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Collaborative Efforts and Strategies for Cholera Outbreak Control in Garissa County, Kenya: Implementation of Water Quality Monitoring Interventions

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Abstract

A multi-faceted Case Area Targeted Intervention (CATI) approach emphasizing the integration of Water, Sanitation and Hygiene (WASH) interventions and Oral Cholera Vaccine (OCV) campaign was employed to respond to the outbreak of cholera in Garissa County. Drinking water sources in areas heavily impacted by cholera were systematically mapped and tested for microbiological quality. The quality assessment was carried out in April 2023 during an ongoing cholera outbreak in the county. A total of 109 samples were collected and tested for thermotolerant coliforms and other in situ parameters. The finding revealed that more than 87% of the samples did not meet the World Health Organization (WHO) standard for thermotolerant coliforms; and 30% had turbidity values above the recommended threshold values. None of the 109 samples had any traceable residual chlorine. Following these findings, the county government implemented the targeted interventions which resulted in a positive impact in the fight against cholera. The WHO supported key interventions which included capacity building in water quality monitoring and prepositioning of critical WASH commodities to the cholera affected areas.

Keywords

Cholera, Drinking Water, Household Water Treatment, Kenya

1. Introduction

Cholera is an acute diarrheal disease associated with fecal-oral transmission of the bacterium, Vibrio cholerae. Globally, it leads to approximately four million cases and 143,000 fatalities annually, with Africa accounting for 54% of these cases [1]. The majority (>90%) of cases and deaths are reported from less developed countries where access to safe water and sanitation is limited [2]. Cholera poses a significant global public health threat, particularly in vulnerable populations, due to its high rates of morbidity and mortality. Between 2010 and 2019, sub-Saharan Africa accounted for 24% of the cholera cases reported to the World Health Organization (WHO) [1]. Several studies have analyzed the prevalence of cholera in sub-Saharan Africa and evaluated the potential benefits of employing geographic targeting to optimize intervention strategies [3] [4]. The studies recommend improving the water and sanitation infrastructure in areas with high cholera incidence for effective and sustainable control of cholera outbreaks.

Cholera is endemic in Kenya, particularly in regions with urban informal settlements, refugee camps, and rural areas adjacent to large bodies of water [5]. Approximately 10 million Kenyans depend on water sources that are contaminated, and 5 million engage in open defecation, which further increases the risk of cholera transmission for the population [6]. A study by [7] assessed a combination of epidemiological and Water, Sanitation and Hygiene (WASH) indicators in 290 constituencies in Kenya and classified 25 sub-counties (8.6%) as a high epidemiological priority, while 78 sub-counties (26.9%) were deemed a high priority in terms of WASH. These counties are plagued by various health concerns and require immediate attention to mitigate the impact on the population's well-being. These counties are plagued by various health concerns and require immediate attention to mitigate the impact on the population's well-being.

Cholera cases were first reported in Kenya in 1971, and the country has since experienced recurring outbreaks [8]. The occurrence of cholera has been linked to climate changes, including El Niño events [9] [10]. A study by [11] analyzed incidence data at the country level and projected that Kenya, as part of East Africa, would likely face more cholera outbreaks in the near future due to El Niño events. The study emphasized the importance of significant investment in the WASH sector. The most recent cholera outbreak in Kenya began in October 2022 and affected 23 out of the country's 47 counties. Unlike typical cholera epidemics during the rainy season, this outbreak occurred in the dry season. As of the 15th of July 2023, a cumulative number of 2853 cases and 17 deaths (CFR = 0.59) were reported from Garissa County Situation Report (SITREP), MoH, the 15th of July 2023). The epidemic curve shown in **Figure 1** shows the decrease in the trend of cases because of the various interventions implemented by the county government of Garissa and its partners.

WASH interventions are crucial in the control of cholera outbreaks. The provision of adequate sanitation facilities, improved waste management systems,

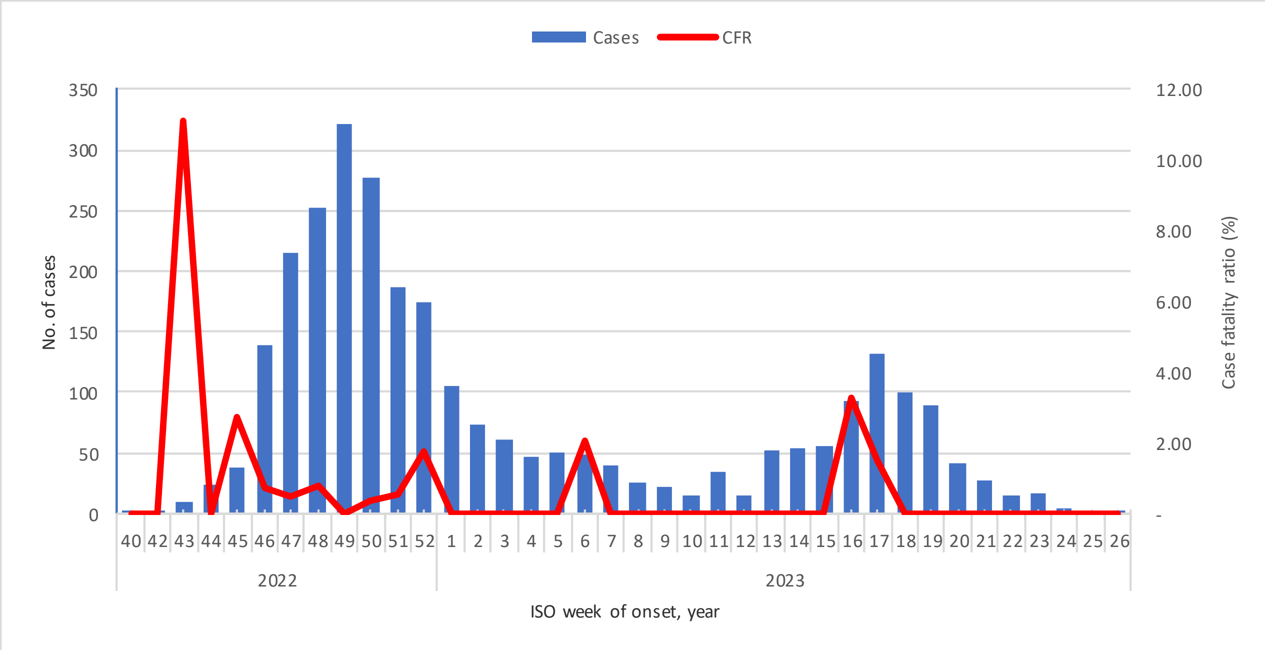

Figure 1. Epidemic curve of cholera cases reported in Garissa between October 2022 and the 15th of July 2023.

and hand hygiene stations has proven effective in preventing the contamination of water sources. The guideline values set by the Kenyan Bureau of Standards (KBS) [12] and the WHO [13] require a value of 0 cfu/100ml for thermotolerant coliforms, which serve as an indicator of compliance. The existence of fecal coliforms in drinking water sources signifies a possible health hazard for those who consume it. Numerous studies have shown that adopting Household Water Treatment (HWT) methods and safe storage practices can have a significant positive impact on the microbiological quality of household water, leading to a reduction in the prevalence of diarrheal diseases [14] [15].

Chlorination is highly recommended as a cost-effective method for water disinfection and prevention of recontamination [16] [17]. The WHO has provided specific guidelines emphasizing the importance of maintaining minimum free chlorine residual levels at various points in the water distribution system. For instance, tanker trucks should maintain a level of 2.0 mg/L at the point of filling, while standpipes and wells should ensure a level of 1.0 mg/L. At the point of use, a residual chlorine level of 0.2 - 0.5 mg/L is recommended [18]. These guidelines are crucial in safeguarding public health and minimizing the risk of waterborne diseases.

Garissa County, situated in the north-eastern part of Kenya, is classified as an arid and semi-arid land (ASAL) county. Out of the ten ASAL counties, Garissa County is particularly notable for having the highest number of recorded cholera cases since the first case was reported in October 2022. Cholera predominantly affects the sub-counties of Garissa, Lagdera, Fafi, and Dadaab, as well as the refugee camps in Dagahaley, Ifo, and Hagadera. The occurrence of drought and security threats resulting from cross-border conflicts contribute to the spread of infectious diseases in Garissa County. These challenging conditions are aggravated by malnutrition, restricted availability of safe drinking water, and inadequate provisions for sanitation and hygiene. It is worth noting that Garissa County is also included among the 15 counties in Kenya responsible for 85% of the country's open defecation [6].

A multi-faceted Case Area Targeted Intervention (CATI) Approach emphasizing the integration of WASH interventions and Oral Cholera Vaccine (OCV) campaign was employed to respond to the outbreak of cholera in Garissa County. Kenyan health authorities launched the country's first-ever oral cholera vaccination (OCV) campaign in February 2023 to bolster cholera outbreak interventions [19]. The 10-day campaign rolled out with support from the WHO and the United Nations Children's Fund (UNICEF) targeted 2.2 million people in some of the worst-affected counties of the country, Garissa, Wajir, Tana River, and Nairobi. However, while the oral vaccine can confer partial immunity, sustained access to safe drinking water, sanitation, and hygiene is crucial for long-term cholera control. In this regard, WHO and partners collaborated with the Garissa County government to enhance WASH interventions in the most affected communities, including refugee settlements. The support included mapping of water sources in cholera hotspots, conducting systematic water sampling and testing for microbial contamination, and building capacity in WASH through staff training and prepositioning of essential supplies such as water treatment chemicals, water test kits, waste incineration cardboards, chlorine sprayers, and water storage tanks. This collaboration was aimed at minimizing the spread and impact of the cholera outbreak. The current study is carried out to evaluate the impact of the evidence-based WASH interventions that contributed to the control of the recent cholera outbreak in Garissa County of Kenya.

2. Methods

2.1. Microbiological Water Quality Assessment

2.1.1. Study Site

The study took place in Garissa County, Kenya. The county has a local population of over 480,000 people and is host to large refugee camps. Located in the north-eastern part of Kenya, the county experiences prolonged droughts that make its communities more susceptible to disasters. One of the primary challenges faced by the local communities is the limited availability of water for both humans and livestock, especially during the dry seasons.

From the 23rd of October 2022, when the first case was confirmed in the Hagadera refugee camp in the Fafi sub-county, until the 14th of July 2023, a total of 2846 cases and 17 deaths were reported from Garissa County. Three (3) of the cases (0.1%) were imported, while the other 2843 cases (99.9%) were local transmissions. As of the 14th of July 2023, Garissa County recorded the highest number of cholera cases in the country. The distribution of cholera cases in the sub-counties is described in **Figure 2**.

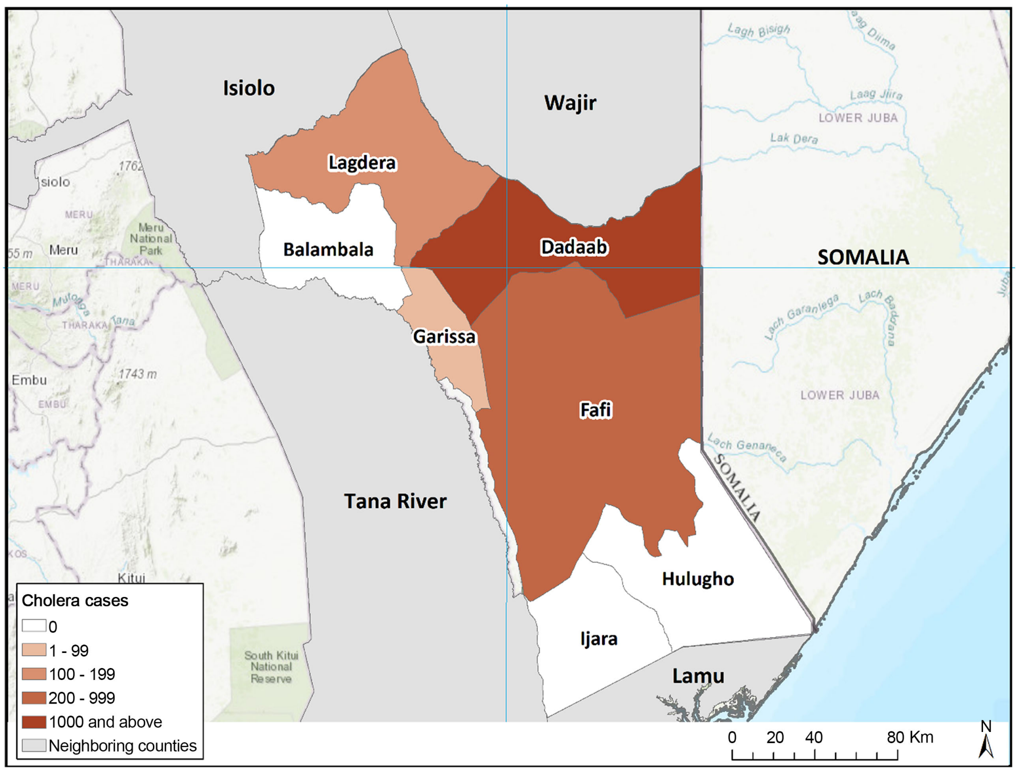

Figure 2. Map of Garissa County with the distribution of cholera cases in the sub-counties as of the 14th of July 2023.

2.1.2. Study Design

We conducted a cross-sectional, descriptive analysis prospective of the implementation of proven water, sanitation, and hygiene interventions that contributed to the control of the cholera outbreak in Garissa County.

2.1.3. Scope of Water Sampling

Garissa has seven sub-counties. Water sampling was conducted only from the four sub-counties of Garissa that were affected by the cholera outbreak (Garissa, Lagdera, Dadaab, and Fafi sub-counties).

2.1.4. Selection of Sample Collection Points

A total of 109 samples were collected from household storage containers (40 samples), community tap stands (12 samples), community water kiosks (6 samples), institution storage tanks (35 samples), water trucks/boozers (7 samples), water bottlers (7 samples), and flowing surface water (2 samples). The selection of sampling points was not arbitrary; it was driven by the community's reliance on these water sources. Each collection site was thoughtfully chosen and geographically referenced.

2.1.5. Data Analysis

Data was analyzed using Microsoft® Excel® for Microsoft 365 MSO (Version 2310 Build 16.0.16924.20054) 64-bit, Microsoft Corporation, Redmond, WA. The Chi-Square (χ^2) test for independence showed a significant association between water sources and compliance with fecal coliform guidelines ($\chi^2 = 5.99$, $p < 0.05$). Sensitivity analysis was conducted where changing the compliance threshold to a small positive value resulted in a slight decrease in the overall non-compliance rate. Fisher's exact test showed similar results, supporting the association between water sources and fecal coliform compliance.

2.1.6. Laboratory Procedures

1) Equipment used

To test for thermotolerant (fecal) coliforms, the researchers utilized the DelAgua water test kits. The measurement of free residual chlorine was done using a HACH Lovibond comparator. The EUTECH PC 650 model photometer was employed to measure electrical conductivity, total dissolved solids, and temperature.

2) Sterilization of Equipment

Before use, the water sample collection bottles and Petri dishes were sterilized in an autoclave at a temperature of 120˚C and a steam pressure of 1 bar for a duration of 40 minutes. The vacuum cup and filtration apparatus were also sterilized using methanol vapour both prior to and during the analysis. All disposable materials were sterilized before disposal to prevent environmental contamination.

3) Sample Collection, Storage, and Transportation

In each site, two bottles of 250 millilitres were aseptically filled with water, capped appropriately and carefully transported in a cold box, maintaining a temperature between 2˚C and 8˚C. Before transportation, the samples were stored in a controlled environment and kept away from direct sunlight. To minimize the risk of contamination, during sample collection from tap stands, the taps were left open for approximately 2 minutes. This precautionary measure allowed any stagnant or potentially contaminated water to flush out, ensuring that the collected samples truly represented the quality of the water source. These measures were crucial in preserving the integrity of the samples during transportation to Garissa town for analysis. Purposive and convenient approaches were used in identifying the sampling points, mainly guided by the community's reliance on these water sources. All collection sites were geo-referenced for traceability (**Figure 3**).

4) Preparation of Media and Processing of Samples

The Membrane Lauryl Sulphate Broth (MLSB) media was prepared by dissolving 38.1 grams of MLSB powder in 500 ml of distilled water. The resulting mixture was sterilized, and then the samples were processed and incubated at a temperature of 44˚C for a period of 17 hours. After the incubation, the Petri dishes containing the samples were taken out of the incubator and laid carefully in sample order on a table. All the yellow colonies which had a diameter of between 1 mm and 3 mm were counted and recorded within 15 minutes. It is worth noting that due to logistical difficulties and long travel durations on rough roads, the samples were analyzed within 9 hours after being collected.

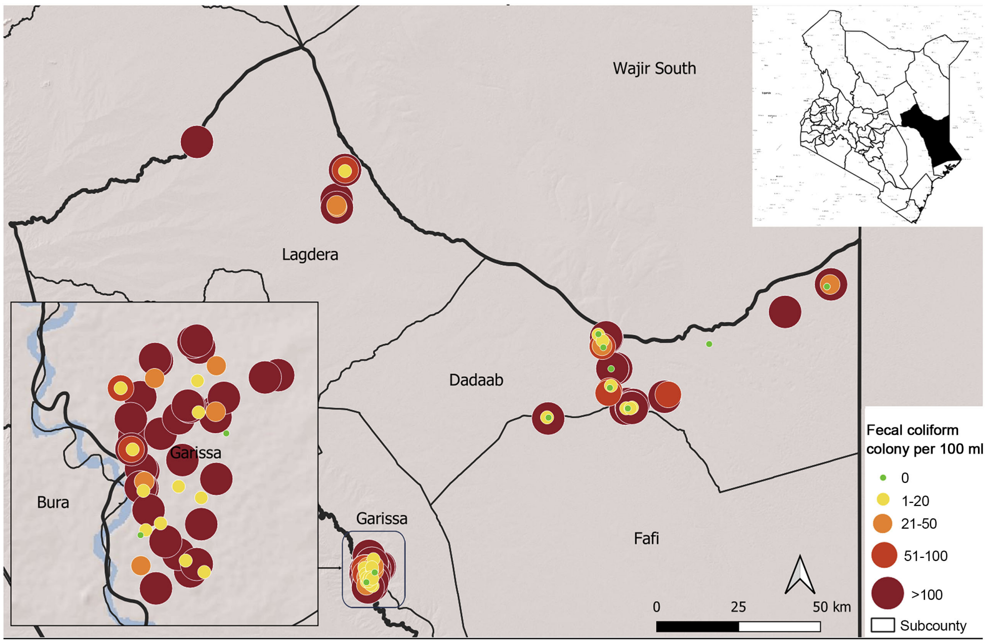

Figure 3. Map showing sampling locations and fecal coliform count per 100 ml in Garissa County.

2.2. Enhancing Skills and Expertise

WHO supported a comprehensive WASH and Infection Prevention and Control (IPC) training program that targeted 16 public health officers (PHOs) from six cholera-affected sub-counties in Garissa. This training was aimed at equipping participants with the necessary knowledge and skills to conduct regular water quality testing, monitoring, and reporting. The training introduced the participants to bacteriological testing, free residual chlorine monitoring, and the determination of other in situ water quality parameters such as pH and turbidity. Through practical exercises, trainees gained hands-on experience in conducting water quality testing, emphasizing proper collection, handling, preservation, and transportation of the samples for bacteriological analysis. Participants were oriented on quality control measures using a control sample (including positive and negative controls), and the significance of monitoring laboratory performance in water quality testing was highlighted. The preparation of culture media, inoculating water samples onto the media, and identifying bacterial colonies using various techniques were emphasized.

Interpreting the results of the bacteriological water quality analysis was demonstrated. Participants were trained to identify bacterial species on culture media based on phenotypic characteristics and sugar fermentation abilities. In addition, participants were taken through criteria for determining whether the levels of bacteria present in water samples were within safe limits. This knowledge is essential for ensuring the safety and quality of water sources, ultimately contributing to the prevention and control of cholera outbreaks. The training program successfully fostered an in-depth understanding of the concepts and mastery of the skills required for conducting water quality analysis. Through engaging in practical exercises and fieldwork, participants demonstrated their ability to apply their newly acquired knowledge effectively.

By investing in relevant capacity-building initiatives, the WHO imparts skills to public health officers to manage waterborne diseases effectively. The training programs were helpful in equipping the participants with the expertise needed to identify potential risks, implement appropriate preventive measures, and respond rapidly to any emerging outbreaks. This comprehensive approach to water quality analysis strengthens WHO's collective efforts in safeguarding public health and ensuring access to safe and clean water for all.

2.3. Strategic Positioning of Essential WaSH Supplies

To increase access to safe drinking water at the household level, especially for those who rely on untreated water for drinking, over 160,000 aqua tabs (NaDCC tablets, 67 mg) were provided by WHO and partners. WHO provided 224,000 tablets for the response. The county government distributed these water treatment tablets to 12,600 households in the cholera-affected regions, including refugee camps and host communities. Other WASH supplies donated included Delagua water test kits, chlorine sprayer machines, Chlorine granules (HTH, 65%), water tanks, waste incineration cardboard, cholera beds, tents, and others. Distribution of water treatment chemicals and other critical WASH items has continued in the hotspot area, particularly in the refugee camps and refugee host communities.

For targeted interventions, WHO and its partners assessed case counts, case-fatality rates, and recent cases of cholera reported by the county. Based on this information, the county government, with support from UNICEF and WHO, disseminated information, education, and communication (IEC) materials on cholera prevention to 17,500 households across four sub-counties in the affected communities. Specifically, the messages provided vital information on proper hygiene practices and preventive measures, ultimately reducing the spread of cholera, and improving overall community health. This collaborative approach was extended to involve other partners, local authorities, and communities. Through such partnerships, WHO and WASH partners remain fully committed to supporting the implementation and monitoring of initiatives aimed at improving access to safe drinking water during the cholera epidemic and beyond.

3. Results

In this study, a total of 109 drinking water samples were collected and analyzed for fecal coliform contamination (**Figure 3**). The guideline values set by the Kenyan Bureau of Standards (KBS) and the WHO require a value of 0 cfu/100ml for thermotolerant coliforms, which serve as an indicator of compliance. It was found that 87.2% (n = 95) of the samples did not meet the threshold values for fecal coliforms (**Table 1**).

As shown in **Table 2**, Household storage containers were the main source of drinking water that was examined, where a total of 40 samples (36.7%) were obtained. Only three (7.5%) met the recommended standard for thermotolerant coliforms. Among thirty-five (35) samples collected from storage tanks in various institutions, such as schools, mosques, hotels, slaughterhouses, cafes, prisons, health centers, and orphanages, only five (14.3%) were within the acceptable coliform values. Of the twelve (12) samples collected from community tap stands, only two (16.7%) met the guidelines' value. Seven (7) samples were collected from water truckers/bowsers, and all were found to have been fecally contaminated. Of the seven (7) samples collected from water bottlers, only two (29%) adhered to the guideline value. From community water kiosks, only 1 out of 6 samples (16.7%) was within the acceptable limits of coliforms. Two (2) samples were collected from surface waters, specifically an unprotected dam and a seasonal river from where drinking water is collected by the community. Both samples were found to be contaminated with thermotolerant bacteria. Regarding the other in-situ parameters, about 84.4% (92/109) of the samples met the required standard for electrical conductivity; 70% met the criteria for turbidity, with a maximum allowance of 5 NTU; but no trace of residual chlorine was detectable in any of the 109 samples at the time of collection. All 109 samples complied with the KBS guidelines for pH and temperature.

Table 1. Distribution of non-potable water samples by sub-county.

Water source type	Sub-county				Total
	Garissa	Dadaab	Fafi	Lagdera	
Households	18	6	8	5	37
Community tap stands	1	5	2	1	9
Community water kiosks	0	2	0	3	5
Seasonal river/unprotected dam	1	0	0	1	2
Institution storage tanks	24	2	4	0	30
Water transporters	7	0	0	0	7
Water bottling company	5	0	0	0	5
Total	56	15	14	10	95

Table 2. Distribution of potable and non-potable water per sub-county.

Water source type	Bacteriological portability		Total
	Potable	Non-potable	
Households	3	37	40
Community tap stands	2	10	12
Community water kiosks	1	5	6
Seasonal river/unprotected dam	0	2	2
Institution storage tanks	5	30	35
Water truckers/boozers	0	7	7
Water bottlers	2	5	7
Total	14	95	109

4. Discussion

The Kenyan government has implemented various initiatives and policies to improve drinking water quality in the country. The Water Act of 2016 [20], for example, aims to effectively regulate and manage water resources by emphasizing on the protection of water sources and setting standards for water supply, treatment, and distribution. However, despite the tremendous efforts, access to safe drinking water is remains inadequate. This is particularly true with the counties which are prone to draught and other emergencies.

Water quality assessments are systematically conducted to identify potential sources of contamination and monitor the microbial content of water sources. These assessments involve collecting water samples from target sites and analyzing them for various microbial indicators. Water testing typically includes the measurement of indicators such as total coliforms, fecal coliforms, and E. coli, which serve as indicators of fecal contamination [21]. These indicators help assess the overall quality of water and determine the level of risk it poses to public health. Regular monitoring allows for the identification of trends and the implementation of appropriate interventions to improve water quality. The finding of this assessment reveals that over 87% of the drinking water sources sampled and tested were fecally contaminated. While the Sub-County was still experiencing a wave of cholera outbreak, flooding occurred due to heavy rains in April 2023 which worsened the situation. The flooding caused the pit latrines to overflow and contaminate the water sources, mainly the shallow wells. The water infrastructure such as piping works and household water tanks were contaminated with the flush floods and fecal matter making household water unsafe for drinking. In addition, due to collapsed household sanitary facilities and flooded yards, open defecation was rampant and this further leads to water contamination. Following these, door to door campaign on cholera messaging, treatment of drinking water, proper sanitation and hygiene, and environmental cleaning was very critical. Several studies indicate that in adequate latrine facilities and limited access to functional sewerage system makes waste disposal uncontrollable hence escalating the rates of diarrhea or cholera outbreaks [3] [8].

One of the main challenges faced by Garissa residents is the limited availability of clean and reliable drinking water sources. The county experiences frequent droughts, making it difficult for households to access sufficient water for their daily needs. This scarcity forces the communities to rely on alternative water sources, such as shallow wells, unprotected boreholes, flowing rivers, and dams, thereby exposing them to waterborne diseases, including cholera. Water tracking is a common practice in the county, going on with no proper regulation and monitoring. Our study reveals that the water distributed through these trackers was not suitable for drinking, as it was often collected from unprotected sources, and the tanks were not regularly cleaned and disinfected.

Latrine coverage is extremely low in Garissa County. For example, among the refugee camps, it is estimated to be only around 53%. Several of the pit latrines were reported to be submerged due to floods in the camps and the host community. Congestion remained a big challenge driving the spread of cholera in the refugee camps. Several studies [22] [23] have explored the impact of flooding on water sources, highlighting how contaminated water can affect public health. During sample collection, we observed that flooding often occurred around tap stands, water kiosks, and water drawing points from storage tanks. This phenomenon contributed to the contamination of water sources, thereby posing a risk to public health. One of the primary causes of flooding is surface runoff, which can carry various contaminants from the surrounding land. In addition to surface runoff, human activities also contributed to the contamination. Before fetching water, individuals often did not clean the containers and therefore, further contaminated the water, compromising its safety. Implementing protective measures against flooding in water sources is crucial in safeguarding the quality of drinking water. Some practical steps individuals and communities can take are:

1) Establishing buffer zones: Creating vegetated areas or green spaces around water sources can help absorb excess water during flooding events, minimizing the risk of contamination.

2) Investing in appropriate water treatment technologies, such as filtration and disinfection.

3) Educating communities about the importance of clean water and the potential risks associated with flooding can empower individuals to take proactive measures to protect their water sources.

From the results, 35% of the water points sampled were turbid. Turbid water is aesthetically unappealing and may represent a health concern. Turbidity can provide food and shelter for pathogens and promote their growth in water leading to waterborne disease outbreaks. On Free Residual Chlorine (FRC) level, we observed that none of the samples (0%) taken met the threshold level according to WHO water quality drinking standards [19]. This shows that water chlorination is a concern in Garissa Sub County. It is advisable to chlorinate water at the source, and possibly also to do boost chlorination at the different storage and distribution points to ensure the water has adequate FRC at the drawing points and at the point-of-use.

Our study reveals that the most likely risk factor for persistence of cholera outbreak in Garissa was the practice of people directly consuming contaminated water from unprotected sources. Several water samples were collected from boreholes located in the cholera hotspot areas of Garissa. The samples appeared clean, but when tested, they were found to be mostly contaminated by fecal coliforms. Assuming borehole water was safe and being advised by some health workers, most communities practiced drinking borehole water without any further treatment. We believe that the prevalence of fecal coliform contamination in these water sources might have exposed the communities to the outbreak. Several factors must have contributed to the fecal contamination of the boreholes. Poor sanitation practices, inadequate waste management systems, and agricultural runoff are among the primary culprits. These factors can contribute to the introduction of fecal coliforms into the groundwater, compromising the safety of the water supply. Addressing the issue of borehole water fecal coliform contamination requires urgent intervention and proactive measures. Community awareness programs, improved sanitation infrastructure, and regular water quality testing are essential steps in mitigating the risks associated with contaminated water sources.

Exploring water quality amidst an ongoing cholera outbreak was met with several challenges. The following were the main limitations.

1) **Sample representativeness and measurement errors**: Some areas were not accessible for sample collection. Mobility restrictions caused by rain and security concerns restricted researchers from reaching these locations. Despite these obstacles, the study team persevered and collected samples from accessible areas, ensuring that valuable data could still be gathered.

2) **Methodological limitations:** Instead of directly testing for Vibrio cholerae, the samples were analyzed for thermotolerant coliforms, a commonly used indicator of fecal contamination. While this approach provided valuable insights into overall water quality, it would have been beneficial to test for V. cholerae directly to establish a more conclusive link between water contamination and the cholera outbreak [24]. Future studies could consider incorporating this approach for a more comprehensive understanding.

3) **Sensitivity analysis** indicates that the findings are robust to changes in compliance thresholds but may be influenced by outliers or extreme values.

4) **Timing**. The assessment was conducted during the dry season, coinciding with an active cholera outbreak. It is worth noting that the water quality might have improved if the study had been conducted after the outbreak ended. Conducting follow-up studies during different seasons could provide a more nuanced understanding of the impact of seasonality on water quality and disease transmission.

5) **Equipment limitations**. Further analysis to isolate or culture potential pathogens in the water sources was not feasible due to limitations with the laboratory capacity in Garissa. This limitation highlights the importance of sufficient resources and infrastructure in conducting thorough research.

Despite the above limitations, it is crucial to acknowledge the significance of the conducted research as it serves as a crucial foundation for further investigations. It underscores the need for comprehensive and well-resourced research to address the complexities of water quality during disease outbreaks. By acknowledging and building upon these limitations, future studies can provide more accurate insights into the relationship between water contamination and the spread of cholera. The limitations faced in this study can be seen as opportunities for further exploration and advancement.

5. Conclusion

The analysis of water quality conducted in the four sub-counties showed that a majority (87%) of the sampled water points were contaminated with fecal matter, making them unsafe for human consumption. The presence of fecal coliforms in these samples suggests the potential presence of harmful microorganisms. Therefore, it is crucial to treat the water properly to ensure its safety for drinking. By implementing preventive measures and raising community awareness, water sources should be protected from contamination, and access to clean and safe drinking water should be guaranteed. The prevalence of borehole water fecal coliform contamination is also a critical concern that demands immediate attention and concerted efforts from all stakeholders. By prioritizing water quality management and investing in sustainable interventions, progress can be made in ensuring access to safe and clean drinking water and prevent cholera epidemics in Garissa and beyond.

6. Recommendations

1) Safe drinking water storage and distribution is often overlooked but plays a crucial role in maintaining water quality. Poor water storage practices can lead to contamination and the proliferation of waterborne diseases. Communities must explore improved storage options, such as sealed containers, to ensure the integrity of their water quality. Education campaigns can also raise awareness about proper storage practices, empowering individuals to make informed choices for the well-being of their families. It is crucial to regulate water trackers to ensure that the water they distribute is adequately treated prior to distribution. This is a pressing concern that requires immediate attention from the county government. Failure to do so could contribute to the spread of diarrheal diseases, including cholera.

2) While dependence on governments and partners for free distribution of water and hygiene items may provide temporary relief, it is not a sustainable solution. Encouraging research and development of locally available water treatment methods empowers communities to take control of their own water quality. By investing in innovative technologies and harnessing traditional knowledge, communities can develop practical and cost-effective solutions tailored to their specific needs.

3) Community engagement and collaboration are paramount to implementing sustainable water solutions. Stakeholders, including local authorities, educational institutions, and development partners, should work together to develop comprehensive water management strategies. By fostering a sense of ownership and collective responsibility, the communities can create lasting solutions that are tailored to their unique circumstances.

4) It is essential for the county government to adopt and implement a comprehensive Water Safety Plan (WSP) to safeguard water quality [25]. This plan should involve a thorough evaluation and management strategy that covers all stages of the drinking-water supply process, from the source to the point of use. Household Water Treatment, with a particular emphasis on the power of chlorination, presents a viable approach to ensuring safe water for communities.

5) Conducting a comprehensive chemical analysis is essential to guarantee the absence of chemical contaminants in drinking water. Certified laboratories, such as the National Environmental Management Authority (NEMA), can play a crucial role in verifying the quality of water. By utilizing their expertise, precise information on contaminants like arsenic, fluoride, and lead can be acquired, facilitating well-informed decision-making. In certain regions of Kenya, the problem of heavy metal contamination in surface water has become a significant concern due to the tendency of individuals to settle in areas with easily accessible water sources, such as rivers. For instance, a study conducted by [26] [27] investigated the causes, levels, and associated health risks of heavy metals in River Sosiani and discovered that the concentrations of lead (Pb) exceeded the permissible limit set by the WHO by 6-23 times, highlighting the need to closely monitor the discharge of effluents into the river and developing a solution for effectively decontaminating the water from heavy metals.

Authors' Contributions

Conception and Design

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Acquisition of Data

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Analysis and Interpretation of Data

Michael Habtu, Mark Nanyingi, Joel Mutyandia Muli, Sonia Chene, and Alan Mwika.

Drafting of the Manuscript

Michael Habtu.

Critical Revision of the Manuscript for Important Intellectual Content

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Statistical Analysis

Michael Habtu, Ali A. Hassan, Joel Mutyandia Muli, Sonia Chene, Alan Mwika, and Mark Nanyingi.

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Supervision

Martins C. Livinus.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] WHO (2022) Cholera. https://www.who.int/news-room/fact-sheets/detail/cholera

[2] Bi, Q., Abdalla, F.M., Masauni, S., Reyburn, R., Msambazi, M., Deglise, C., *et al.* (2018) The Epidemiology of Cholera in Zanzibar: Implications for the Zanzibar Comprehensive Cholera Elimination Plan. *The Journal of Infectious Diseases*, **15**, 173-180. https://doi.org/10.1093/infdis/jiy500

[3] Lessler, J., Moore, S.M., Luquero, F.J., McKay, H.S., Grais, R., Henkens, M., *et al.* (2018) Mapping the Burden of Cholera in Sub-Saharan Africa and Implications for Control: An Analysis of Data across Geographical Scales. *Lancet,* **12**, 1908-1915. https://doi.org/10.1016/S0140-6736(17)33050-7

[4] Mageto, L.M., Mutono, N., Aboge, G., *et al.* (2023) Spatial and Temporal Analysis of Cholera Cases in High-Risk Areas of Kenya. *BMJ Yale*, **2225**, 1-24. https://doi.org/10.1101/2023.10.13.23296989

[5] Anis, H., Uwishema, O., Hamitoglu, A.E., Essayli, D., *et al.* (2023) Multicountry Cholera Outbreak Alert in Kenya: Current Efforts and Recommendations. *International Journal of Surgery*, **109**, 555-557. https://doi.org/10.1097/JS9.0000000000000130

[6] UNICEF (2021) Kenya Sanitation Alliance Launched by Government and UNICEF, Targeting 15 Counties with Highest Rates of Open Defecation. https://www.unicef.org/kenya/press-releases/kenya-sanitation-alliance-launched-government-and-unicef-targeting-15-counties

[7] Kiama, C., Okunga, E., Muange, A., Marwanga, D., Langat, D., *et al.* (2023) Mapping of Cholera Hotspots in Kenya Using Epidemiologic and Water, Sanitation, and Hygiene (WASH) Indicators as Part of Kenya's New 2022-2030 Cholera Elimination Plan. *PLOS Neglected Tropical Diseases*, **17**, 1-17. https://doi.org/10.1371/journal.pntd.0011166

[8] Boru, W., Xiao, S., Amoth, P., Kareko, D., Langat, D., Were, I., *et al.* (2023) Priori-

tizing Interventions for Cholera Control in Kenya, 2015-2020. *PLOS Neglected Tropical Diseases*, **17**, 1-13. https://doi.org/10.1371/journal.pntd.0010928

[9] Usmani, M., Brumfield, K.D., Magers, B.M., *et al.* (2023) Combating Cholera by Building Predictive Capabilities for Pathogenic Vibrio Cholerae in Yemen. *Scientific Reports*, **13**, 1-13. https://doi.org/10.1038/s41598-022-22946-y

[10] Perez-Saez, J., Lessler, J., Lee, E.C., Luquero, F.J., Malembaka, E.B., Finger, F., Langa, J.P., Yennan, S., Zaitchik, B. and Azman, A.S. (2022) The Seasonality of Cholera in Sub-Saharan Africa: A Statistical Modeling Study. *The Lancet Global Health*, **10**, 831-839. https://www.thelancet.com/action/showPdf?pii=S2214-109X%2822%2900007-9

[11] Moore, S.M., Azman, A.S., Zaitchik, B.F., Mintz, E.D., *et al.* (2017) El Niño and the shifting geography of cholera in Africa, *PNAS*: *Biological Sciences*, **114**, 4436-4441. https://doi.org/10.1073/pnas.1617218114

[12] WASREB (2008) Guidelines on Drinking Water Quality and Effluent Monitoring. Guidelines on Drinking Water Quality and Effluent Monitoring. 1-41. https://wasreb.go.ke/downloads/Water_Quality_&_Effluent_Monitoring_Guidelines.pdf

[13] WHO (2018) Housing and Health Guidelines. WHO Guideline Values for Drinking-Water Quality: Bacteria. https://www.ncbi.nlm.nih.gov/books/NBK535301/table/ch8.tab3/

[14] Lantagne, D. and Yates, T. (2018) Household Water Treatment and Cholera Control. *The Journal of Infectious Diseases*, **15**, 147-153. https://doi.org/10.1093/infdis/jiy488

[15] Stubbe, S.M.L., Pelgrim-Adams, A., Szanto, G.L., and Halem, D. (2016) Household Water Treatment and Safe Storage-Effectiveness and Economics. *Drinking Water Engineering and Science*, **9**, 9-18. https://doi.org/10.5194/dwes-9-9-2016

[16] Blanton, E., Wilhelm, N., O'Reilly, C., Muhonja, E., Karoki, S., Ope, M., *et al.* (2015) A Rapid Assessment of Drinking Water Quality in Informal Settlements after a Cholera Outbreak in Nairobi, Kenya. *Journal of Water and Health*, **13**, 714-725. https://doi.org/10.2166/wh.2014.173

[17] Ramachandraiah, C. (2001) Drinking Water as a Fundamental Right. *Economic and Political Weekly*, **36**, 619-621. http://www.jstor.org/stable/4410314

[18] Wang, A., Hardy, C., Rajasingham, A., Martinsen, A., *et al.* (2016) Notes from the Field: Chlorination Strategies for Drinking Water during a Cholera Epidemic—Tanzania, 2016. *The Morbidity and Mortality Weekly Report (MMWR)*, **65**, 1150-1151. https://doi.org/10.15585/mmwr.mm6541a6

[19] Walton, B. (2023) Cholera Cases Spike Amid Extreme Weather, Conflict. https://policycommons.net/artifacts/3751954/cholera-cases-spike-amid-extreme-weather-conflict/4557261/

[20] Korir, B. (2020) An Analysis of Kenya's Water Sector Institutional and Regulatory Framework from 2002-2017. Master's Thesis, Strathmore University, Nairobi. https://su-plus.strathmore.edu/handle/11071/10192

[21] Tambi, A., Brighu, U. and Gupta, A.B. (2023) Methods for Detection and Enumeration of Coliforms in Drinking Water: A Review. *Water Supply*, **23**, 4047-4058. https://doi.org/10.2166/ws.2023.247

[22] Si, F., Huang, T.L., Li, N., Li, K., *et al.* (2022) Effects of Flood Discharge on the Water Quality of a Drinking Water Reservoir in China—Characteristics and Management Strategies. *Journal of Environmental Management*, **314**, 1-7. https://www.sciencedirect.com/science/article/abs/pii/S0301479722006454

[23] Sun, R., An, D., Lu, W., Shi, Y., *et al.* (2016) Impacts of a Flash Flood on Drinking Water Quality: A Case Study of Areas Most Affected by the 2012 Beijing Flood. *Heliyon*, **2**, E00071. https://doi.org/10.1016/j.heliyon.2016.e00071

[24] Forster, B. and Pinedo, C.A. (2016) Bacteriological Examination of Waters: Membrane Filtration Protocol. American Society for Microbiology, 1-15. https://asm.org/image-gallery/membrane-filtration

[25] GTFCC (2019) Technical Note: Water, Sanitation and Hygiene and Infection Prevention and Control in Cholera Treatment Structures. https://www.gtfcc.org/resources/technical-note-on-water-sanitation-and-hygiene-and-infection-prevention-and-control-in-cholera-treatment-structures/

[26] Munene, E.N., Hashim, N.O. and Ambusso, W.N. (2023) Human Health Risk Assessment of Heavy Metal Concentration in Surface Water of Sosian River, Eldoret Town, Uasin-Gishu County Kenya. *MethodsX,* **11**, 1-8. https://doi.org/10.1016/j.mex.2023.102298

[27] Oduor, O.J., Kinuthia, K.D. and Wachira, D.N. (2019) Assimilation of Pollution Loading on Sosiani River in Eldoret Municipality, Kenya: As a Wastewater Management Strategy. *American Journal of Water Resources*, **7**, 155-162.