Mapping Cholera Risk in Nairobi County, Kenya: A Comprehensive Analysis of Environmental, Socio-Economic, and WASH Factors

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Abstract

BACKGROUND

Cholera, a globally prevalent waterborne disease, is closely monitored in Kenya as part of the Integrated Disease Surveillance and Response strategy. Understanding regional variations in cholera risk factors and trends is crucial, particularly in Sub-Saharan Africa. This study aimed to construct a risk map for cholera outbreaks in Nairobi County, based on the spatial-temporal dynamics of environmental and socio-cultural factors, Water, Sanitation, and Hygiene (WASH) conditions, and historical cases reported between 2009 and 2019.

METHODOLOGY

We retrospectively analyzed historical cholera cases in Nairobi, employing spatial analysis to map the spatiotemporal variations in factors associated with cholera outbreaks. A cross-sectional descriptive research design was adopted to investigate the relationship between WASH conditions and cholera outbreaks. Stratified random sampling selected 399 respondents from all 85 wards in Nairobi County. We employed descriptive statistics (percentages and frequencies) and inferential statistics (Chi-square) to assess variable relationships.

RESULTS

Cholera cases are concentrated in densely populated, especially informal, settlements. Population size significantly correlated with cholera cases (p-value=0.03). Dumping sites in Nairobi emerged as potential cholera sources within residential areas, with the vicinity showing a slight association with reported cases. Rainfall patterns and humidity levels across Nairobi County also influenced cholera risk.

CONCLUSIONS

Areas within 400 meters of rivers and sewage lines faced elevated cholera risk. Most cases occurred in slum or regular residential areas. Proximity to dumping sites increased the risk of cholera outbreaks. These findings offer valuable insights for cholera prevention and control strategies in Nairobi County.

Keywords: *Cholera Risk Mapping, Environmental Factors, Socio-Economic Factors, WASH, Nairobi, Kenya*

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Introduction

Cholera is a major global waterborne disease caused by *Vibrio cholerae* serogroups O1 and O139. Epidemics occur mainly in Africa, Asia, the Middle East, and South and Central America. Developed countries experience cholera outbreaks during natural disasters while developing nations face outbreaks due to poor sanitation, hygiene, inadequate water supply [1], food handling practices, and lack of awareness. Jutla, Whitcombe, and Hasan [2] noted that in Asia and Latin America, factors like residence area, rainfall, sanitation, infrastructure, and proximity to rivers significantly influence cholera outbreaks.

In Nigeria, Jaber and Fame [3] reported that environmental, social, and WASH factors played a crucial role in cholera outbreaks in displacement camps in Northeast Nigeria. Ishaku *et al.* [4] identified poor hygiene and water contamination as key factors in cholera spread in Nigerian residential areas. In Kenya, Stoltzfus, Carter, and Akpinar-Elci [5] observed significant interactions between environmental, social, and demographic factors in cholera outbreaks across the country. They highlighted residents' pollution of the main water source, a river, through defecation, post-defecation activities, and the use of untreated river water.

Kenya has faced recurring cholera outbreaks since 1971, with the fatality rate rising from 3.6% before 1989 to 5.6% in 2007 [6]. The most significant outbreaks occurred between 1997 and 1999, affecting Nyanza and the entire western region, resulting in 26,901 cases and 1,362 deaths [7]. Another outbreak occurred from 2007 to 2009, with 16,616 cases and 454 deaths. According to WHO's May 2018 bulletin, between October 2016 and April 6, 2018, 6,532 cases and 139 deaths were reported [8]. In 2018, 25 new cases emerged in Turkana, 8 in West Pokot, 2 in Trans Nzoia, and 2 in Garissa, totalling to 2,333 cases and 50 deaths between January and April [3].

The increase in cholera cases in Kenya has been attributed to socio-economic challenges, cultural factors, and environmental issues [9]. Poor personal hygiene, inadequate public health systems, deficient water and sanitation infrastructure, and improper waste management contribute to outbreaks in urban and rural areas. Additionally, poor drainage systems leading to flooding and stagnant water exacerbate cholera outbreaks in many parts of the country.

Previous research has made limited efforts to map cholera risk factors in both rural and urban areas. To address this gap, this study aimed to map incident cases in hotspots and establish spatial relationships between behavioural and environmental cholera risk factors in an urban setting, focusing on Nairobi County. The study aims to develop a cholera risk map based on environmental, socio-economic, and WASH factors for Nairobi County.

Materials and Methods

Study area

This investigation was centred in Nairobi County, situated between 1.2921° South and 36.8219° East. Nairobi's highest elevation reaches around 1,930 meters (6,332 feet) above sea level. The city experiences an average temperature range of 21-22°C. It boasts a total population of approximately 4 million residents, with an annual growth rate of 5.5%. This results in a population density of 4,800 individuals per square km. Nairobi County encompasses 17 constituencies, and 85 wards, and spans an area of 696 square km. The climate is warm from December to March, while June to July brings cooler temperatures, accompanied by moderate rainfall and occasional drizzles in summer and autumn.

Study design

A retrospective approach was adopted to investigate historical cholera cases documented in Nairobi and spatial epidemiology was employed to map the spatial-temporal variation of environmental factors linked to cholera outbreaks. To establish the connection between WASH conditions and cholera outbreaks in Nairobi County, a cross-sectional descriptive research design was utilized. This design yielded valuable insights into specific aspects of the cholera epidemic, including hygiene practices, water supply, food handling practices, waste management, community awareness, and environmental regulations, among other elements.

Study population

The study encompassed residents of Nairobi County aged 18 years and older, including household heads (i.e., fathers, mothers, or guardians). According to population projections, Nairobi County's total population stood at 3,078,180, with 2,154,726 individuals aged 18 years and above (Kenya National Bureau of Statistics, 2016). Key informants comprised officials from public health facilities, sub-county health officers, county-level Ministry of Health officials, and Sub-County Disease Surveillance Coordinators (SCDSC). The population studied represented a subset of the 2,154,726 individuals residing in the Nairobi area.

Sample size and sampling

Slovin's formula was used to arrive at a sample size of 399. This formula, designed for random sampling, was well-suited to our study given our target population.

We conducted stratified random sampling, ensuring our sample accurately represented the study population. Using proportionate stratification, we distributed the sample size across the 85 wards within Nairobi County. Each ward's sample size was proportional to its population. We employed simple random sampling within each ward, selecting respondents randomly from various villages. This approach allowed us to capture diverse environmental, water supply, food-handling, and social factors, such as water sources, waste management, proximity to sewer systems, and open-air food consumption.

Data collection

Our study incorporated both primary and secondary data sources. Secondary data came from various sources, including Ministry of Health reports, County health annual reports, reports from UN agencies and NGOs, population data from the Kenya National Bureau of Statistics (KNBS), Nairobi shape files from the Survey of Kenya, and Rainfall and Temperature data from the Kenya Meteorological Department (KMD) National office.

We collected primary data through questionnaires and key informant interviews. We used semi-structured digital questionnaires for household surveys among Nairobi County residents. Qualitative data was obtained via open-ended questions, encouraging participants to express their opinions freely. Structured questions were employed for quantitative data gathering [10]. We also conducted observations during data collection, particularly focusing on the hygiene conditions in visited households. Additionally, we conducted one-on-one interviews with key informants, including the head of public health in the Ministry of Health at the national level, the head of public health in the county government of Nairobi, and one public health officer from each of the seventeen constituencies.

Data analysis

For data analysis, we utilized Statistical Software for Social Sciences (SPSS) version 22. Descriptive statistics, including frequency distributions, were employed to summarize and assess variability in the study's quantitative data. Inferential statistics encompassed Chi-square (X2), regression analysis, Pearson correlation analysis, and Analysis of Variance. Correlation analysis evaluated relationships between various factors (population density, population size, rainfall, temperature, and humidity) and the patterns of cholera outbreak and spread (population). Linear regression analysis established associations between independent variables (environmental factors) and the dependent variable (cholera spread).

We applied a 95% confidence level, indicating a significance level of 0.05. A significant effect of an independent variable on the dependent variable was indicated by a p-value below the significance level of 0.05. The R2 statistic was used to quantify the variation in the number of cholera cases explained by environmental risk factors.

Ethical considerations

Ethical approval was sought and obtained from the Kenyatta National Hospital – University of Nairobi (NH-UoN) Ethical Review Committee before the study was implemented. Informed consent was received from participants before participation and data collection.

Results

Demographic characteristics

We administered a total of 399 questionnaires to Nairobi residents in various Sub-Counties. Of the 399 respondents, 198 (49.6%) were male, and 201 (50.4%) were female. Some respondents, 172 (43%), were surveyed in their households, while others, 207 (52%), were encountered at their workplaces. A minority, 20 (5%), were found in premises where they both lived and worked.

The majority of respondents (43%) fell within the 25-35 age group. Mature adults, aged 35-45 and 45-55, accounted for 33% and 14%, respectively. A smaller number of respondents, 28 (7%) and 12 (3%), were in the age groups of 18-25 and over 55 years old, respectively.

Regarding education, 40% of respondents had completed secondary education, while 30% held diplomas. Primary education was attained by 21%, and 9% were degree holders. Only 2 individuals had postgraduate qualifications, and 5 respondents had no formal education (Figure 1).

Spatial distribution of cholera cases

Our results indicated that cholera outbreaks were more common in central and eastern parts of Nairobi. Specifically, the most populous sub-counties—Embakasi, Kasarani, Langata, and Starehe—had a high number of cholera cases. Standard deviation ellipse (SDE) analysis revealed that cholera outbreaks in Nairobi followed an East-West direction, affecting areas like Kangemi, Kibera, Makadara, and several areas in Embakasi South and North, including Makadara and Mkuru kwa Ruben. (Figure 2).

Population size and cholera cases

A two-tailed t-test analysis (Alpha = 0.05) showed that population size had a significant relationship with the number of cholera cases (p-value=0.03). Cholera cases were more common in areas with larger populations.

Cholera susceptibility mapping

We used various factors, including proximity to rivers, to create a cholera susceptibility map.

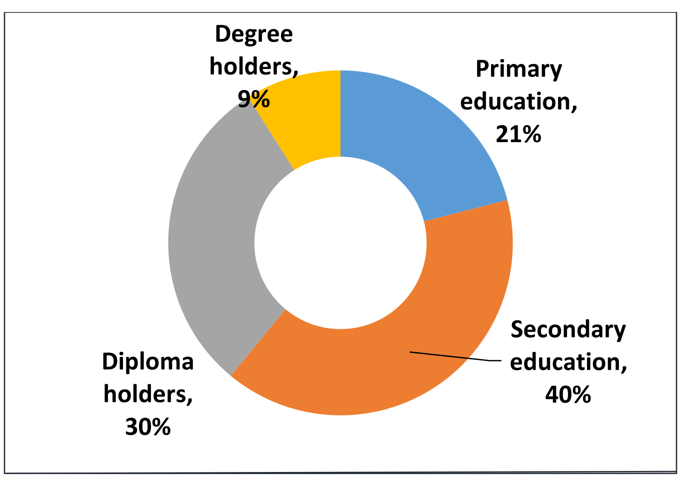

Figure 1:
Participants' level of education

Areas within 100m of rivers were considered highly vulnerable (orange shades), while those within 200m and 300m were moderately risky. Areas beyond 400m were less risky. Notably, previous cholera cases were reported mainly within the 400m range from rivers (Figure 3).

Dumping sites and cholera spread

Areas near dumping sites were associated with more cholera cases. Areas within a 1 km radius of the Dandora dumping site, for instance, were categorized as high-risk areas, while those further away (>1.5 km) had fewer cases.

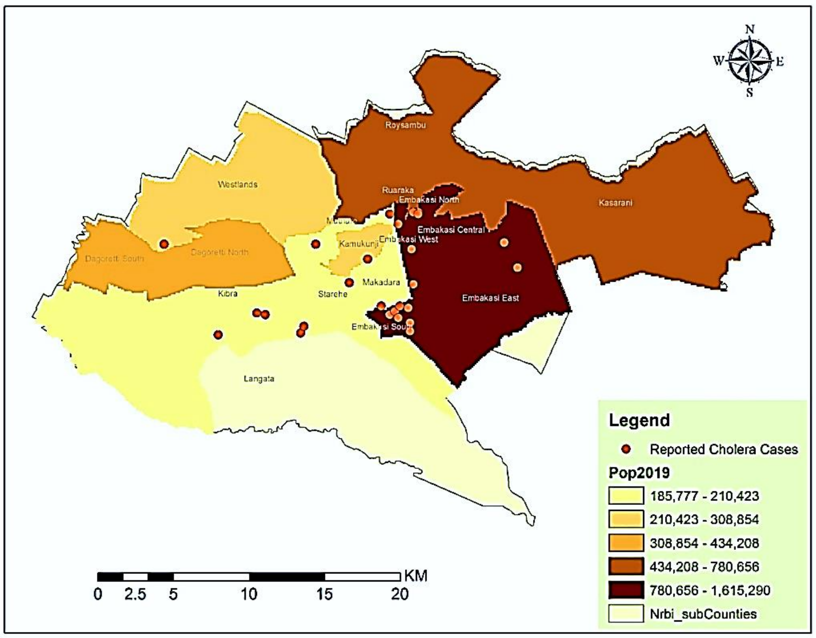

Figure 2:
Spatial distribution of cholera incidences reported in Nairobi between 2009-2019

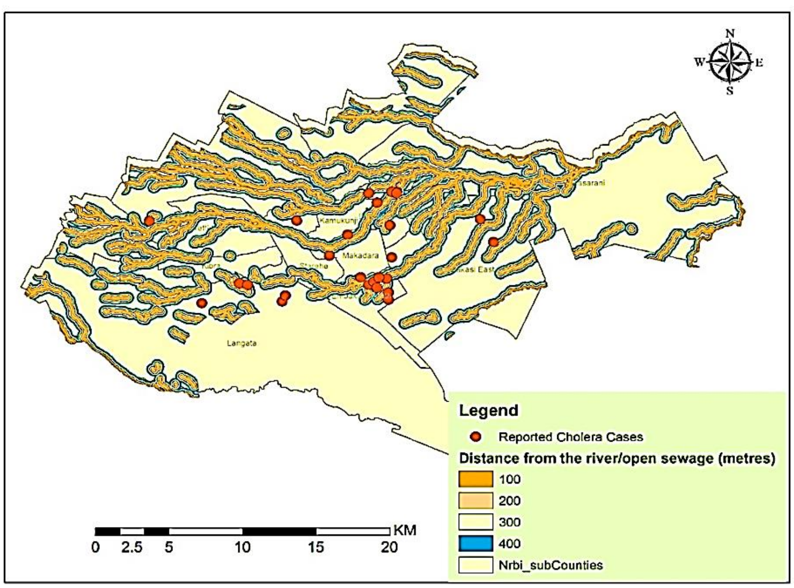

Figure 3:
Vulnerability of areas located close to the rivers and open sewage lines in Nairobi

The buffer zones within 500m of dumping sites were considered very high risk (red shades), while those between 500m and 1500m were moderately risky (yellow and green zones) (Figure 4). Slum areas face higher cholera risk due to overcrowding and limited water/sanitation facilities. Moderate-population zones are also high-risk, while industrial areas have lower risk. Commercial/public service areas are more crucial in cholera risk assessment than institutional/transportation areas (Figure 5).

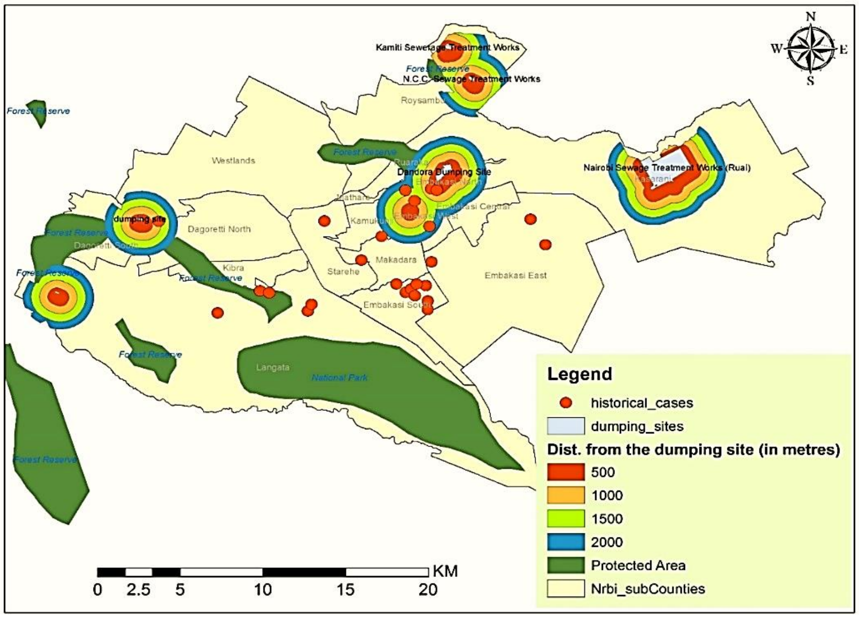

Figure 4:
Location of damping sites in Nairobi and the location of cholera cases reported in the period between 2020-2021

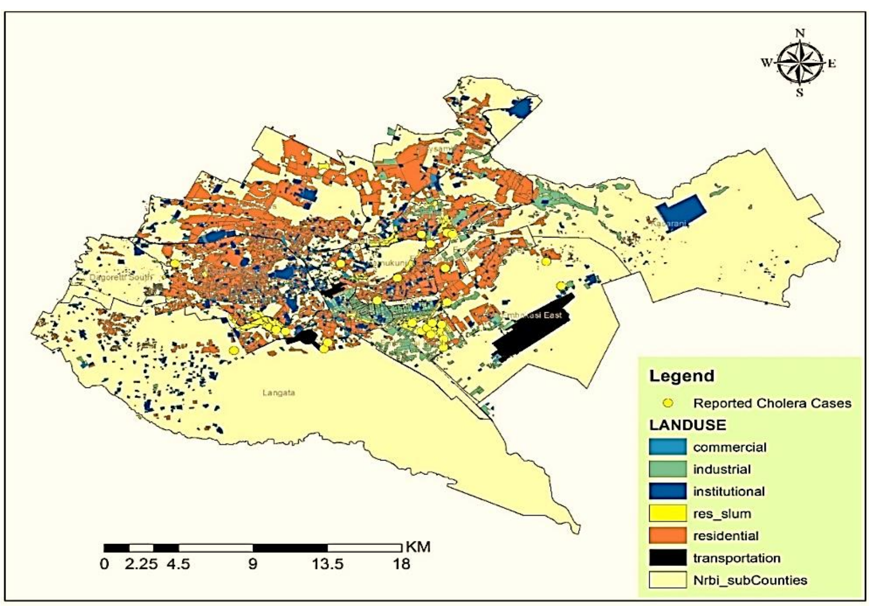

Figure 5:
Major categories of land use and land cover in the Nairobi County

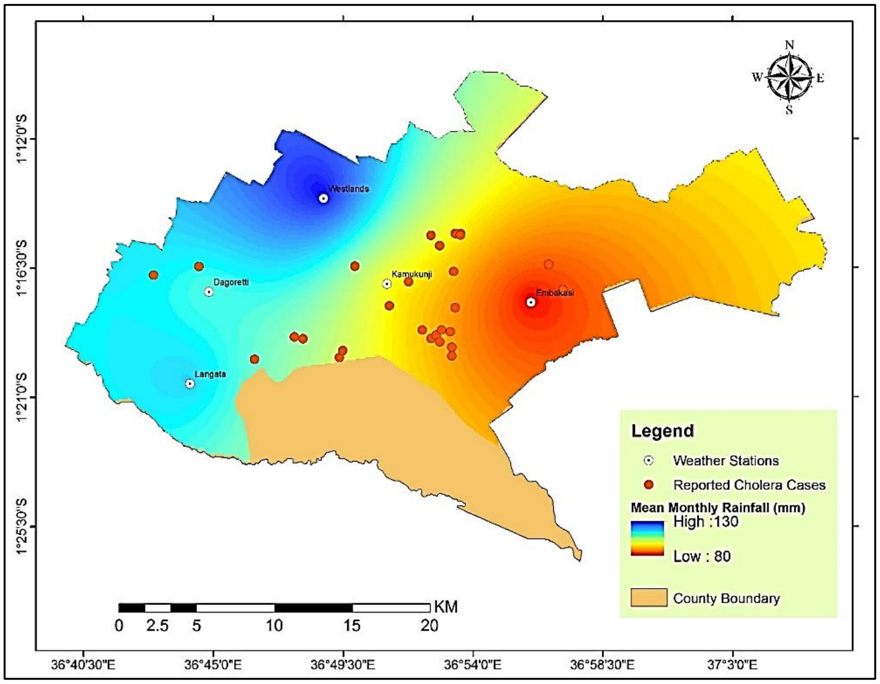

Figure 6:
Mean monthly rainfall distribution in Nairobi County **-** Data sources: Kenya Meteorological Department

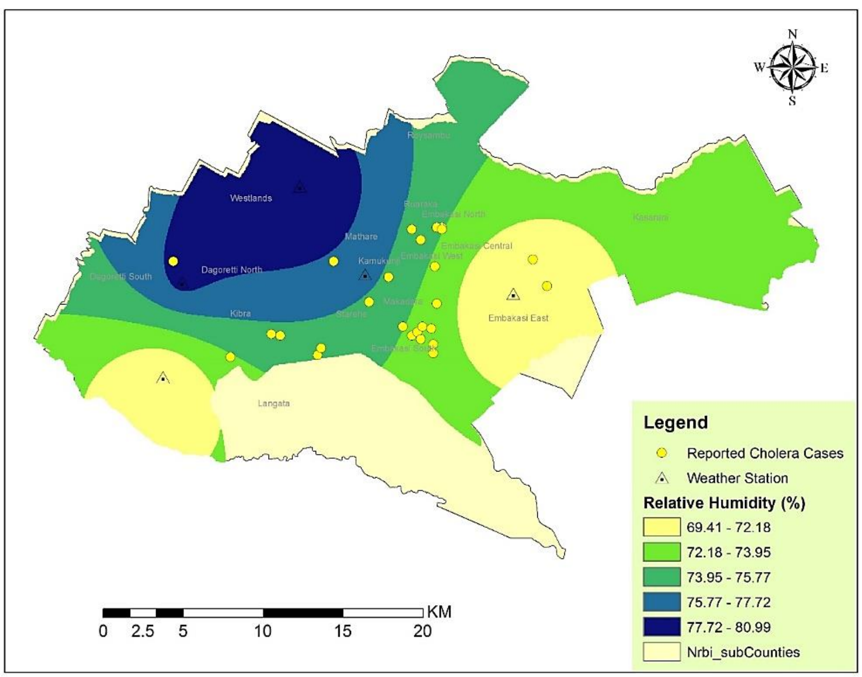

Figure 7:
Relative humidity distribution in Nairobi County **-** Data Source: Kenya Meteorological Department

Cholera incidence correlated with rainfall patterns. Areas with low monthly rainfall (80-104mm) had more cases, while those with the highest rainfall (128mm) had none (Figure 6).

Higher relative humidity was observed in western Nairobi compared to the east. Central areas, with lower humidity, typically experienced high cholera cases (Figure 7). Temperature patterns corresponded to humidity, with higher temperatures in the south and east and lower temperatures in the west (Figure 8).

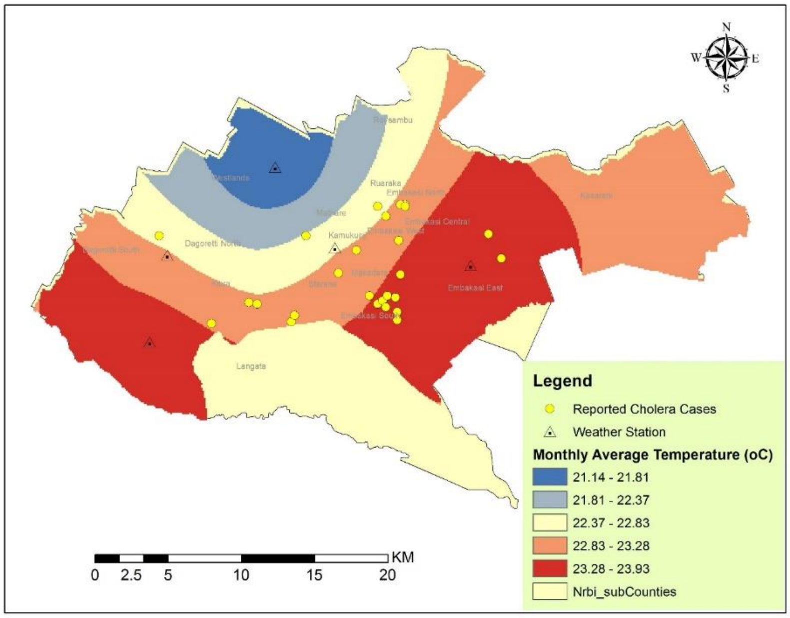

Figure 8:
Monthly average temperature distribution in Nairobi County - Data source: Kenya Meteorological Department

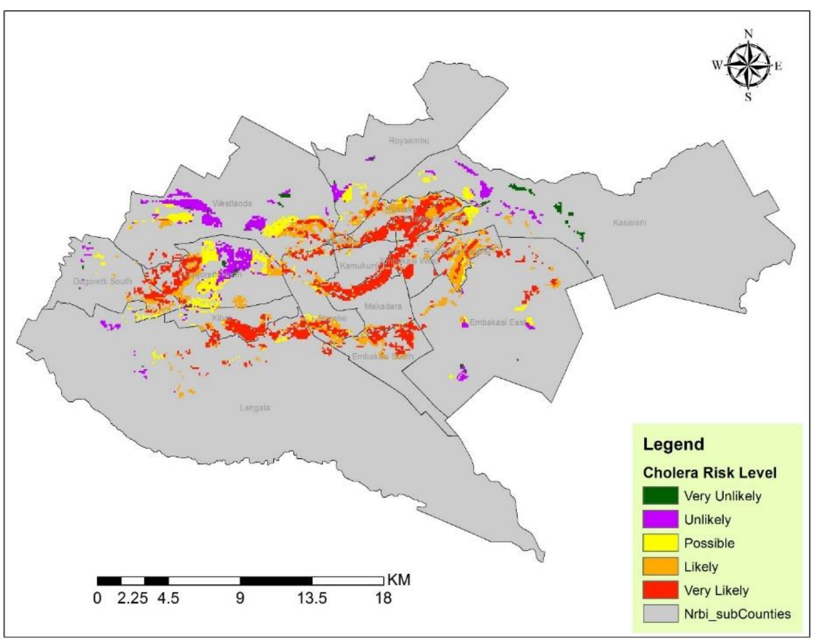

Figure 9:
Cholera Susceptibility Map of Nairobi County

Cholera susceptibility map

A cholera susceptibility map indicated central areas of Nairobi as likely to experience higher cholera outbreaks (red shades), while western areas had a lower risk (purple and yellow shades). Westlands was unlikely to have outbreaks, as were some areas towards Kamulu in the east (Figure 9).

Water, sanitation, and hygiene (WASH) factors

Among respondents who experienced cholera outbreaks in their villages, 47% reported at least one family member infected, while 53% had no infections. Poor sanitation, hygiene, contaminated water and food, and unhygienic eateries were linked to cholera cases. Open defecation in neighbourhoods was observed by 30% of respondents.

Waste disposal methods

Most respondents (76%) used flush toilets, while 18% used pit latrines, and 4% used public toilets. A small percentage (1.2%) used buckets, and 0.5% had no toilet. The distance between households and waste disposal sites significantly influenced cholera cases (p-value=0.032) (Table 1).

Table 1:
General water and sanitation conditions associated with spreading cholera disease

Water and Sanitation conditions	Chi-square	P-value
Dist. between the toilet and an eatery point	29.92	0.169
Dist. between toilet and water point	7.919	0.048
Dist. between dumping site and water point	8.794	0.032
Open defecation	4.64	0.098
Waste disposal method (waste bags, public dumping site, others)	9.86	0.02
Use of borehole water	5.473	0.017
Water sourced from vendors	1.429	0.23
Drinking water at the source (shared tap, water kiosk, water vendors, borehole water, H.H-tap)	6.053	0.014
Unauthorized water connections	6.244	0.012
Poor solid waste management	3.214	0.073

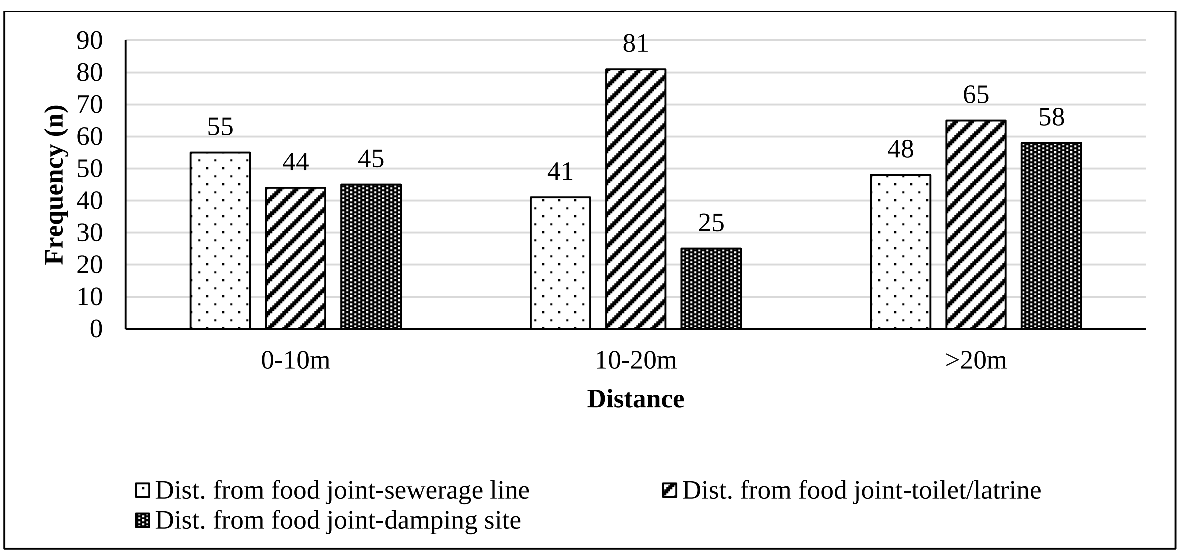

Figure 10:
Proximity of food joints/eateries to poor sanitation

Water sources

Personal taps were common in households (48%), followed by shared yard taps (33%). Water vendors and kiosks supplied water to 30% of respondents. Fewer used boreholes (17%), bottled water (12%), or rainwater harvesting (2%).

Water challenges

Common water challenges included irregular water supply (77%), limited access to safe drinking water (58%), and lack of tap water in households (44%). Other issues included unhygienic water vending facilities (57%), poorly treated water (38%), and limited household water treatment (42%).

Hygiene practices

Respondents practised hygiene by regularly washing hands (88%), using clean toilets (72%), proper waste disposal (61%), consuming thoroughly cooked food (61%), and maintaining clean water storage (60%). Some also drank boiled water (43%), improved cholera awareness (39%), and avoided informal food eateries (28%).

Food hygiene

Hygiene issues in food joints included exposure to flies and dust (76%), unclean environments (81%), poor personal hygiene among vendors (62%), and unhygienic food preparation (58%). Other factors included poor food storage (40%) and lack of government health controls (47%).

Water sanitation and hygiene (WASH) challenges

Challenges included lack of sufficient water supply (76%), poor personal hygiene (54%), inadequate wastewater management (54%), poor community hygiene and sanitation (55%), and poorly maintained sewage facilities (44%). Other challenges involved poorly maintained water infrastructure (31%) and unauthorized water connections (23%), among others.

Control measures

Recommendations for minimizing cholera risk included improving food hygiene, ensuring access to clean and safe drinking water, promoting regular handwashing, and addressing waste management issues. Hygiene education and regulation of water costs were also suggested.

Preventing cholera spread

Respondents in Nairobi adopted measures to prevent cholera spread in their households, including regular handwashing (88%), using clean toilets (72%), proper waste disposal (61%), consuming well-cooked food (61%), and maintaining clean water storage (60%). Some also drank boiled water (43%), raised cholera awareness (39%), and minimized consumption of food from informal eateries (28%).

Table 2:
Food handling practices and the risk of cholera disease

Food Handling Practices	YES	%	NO	%
Consumption of poorly cooked food	72	18	327	82
Unhygienic practices in food preparation	231	58	168	42
Unclean environment near the food joints	323	81	76	19
Lack of clean water for domestic uses	235	59	164	41
Unhygienic food handlers	247	62	152	38
Poor storage of foodstuff	160	40	239	60
Lack of strict health controls from the government	188	47	211	53
Close exposure of food to flies and dust	303	76	96	24

Hygiene at food joints

Hygiene practices in food joints were assessed in terms of proximity to sewage lines, toilets/latrines, and dumping sites. Most food eateries (38%) were within 0-10m of sewage lines, while 43% were within 10-20m of toilets or latrines. Forty-five per cent were located more than 20m from dumping sites (Figure 10).

Food handling practices

Unhygienic food handling practices included exposure to flies and dust (76%), unclean environments (81%), poor vendor personal hygiene (62%), and unhygienic food preparation (58%). Other issues included poor food storage (40%) and a lack of government health controls (47%) (Table 2).

Water sources and challenges

Personal taps were the most common water source in households (48%), followed by shared yard taps (33%). Water vendors and kiosks supplied water to 30% of respondents. Fewer used boreholes (17%), bottled water (12%), or rainwater harvesting (2%). Challenges included irregular water supply (77%), limited access to safe drinking water (58%), and a lack of tap water in households (44%). Other issues included unhygienic water vending facilities (57%), poorly treated water (38%), and limited household water treatment (42%).

Discussion

The Embakasi area in Nairobi County was worst hit by cholera outbreaks in the period between 2009 and 2019. Spatial analysis showed that the affected people particularly in Embakasi mainly came from the highly populated areas. Kasarani and some parts of Dagoretti in the western parts of Nairobi were highly populated and reported a high number of cholera cases. Areas where the population density was low showed a significantly low number of cholera cases. The study found that areas that were prone to cholera outbreaks were characterized by dense housing environments and crowded residences. This included areas in the informal settlements in Dagoretti North, Kangemi, Kibera, Makadara, Mkuru kwa Ruben, Dandora, Kariobangi, Kayole and Utawala. Studies elsewhere have associated similar characteristics of the environment with an increase in number of cholera cases [11]. The study findings concurred with previous studies that established that contaminated drinking water, food contamination and poor hygiene at the eateries played a significant role in the spread of cholera diseases in the affected areas in Nairobi County. The study also observed that areas that reported cholera cases previously were the households located less than 400m from the rivers and open sewage lines. The elevated number of cholera cases was attributed to poor waste management, and uncontrolled and open sewage systems in the residential areas. Dumping and effluents directed to the rivers was a major cause of water pollution.

Historical data showed that the elevated number of cholera cases was associated with areas where socio-economic status is low, densely populated and lacked standard sanitation. These areas included Kibra, Dagoretti North, all sub-counties in Embakasi and several areas in Mathare and Kamukunji. These results agreed with Rasam *et al* [12] who observed a high number of cholera cases in similar environments. Our findings also concur with a study conducted in Haiti that reported a positive relationship between rainfall and cholera incidences [13]. Rasam *et al* [12] found that cholera outbreaks could be endemic in populous areas, unhygienic environments, and close to contaminated water.

The analysis of the relationship between rainfall and the number of cholera cases showed that an increase or decrease in rainfall is likely to contribute to the increase or decrease in the number of cholera cases. Other factors associated with rainfall for example WASH may have contributed to changes in the number of cholera cases. Areas served with limited water and sanitation were likely to be contaminated during rainy seasons [14,15]. This also supports the findings of this study particularly in densely populated residences. This study also revealed that during high temperatures (>25°C), more cholera cases were reported. Emilien asserted that cholera bacteria can easily spread in moist environments where temperature is above 17°C therefore high number of cholera cases are likely to be reported during high humidity and temperature conditions [11]. This explains the findings. During high humidity conditions (>78%), the number of cholera cases is also likely to be significantly high. The study revealed that relatively low humidity conditions are not significantly associated with the increasing number of cholera cases.

This study established several environmental factors that exposed the residents to the risk of cholera outbreaks in various constituencies in Nairobi. It was clear that poor sanitation was one of the key problems that contributed to the increased risk of cholera outbreaks. This included a limited water supply that would likely influence the maintenance of proper hygiene at the household level. Similarly, most of the participants in this study expressed that the water supply was limited, and several cases of unauthorized water connections and cross-connections were identified as malpractices that contributed to an inadequate supply of water in some areas. All the Sub-County Disease Surveillance Coordinators (SCDSC) and other participants in this study expressed the need for adequate water supply so that the risks of cholera outbreak can be minimized in the estates. This would also mean that the potential health risks associated with poor personal hygiene could be eliminated.

The problem of poor waste management in the estates was also revealed as a common problem in the estates. The households affected by cholera reported a lack of designated points or specific methods for disposing of their waste. Poor solid and water waste contributed to contamination in the environment as well as poor community hygiene. The majority of the sites visited during the study had open sewage lines that carried wastewater and sewage. This challenge was attributed to the contamination of drinking water, especially through the public water distribution lines in the estates. Although the level of contamination of water was not ascertained in this study, consumption of this kind of water in households may result in an outbreak of waterborne diseases including cholera. The local authorities should improve in waste collection and maintenance of sewage facilities in the estates to minimize general environmental pollution and water contamination.

Conclusions

This study identified key cholera risk factors in Nairobi County. Densely populated areas, especially informal settlements, recorded higher cholera cases. Proximity to dumping sites was linked to increased risk, and population size influenced case numbers. Areas within 100 meters of rivers were more vulnerable.

The study noted the impact of rainfall patterns on cholera risk. Higher humidity in western Nairobi correlated with temperature variation. Inadequate Water, Sanitation, and Hygiene (WASH) practices included limited water supply, poor personal hygiene, and unsatisfactory wastewater management. Unregulated water vendors and open-air food vendors posed health risks.

Recommendations

Controlling informal settlement expansion, ensuring a 400-meter buffer from rivers, and enforcing hygiene standards for food vendors is required. These actions are vital for public health and cholera reduction in Nairobi County.

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