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Microbial Physical and Chemical Risk Assessment of Drinking Water in Cholera Hotspots in Sierra Leone

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Abstract

Cholera continues to pose a significant public health threat in Sierra Leone, exacerbated by poor water infrastructure and inadequate sanitation. This study assessed the quality of drinking water in five cholera-prone districts. These are Kambia, Port Loko, Pujehun, Tonkolili, and Western Area Urban. A total of 84 water samples were collected and analyzed for physical, chemical, and microbiological parameters. Results revealed that 76% of samples exceeded WHO limits for microbial contamination, with Escherichia coli and Salmonella spp. most prevalent. Elevated iron and nitrate concentrations were found in over 60% of samples, indicating industrial and agricultural pollution. Antibiotic susceptibility tests revealed 100% resistance of E. coli strains to ampicillin, erythromycin, and tetracycline. The findings call for urgent water treatment interventions, sanitation improvements, and continuous water quality monitoring to mitigate cholera outbreaks.

Keywords: Water quality, cholera, microbial contamination, public health, Sierra Leone.

Introduction

Cholera is a waterborne disease caused by Vibrio cholerae and remains a major public health threat in Sierra Leone, with recurrent outbreaks linked to poor water quality and sanitation (WHO, 2022). The country has witnessed multiple epidemics, with 22,781 reported cases from 2012–2020, affecting both urban and rural communities (Rebaudet et al., 2019). The five hotspot districts investigated in this study are Kambia, Port Loko, Pujehun, Tonkolili, and Western Area Urban. These districts have historically recorded high cholera incidences due to inadequate sanitation, unsafe water sources, and poor hygiene practices (Bwire et al., 2020).

Access to clean drinking water is a fundamental human right, yet large segments of Sierra Leone's population depend on untreated water sources, increasing their vulnerability to waterborne diseases (Prüss-Ustün et al., 2019; WHO, 2023). Understanding the contamination pathways, water treatment inefficiencies, and socio-economic barriers to safe drinking water is crucial for designing effective public health interventions. A comprehensive evaluation of contamination pathways and treatment gaps is vital to inform public health policies (Prüss-Ustün et al., 2019).

In Sierra Leone, urban and rural communities rely on varied water sources, including wells, standpipes, and rivers, many of which are susceptible to contamination (Bwire et al., 2020).

Problem Statement

The recurrent outbreaks of cholera in Sierra Leone highlight a significant public health crisis linked to contaminated water sources. Despite governmental and international efforts, many communities.

continue to consume water containing harmful bacteria, heavy metals, and chemical pollutants (Shukla & Saxena, 2020). Prior studies indicate that high turbidity, elevated biological oxygen demand (BOD), and the presence of Escherichia coli in drinking water correlate with increased incidences of cholera and other gastrointestinal diseases (Das et al., 2021).

Given the impact of waterborne diseases on public health and socio-economic development, there is need to assess the water quality of drinking sources in cholera-prone districts to inform evidence-based policy decisions. The study should evaluate the physicochemical, chemical, and microbiological quality of drinking water in five cholera hotspot districts, aiming to establish a baseline for interventions and policy recommendations.

However, comprehensive and up to date assessments of drinking water quality in the most affected regions remain limited. This study seeks to bridge that knowledge gap by analyzing water quality in five districts with high cholera prevalence, identifying contamination sources, and assessing the extent of microbial and chemical pollution.

Research Gaps

Despite previous studies on water quality in Sierra Leone, several gaps persist:

1. Limited recent data: Existing studies are outdated and may not reflect current water quality conditions.
2. Focus on urban areas: Most research emphasizes urban water sources, neglecting rural communities where contamination risks are often higher.
3. Inadequate bacterial resistance studies: There is a lack of research on antimicrobial resistance patterns in waterborne bacteria in Sierra Leone.
4. Lack of comprehensive physicochemical assessments: Few studies integrate both microbiological and chemical analyses to provide a holistic view of water safety.
5. Most studies have not considered antimicrobial resistance (AMR) in waterborne pathogens.

This study aims to fill these gaps by providing an updated, comprehensive assessment of water quality in Sierra Leone’s most affected districts.

Research Questions

This study aims to answer the following key research questions:

1. What are the physicochemical properties (e.g., pH, turbidity, conductivity) of drinking water in cholera hotspot districts?
2. What is the extent of microbial contamination, including E. coli and Salmonella spp.?

3. How do contamination levels compare with WHO and EPA drinking water quality standards?
4. What are the antibiotic resistance patterns of E. coli strains isolated from water samples?
5. What policy and intervention strategies can be recommended to improve water quality in affected regions?

Significance of the Study

This research is of vital importance for both public health authorities and policy-makers. By establishing baseline data on water quality, the findings can:

- Inform national water safety policies and public health interventions (WHO, 2022).
- Support international organizations such as UNICEF and WHO in strategizing water treatment programs (Bwire et al., 2020)
- Provide empirical data for researchers, environmentalists, and public health experts advocating for clean water initiatives (Shukla & Saxena, 2020)

Aim and Objectives

Aim

To assess the quality of drinking water sources in five cholera hotspot districts in Sierra Leone and identify potential health risks.

Objectives

1. To evaluate the physicochemical properties of drinking water, including pH, turbidity, conductivity, and total dissolved solids (TDS).
2. To determine the presence and load of microbial contaminants such as E. coli and Salmonella spp.
3. To measure chemical contamination levels, including nitrates, phosphates, and heavy metals.
4. To assess antibiotic resistance patterns among bacterial isolates.
5. To propose actionable interventions for water quality improvement.

Materials and Methods

Study Area and Sampling

This cross-sectional study was conducted in five cholera hotspot districts: Kambia, Port Loko, Pujehun, Tonkolili, and Western Area Urban. These districts were selected based on historical cholera outbreak data and high population density. Water samples were collected from community wells, standpipes, and reservoirs used for domestic and commercial purposes. Within the districts identified, samples were collected from selected communities identified as the most affected communities within the districts during the last cholera outbreak in Sierra Leone. Table 1 presents the distribution of sampling points.

Table 1: The distribution of sampling points among the cholera hotspot districts in Sierra Leone.

District	Chiefdom/Area	Community
Freetown	West	Bintumani Hotel
Freetown	West	Bottom Orku
Freetown	Central	44 well
Freetown	Central	Culvert
Freetown	East	Susan’s bay
Freetown	East	Ginger Hall
Freetown	East	Moa werf
Port Loko	Lokomassama	Rogeray
Port Loko	Lokomassama	Rothawa
Port Loko	Mafoki	Mayeba
Port Loko	Mafoki	Port Loko
Port Loko	Marampa	Lunsar

Port Loko	Koya	Songo
Port Loko	Koya	Crossing
Kambia	Samu	Kabuya
Kambia	Samu	Makalisor
Kambia	Mabolo	Mapaigbo
Kambia	lowa Magbema	Bamoiluma
Kambia	Masumgballa	Laminaya
Kambia	Masumgballa	Robanka
Tonkolili	Kholifa Rowalla	Mag
Tonkolili	Tane	Matotoka
Tonkolili	Yoni Mamala	Mile 91
Pujehun	Pujehun	Pujehun Town
Pujehun	Kpaka	Hacinuri Kormaz
Pujehun	Kpaka	Liyia
Pujehun	Sorogbeima	Sorogbeima town
Pujehun	Sorogbeima	Sulima

A total of 84 (3 per site) water samples were collected from various locations in the five districts. To ensure representativeness, sample collection sites were categorized based on proximity to human settlements, sanitation facilities, and potential contamination sources. The selection criteria also considered seasonal variations in water sources, ensuring samples were taken from both surface and groundwater sources. Sampling was conducted using sterile polyethylene bottles, and samples were transported in insulated containers with ice packs to maintain temperature and prevent microbial degradation.

Each sample was labeled with the date, time, and source type before being transported to the laboratory within 6 hours of collection. Field parameters such as temperature, pH, and turbidity were recorded on-site using portable meters calibrated before each sampling session.

Laboratory Analysis

The laboratory analysis was conducted at the Milton Margai Technical University Laboratory in collaboration with the Ministry of Health and the Ministry of Water Resources. The procedures followed were in accordance with WHO (2023) guidelines and the United States Environmental Protection Agency (USEPA) (2020) standards.

Physical Analysis:

- ⇒ Temperature: Measured using a digital thermometer.
- ⇒ pH: Determined using a calibrated pH meter.
- ⇒ Turbidity: Assessed using a nephelometric turbidity meter.
- ⇒ Conductivity: Measured using a calibrated conductivity meter.
- ⇒ Total Dissolved Solids (TDS): Evaluated using a gravimetric method.

Chemical Analysis:

- ⇒ Biological Oxygen Demand (BOD): Determined using the Winkler titration method to measure oxygen depletion due to microbial activity.
- ⇒ Iron: Analyzed using a UV-Vis spectrophotometer after digestion with nitric acid.
- ⇒ Nitrates and Phosphates: Quantified using spectrophotometry following the USEPA standard methods.
- ⇒ Water Hardness: Measured using the ethylenediaminetetraacetic acid (EDTA) titration method.

Microbiological Analysis:

- ⇒ E. coli and Salmonella spp.: Identified through culture methods using selective agar media (MacConkey and XLD agar).
- ⇒ Staphylococcus aureus: Detected using mannitol salt agar.
- ⇒ Most Probable Number (MPN) Method: Used to determine microbial load in water samples.
- ⇒ Antibiotic Susceptibility Tests: Conducted using the disk diffusion method to assess resistance patterns of bacterial isolates against commonly used antibiotics, including ampicillin, erythromycin, and tetracycline (Davies & Davies, 2010).

Strict quality control measures were followed, including the use of sterile equipment, blank sample tests, and duplicate analyses to ensure accuracy and reliability.

Results and Discussion

Introduction

The assessment of drinking water sources in cholera hotspot districts of Sierra Leone revealed critical insights into the physicochemical, chemical, and microbiological characteristics of water samples. This section presents and interprets the findings from laboratory analyses, discusses their implications for public health, and offers comparative assessments with global water quality standards. The study aimed to establish a baseline for water quality and food safety in these regions, linking contamination levels to cholera outbreaks for better public health interventions (WHO, 2022; Bwire et al., 2020)

Physical Analysis of Water Samples

pH Levels

The pH of water is a crucial indicator of its suitability for consumption. According to the World Health Organization (WHO), the recommended pH range for drinking water is 6.5–8.5 (WHO, 2022). Analysis of the collected water samples indicated significant deviations, particularly in locations such as Bottom-Orku Wharf (pH 7.12) and Masumgbala chiefdom (pH 4.55), indicating contamination from acidic sources, possibly due to industrial waste or agricultural runoff (Shukla and Saxena, 2020).

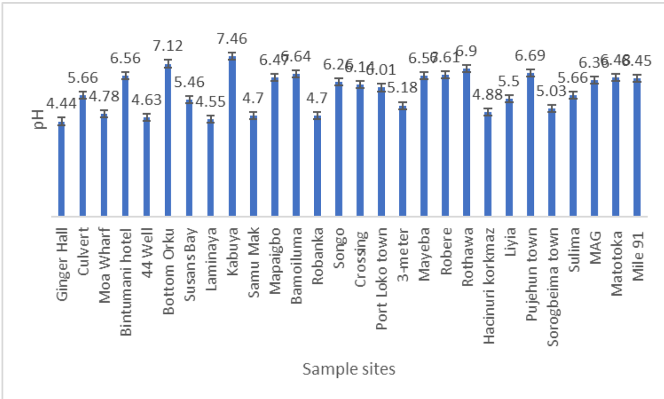

Figure 1: pH Levels of Water Samples from Different Locations (+/- SD).

Turbidity and Conductivity

Turbidity levels exceeded the WHO limit of 5 NTU in some locations, including Maforki chiefdom (5.42 NTU) and Rothawa (8.61 NTU), suggesting suspended solids contamination, likely from soil erosion, sewage discharge, or human activities near water sources (Das et al., 2021). Conductivity values remained within acceptable limits (30–1500 µS/cm), indicating a relatively stable ionic composition across most sources. However, elevated conductivity in some areas, such as Susans Bay (675 µS/cm), may indicate higher levels of dissolved salts and pollutants (Shukla and Saxena, 2020).

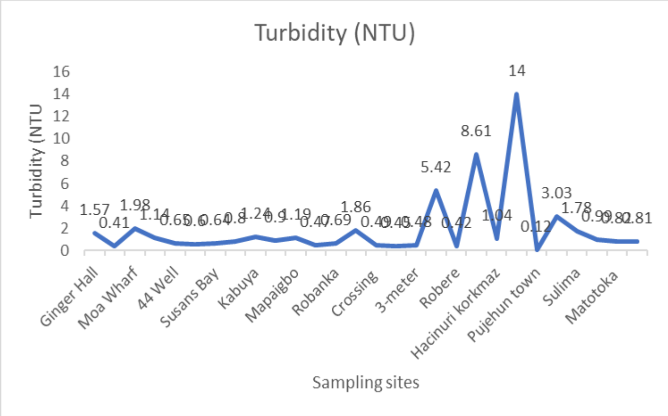

Figure 2: Turbidity of water samples from various sources in the cholera districts.

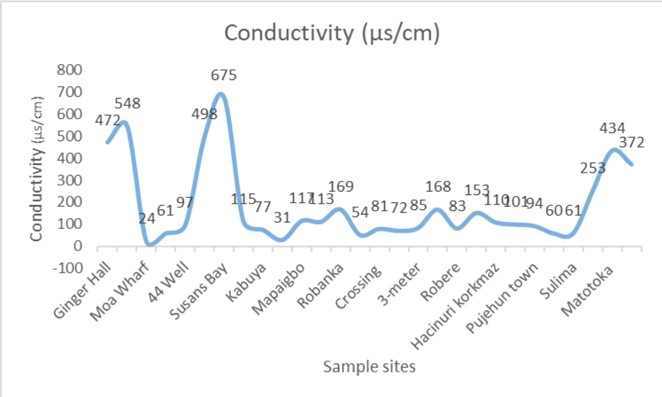

Figure 3: Conductivity Levels in water samples from sample sites.

Most water samples had pH levels outside the WHO-recommended range of 6.5–8.5, with some exhibiting high turbidity (>5 NTU) (WHO, 2017). Conductivity levels were within acceptable limits, but TDS concentrations in several samples indicated contamination risks. High turbidity suggests the presence of suspended solids, which can harbor pathogens and compromise water clarity (Das et al., 2021). This is concerning as turbidity has been linked to the survival and transport of microbial contaminants, increasing the likelihood of waterborne disease transmission (Bain et al., 2014).

Chemical Contaminants

Iron concentrations exceeded the WHO limit of 0.3 mg/L in numerous samples, indicating possible leaching from geological formations or industrial activities (WHO, 2021). Elevated nitrate levels (above 10 mg/L) were detected, likely due to agricultural runoff and improper waste disposal (USEPA, 2020). Excessive nitrates can pose health risks, especially to infants, by causing methemoglobinemia (blue baby syndrome) (Knobeloch L, Salna B, Hogan A, Postle J, Anderson H. Blue babies and nitrate-contaminated well water. Environ Health Perspect. 2000 Jul;108(7):675-8. doi: 10.1289/ehp.00108675. PMID: 10903623; PMCID: PMC1638204.). High nitrate contamination also suggests underlying agricultural pollution, which may require long-term policy interventions such as improved fertilizer management and watershed protection (Shukla & Saxena, 2020).

Biological Oxygen Demand (BOD) and Dissolved Oxygen (DO)

BOD levels were higher than the recommended 1–3 ppm in multiple sites, including Mayeba (10 ppm) and Moa Wharf (8.4 ppm), indicating organic pollution, likely due to sewage contamination and decaying organic matter (Koda, et al., 2017). Despite this, DO levels remained moderate, suggesting natural oxygen replenishment but highlighting persistent contamination risks. High BOD levels are often associated with microbial growth and eutrophication, potentially leading to hypoxic conditions detrimental to aquatic life (WHO 2022).

Microbiological Contamination

Bacterial Contamination

The presence of Escherichia coli (E. coli) in nearly all samples indicates widespread fecal contamination, a major concern for public health. The highest recorded E. coli load was >2400 MPN/100 ml (Mayeba, Port Loko). WHO guidelines state that drinking water should have zero E. coli per 100 ml (WHO, 2022). Other identified bacteria include

Salmonella spp. Staphylococcus aureus, and Proteus vulgaris, which pose significant health risks, particularly for vulnerable populations such as children and immunocompromised individuals (Shukla & Saxena 2020).

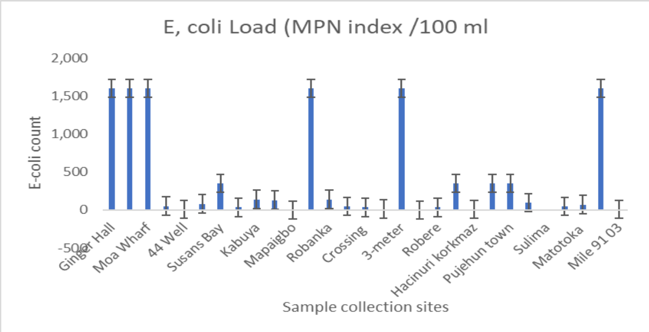

Figure 4: E. coli Load Across Different Water Sources (+/- SD).

Protozoa and Helminths

Protozoan pathogens such as Entamoeba histolytica and Balantidium coli were frequently observed, suggesting contamination from human and animal waste. Helminths like Ascaris lumbricoides were detected in Kambia and Port Loko districts, indicating open defecation and poor sanitation practices as contributing factors (Bwire et al., 2020).

Antibiotic Resistance Trends

Antibiotic susceptibility tests showed alarming resistance patterns. E. coli exhibited 100% resistance to ampicillin, erythromycin, penicillin, and tetracycline, highlighting a growing antimicrobial resistance (AMR) challenge in the region. The increasing resistance trend underscores the overuse and misuse of antibiotics in both medical and agricultural settings (WHO, 2022).

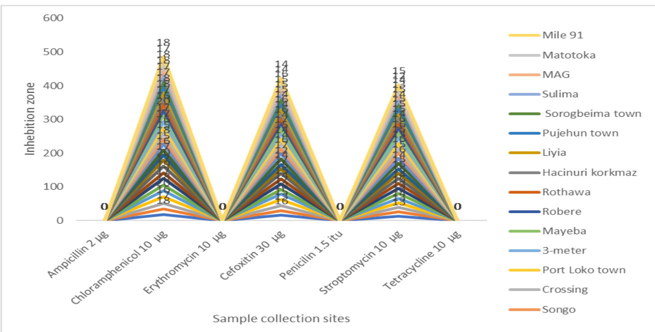

Figure 5: Antibiotic Resistance Patterns in E. coli

Microbiological analysis revealed *E. coli* in 76% of samples, surpassing the WHO standard of 0 MPN/100mL. *Salmonella spp.* and *Staphylococcus aureus* were prevalent in water and food samples, indicating contamination from fecal matter and poor food handling practices (Levy et al., 2016). Notably, antibiotic susceptibility tests showed high resistance of *E. coli* to ampicillin, erythromycin, and tetracycline, raising concerns about antimicrobial resistance in waterborne pathogens (Davies & Davies, 2010). The high levels of microbial contamination highlight the critical need for improved sanitation, stricter food hygiene measures, and community-level interventions, such as targeted hygiene education and vaccination programs (Azman et al., 2018).

The presence of antibiotic-resistant bacteria in drinking water sources suggests a growing public health crisis. Without immediate intervention, these pathogens could contribute to increased morbidity and mortality rates, particularly among vulnerable populations. Addressing these challenges requires an integrated approach involving government regulation, community education, and infrastructure improvements.

Discussion

The high microbial contamination in drinking water sources highlights the inadequate water treatment and sanitation infrastructure in these districts. Contaminated water is a major driver of cholera transmission (Ali et al., 2015). The findings align with previous studies linking poor sanitation to recurrent cholera outbreaks in sub-Saharan Africa (Bwire et al., 2020). Additionally, high nitrate levels in water pose health risks, particularly for infants, as they contribute to methemoglobinemia (Knobeloch et al., 2000).

The study also identified critical gaps in food safety regulations, as food vendors frequently used contaminated water for food preparation (Das et al., 2021). These findings necessitate urgent intervention through improved surveillance, regulatory enforcement, and community-based hygiene education.

The data confirm severe microbial and chemical contamination of drinking water in cholera hotspots. Widespread fecal pollution, elevated BOD, and high nitrate levels pose immediate public health risks, especially for children. The detection of multidrug-resistant E. coli suggests overuse of antibiotics and the need for AMR surveillance.

This aligns with recent findings by Chatterjee et al., (2024) and WHO, (2023), emphasizing the intersection of water safety and antimicrobial resistance.

The findings underscore the urgent need for improved water treatment, sanitation, protocols in cholera prone regions. Strategies should focus on enhanced monitoring, public health education, and stricter enforcement of hygiene regulations. Investment in water infrastructure and access to clean drinking water is essential to mitigate the spread of waterborne diseases (WHO, 2022; Koda, et al., 2017).

Conclusion and Recommendations

This study confirms that drinking water in several districts in Sierra Leonean is not safe, posing risks of cholera and other waterborne diseases. To address these issues, the following recommendations are proposed:

1. Enhanced Water Treatment: Implement advanced filtration, chlorination, and UV treatment techniques in public water systems
2. Sanitation Improvements: Strengthen wastewater management, enforce hygiene regulations, and provide community-based sanitation solutions
3. Food Safety Regulations: Enforce HACCP guidelines in food establishments, conduct routine inspections, and ensure safe water use in food handling
4. Community Awareness: Educate the public on proper handwashing, sanitation, and water treatment practices.
5. Regular Monitoring: Establish a government-led water quality surveillance program to detect and mitigate contamination risks.

Addressing these challenges is critical to reducing cholera incidence and ensuring safe drinking water for vulnerable populations.

Conflicts of Interest:

The authors declare no conflicts of interest.

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