases in specific areas, particularly in high-density zones and near malfunctioning sewer lines. Public health strategies should focus on improving sanitation infrastructure, maintaining water sources, and addressing socio-economic and environmental challenges to reduce cholera transmission. By targeting interventions in high-risk zones, particularly those within 300 meters of identified hotspots, it is possible to reduce the spread of cholera and improve the overall health conditions in these vulnerable communities.

4.10 Summary

The findings illustrate that cholera outbreaks in Budiriro and Glen-View are not uniformly distributed. Instead, they are concentrated in particular micro-areas within the community. These cholera high-risk zones often align with flood-prone areas intersecting with locations experiencing sewer chokes and non-collection of solid wastes while relying on boreholes for drinking water. Furthermore, socio-economic factors such as gender, age, household hygiene behaviours and water treatment practices, play a significant role in amplifying cholera risks. The results provide critical insights for public health interventions and policy formulation aimed at strengthening cholera prevention, early detection and control.

CHAPTER 5: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The conclusion and recommendations chapter synthesizes the key findings from this research on the spatial analysis of cholera cases and associated socio-economic factors in Budiriro and Glen View. This chapter aims to consolidate the main insights drawn from the spatial distribution patterns of cholera outbreaks, the influence of socio-economic vulnerabilities, and the infrastructure-related risks identified throughout the study. By providing a cohesive summary of these findings, this chapter emphasizes the critical factors that contribute to cholera susceptibility in these urban areas, offering a foundation for actionable recommendations.

5.2 Summary

Cholera remains a significant public health challenge in urban areas, particularly in regions prone to flooding where waterborne diseases are prevalent. This study investigated the spatial distribution of cholera cases and the associated socio-economic and environmental factors in Budiriro and Glen View, two flood-prone suburbs of Harare, Zimbabwe. A household survey was conducted to obtain household level data on sanitation hygiene behaviours and practices and related socio-economic factors. Additional data was obtained through key informant interviews and historical cholera, sewer and water infrastructure data obtained from City of Harare. Using spatial analysis techniques within a Geographic Information System (GIS) framework, cholera hotspots were identified and correlated with flood-prone zones, household water sources, and sewer chokes. The study incorporated spatially referenced cholera case data, environmental risk factors, and socio-economic variables, including household size and access to clean water.

Results revealed that cholera clusters were predominantly located around communal boreholes and wells in low-lying, flood-prone sections of Budiriro and Glen View. These cholera clusters are located where seasonal flooding exacerbates water contamination and cholera spread, especially those located near areas experiencing regular sewer chokes in densely populated areas. These areas are prone to micro and localised urban flash floods, that overwhelm poor drainage system. This highlights the interplay between urban flooding and disease transmission. The study identified critical factors associated with cholera distribution and risk in flood-prone urban areas of Budiriro and Glen View, focusing on hotspots, environmental factors, and community preparedness. The influence of socio-economic factors on cholera cases varied. While knowledge about cholera prevention is important, it was not significantly associated with reduced cases, indicating gaps in translating awareness into behaviour. Cholera risk also significantly varied across age groups, with individuals aged 15+ years most affected. Younger children had lower cases, possibly due to protective caregiving practices.

Also, knowledge levels showed no significant association with cholera risk. This suggests a gap between knowledge and practice. Perception is an important hygiene determinant. However, no significant association was observed between perceptions of baby faeces and cholera risk. This implies that other systemic factors may outweigh perception in cholera transmission. Meanwhile, handwashing practices were significantly associated with cholera risk. Regular handwashing reduced risk but did not eliminate it completely. This underscores the need for strengthening handwashing campaigns, but complementary interventions such as improved water quality and sanitation are necessary for comprehensive prevention. While water treatment is expected to result in high protection, the study showed that water treatment practices were not significantly associated with cholera risk. This was counterintuitive and highlighted gaps in water treatment practice in Budiriro and Glen view. Treated water could become re-contaminated due to improper storage or inconsistent water treatment practices. Emphasis should be placed on educating households on consistent and effective treatment and safe water storage practices.

In conclusion, proximity to sewer chokes and boreholes was a key determinant of cholera risk. As such high-risk zones require immediate intervention. Geospatial mapping becomes significant tool to identify and monitor cholera hotspots for targeted interventions. Prioritization should be given to sewer maintenance and infrastructure upgrades in flood-prone areas. This can be integrated with affordable water treatment solutions and conduct regular water quality monitoring, especially for boreholes and wells. Behaviour change campaigns promoting consistent handwashing and safe water handling practices needs to be scaled up. This should be done through development of community-level and household-focused cholera preparedness plans, including emergency response teams and seasonal risk mitigation measures. By addressing hotspots, environmental risk factors, and gaps in preparedness, these recommendations provide a holistic strategy to reduce cholera incidence in flood-prone urban areas.

5.3 Conclusions

Based on the findings of the research, the following conclusions are made:

Cholera hotspots and related socio-economic factors

Socio-economic factors have varied effect to cholera outbreak. Critical social aspects such as handwashing with soap practices are inconsistent. While handwashing frequency is associated with reduced cholera risk, it is not universally practiced. In addition, knowledge about cholera prevention does not consistently translate into effective behaviour, underscoring a need for integrated community education alongside with consistent hygiene practice and structural improvements in water, sanitation, and hygiene (WASH) infrastructure. Enhanced preparedness strategies should include affordable water treatment options, sustained behaviour change campaigns, and targeted sanitation interventions during rainy seasons.

Environmental risk factors related to cholera distribution

The intersectionality between socio-economic and environmental vulnerabilities, play a significant role in cholera susceptibility. Environmental factors such as sanitation infrastructure and water quality significantly influence cholera distribution. Proximity to sewer chokes increases cholera risk, likely due to contamination of surrounding areas during flooding. Conversely, no significant relationship was found between water source types and cholera risk, suggesting that contamination occurs across water sources through systemic failures, such as poor maintenance or inadequate sanitation. Effective environmental interventions, such as timely sewer maintenance and improved water safety protocols, are crucial to reducing cholera transmission pathways.

Cholera preparedness, management and control

Cholera prevention, treatment, and control in flood-prone areas face significant challenges, exacerbated by inadequate water treatment practices, limited health-seeking behaviours, poor waste management, and under-resourced healthcare facilities. During the rainy season, a significant percentage of residents do not treat their water despite the heightened risk of contamination, with barriers such as energy challenges for boiling water. Health-seeking behaviours show promise, but cultural misconceptions and inaction among some households hinder effective cholera treatment and control. Waste management is another critical issue, with irregular garbage collection leading to dumping, which clogs drains and contributes to flooding and contamination. While cholera treatment is available for free at Municipal clinics, these health centres face severe resource shortages, including staff, testing materials, and essential supplies. Support from NGOs helps fill gaps, but sustainable efforts, including improved water and waste management, enhanced public health messaging, and better resourcing of health systems, are urgently needed for effective cholera control.

5.4 Recommendations

Based on the key findings and conclusions sited above, the following recommendations are made:

Cholera Hotspots and Related Factors

- Given the convincing evidence of cholera hotspot formation and existing environmental and socio-economic factors, it is critical to enhance surveillance in high-risk zones. This can be achieved through establishment of community-based cholera monitoring systems focused on immediate sewer chokes and boreholes to rapidly identify and respond to outbreaks.
- Use of GIS technology to map cholera hotspots and prioritize resource allocation for high-risk zones, enhances efficiency especially during emergencies.
- Integrate and institutionalise anticipatory action and forecast-based financing policy frameworks into urban planning policies, including zoning regulations that consider cholera risk factors like elevation, flood risk, and population density. This includes formalizing early warning systems, resource allocation for proactive WASH interventions, and regular vulnerability assessments in high-risk areas, hence creating safer and more resilient urban environments.
- Targeted water supply, sanitation and hygiene interventions in identified hotspots are critical to address cholera risks and promote adoption of preventive/protective behaviours such as consistent water treatment and safe sanitation practices.

Environmental Factors Related to Cholera Distribution

- Conduct regular water quality monitoring for contamination, particularly boreholes and wells. Behaviour change practices such as point-of-use water treatment, such as chlorination and filtration, with subsidies or distribution programs for low-income households, are critical in addressing socio-economic cholera risk factors.
- Combined improvements in sanitation infrastructure with investments in safe water supply should be considered to address systemic contamination. This may include protection of water points and drainage systems to reduce cross-contamination risks.

Cholera Preparedness, Management, and Control

- Behaviour change communication programs should be scaled up to promote consistent handwashing with soap and proper disposal of waste, emphasizing their importance during high-risk periods like the rainy season.
- Localized cholera preparedness plans should be developed and implemented, involving residents in regular simulations and the establishment of emergency response teams in flood-prone neighbourhoods.
- Increase community awareness about the heightened cholera risks during the rainy season and promote practical, cost-effective mitigation measures, such as point of use water treatment.

Further research

- While this research has provided insights into understanding how spatial distribution of cholera cases interacts with socio-economic risk factors in hotspot formation to influence effectiveness of interventions, more needs to be done particularly in predictive modelling of cholera outbreaks for better health planning through integration of spatial analysis with machine learning methods. Research in this area could improve the accuracy and utility of cholera predictive models for cholera elimination and public health planning.

5.5 Summary

The spatial and socio-economic analysis of cholera vulnerability in Budiriro and Glen View reveals a pattern of localized outbreaks influenced by both environmental factors, such as elevation and water source proximity, and socio-economic conditions, including sewer chokes and low adoption of protective hygiene behaviours and practices. The interplay between spatial and socio-economic factors fosters an environment where cholera transmission is highly likely. Low-lying, flood-prone areas, combined with socio-economic and environmental risks, create a cycle of vulnerability that perpetuates cholera spread and hotspot formation. Effective intervention strategies must consider both spatial vulnerabilities and socio-economic barriers to improve public health resilience and reduce cholera risks in these communities. Effective cholera prevention strategies should address these intersecting factors, prioritizing infrastructure improvements, targeted WASH interventions, health education, and socio-economic support in the most vulnerable areas.

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APPENDICES

Annex 1: Household Survey Questionnaire

Spatial analysis of cholera cases and related risk factors in flood prone hotspot areas of Glen-View and Budiriro, Harare

INTRODUCTION & BACKGROUND

My name is Addmore Nyawasha. I am a student with the Bindura University of Science Education (BUSE), studying Masters in Climate change and sustainable development. As part of my studies, I am researching on cholera and acute watery diarrhoea risks in flood prone areas with a view to developing targeted and context specific solutions in preparedness, control and management of the disease. All responses shall be anonymous and the information will be used for academic purposes only. Results of the study shall also be available for use by the Government, City of Harare and its partners to inform policy and development. I am therefore kindly requesting to interview you. The interview will take about 30 minutes. Thank you.

Consent Granted……….Yes No

NB: *This interview should be administered to the HEAD of household or the oldest person available at the time of the interview.*

Start time: ………………..

Take GPS Coordinates:…………

Questionnaire ID………

SECTION A: DEMOGRAPHICS

2. Sex
   - Male
   - Female
   - Other ………………………..
3. What is the level of education of the respondent?
   - Secondary or less.
   - Tertiary
   - No school.
   - Vocational training.
4. Age
   - Below 18
   - 18-35
   - 35-49
   - 50-59
   - 60 +
   - Other
5. Household size? (Numbers disaggregated by sex)
   - 0-5
   - 5-9
   - 9-18
   - 18-35
   - 35-49
   - 50-59
   - 60 +

6. Occupation
- Formally employed
- Informally employed
- Vending
- Trading
- None

Other, specify ……………………

SECTION B: Community Knowledge on Cholera during flooding

1. What is your understanding of the term "cholera"?
    - General diarrhoea
    - Severe rice-like watery diarrhoea with blood stains
    - Headache
    - Stomach-ache disease
    - Flue like disease
    - Other specify
2. Can you name common signs and symptoms of cholera? Tick all applicable
    - Diarrheal with more than 3 stools a day
    - Watery blood-stained stools
    - Vomiting
    - Stomach cramps
    - Dehydration
    - other specify
3. How cholera is primarily transmitted during flooding?
    - Through contaminated water
    - Through the air
    - Through physical contact with an infected person
    - Through contaminated food
    - Other specify

Section C: Preparedness, control and management of cholera during flooding or rainy season

4. Have you received any information or training on cholera prevention and treatment during flooding in the past year?
    - Yes
    - No
5. Do you know how to prevent the spread of cholera during flooding?
    - Yes
    - No
6. If yes, can you tell me at least 2 different ways of preventing the spread of Cholera under flooding conditions?
    - Cannot be prevented.
    - Herbs
    - Washing hands with soap at critical times.
    - Consistent and appropriate use of toilet
    - Eating food whilst its hot
    - Covering food
    - Thorough cooking
    - Using protected sources of drinking water.
    - Other specify

9. Do you know how to treat suspected cholera cases at home during flooding emergency?

- Yes
- No

10. If yes tell me at least 1 method of treating suspected cholera patients during flooding emergency.

- Oral rehydration therapy
- Cholera vaccination
- Other specify

11. Do you know the importance of hand hygiene in preventing cholera?

- Yes
- No

12. If yes name at least one importance.

- To remove disease causing germs
- Hygiene purposes (to remove dirt)
- To prevent myself from contracting diarrhoeal diseases.
- Others

13. Has any member of your Household been affected with suspected cholera or acute watery diarrhoea in the last 3 months?

- Yes
- No

14. If yes, how old were they?

- 0-5
- 5-9
- 9-18
- 18-35
- 35-60
- 60+

15. If yes, what did you do when your household member was affected by Cholera?

- ORS
- Went to nearest Health facility
- Called for faith healer
- Sought assistance from traditional healer
- Did Nothing
- Other (specify)

16. Do you think baby faeces are harmful?

- Yes
- No

17. If yes/no give reasons

……………………………………………………………………………………………………

SECTION C: Household Water Infrastructure

1. What is the main source of drinking water for your household during flooding periods?
    - Tap water
    - Borehole
    - Unprotected Well
    - Protected well
    - River/stream
    - Other (please specify)

2. How long does it take to go to your main water point, fetch water (including waiting time) and return (at peak time)?
   1. 30 min or less
   2. More than 30 min, up to 1 hour
   3. More than 1 hour
   4. Don't know.

3. Do you feel the activity of fetching water (distance and/or queuing time) constitutes a problem for your household?
   1. Distance is a problem 3. Both distance and queuing time are a problem
   2. Queuing time is a problem 4. No problem
4. Do you treat your drinking water before consumption during flooding periods?
   - Yes
   - No
5. If Yes, which water treatment methods do you use, if any?
   - Boiling
   - Chlorination
   - Solar disinfection
   - Filtration
   - None
6. Have you faced any water shortages in the past month?
   - Yes
   - No
7. Do you use a separate container for water storage?
   - Yes
   - No
8. If yes, which type of water storage do you use?
   - Narrow mouthed/container bucked with lid
   - Wide mouthed/container bucked with lid
   - Narrow mouthed/container bucket without lid
   - Wide mouthed/container bucket without lid
9. Do you use water from alternative sources during flooding?
   - Yes
   - No
10. If yes, what source(s) do you use? (Tick multiple responses)
    - Rainwater harvesting
    - Buy bottled water
    - Use the same sources

SECTIO N D: Sanitation

1. Does your household have access to a toilet facility?
   - Yes
   - No
2. If yes, what type of toilet facility does your household have?
   - Flush toilet connected to a sewer system
   - Pit latrine
   - Ventilated improved pit latrine (VIP latrine)

- Composting toilet
- No toilet facility

3. If yes, is your toilet facility shared with other households?
    - Yes
    - No
4. Is your toilet facility regularly maintained and cleaned?
    - Yes
    - No
5. Do you have a handwashing facility? (observe and comment)
    - Yes
    - No
6. Is there soap at your handwashing facility? (Observe and comment)
    - Yes
    - No
7. If yes is there water for handwashing? (observe and comment)
    - Yes
    - No
8. Name all situations when you wash your hands with soap
    - Before and after eating
    - Before cooking
    - After eating
    - Other specify
9. How often do you wash your hands after using the toilet?
    - Always
    - Occasionally
    - Most of the time
    - Rarely
    - Never.

SECTION E: Solid waste management

10. Does your household have a designated area for proper waste disposal?
    - Yes
    - No
11. How do you dispose of your household waste during flooding periods?
    - Municipal waste collection
    - Burning
    - Burying
    - Dumping in open areas
    - Other (please specify)
12. How frequently was garbage collected in the last 30 days?
    - Select one that applies
    - More than once a week
    - Once a week
    - Once every 2 weeks
    - Once every month
13. How do you dispose of your diapers?
    - Bury
    - Burn

- Open dumpsite
- Flush in toilets
- Others (please specify)

14. Are there any locations with uncontrolled dumping of wastes in your neighbourhood?
    - Yes.
    - No.

15. If Yes, what could be the reason for dumping of wastes in such locations?

SECTION F: Preparedness, Control and Management during flooding periods

16. During the rainy season or periods of flooding, how do you ensure that your household has access to clean and safe drinking water?

……………………………………………

17. Do you treat your drinking water?
    - Yes
    - No

18. If yes, what method(s) do you use?

19. What measures does your household take to ensure proper sanitation during flooding or heavy rains to prevent cholera outbreaks?
    - Use of latrines all the time
    - Safe waste disposal
    - None

20. Are there any specific challenges your household faces regarding sanitation during the rainy season?

………………………………………………………………………………………………………

21. Does your household have a preparedness plan for cholera outbreaks during the rainy season or flooding?
    - Yes
    - No

22. If yes, what steps are included in the plan? Tick all appropriate
    - Evacuation,
    - Emergency supplies,
    - Access to treatment

23. If a cholera outbreak occurs during the rainy season, where would your household seek medical help?
    - Clinic,
    - Hospital,
    - Community health workers
    - Traditional healer

24. Are you aware of the nearest cholera treatment center or health facility? YES/NO

Ending Time……..We have come to *the end of the interview. Thank you so much for your time. Your responses are valuable and will go a long way in informing decision making in the sector.*

Annex 2: Key Informant Interview guide

Spatial analysis of cholera cases and related risk factors in flood prone hotspot areas of Glen View and Budiriro, Harare

INTRODUCTION & BACKGROUND

My name is Addmore Nyawasha. I am a student with the Bindura University of Science Education (BUSE), studying Masters in Climate change and sustainable development. As part of my studies, I am researching on cholera and acute watery diarrhoea risks in flood prone areas with a view to developing targeted and context specific solutions in preparedness, control and management of the disease. All responses shall be anonymous and the information will be used for academic purposes only. Results of the study shall also be available for use by the Government, City of Harare and its partners to inform policy and development. I am therefore kindly requesting to interview you. The interview will take about 30 minutes. Thank you.

Consent Granted……….. Consent Not granted………………………….

NB. *This interview should be administered to a representative of the institution or any senior designated person available at the time of the interview.*

Start time: ………………..

A.) Water Supply

1. Describe your water situation. What sources of drinking water do you use? Explain their functionality and water quality status. Are there any water points in place?
2. How often do your water points break down and what arrangements are in place to maintain and repair them?
3. Explain the major causes of waterpoint breakdowns?
4. For communal water points, are water supplies chlorinated or require regular chlorination? What do you think about the quality of the water (taste, smell, colour, contamination)?
5. How does the yield or quality of the water change much during the year?
6. What do you think can be done to improve the quality of the water?

…………………………………………………………………………………………………

B) Sanitation.

7. Describe your sanitation situation. Do you have public toilets in your area? Explain their functionality status
8. Describe your handwashing practice including your access to water for handwashing with soap/disinfectant?
9. Do you experience sewer pipe burst and to what extent do they affect your water points?

C). Waste Management

10. How do you manage your waste? Are there designated waste collection points.
11. Describe the type of waste collection points are they and how frequently is waste collected?
12. Are there any locations with uncontrolled dumping of wastes? What activities are being undertaken to reduce, recycle or reuse solid wastes?.

D) Preparedness, prevention, management and control

13. What preparedness measures have been put in place by local authorities and health organizations to prevent cholera outbreaks during the rainy season or flooding periods in this area?

14. How do you assess the level of preparedness in this community, and are there any gaps in readiness?
15. Does your organization have an early warning system in place to detect potential cholera outbreaks during the rainy season or after flooding?
16. How effective are the communication strategies in reaching vulnerable populations, especially in flood-prone areas?
17. How prepared are local health facilities and staff to respond to cholera cases during the rainy season or flooding?
18. Are there any challenges in providing adequate treatment and medical supplies during these periods, and how are these challenges being addressed?

Ending time: ……………….

We have come to the end of the interview. Thank you so much for your time. Your responses are valuable and will go a long way in informing decision making in the fight against cholera and other acute watery diarrheal diseases during flooding in our city.