Assessment of Bacteriological Quality and Physicochemical Properties of Borehole Water Supplies in Eastleigh, Nairobi County, Kenya

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Abstract

BACKGROUND

A borehole is a valuable source of fresh, potable water that globally feeds around 1.5 billion people daily. It is, however, vulnerable to both microbial and chemical pollution, which poses health risks to the population if consumed without proper treatment. It is from this perspective that this study aimed to assess the quality of borehole water supplies in Eastleigh, considering their implications for human health.

METHODOLOGY

A repeated cross-sectional design was employed to study physicochemical and microbiological parameters of the boreholes. A proportionate stratified sampling method was used to sample 25 boreholes. Water samples from the storage tanks of the boreholes were collected in sterilised 250 ml glass bottles and transported to Kenyatta University microbiology laboratories for analysis. Temperature, pH, Turbidity and Fluoride levels were measured by their respective meters. Lead, cadmium and Arsenic levels were determined by the Atomic Absorption Spectrophotometer. The Most Probable Number technique quantified the coliform and Microbial culturing for bacterial detection. A 12-month retrospective case-control design determined the prevalence of waterborne illnesses from the Eastleigh Community Wellness Centre, Eastleigh Health Centre and Biafra Health Facility hospitals. Mean values obtained for physicochemical and microbiological parameters during the wet and dry seasons (April-May, 2024 and July, 2024, respectively) and across the road streets were analysed using one-way analysis of variance, with $p \leq 0.05$ being significant.

RESULTS

All physicochemical parameters were generally within Kenya Bureau of Standards (KEBS) permissible standards for drinking water, except for cadmium, fluoride and pH. The total coliform exceeded the KEBS permissible requirements. At least one of the pathogenic bacteria of interest (*Escherichia coli, Vibrio cholerae, Salmonella spp and Shigella spp*) was detected in every borehole. Review of the patient's clinical data showed an overall prevalence rate of 8.5%, with patients <5 years and >5 years recording 11.06% and 7.33%, respectively.

CONCLUSION

Borehole water in Eastleigh is contaminated, and with the prevalence rate of 8.5%, it concludes waterborne diseases in the region as a public health concern. Consumption of water from questionable sources like these boreholes should be limited.

Keywords: *Borehole Water Quality, Heavy Metals, Waterborne Illnesses*

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Introduction

Access to a clean water supply is a key factor in a rapidly growing population [1]. Populations get their water mainly from municipal supply and groundwater water with about 85% of the world's population having

access to municipal water[2]. Since the supply of municipal water systems is costly and unreliable, communities resort to alternatives such as groundwater. Around the globe, 1.8 billion people utilise contaminated water[3]. Groundwater supplies are, however, vulnerable to contaminants that consequently lead to waterborne illnesses that kill around 5-10 million people annually[1]. In Eastleigh, the residents receive treated municipal water from the Nairobi County government. Due to the unreliable nature of this municipal water supply, the residents have private boreholes as an alternative. Unlike municipal water, which goes through a treatment plant before reaching the consumers, the borehole water is channelled directly to the consumers, hence exposing them to potentially hazardous health issues. High levels of bacteriological and heavy metal contamination have been reported in boreholes across several Nairobi estates, including Umoja and Pangani, highlighting ongoing water safety concerns within the Nairobi metropolitan area 4,5. The rapid increase in private borehole drilling in Eastleigh, coupled with limited health authority surveillance, poses significant risks of contaminant exposure to consumers, potentially accelerating occasional outbreaks of waterborne diseases. Similarly, reported cases of waterborne illnesses are frequent in Nairobi County[6]. In 2013, diarrhoea illness was estimated to be the leading cause of morbidity in Africa[7]. The Global Burden of Disease estimated that in 2016, Kenya had 97,762 typhoid cases[8]. Furthermore, 20% of deaths among children under the age of five years in Nairobi were a result of waterborne illnesses[9]. To determine the water suitability of boreholes in Eastleigh, Nairobi County, the objective of this study was to assess the presence and levels of bacteriological and physicochemical properties in relation to the established drinking water quality standards. Additionally, the prevalence rate of waterborne illnesses was determined, thereby evaluating the severity level associated with consumption of such contaminants in Eastleigh.

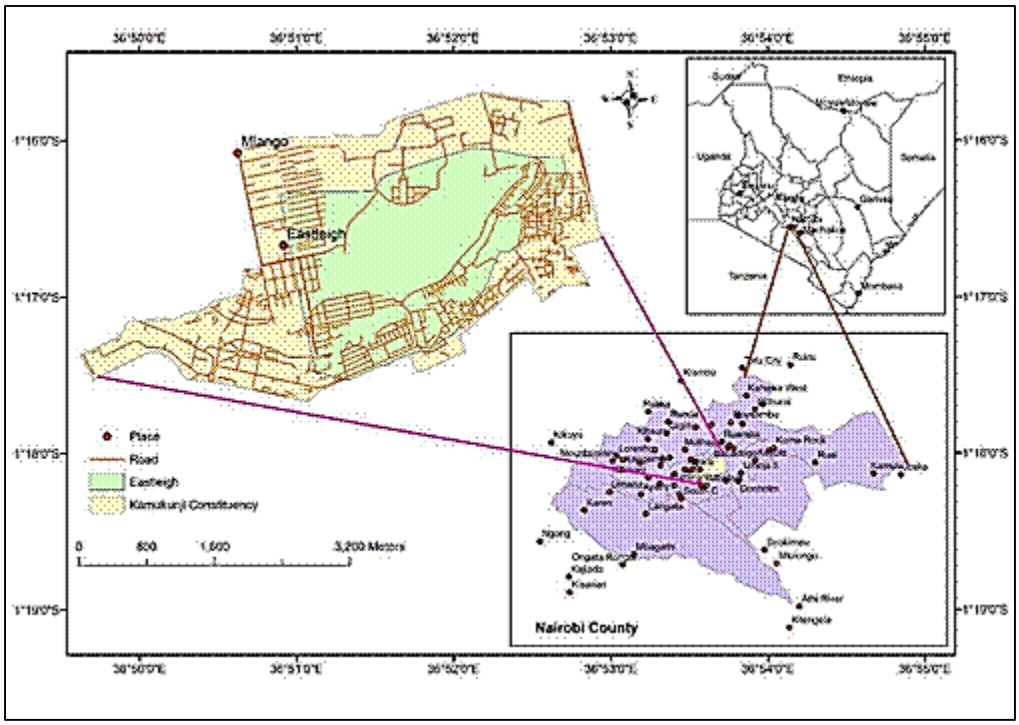

Figure 1
Map of Eastleigh in Nairobi, Kenya.

Materials and Methods

Study site

This study was conducted in the Eastleigh area in Nairobi County (Figure 1). Nairobi is situated in South-Central Kenya, 140 kilometres south of the Equator and lies within a geographical coordinate of 1°09′S 36°39′E and 1°27′S 37°06′E. Eastleigh has a geographical area of 6.9 km2, coordinates of 1° 16'00" S and 36° 51' 00" E and a total population of around 152 484[10]. The area has nineteen road streets, where private boreholes to be analysed are irregularly distributed across the residential areas. Furthermore, the hospitals selected for analysis are situated within these residential zones, thereby offering convenient access to the residents.

Study design

A repeated cross-sectional design was employed in the study of physicochemical and microbiological parameters of the boreholes in the study area, while a retrospective case-control design was used in the determination of the prevalence of waterborne illnesses.

Sampling procedure and sample collection

Proportionate stratified sampling was used in the selection of the boreholes. To ensure that sampling points were sufficiently distanced from one another, leading to more representation of the water drawn from the underlying aquifers, at least a 200-meter spacing between boreholes was established. In addition, borehole storage tanks had to source their water exclusively from the boreholes in order to limit cross-contamination. Due to these, eight streets were identified where if a particular street was picked, the immediate one was skipped. The last two streets failed the selection criteria. Each selected street yielded three boreholes selected for sampling, except the sixteenth street, which had four. Each borehole was sampled twice, during the wet and the dry seasons (April-May, 2024 and July, 2024, respectively), in order to examine the specific impacts of these conditions on water quality. Water samples were collected from the borehole storage tanks in sterilised 250 ml glass bottles by applying the APHA method[11] and transported to microbiology laboratories at Kenyatta University for analysis within 24 hours of sampling. Due to their stringent policy to limit accessibility of patients' health records to the public, the private hospitals in the study area could not be selected. The only two public hospitals in the study area (Eastleigh Health Centre and Biafra Health Facility), alongside one Non-Governmental Organisation hospital (Eastleigh Community Wellness Centre), were selected and their health records carefully examined, and in contrast to water quality time-frame data, this health record analysis spanned 12 months. This time frame was selected to offer a comprehensive understanding of the seasonal trend.

Inclusion criteria

The water storage tank to be sampled had to be sourcing water only from the borehole, and the borehole had to be at least two hundred meters from the already sampled one. Data collected from hospital records included only those with symptoms related to waterborne illnesses.

Exclusion criteria

The water storage tanks that had a mix of borehole water and other sources like municipal water and boreholes within a two-hundred-meter distance from the already sampled ones were not sampled. For hospital data, records containing symptoms unrelated to waterborne illnesses were disregarded.

Physio-chemical analyses

In-situ measurements were taken for the following parameters: Temperature, pH and Turbidity levels were measured by their respective calibrated meters. A calibrated ion-selective electrode machine measured the fluoride levels. Lead (Pb), Cadmium (Cd) and Arsenic (As) levels were quantified by the Atomic Absorption Spectrophotometer by

adhering to procedures established by the International Atomic Energy Agency[12]. The resonance wavelengths of each metal used during the experiment were Pb at 217.0 nm, Cd at 228.8 nm and As at 193.7nm.

Microbiological analyses

Most Probable Number Technique determined the total coliform count according to APHA[11]. MPN involves a Presumptive test using lactose broth, a confirmatory test using brilliant green broth and a completed test for *Escherichia coli* detection using Eosin methylated blue agar. Pathogenic bacteria were detected according to APHA[11] methodologies. For *Salmonella* and *Shigella spp* isolation, 1 ml of the water sample was enriched with sterile selenite F broth and incubated at 35 °C for 24 hours, followed by streaking of the culture on Salmonella-Shigella agar and then incubation at 35 °C for 24 hours. For *Vibrio cholerae* isolation, 1ml water from each sample was enriched with sterile peptone water and incubated at 35 °C for 6-8 hours, followed by streaking of the culture on thiosulphate citrate bile salts agar and then incubated at 35 °C for 24 hours. After identification of the isolates from their respective culture media, they were further subjected to a series of biochemical tests, including Gram stain, Triple Sugar Iron, Motility, Oxidase, Indole and citrate tests.

Determination of the prevalence of waterborne illnesses

A 12-month retrospective review of patient health records from August 2023 to July 2024 was conducted across the three selected hospitals. In each institution, over 5 years and under 5 years health records were reviewed, and data on the incidence of waterborne illnesses such as vomiting and diarrhea[13] extracted.

Data analysis

Mean values obtained for heavy metals, physicochemical parameters and microbial load analysis from different sampling sites during both the dry and wet seasons were analysed using one-way analysis of variance (ANOVA) at a 95% confidence level. Mean separation was done using the Tukey technique. Prevalence rates of the pathogenic bacteria between the two seasons were assessed using the chi-square test. The integer mean values for every parameter were compared with the standards of the Kenya Bureau of Standards (KEBS). The prevalence rate was calculated by dividing the incidence rate recorded by the number of patients who reported to the health facilities in 12 months.

Ethical approvals

The Research permit was obtained from the licensing body, the National Commission for Science and Technology (License number: NACOSTI/P/24/36874). Ethical approval was obtained from the County Health Research Ethics Committee, Nairobi City County (Reference number: NCCG/HWN/REC/616) and research authorisation from the medical officer of health, Kamukunji Sub-County.

Results

Physicochemical properties

The results revealed that all physicochemical parameters obtained from different sampling streets were not significantly different ($P \leq 0.05$) (Table 1).

Temperature. The temperature ranged from 21.5°C to 31°C in the wet season and 21.5 °C to 29.5°C in the dry season. Mean water temperature varied narrowly among the sampling sites with a mean range of 24.5 °C to 27.5 °C (Table 1). The water temperature was, however, within the KEBS standards.

Turbidity. The turbidity values ranged from 0.61 NTU to 3.27 NTU, with an average mean of 1.65 during the wet season, and a range of 0.31 NTU to 2.73 NTU with an average mean of 1.46 during the dry season. There was no significant variation in mean turbidity levels in the dry and wet seasons ($P=0.359$, $df=1,48$). The overall turbidity was within the acceptable KEBS limit of 5 NTU.

pH. The pH values of water from the boreholes varied throughout the study. The water samples had a slightly basic pH, where the values ranged from 7.9 to 9.8 in the wet season and 6.9 to 8.9 in the dry season. The average pH value of 7.93 for all the boreholes during the dry season fell within the acceptable range set by KEBS, which is 6.5 to 8.5. However, the average value of 8.79 during the wet season was beyond the range. Using a one-way ANOVA test, it was observed that there was a significant difference between the values of the wet and dry season (P=0.000, df=1,48). Tukey's technique revealed the mean between the two seasons to be significantly different.

Fluoride. The Mean Fluoride level recorded during the wet season was 7.713 mg/l, with a range of 0.21 mg/l to 15.96 mg/l. The mean concentration during the dry season was 7.99 mg/l, with a range value of 0.114 mg/l to 13.22 mg/l. There was no significant difference in concentration between the dry and wet season (P=0.803, df=1,48). The mean fluoride levels from the sampled water were higher than the KEBS permissible standard of 0.5mg/l.

Arsenic. Arsenic values ranged from 0 mg/l to 0.06 mg/l, with an average of 0.01044 mg/l during the wet season and a range of 0 mg/l to 0.111 mg/l and an average of 0.0366 mg/l during the dry season. Using a one-way ANOVA test, the difference between the dry and wet season was statistically significant (P=0.002, df=1,48). Mean separation using Tukey's technique revealed the difference between the two seasons. The mean Arsenic concentrations were within the KEBS permissible limit of 1.5mg/l.

Lead. The lead values in the water samples ranged from 0 mg/l to 0.1412 mg/l with an average of 0.0122 mg/l during the wet season, and ranged from 0 mg/l to 0.192 mg/l with a mean of 0.039 mg/l during the dry season. The difference between the dry and wet season was not significant (P=0.052, df=1,48). The mean lead concentrations were within the KEBS acceptable limit of 0.05mg/l.

Cadmium. During the wet season, the mean concentration of Cadmium level was recorded at 0.095 mg/l with a range of 0.0043 mg/l to 0.2441 mg/l. The mean concentration was higher during the dry season, with a value of 0.1339 mg/l and a range of 0.0088 mg/l to 0.2733 mg/l. The one-way ANOVA test calculated the difference between the dry and wet season not to be significant (P=0.062, df=1,48). The mean cadmium values were higher than the KEBS standard of 0.005mg/l.

Table 1:
Overall Physicochemical Properties of Water from the Various Streets in Eastleigh

Parameter	2nd street	4th street	6th street	8th street	10th street	12th street	14th street	16th street	F statistics	P value
Temp (°C)	25.25	25.75	26.59	24.5	27.5	26.59	24.83	24.88	1.3657	0.245
Turbidity (NTU)	1.92	1.61	2.23	1.41	0.68	1.29	1.68	1.59	1.5537	0.1761
pH	8.09	8.0	8.67	8.5	8.25	8.57	8.2	8.54	0.7129	0.6613
Arsenic (mg/l)	0.0455	0.04	0.0255	0.004	0.034	0.02	0.005	0.018	1.6309	0.1533
Lead (mg/l)	0.005	0.025	0.008	0.024	0.005	0.009	0.054	0.059	1.4736	0.203
Cadmium (mg/l)	0.176	0.1457	0.1011	0.1343	0.07	0.1079	0.0689	0.1133	1.6212	0.156
Fluoride (mg/l)	9.78	9.317	6.737	7.279	8.35	7.849	5.38	8.066	0.7437	0.6366

Bacterial properties

Total coliforms MPN/100 mL. Total coliform was detected in all sampling sites in both seasons. There was a variation in total coliform counts in water from various boreholes, ranging from 2 to over 1800. The mean value of total coliform was higher in the dry season, with 779.88 MPN/mL as compared to 639.44 MPN/100mL mean obtained during the wet season. From the one-way ANOVA test, the average difference between the two seasons and among the sampling streets did not vary significantly (p= 0.528, df= 1,48) and (P=0.427, df=7,42) respectively.

Pathogenic bacteria. The frequency of occurrence of *Salmonella spp* was at 42 % with the occurrence frequency higher during the dry season (52%) as compared to the rainy season (32%). *Shigella spp* and *Vibrio cholerae* occurrence frequencies were at 30% and 46 % respectively. The occurrence frequency of *Shigella spp* was at 36% and 24% during the dry and wet season, respectively, while *Vibrio cholerae* was at 48% and 44% during the dry and wet season, respectively. *Escherichia coli* frequency of occurrence during the dry and wet seasons was 44% and 32% respectively. All the sampling streets had equal occurrence of the isolates, except the 10th street, which only recorded *Vibrio cholerae*. With a critical value of 3.841, the chi-square test indicated the prevalence rate of *Salmonella spp*, *Shigella spp*, *Vibrio cholerae* and *Escherichia coli* (X^2 = 1.694, 0.741, 2.762 and 0.33), respectively, not to be seasonally dependent.

Prevalence of waterborne illnesses

During the study period, a total of 30,745 patients were treated across the three participating health facilities. Eastleigh Health Centre accounted for the highest proportion of patients (42.99%), followed by Eastleigh Community Wellness Centre (38.93%) and Biafra Health Facility (18.07%).

Children under 5 years comprised 31.08% of the total patient population, while those aged over 5 years made up 68.92%. Among patients under 5 years, the majority were treated at Eastleigh Health Centre (48.79%), followed by Biafra Health Facility (27.43%). In contrast, for patients over 5 years, the highest proportion was seen at Eastleigh Community Wellness Centre (45.76%), with Eastleigh Health Centre following at 40.38%.

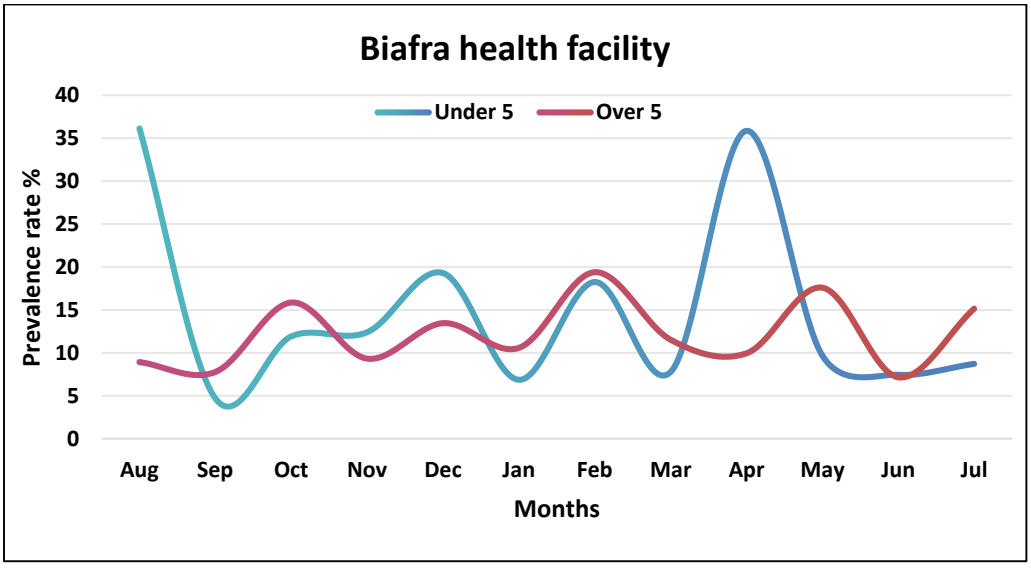

Figure 2
Monthly Variation of Reported Cases of Waterborne Illnesses in the Biafra Health Facility

The prevalence rate of waterborne illnesses

Out of the patients treated at the three hospitals, 8.5% (n = 2,611) reported experiencing at least one symptom associated with waterborne illnesses. The Biafra health facility, Eastleigh community wellness centre, and Eastleigh health centre reported waterborne infection rates of 12.36%, 8.65%, and 6.74%, respectively. Patients <5 and those >5 years demonstrated general prevalence rates of 11.06% and 7.33%, respectively. Using a one-way ANOVA test, no statistically significant difference was observed in the mean prevalence rates obtained from the three health facilities for both age groups (P = 1.104, DF = 0.343 and P = 1.917, DF = 0.1631, respectively). Furthermore, no notable variation was observed between seasons (Figures 2, 3, and 4).

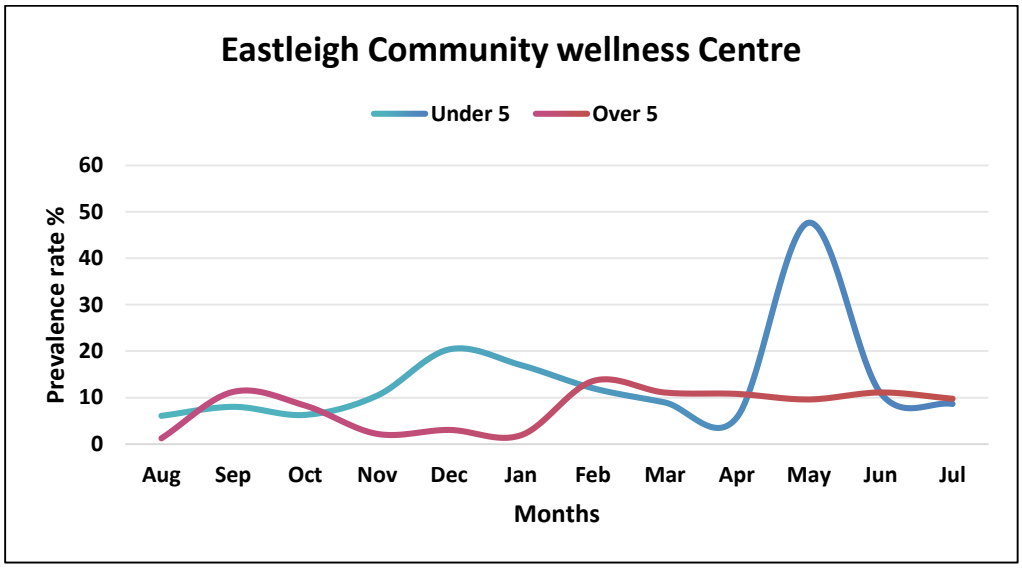

Figure 3

Monthly Variation of Reported Cases of Waterborne Illnesses in Eastleigh Community Wellness Centre

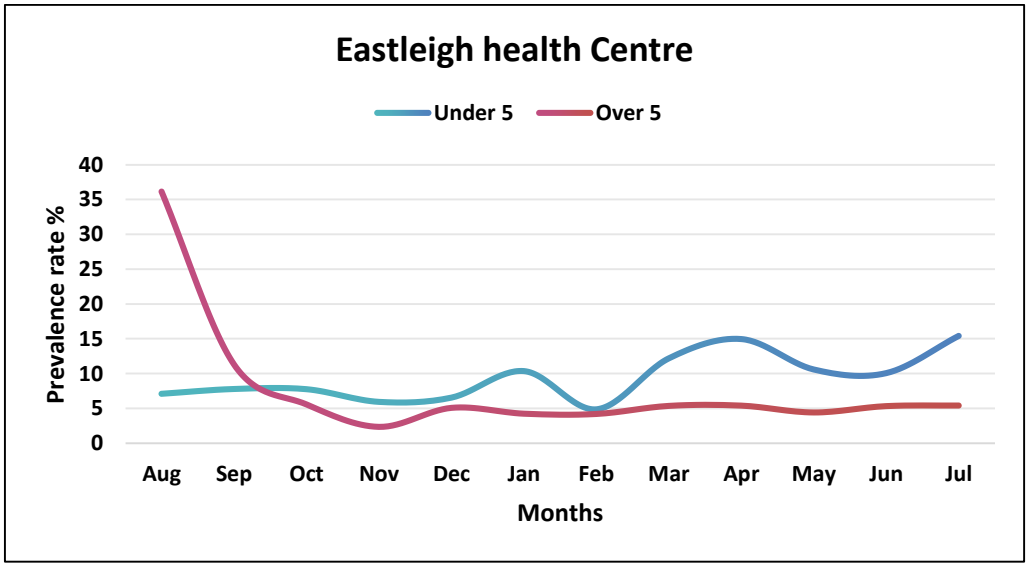

Figure 4

Monthly Variation of Reported Cases of Waterborne Illnesses in Eastleigh Health Centre

Discussion

The findings of this research reveal that boreholes in Eastleigh are not safe for consumption due to the massive presence of bacterial and chemical contaminants. The study also reveals that waterborne illnesses in the study area are a serious public concern that calls for public health awareness campaigns on preventive measures.

Physicochemical parameters

The general temperature was within the KEBS permissible range of 20-35°C. Temperature is a key parameter in determining the bacterial and chemical quality of water, as research showed that the relative abundance of bacterial and biofilm composition in water was favoured by an increase in water temperature[14].

The Mean turbidity values were within the KEBS permissible limits. This observation is closely similar to a previous study on selected boreholes in Nairobi[15] where 71.5% of the boreholes were within the recommended level. During water sample collection, it was observed that the boreholes were equipped with turbidity filter machines to remove sediments. Turbid water can harbour pathogens, increasing the risk of waterborne illnesses[16].

The borehole water was mildly alkaline, with similar results obtained in Ethiopia[17]. Such pH levels play a crucial role in the bioavailability of heavy metals such as Arsenic from the aquifer into the groundwater[18]. The higher pH values obtained during the wet season could be due to the dissolution of limestone rocks present in the aquifer formation, releasing CaCO3 into the water[19] and possibly due to hydrogen ion reduction due to the lower temperature. pH values ranging from 3 to 10.5 are favourable for the growth of pathogenic microorganisms [20].

Lead and Arsenic concentrations were within the KEBS permissible limits. These may be attributed to the absence of their respective chemical compounds in the underlying geological rocks and the lack of anthropogenic activities in the area [21]. Similar findings were reported in the counties of Turkana[22] for lead and Kakamega[23] for arsenic. It is noteworthy that lead poisoning leads to cancer and affects the nervous system[24] while arsenic leads to cardiovascular diseases[25].

Cadmium levels surpassed the permissible threshold of 0.005 mg/l established for potable water. These findings corroborate a study conducted in various estates of Nairobi [5], where concentrations exceeding the acceptable limits were detected. The cadmium availability may be due to the mineralisation of cassiterite compounds found in the underlying geological rocks, hence the leaching of cadmium into groundwater. Cadmium toxicity engenders significant reproductive and cardiovascular health complications [26]. Furthermore, the bio-accumulation of cadmium within the renal system takes time before complete excretion[27].

Fluoride levels were beyond the permissible limit of 1.5 mg/l set for potable water. These findings are consistent with previous work done in boreholes in the Rift Valley, where values of up to 19 mg/L were recorded[28]. These findings can be attributed to the weathering of fluoride-rich volcanic bedrocks [29]. Lack of significant variation of fluoride levels from different sampling streets is a gesture of similarity in underground lithology. High levels of fluoride ions cause dental and skeletal fluorosis[30].

Coliforms count

The total coliform count was greater than the KEBS permissible limit of 0 CFU/100 ml for drinking water. Similar results were obtained in boreholes in Nairobi Estates [5]. High coliform count may indicate the presence of faecal contaminants[31].

Pathogenic bacteria

At least one bacterial species of interest was detected in every borehole sampled, with Similar findings reported in boreholes in neighbouring Machakos[32] and Kajiado[33] counties. These isolates cause serious health illnesses.

Some strains of E. coli can cause severe bloody diarrhoea and vomiting[34]. In 2022, 5% cases of *Salmonella typhi* infections were recorded in Mukuru informal settlement in Nairobi County [35].

Cholera disease caused by *Vibrio cholerae* has been considered an acute, life-threatening diarrheal disease[36]. Conversely, *Shigella spp* leads to bloody diarrhoea and fever[37]. From the preliminary study, time-to-time cleaning of the storage tanks was not in place, and this negligence, together with possible wastewater leakage, could be possible routes of microbial contamination.

Prevalence of waterborne illnesses

Disease symptoms may be mild in some people who might not seek medical attention from health facilities. Moreover, home medication limits the chances of visiting healthcare facilities for treatment for some individuals who experience illness. With these factors in place and an 8.5% prevalence rate reported, it indicates that at least 1 in every 11 people experienced waterborne illnesses. This finding is consistent with a related study done in Kenya [38].

Conversely, the detection of at least one pathogenic bacterial species in every borehole suggests a high likelihood of illness upon water consumption. Lack of proper public health sensitisation on preventive measures against waterborne illnesses and inadequate supply of safe drinking water may be possible causes of these illnesses. From this study, a higher incidence of waterborne illness was reported in children below five years of age compared to their older counterparts.

A similar study in Nigeria [39] also revealed a higher disease incidence in the same age group. This may be attributed to their low body immunity as compared to the >5 years age groups. Lack of proper hygiene practices by caregivers, coupled with the explorative feeding behaviour in children, may also be a possible cause.

Limitations of the study

The hospital records only showed the symptoms presented by the patients but did not indicate a diagnosis; therefore, analysis of the prevalence of specific waterborne illnesses was not tenable. Due to the absence of direct patient-level questionnaires on water exposure, it was impossible to attribute the borehole water as the precise route of contamination leading to these waterborne illnesses. Data on waterborne illnesses was collected over 12 months, while that on water quality was focused exclusively on wet and dry periods, thereby introducing potential temporal biases between the two datasets. Consequently, establishing an accurate correlation between them was challenging. Absence of laboratory resources in these health facilities to detect effects of the heavy metals in patients' blood limited the prevalence tests only to those illnesses suspected to be of microbial contaminants.

Conclusion and Recommendation

All the physicochemical parameters were generally within permissible standards for drinking water recommended by the Kenya Bureau of Standards, except for cadmium, fluoride and pH. The total coliform count exceeded the KEBS permissible limits. At least one of the pathogenic bacteria of interest was detected in every borehole. With the overall prevalence rate of 8.5%, waterborne diseases are a public health concern in Eastleigh. However, due to the uncertainty of the precise vector of contamination leading to these illnesses, it is recommended that appropriate measures be taken to save the residents from possible threats of such contamination, including provisions of safe drinking water and education on potential biohazards associated with water consumption from questionable sources such as boreholes. Further studies for detecting the effect of Cadmium and Fluoride levels on the residents are recommended.

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Conflict of interest. None.

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