ASSESSMENT OF VENDED WATER QUALITY: A CASE STUDY OF WATER TANKERS AND KIOSKS IN LODWAR TOWN, TURKANA COUNTY, KENYA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Master of Science Degree in Limnology of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented in this university or any other for the award of a degree.

Signature: ………………….. Date: 6th October 2025

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SM18/19019/18

Recommendation

This thesis has been submitted with our approval as University supervisors.

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DEDICATION

I dedicate this work to my dear Mother and Guardian, the late Mr. Micah Emuria who stood with me throughout my academic journey. This effort has purely been motivated by their consistent support and encouragement.

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ABSTRACT

Informal water vendors emerge in many urban areas to fill the water supply gap due to inability of water utilities to meet water supply needs of the urban populations. However, there has been concerns about the quality of water delivered by vendors due to uncertainty of the hygienic condition of transportation and storage tanks, and the status of the water sources. This study assessed selected water quality parameters of vended water in Lodwar town across water tankers, kiosks and piped water supply chains from the source to consumers. Electrical Conductivity (EC), pH, temperature, salinity and Total Dissolved Solids (TDS) were determined by universal meters Model HACH HQ 40d; HACH HQ 30d for Dissolved Oxygen (DO) and HACH HQ 11d for turbidity. NO_3-N, NO_2-N, NH_4-N, sulfate and fluoride were determined by calorimetric methods using light spectrophotometer at specific wavelengths. Alkalinity and chloride were determined by titration method. The concentrations of iron and lead were determined by Atomic Absorption Spectrometry (AAS) method. Faecal coliform densities were determined by Membrane Filtration Technique (MFT) using Oxfam- DelAqua water testing kit (DWT code 11240). SPSS statistical software at a significance level of 0.05 using One-Way ANOVA was used to test for the difference of water quality parameters across the supply chains while, Pearson correlation analysis was used to test for relationships among tested water quality parameters. Independent – Samples Kruskal - Wallis test was used to test the prevalence of waterborne health risks from 2016 to 2020. The temperature (28.27-32.46°C), DO (3.66-7.50mg/L) and pH (7.58-8.65) were significantly different ($p<0.05$) using one-way ANOVA test across all the supply chains while, Free Residual Chlorine (FRC) (0-0.19mg/L), nitrite (0.004-0.005mg/L) and faecal coliforms (6.40-340.79CFUs/100mL) were significantly different ($p<0.05$) across water tankers and piped water supply chains using one-way ANOVA test. Turbidity (1.85-5.90mg/L), ammonia (0.0425-0.0426mg/L) and sulfate (0.019-0.021mg/L) were significantly different ($p<0.05$) across water tankers supply chain while, nitrate (0.052-0.068mg/L) was significantly different ($p<0.05$) across kiosks supply chain using one-way ANOVA test. Inadequate water treatment, poor hygiene and improper water handling, lack of vendors monitoring and regulation, poor maintenance of piped system, water shortage and unreliable electricity supply at the water sources were identified to influence water quality in Lodwar town. The findings from this study provide the basic information on the status of water quality delivered by water vendors in Lodwar Town and inform water quality monitoring and regulation for the County Government of Turkana to improve water services and policy.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrometry
ANOVA	Analysis of Variance
ATM	Automated Teller Machine
CFUs	Colony Forming Units
CIDP	County Integrated Development Plan
DO	Dissolved Oxygen
DHIS	District Health Information System
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic Acid
KEBS	Kenya Bureau of Standards
KPHC	Kenya Population and Housing Census
LCRH	Lodwar County Referral Hospital
LOWASCO	Lodwar Water and Sanitation Company
MDGs	Millennium Development Goals
MFT	Membrane Filtration Technique
NAWASSCO	Nakuru Water and Sanitation Services Company Limited
NTU	Nephelometric Turbidity Units
SDGs	Sustainable Development Goals
SPADNS	Sulfanilic acid-azochromotrop. 1, 8-Dihydroxy-2-(4-sulfophenylazo) naphthalene-3, 6-disulfonic acid trisodium salt
TDS	Total Dissolved Solids
UNDP	United Nations Development Programme
UNICEF	United Nations Children's Fund
WASREB	Water Services Regulatory Board
WHO	World Health Organization

CHAPTER ONE
INTRODUCTION

1.1 Background information

Globally, by 2020, one in four people (2 billion people) lacked safely managed drinking water in their homes (WHO/UNICEF, 2021). It is reported that if there are no interventions for improvement of water quality management by 2030, only 81 percent of the world's population will have access to safe drinking water at home, leaving 1.6 billion people without access to safe water (WHO/UNICEF, 2021). Many countries have been reported to lose productivity to water and sanitation related diseases spending up to 5 percent of their Gross Domestic Product (GDP) (WHO, 2012). Additional economic losses can be attributed to time wasted when fetching water sometimes in distant areas from home. Further, a report by UNICEF in 2021 revealed that 700 children under the age of five die every day from diarrhoeal diseases due to unsafe drinking water, poor sanitation, or poor hygiene (UNICEF, 2021). However, the Human Right to Water and Sanitation (HRWS) has long been recognized by United Nations General Assembly (UNGA, 2010) as an essential right for the full enjoyment of life. Thus, access to safe drinking water in adequate quantities is considered a human right irrespective of age or social status in the society (Howard & Bartram, 2003).

Water vending is as old as human society and trade, although it is currently taken as a sign of failed piped systems (Kjellen & McGranahan, 2006). Nevertheless, water vending is still used to provide water mainly to minority of urban dwellers in many parts of the world. Water vendors provide an important service to the consumers. Thus, preventing water vending would create a void towards denying deprived residents access to water. These water providers act as "gap fillers" ensuring water provision coverage to a large population, though presumed to be or probably of lower water quality. They have been "pioneers" in extending water access to areas with poor infrastructure and system of delivery like Turkana among other areas. The vendors also act as "sub-concessionaires" by buying from the water utility and reselling to the customers (Kariuki & Schwarz, 2005; UNDP, 2011). A study by UNDP in Kenya on small scale water providers (UNDP, 2011) found out that, 53% of the water provided by small-scale providers comes from improved sources with good water quality. However, mobile vendors such as pushcarts and tankers do obtain water from various unfamiliar sources especially during times of water shortage creating an information gap in regard to the quality of water sold by the vendors. This is a major concern for water safety as the end water users have little means of verifying the safety of the water they purchase from the vendors.

According to Kjellen and McGranahan (2006), water vendors are often blamed for supplying unsafe water despite the fact that most vendors display their goods as “clean water” or “pure water”. Furthermore, it is quite likely that the transfer of water from one vessel to another (which is not necessary from a piped supply) exacerbates the risk of contamination (Okoko & Idise, 2014). The consumption of packaged water purchased from vendors in markets has been associated with diarrhoea among children in Ibadan, Nigeria (Oyemade *et al*., 1998). In Accra (Ghana), water from “ice-water vendors” was found to have alarmingly high counts of coliform bacteria (Benneh *et al*., 1993). However, Kjellen (2000) found pushcart water vendors in Dar es Salaam to be surprisingly of good quality. Moreover, a study covering several places in East Africa found water from vendors and kiosks as well as that which is piped directly to houses to be relatively safe in terms of low diarrhoea prevalence among children in families relying on those sources (Thompson *et al*., 2001; Tumwine *et al*., 2002).

Water vendors typically operate outside or at the margins of established legal frameworks. However, most utilities who are licensed water providers choose not to “punish” water vendors, but rather acknowledge that such trade is a consequence of the water utilities inability to reach all customers (Kjellen & McGranahan, 2006). This gives the vendors some sort of freedom to do what is best for them. The Joint Monitoring Programme by WHO and UNICEF (WHO/UNICEF, 2017) reclassified packaged water and delivered water by water tankers as improved sources because they have a potential to be safely managed to meet the three criteria for improved source type. These criteria include; accessibility on the premise, availability when needed and free from contamination (compliant with standards for faecal and priority chemical contamination). The presence of microbial organisms such as faecal and total coliforms, water nutrients and other substances in water contribute to diseases and illness causing enteric pathogens; particularly water from vendors and storage facilities (Kwami & Sawyerr, 2018). Further, water storage facilities and water vendors provide a conducive environment for microbial and faecal coliforms to develop due to lack of hygiene, proper cleaning of such containers and facilities, and sanitation (Okoko & Idise, 2014).

In Kenya, 45% of population has no access to piped water within easy reach (WASREB, 2019), thus creating a conducive environment for water vendors to breech the gap. Whittington *et al.* (1989) identified three kinds of water vendors along the coastal region in Ukunda; wholesale vendors (obtain water from the source and sell to distributing vendors), distributing vendors (obtain water from either the source or wholesale vendors and sell to consumers door to door) and direct vendors (sell water to consumers from the source). It is important to note that economic development of an area can be influenced positively if water vending systems are improved to supply good water quality. However, water vending can be a financial burden and a health threat to millions of people besides encouraging the water utility from forfeiting provision of water services as provided by the law. Additionally, this leads to formation of cartels and other anti-development groups that destroy water provision infrastructure. Furthermore, water vending is a worthy area of study due to uncertainty of continuous supply of clean water from piped systems caused by severe shortages of capital or inability to purchase hand pumps in developing countries. Thus, water vending may continue to exist in the foreseeable future. Water availability and supply in many towns in Kenya is unreliable, mainly because of extensive rationing by the utility companies that arise from high demands and water shortages (UNDP, 2011) making human right to water untenable. Notably, vending in some circumstances may prove to be an appropriate technology for communities at a given level of economic and social development. This is because it is typically a more reliable means of water provision. Therefore, information on water vending practices, particularly costs and charges, may be useful for public water supply planning decisions.

According to UNDP (2011) report on small scale water providers in Kenya, fixed point water suppliers such as public taps and water kiosks are safer and more affordable compared to mobile water vendors (pushcarts and tankers). Households that used vendor's water in Ukunda, Kenya were reported by Whittington *et al*. (1989) to enjoy a high level of service; presumably good quality water was delivered to their doorstep on demand, though no water quality testing of the vended water was done during the study.

Water coverage in Lodwar town is at 59% (acceptable coverage is 80% and above) according to WASREB (2020) with water quality approval of 66% (a composite of free residential chlorine and bacteriological standards) against a recommended approval of not less than 90% (WASREB, 2020). Given the fact that both the water coverage and water quality approvals is below the recommended rates, there exist a water supply gap. This gap creates an opportunity for water vendors to participate in the water supply chain. Consequently, the households living in Lodwar town may be vulnerable to water borne diseases like cholera, typhoid, and dysentery among others that have been previously reported in the area as a result of compromised water quality (IFRC, 2020; WHO, 2008). Many previous studies on water vending have focused on water markets: profits, affordability, reliability and accessibility but not much on water safety in regards to water quality. It is against this outstanding gap that this study seeks to assess vended water quality by informal water vendors (both fixed point and mobile) focusing on water sold at kiosks and water delivered by the tankers in comparison to piped including the quality of the water source in Lodwar town, Turkana County.

1.2 Statement of the problem

Informal water vendors have thrived in Lodwar town to supply water to the underserved areas of the town where the local water utility; Lodwar Water and Sanitation Company (LOWASCO) has not been able to reach with its service. This is because water supply by the utility is less than the demand by the town population. Thus, informal water vendors tend to bridge the water supply gap by providing access to water services. However, the underlying concern in relation to these services is the uncertainty of the quality of water supplied by these informal water vendors. This concern arises due to lack of water quality monitoring and regulation of vendors, improper handling of water by vendors, and unguaranteed hygiene conditions of the water tanks used to transport water (whether properly cleaned) coupled with uncertain hygienic conditions of storage facilities at the point of use. Since the quality of water supplied by these vendors has not been critically assessed or verified, the residents of Lodwar town are exposed to a high risk of contracting waterborne diseases (e.g. cholera, typhoid, amoebic and bacillary dysentery, among other diarrhoeal diseases) from consumption of contaminated water. Furthermore, there is a possibility that some of the water tankers are also used for transportation and delivery of both construction water drawn from untreated sources as well as drinking water, hence increasing the risks further on water safety. It is for these reasons that this study seeks to analyse the quality of water delivered by vendors across water tankers and kiosks supply chains to ascertain its safety, and whether water handling at different points across the supply chains had a significant effect on the overall water quality consumed by the community to identify the weakest link in the connections.

1.3 Objectives

1.3.1 General objective

The general objective of the study was to contribute to vended water quality analysis across water supply chains from the water source to the consumers' point of use in Turkana County, Kenya.

1.3.2 Specific objectives

i. To determine physical-chemical parameters (temperature, turbidity, electrical conductivity, salinity, total dissolved solids, dissolved oxygen, FRC, pH, nitrates, nitrites, ammonium, sulfates, total alkalinity, chloride, fluoride, iron and lead) of vended water across the water tankers, kiosks and piped water supply chains from the water source to the consumer endpoint in Lodwar town.

ii. To determine densities of faecal coliforms (*E. coli*) in vended water across water tankers, kiosks and piped water supply chains from the water source to the consumer endpoint in Lodwar town.

iii. To evaluate the prevalence of waterborne diseases (such as diarrhoea, dysentery, cholera, amoebiasis, gastroenteritis, typhoid fever, hepatitis and bilharzia) among residents within Lodwar town in a retrospective five-year period (2016 to 2020).

1.4 Hypotheses

The following hypotheses were tested in this study;

i. There is no significant difference in the physical-chemical parameters (temperature, turbidity, electrical conductivity, salinity, total dissolved solids, dissolved oxygen, FRC, pH, nitrates, nitrites, ammonium, sulfates, total alkalinity, chloride, fluoride, iron and lead) of vended water across the water tankers, kiosks and piped water supply chains from the water source to the consumer endpoint in Lodwar town.

ii. There is no significant difference in the densities of faecal coliforms (*E. coli*) in vended water across the water tankers, kiosks and piped water supply chains from the water source to the consumer endpoint in Lodwar town.

iii. There is no significant prevalence of waterborne diseases (diarrhoea, dysentery, cholera, amoebiasis, gastroenteritis, typhoid fever, hepatitis and bilharzia) among residents within Lodwar town in the last five years from 2016 to 2020.

1.5 Justification

Turkana County climatic conditions are hot and dry, leading to water shortages. Geographically, Turkana County is within the Arid and Semi-Arid (ASAL) region, hence fresh freshwater sources are limited. This has led to some areas of the town not being provided with water by local water provision company, LOWASCO. Consequently, there is a rise in water vending business to meet water supply needs for households not connected to public water supply system. This study is critical to understanding the physical, chemical and microbiological quality of water delivered or distributed by water vendors (especially water sold from kiosks and delivered by water tankers) in Lodwar town, Turkana County. The study provides baseline information on the role played by water vendors in the supply and accessibility of water to the community. The role of vendors as an alternative water service provider where the public water utilities are not able to supply treated water cannot be underestimated. The study contributes to the improvement of public health among households especially from water borne diseases like typhoid, cholera and diarrhoea. This is achieved through identification of water quality related risks (waterborne health conditions) faced in using vended water from kiosks and tankers. Therefore, the results from this study provide baseline data for Turkana County Government to improve policies on water services. In addition, vendors are likely to benefit from the baseline information on vended water quality and come up with safety measures within their supply chain. These measures will enhance sustainable water vending business, coupled with business reliability rights, formalization, maintenance of prices and profits as well as winning trust among the consumers.

Finally, this study provides key data to be considered in the reclassification of vended water as "*Improved sources*" contrary to the previous position which classified them as "*Unimproved sources*". Thus, the study contributes to the achievement of Sustainable Development Goal(s) number 6 (Clean Water and Sanitation: especially target 1 on achieving access to safe and affordable drinking water) and indirectly 3 (Good health and Well-being) by giving a snapshot of the safety status of the water supplied in Lodwar town, both vended and piped water. The study is important in the implementation of the Turkana County Integrated Development Plan (CIDP) as it contributes to the achievement of development priorities especially on the environmental pillar (water quality and quantity dimension) by providing key information on vended water quality monitoring.

CHAPTER TWO
LITERATURE REVIEW

2.1 Water supply systems in urban areas

There exist formal and informal systems in water service provision in most urban centres, especially in developing countries. Formal systems refer to the conventional ways of water supply, such as municipal water piped systems managed by water utilities. In Lodwar town, the formal system (piped) was managed by LOWASCO. On the other hand, informal systems of water supply known as 'off-grid' or small-scale water enterprises refer to various water vendors providing water to areas or households not served by LOWASCO or having intermittent utility water supply. This may be due to infrastructural challenges or due to finite water resources, as suggested by other researchers (Awere & Anornu, 2016).

These informal vendors include small scale and private water service providers such as source water markets (river, borehole and shallow wells), mobile or distributing vendors (water tankers, handcarts, bicycles, motorbikes and trawlers), bottling services and direct vendors (sachet markets, bottles filling stations, direct bottled water by vendors), purification services (small scale at point and sophisticated treatment facilities), private water supply networks (small piped water systems, large piped water systems) and water kiosks (Garrick *et al*., 2019). They can also be categorized broadly as standalone/fixed or mobile vendors (Ayalew *et al*., 2014). It was noted by Stoler (2014) that in Ghana, the number of urban water users relying on sachet water as a primary drinking water source had risen from 13.8% in 2010 to 43.1% in 2014. Tankers in Kathmandu, Nepal supplied close to 20% of the water supply (Gurung *et al*., 2017). Thus, such water vending is not unique to Turkana County alone.

Delivery of safe and sustainable water supplies presents a fundamental challenge for the urbanizing world. With the increasing populations in urban areas due to rural-urban migration, piped water systems are struggling to keep pace. This has resulted in the languishing of formal systems compared to informal water systems, which have thrived due to the high demand for water supply (Garrick *et al*., 2019). The cost to supply water to the estimated 10 billion people globally by the year 2050 is projected to be 60 trillion US Dollars (Larsen *et al*., 2016). This would prove to be unachievable for the struggling developing countries due to the investment cost required, hence giving evidence that informal water vendors would continue to play a key role in water service provision in developing countries.

2.2 The paradox of formal water markets lagging and informal water markets flourishing

In many countries, urban areas, especially in developing countries, are fragile areas due to climatic conditions or social conflicts; hence, public water supply systems have limited water supply (Cain, 2018). This has stimulated the emergence of informal water vendors, which have taken advantage of the limited formal water supply for profit-making businesses with minimal water quality control. This has created a paradox in the sector which can be explained by the fact that public water supply systems, also known as 'formal water markets' have continued to face challenges such as infrastructural inadequacy due to limited funding from the exchequer, governance failures, vested interests, as well as the physical, social and economic characteristics of water (Garrick *et al*., 2019). On the other hand, informal water vendors can be traced to pressures of rapid urbanization coupled with demand in food production through irrigation development. In urban area contexts, informal water vendors fill up the gap left by unavailable and inadequate piped water supply.

A study by Kariuki and Schwartz (2005) reported that close to half of urban dwellers in Africa and a quarter of the urban population in Latin America rely on water vendors for at least a portion of their water supply. The Joint Monitoring Programme report by WHO/UNICEF (2021) notes that 46% of urban households in sub-Saharan Africa rely on water sources outside their homes. In Ghana and Kenya alone, residents in the cities of Accra (48%) and Wa (65%), Ghana and Kisumu (26%), Kenya depend on vendors for their drinking water needs (Dery *et al*., 2024). Moreover, reliability and water quality problems in the piped systems have increased the demand for the vended water even where the piped water systems exist (Garrick *et al*., 2019).

2.3 Role of informal water vendors in water supply

Informal water vendors exist to address two main purposes: to facilitate the reallocation of water across competing uses and to provide value-added services in the distribution, treatment or packaging of water for irrigation and urban uses (Garrick *et al*., 2019). Despite this, water quality supplied by tankers and other informal vendors has been under criticism on their safety but not clearly verified. However, governments in developing countries view these vendors as a practical way of serving low-income households and populations in peri-urban and rural areas (Mehta *et al*., 2007). In some cases, informal markets have proven to be competitive and complementary to formal water systems, serving as extensions to piped networks and forming part of public-private partnerships. In other cases, informal water vendors are the only option for water supply where formal systems have failed. Although informal water vending may be beneficial providing access to water supply, it has also attracted some criticisms especially on the safety of their water and high prices the consumers are charged attributed limited economies of scales and high, unsubsidized costs of acquisition of the tankers, water treatment and distribution (transportation, distance and fuel) compared to piped systems which are normally subsidized by the governments (Garrick *et al*., 2019).

The WHO/UNICEF Joint Monitoring Program (WHO/UNICEF, 2017) for the first time recognized packaged and tanker water as viable water source options that are contributing to the achievement of SDG 6.1. This is because of the potential of informal water vending systems to provide safe and affordable water services, especially if easily accessible and free of contamination. Nevertheless, Garrick *et al*. (2019) suggest that realizing informal water vending potential in water supply to communities would require low-cost monitoring and well-targeted interventions for both the regulators, vendors and consumers. Informal water vendors' activities in Africa and Asia have proved to be critical to water supply. For instance, Venkatachalam (2015) underpinned that in Chennai City (India), 25% of water demand is met by the 700 privately owned tankers, which deliver 125 million litres per day. In Cape Coast metropolis in Ghana, 20% of the households that are not connected to the water utility piped network accessed water through sachet water "pure water", wells & boreholes, and water tankers services (Awere & Anornu, 2016) for drinking and domestic use. In Tanzania, 18.5% of households are supplied by vendors (Bayliss & Tukai, 2011). In Kisumu, Kenya, 24.4% of households rely on public water taps or kiosks as a primary water source and 3.8% on handcart (Ayalew *et al*., 2014), while in Ukunda, Kenya, 45% of water consumed by households was obtained from informal water vendors (Whittington *et al*., 1989).

2.4 Evolution of informal water vending

According to the World Bank review (Garrick *et al*., 2019), studies on informal water markets are categorized into three. They include isolated field studies (1960s to 1980s), global surveys and studies during the early phases of privatization (1990s and early 2000s) and lastly studies during the period of Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) implementation (Post 2000).

In the period between the 1960s and the 1980s, the focus was on four areas: the role of informal water vendors as an alternative water supply source for urban areas, the willingness to pay by consumers, water market competitiveness, and the costs of delivering vended water. This phase was mainly marked by three in-depth studies on the water vendors' operations, which came up with the following conclusions. First, that vended water was expensive for the poor and not necessarily profitable for the water vendors due to the huge transportation costs, as recorded in Ukunda, Kenya (Whittington *et al*., 1989). Secondly, the perception by consumers that vended water was of good quality motivated their willingness to pay for vended water as noted in Onitsha, Nigeria (Whittington *et al*., 1991). Thirdly, on "Market Power" by water vendors, there was no sufficient evidence to indicate that water vendors had control of prices according to a study in Khartoum, Sudan (Cairncross & Kinnear, 1991).

In the early phase of water vending research (1990s to early 2000s), the focus was in water privatization and the role of water vendors and public water systems in providing water for the poor. The key findings during this period included; that informal water vendors complement public water systems (Kjellen, 2000; Kjellen & McGranahan, 2006), informal water vendors were the main water source supply for the urban poor (up to 75%) (Collignon & Vezina, 2000) and the realization of the 'speciation' phenomenon that underpins the emergence of informal water vendors as a result of the local area conditions (Solo, 1999).

The last and current focus of research is marked by the period of the implementation of MDGs and SDGs (post 2000 to date). It is also marked by the consideration of rapid urbanization and the global climate change debate. Research in this phase understands informal water vendors in areas of water and financial flows, consumption patterns and motivations, price dynamics/trends across the supply chain and price determinants, competition and organization among vendors, regulation and enforcement issues by the authorities and more importantly, water quality (Garrick *et al.,* 2019). Further, the existing evidence on the performance of informal water vendors was insufficient and contradictory, thus yielding five (5) unsettled questions indicated in Table 1 addressing the informal water markets. These 5 questions exhibit the existence of gaps in understanding the informal water vendors' markets. Therefore, this study will help understand the unsettled question 3, on whether the informal water markets deliver poor quality water to users by assessing selected water quality parameters through the delivery chain in Turkana County, Kenya, adopted from Garrick *et al*. (2019) (Figure 1).

Table 1: Existing gaps in informal water markets/water vendors

Question 1	Do informal water markets prey on the poor?
Question 2	Do informal water markets crowd out formal water systems?
Question 3	Do informal water markets deliver dirty water?
Question 4	Are informal markets unsustainable?
Question 5	Would regulation improve the performance of informal markets?

Source: Summarized from Garrick *et al.* (2019).

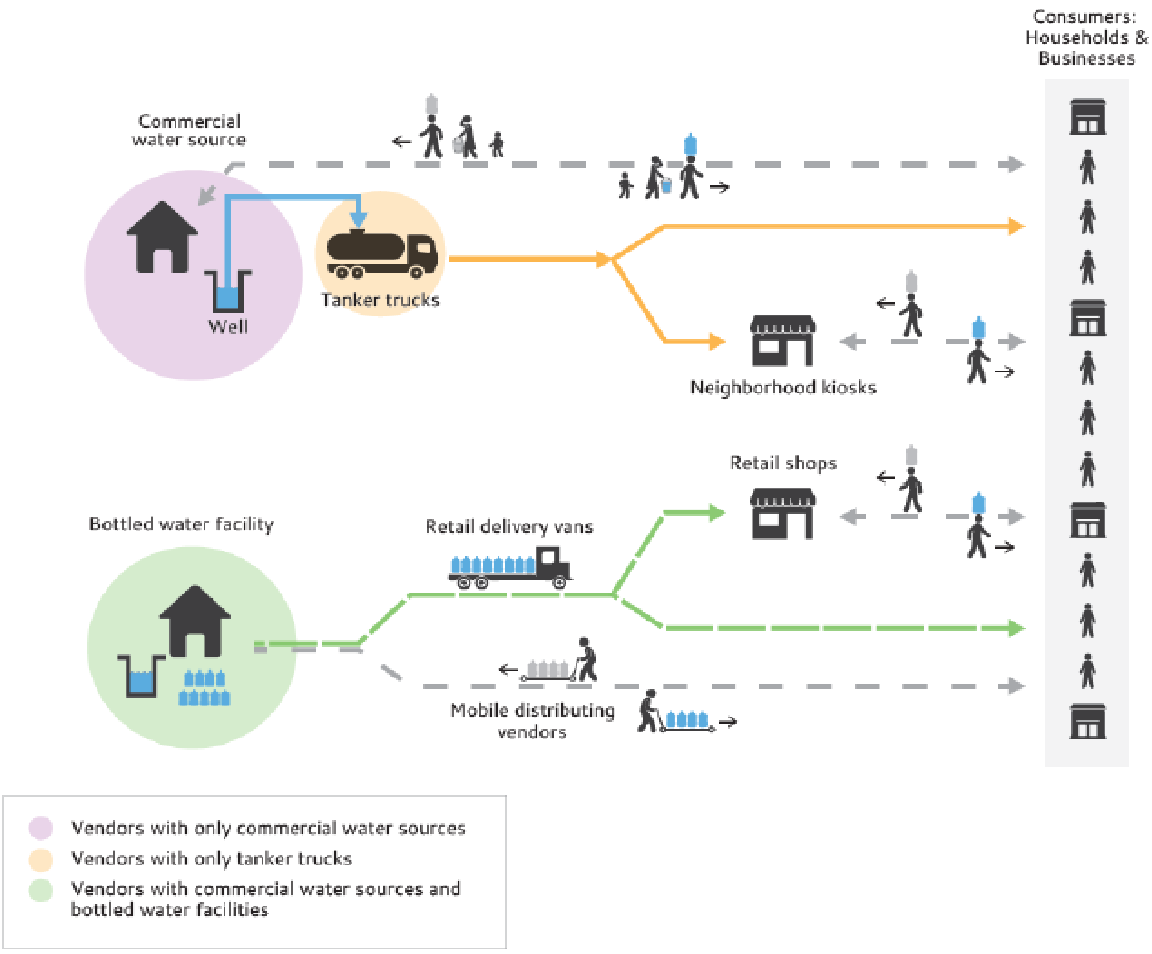

Figure 1: Supply chain and structure of informal water vending in Kathmandu, Nepal

Source: Garrick *et al.* (2019)

2.5 Water quality from informal water vendors

Water quality is often related to the degree of bacterial and chemical contamination (Zamberlan da Silva *et al*., 2008) and the health of consumers (WHO, 2003). Further, it is asserted that microbiological and chemical characteristics of vended water remain uncharted (Ayalew *et al*., 2014). Through analysis of thermotolerant coliforms across the supply chain of vended water in Kisumu (Kenya) and Addis Ababa (Ethiopia), Ayalew *et al*. (2014) showed deterioration of water quality in consumers' storage facilities compared to tap, standpipes and borehole water. Similarly, Donde *et al*. (2013) in a study conducted in Naivaisha, Kenya found out that water at the borehole point of access, vendors and households had bacterial quality above recommended standards for drinking water. Further, Macharia *et al*. (2015) asserted that microbial quality of drinking water from boreholes deteriorated from the point of collection through conveying containers of small-scale water vendors to household storage containers in a study conducted in Njoro, Kenya.

Physical-chemical characteristics (taste, odour, colour, turbidity, total dissolved solids, alkalinity, total iron, chloride, fluoride, nitrite and nitrate) and bacteriological characteristics (*E. coli*) of water supplied by tankers in Cape Coast Metropolis, Ghana were analysed by Awere and Anornu (2016). The study showed that water from tankers had poor quality when measured against WHO guidelines, as it failed in colour, turbidity, total iron and bacteriological characteristics. High levels of iron obtained could have originated from rusting of the tanks, making the water turbid and changing in colour. Even though the water samples failed in total iron, there was no objectionable taste recorded, contrary to the WHO (2008) findings that objectionable taste is associated with iron presence in water. Additionally, it was noted that the poor water quality in the tankers was attributed to poor management of the tankers, including improper cleaning and lack of disinfection. High turbidity resulted in high levels of *E. coli* since turbidity has been associated with higher levels of disease-causing microorganisms like bacteria (Awere & Anornu, 2016; Schafer *et al*., 2009; Shittu *et al*., 2008). High turbidity and colour levels in water demand a higher dosage of disinfection, thus making it expensive to treat such water (Hoko, 2008). However, samples collected from the piped system and the source (hydrant from a borehole), satisfied WHO guidelines since it was treated.

In Nigeria, 85% of water vendors supply untreated water (Olajuyigbe *et al*., 2012). In Cape Coast (Ghana), Obeng *et al*. (2010) found increased levels of *E. coli*, total iron, turbidity and colour in water supplied by tankers. Bacteriological quality analysis (*E. coli*) of water sources for household resale (standpipes and private taps) in Maputo, Mozambique, showed no significant difference in water quality between the source and the point of resale (Zuin *et al.,* 2011). Bacteriological quality assessment of water sold in polyethene plastic bags sachets in Greater Accra, Ghana, revealed that water samples met recommended levels (Stoler *et al*., 2014).

Poor management at the source, either by water utility and tanker operators, was identified by Obeng *et al.* (2010) as the cause of poor quality of water delivered by water tankers to customers in Cape Coast Metropolis, Ghana. World Bank report by Garrick *et al*. (2019) asserts that the quality and sustainability of informal water vendors are uncharted, which suggests that improved monitoring and informational interventions are urgently needed even when regulation is unwise or seems infeasible in such settings. In some places, like Luanda in Angola and Kathmandu in Nepal, some vendors use chlorination and reverse osmosis processes to treat water to improve its quality (Cain, 2018), which is not the case in Lodwar town. However, pre-treatment of water before supply has proved to be expensive for the vendors, forcing them to hike prices, something consumers are not ready to adopt.

2.6 The perception of consumers on water quality from vendors

Perceived good quality of vended water was reported as one of the key drivers to its demand by the consumers (Ayalew *et al*., 2014), as they based their perceptions on organoleptic properties such as colour, odour and taste together with vendor's reputation (Garrick *et al*., 2019) which do not necessarily indicate the accurate quality of water. There have been divergent views about the quality of water supplied by the water vendors. Some customers perceive the quality of water supplied by the vendors as good (Stoler *et al*., 2014), while, on the other hand, the quality of vended water has come under criticism by some of the customers (Awere & Anornu, 2016). Respondents rated taste, smell, colour and particulate matter as important water quality indicators in a study carried out by Magwood (2005) on water quality and consumer perceptions in British Columbia, Canada.

Most studies on vended water quality have reported perceptions of consumers about the water quality of vendors compared to the public water system. In these studies, consumers perceived some forms of vended water to be of good quality (Bayliss & Tukai, 2011) compared to public water systems, and this influenced their willingness to pay for vended water even when prices were high (Whittington *et al*., 1989). This may be a spurious misconception, as the actual laboratory analysis of the water quality parameters (chemical and microbiological contents) has indicated contamination of such vended water according to other studies (Awere & Anornu, 2016; Obeng *et al*., 2010). In Lodwar town, there were perceptions among the customers, although they had no means of verifying the water quality. As such, there was a need to investigate the perception of water quality from different groups to know the best strategies for providing awareness and bridging the gaps on the wholesomeness of water for healthy global communities.

2.7 Public health risks from contaminated water and quality improvement measures

Consumption of contaminated drinking water exposes users to public health risks like waterborne diseases such as typhoid, cholera, infectious hepatitis, dysentery, diarrhoea, among others (WHO/UNICEF, 2017). The poor quality of water consumed by the households is therefore an important route for transmission of infectious diarrhoeal diseases, a primary component of water-related disease burden (Howard & Bartram, 2003). Eighty per cent (80%) of all diseases and over one-third of deaths in developing countries, with about 90% being children under the age of 5 years, are caused by consumption of contaminated water (Elimelech, 2006; Nath *et al*., 2006). Tanker water has been associated with outbreaks of diarrhoeal diseases (Awere & Anornu, 2016; Hutin *et al*., 2003; Kjellen & McGranahan, 2006). The data from the Central Regional Health Directorate of Ghana Health Service in Cape Coast

Metropolis in 2013 revealed that 88% of the diseases recorded were waterborne, with diarrhoeal diseases accounting for 70% of the reported cases (Awere & Anornu, 2016). However, Stoler *et al*. (2012) found reduced cases of diarrhoea in children relying on sachet-vended water.

When regulatory capacity is limited to control informal vendors, consumers should be empowered with information and treatment options to deal with water quality and public health risks and exert market pressure on suppliers to lift standards of service. However, this is a challenge in developing countries because, in most cases, regulations are not enforced, and most people relying on this vended water have no other alternatives. Vended water quality can be improved through cost-effective water treatments, improved storage facilities to prevent contamination, capacity building of vendors, as well as opportunities for vendors to access inexpensive credits for improved treatment technologies (Garrick *et al*., 2019). Moreover, contamination of water tankers can be minimized through regular disinfection of the tanks, followed by *E. coli* test at a reputable laboratory or the use of water kits available in the market. Immediate disinfection of the water tanker after being used to transport non-potable water, and ensuring that the hydrant used to fill the tanker is cleaned and well drained when not in use (MoH, 2008; Obeng *et al*., 2010; WHO, 2008). Tankers used for drinking water delivery should not be used for any other purpose.

2.8 Informal water supply quality monitoring

Monitoring of vended water quality is important in understanding the dynamics involved in water vending, trends, and the quality of water delivered by the vendors. Water quality monitoring provides an avenue for informal water vendors' regulation and improvement of public health among the consumers using vended water. The World Bank review on informal markets in the developing world has pointed out areas that should be prioritized in the monitoring of informal water vendors (Garrick *et al*., 2019). These include impacts on water quality, sustainability and the urban poor households; assessment of competitiveness in terms of profitability, prices and vendors organization; mapping the vendors' supply chain and their network from the source to storage and to consumers, and measurements of the participation in decision making by vendors and consumers and their potential drivers.

Consequently, there has been limited information on the impacts of water vending on the water quality. This is because of the costs related to water quality monitoring, which is key in understanding demand for ve nded water, its effects on public health and strategies for testing and treatment. There have been no clear systems and approaches put in place to monitor water provided by informal vendors due to their dynamic nature, coupled with lack of framework, especially on how to get a representative sample, frequency of monitoring or sampling and accuracy and reliability of data available (Garrick *et al*., 2019). According to New Zealand Drinking-water Standards, 2005 (revised 2008) (MoH, 2008), vended water samples should be tested for *E. coli* in a reputable laboratory, and water tankers must be washed thoroughly in cases where they carry non-potable water. In addition, *E. coli* analysis must be done at the source and discharge points to confirm the safety of the water. WHO (2017) guidelines for drinking water propose that the quality of water be within given guidelines to avert public health risks related to poor water quality.

2.9 Research priorities and policy interventions in informal water vending

Key priorities for research and policy in informal water vending include water quality, water quantity impacts, hygiene promotion, health risks, community perceptions, financing, pricing and demand, costs and market structures (Opryszko *et al*., 2009). Policy interventions to improve informal water vendors' performance can be done at three levels. That is by the water utilities, the water vendors, and consumers who are the end users of vended water. Interventions to regulate informal water markets need to pay close attention to incentives, oligopoly and informational asymmetry, especially in circumstances where regulatory capacity is weak and enforcement is limited. Public water utilities are mandated to provide water for the citizens, thus being responsible for regulating the water quality across the supply chain, both for public water supply systems and water vendors. Consequently, they ought to come up with strategies to reach populations not served by the piped system by ensuring vendors supply water of higher quality or invest to expand piped water systems. Interventions such as permitting and licensing enable the water vendors to operate legitimately and efficiently. This minimizes entry barriers to the market and fosters competition, coupled with the sustainability and regulation of water quality. In addition, consumers need to be empowered to have more market power and be responsible for the quality of water they buy (Garrick *et al*., 2019). Consumer campaigns that aim to increase consumer awareness of the water sources, water quality from vendors, prices and treatment options available at the point of use should be enhanced. This information will equip consumers to safeguard themselves from risks that may arise from poor-quality vended water.

From the above literature review, it is imperative to note that there exist water supply challenges in urban centres, which are occasioned, among other factors, by increasing population, global climate change and limited piped water supply. Thus, informal water vendors have thrived to bridge the water supply gap by providing water to peri-urban areas of towns where piped water supply is limited due to infrastructural challenges and finite water resources. Informal water vendors’ main purpose is to facilitate reallocation of water across competing needs and provide value-added services in terms of distribution, treatment or packaging. More research is required to assess the effectiveness of the existing institutional framework for monitoring and regulation of the operation of informal water vendors' services due to its important role in meeting water supply needs for populations not served by the water utility (Obeng *et al*., 2010).

Further, the focus should be on finding out if tankers’ activities (during transportation) between the source and the consumer present a pathway for water contamination. Despite the above, the quality of water supplied by tankers and other informal vendors has been under criticism, though not widely assessed. However, it is noted that some consumers use vended water as it is perceived to be of good quality. This study will contribute to the water quality research gap existing in explaining the role of water vendors in the supply of safe and affordable water beyond the capacity of public main water supply systems. It will focus on the impacts of water vending activities (during transportation) between the source and the consumer on the water quality supplied, and identify any pathways for water contamination along the water supply chain by analysing selected water quality parameters of the water supplied by vendors. Thus, the study will investigate the perception that vendors’ water quality deteriorates along the supply chain. It will also investigate the relationship between waterborne diseases in Lodwar town and water being used by the residents in light of faecal contamination of the water supply chains.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

Lodwar town, Turkana County, is located at 35.62°E and 3.14°N (Figure 2) at an altitude of 477 metres above sea level (Olango, 2019). A large part of Turkana County (80%) is categorized as arid or semi-arid. The temperatures range from 20 to 41 °C, with an average of 30.5 ºC (Turkana CIDP, 2018). The mean annual rainfall received in the area is about 217 mm (Olango, 2019; Opiyo *et al.*, 2014), and the annual potential evaporation is about 2,300 mm (Ferguson & Harbott, 1982) with prolonged dry periods in January, February and September. These harsh climatic conditions make the town's water scarce and stressed by default, thus becoming the best candidate for this study. The town population has been estimated to be around 82 970 according to 2019 Kenya Population and Housing Census (KPHC) preliminary report (KPHC, 2019). The town is rapidly growing as a result of inception of devolution attracting increased developments, commercial activities and population. Moreover, the demand for services including clean and safe water has also increased, triggering the emergence of water vendors to fill the water supply gap evident in the town.

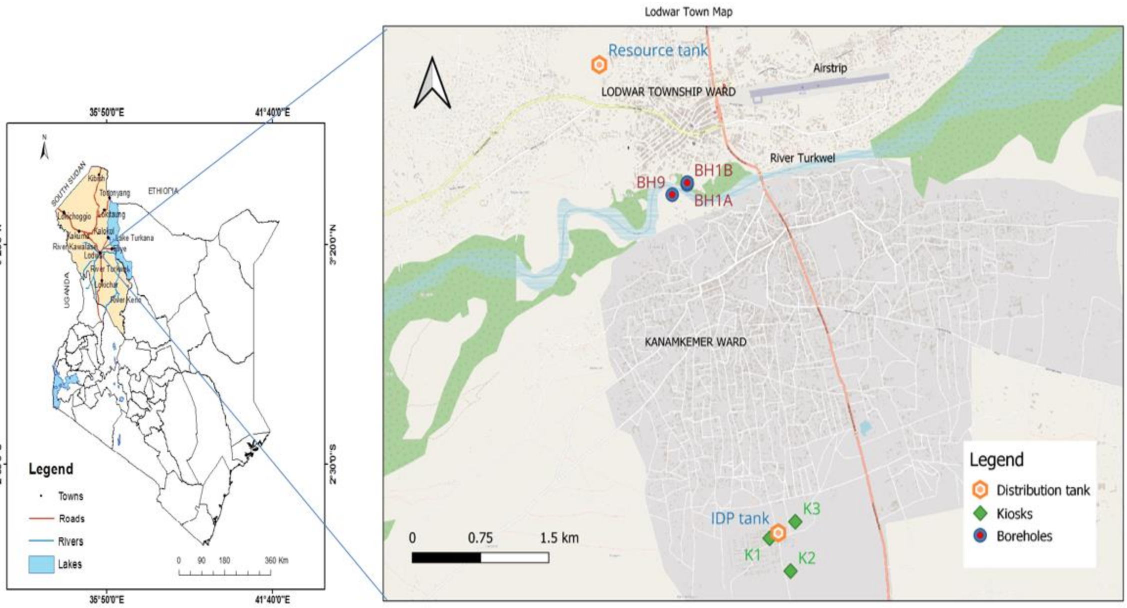

Figure 2: A map of Lodwar town showing water sources and kiosks

Source: Redrawn by the Author; Base map adapted from OpenStreetMap and contributors, CC-BY-SA

3.2 Research design

This study was implemented first by undertaking a vendors' census and recruitment, followed by sample collection and analysis. Water vendors' census was done by physically counting water tankers at the LOWASCO's main water source, commonly referred to as "*Moi Garden*" and the parking stages. Key information of tankers such as registration numbers, tanker type, owner, driver and capacity were tabulated using the form listed in Appendix I, the water tankers census tool. In addition, the number of kiosks and tankers was obtained from LOWASCO records since the company is in-charge of all operating water kiosks in Lodwar town and is responsible for registration of vendors. According to the vendors' census, 20 water tankers and 6 kiosks were identified to operate in Lodwar town and were all available for study. This was important in ascertaining the number of kiosks and tankers involved in water vending activities in Lodwar town.

Water vendors' recruitment entailed the identification of potential water vendors who were willing to participate in the study and allow the collection of water samples from their tanker or kiosk. This phase also included the introduction of the study and its objectives to both the drivers and tanker owners (in cases where the driver could not decide), so they agreed to participate in the study. It entailed assuring them of non-intent by the study to affect their business in any way through assurance of confidentiality of data collected. In cases where the vendors withdrew their water tanker/kiosk from participating in the study, a random sample was drawn from all the other water tankers' population without repeating the ones already involved in the sample size to replace the withdrawn tanker. Simple random sampling and stratified random sampling designs were used to determine the sample size for kiosks (water ATM) and water tankers.

In-situ parameters such as temperature, dissolved oxygen, EC and pH were determined at the field using universal meters; Model HACH HQ 40d (USA) for Electrical Conductivity (EC), pH and Temperature and HACH HQ 30d (USA) for Dissolved Oxygen (DO). Other parameters such as turbidity, salinity and TDS were determined at Egerton University, Limnology and Wetland Management (LWM) water quality laboratory using universal meters; HACH HQ 11d (USA) for turbidity and HACH HQ 40d (USA) for salinity and Total Dissolved Solids (TDS).

Samples for chemical parameters (nitrate, nitrite, ammonium, sulfate and total alkalinity) analyses were transported to Egerton University LWM water quality laboratory for analyses due to the availability of testing equipment. On the other hand, heavy metals (iron and lead), fluoride and chloride samples were transported to NAWASSCO's water quality testing Laboratory in Nakuru City for analyses, while microbiological (faecal coliforms densities) analyses were carried out at Turkana University Laboratory using Oxfam-DelAqua water testing kit.

A few random water samples were collected for analyses of fluoride, chloride, iron and lead metals across the supply chains during the sampling period. These analyses formed a baseline for further systematic analysis of the 4 parameters in future, since it was an expensive venture. The analysis of iron and lead was to understand if water tankers presented heavy metals risks to consumers given the fact that most vendors painted inside the tanks to avoid corrosion according to driver's interviews. Thus, heavy metals analyses became of interest in this study as lead is mainly present in the paints used to paint the tanks whereas, presence of iron could be responsible for corrosion of the metal tanks resulting to turbidity of the water transported. Therefore, water samples were collected from each sampling points (Figure 3) across the supply chains at the start of the sampling session. Further, collection of the second or third samples for the 4 parameters was dictated by microbiological and physical characteristics such as turbidity behaviour of the supply chain.

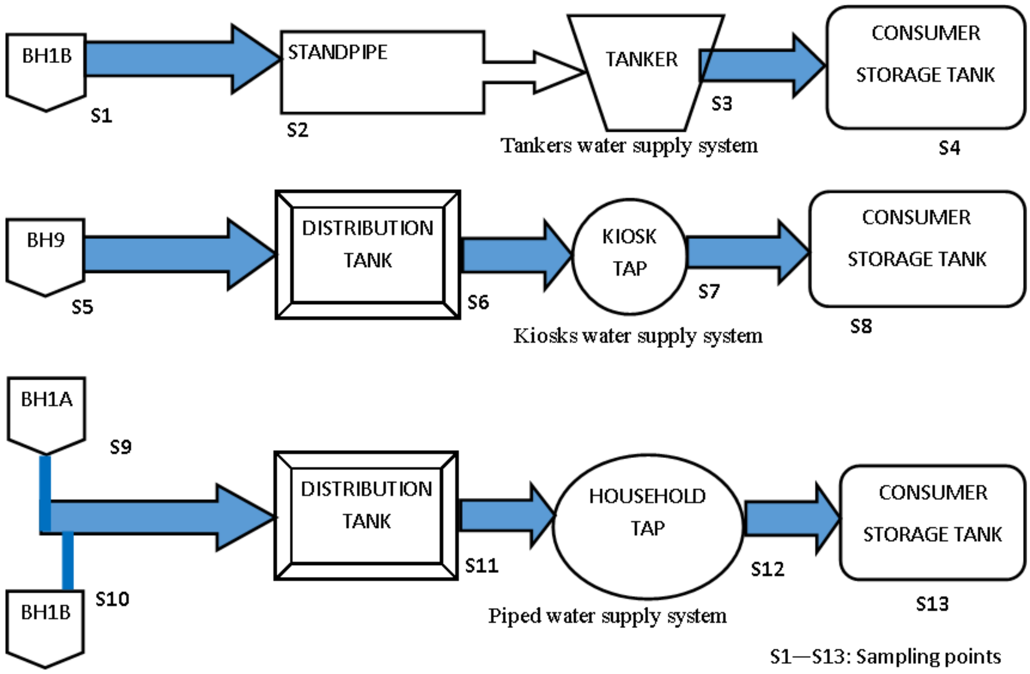

Figure 3: A schematic representation of Lodwar town water supply network

3.2.1 Sampling points and sample size

There were three water supply chains studied for physical, chemical and bacteriological water quality at different dates within a period of 7 weeks from May to July 2021. Each supply chain had several sampling points as shown in Figure 3 and explained in subsections below.

3.2.1.1 Tankers supply chain

Water tankers whose owners accepted to participate in the study formed the sample frame. A total of 20 water tankers were available for the study but only 15 were sampled over the study period. The 15 water tankers were randomly selected among those supplying water within Lodwar town and excluding those that transported water to far places outside the municipality. Each tanker was sampled only once over the study period from the source to the consumer endpoint. The tanker owners and drivers to accept to participate in the study contrary to the belief they had earlier developed that the study was meant to spy on their business. Therefore, the tankers supply chain had four sampling points (S1-S4) as shown in Figure 3; that included borehole BH 1B (to assess quality of water being pumped from the ground), the Stand pipe (to ascertain the quality of water at the filling station), tanker at the delivery (to check quality changes due to vendor activity and handling) and vendor's consumer storage tanks for each tanker (to assess the quality of water at the households' storage facility). It is worthwhile to note that most tankers' consumer households at the time of this study were not sampled because their storage tanks were empty since, they had ordered for the water after the tanks were completely emptied. Thus, from the fifteen (15) water tankers sampled in this study, only six (6) tankers' consumer household storage tanks were sampled. These were the ones who ordered for the water while the storage tanks had some water in them. Moreover, water supplied under the water tankers supply chain was not treated unless the consumer does so at their storage tanks.

3.2.1.2 Kiosks supply chain

The kiosks supply chain had four sampling points (S5 – S8); the source i.e., BH 9, the kiosk distribution tank, the kiosks outlet taps and the consumer endpoints storage (water transported using jerricans) (Figure 3). This was important in assessing the changes in water quality from the source to the consumer's endpoints. As well as to provide insights on the efficiency of pre-treatment efforts at the distribution tank between the water source and consumer by the water utility as assessed through free residual chlorine (FRC) tests. There were only six (6) operational kiosks (water ATMs) at the time of the study which supplied water to the internally displaced persons (IDPs) Camp, commonly known as "*Kanan*". Three (3) kiosks out of the six (6) were randomly selected for this study. Among the 3 kiosks selected for sampling, one was later discovered that it was supplied from a different water source (not S5 used by other 2 kiosks) which was not available for sampling hence the kiosk was discarded from the study. The remaining two kiosks were sampled on weekly basis for five (5) weeks excluding the third week where sampling couldn't be done due to power outage that cut water supply. The water kiosks were supplied by the same borehole (S5) through a plastic distribution tank (S6). The kiosks were fitted by water ATMs and the community members were provided with cards where they loaded tokens for them to access water. From the kiosks, the consumers used different means of transport to carry water filled containers to their households including motorbikes, wheelbarrows, handcarts, carrying on head and pushing of jerricans among others.

3.2.1.3 Piped water system supply chain

The piped water system had five sampling points (S9 – S13) as shown in Figure 3; the source (borehole 1A and 1B), distribution tank, household taps and consumer's storage facilities. The two boreholes discharged water to the same distribution tank commonly known as "*Resource*". The distribution tank served the western side of the town centre including California, Soweto, Central Business District (CBD), Kambi Mawe among other areas. This allowed for the assessment of piped water system quality as well as efficiency of pre-treatment at the distribution tank by the water utility. A total of twenty-two (22) taps both commercial and households were randomly selected from the areas supplied by the utility's main distribution tank at the resource centre. The piped water quality analysis allowed comparison with the vendors delivered water quality. The reason being these were households or facilities served by the same source where the tankers draw water they delivered to the people. However, the distribution tank received water from two boreholes (BH 1A and BH 1B) unlike vendors who used only borehole 1B as their source. Notably, the piped water supply chain had a water sources and distribution tank independent of the kiosks supply chain. The distribution tank of the piped water supply chain was made of concrete whereas kiosks supply chains used a plastic distribution tank.

3.2.2 Sampling procedures

Water samples were collected for analysis of physical-chemical, heavy metals and microbiological characteristics from different stages of the water supply chains. Outlet taps for boreholes, tankers and kiosks were wiped with a 70% alcohol-soaked tissue paper and then flushed before sample collection to avoid contamination of water samples as recommended by other researchers (Awere & Anornu, 2016). For sampling points without outlet taps, water samples were taken using a pre-cleaned bucket or jug then transferred to the plastic bottles. All water samples were collected and analysed in triplicates.

3.2.2.1 Physical-chemical and heavy metals characteristics

Temperature, Dissolved Oxygen, Conductivity, FRC and pH were measured *in-situ* at the sampling sites while Salinity, Total Dissolved Solids and Turbidity were measured after sampling at Egerton University LWM water quality laboratory together with nitrates, nitrites, ammonium, sulfates and alkalinity. Water samples for *in-situ* measurements (Temperature, pH, EC, DO, TDS, Turbidity and Salinity) along all the supply chains were collected in a small bucket thoroughly pre-washed to minimize contamination. The readings were taken in triplicates from the field using Hach Multimeters: HACH HQ 40d (USA), HACH HQ 11d (USA) and HACH HQ 30d (USA) respectively. The Hach Multimeters were calibrated prior to avoid any errors according to manufacturer's instructions. The meters electrodes were rinsed thoroughly with distilled water before being placed in the sample for readings to be taken.

The glassware and the sampling bottles used for physical-chemical parameters and heavy metals analyses were thoroughly pre-washed with acid water and then rinsed with distilled water before use for water samples collection. Water samples for chemical and heavy metals analysis were collected using 1L plastic bottles where 500mL were preserved unfiltered for heavy metals analyses and another 500mL were filtered immediately after collection for chemical parameters analyses. The samples were refrigerated at 4°C at Turkana University Laboratory after which they were transported in cool boxes for analyses at Egerton University, LWM water quality Laboratory (nutrients and alkalinity) and NAWASSCO water quality laboratory in Nakuru City. Selected samples of Chloride, Fluoride, Iron and Lead all totalling to thirty-nine (39) were taken for analysis at NAWASSCO laboratory in Nakuru.

3.2.2.2 Microbiological characteristics

All water sample bottles for microbiological analyses and the filtration apparatus and other apparatus contained in the Oxfam-DelAqua water testing kit were sterilized as per manufacturer's instructions before use to avoid recontamination. Microbiological water samples were collected using 500mL plastic bottles. The samples were then kept in cool boxes to minimize growth of microorganisms while in the field during the day. Later, the samples were immediately analysed after field work at Turkana University Laboratory, with the first and last sample done within 3 hours to limit resuscitation time of bacteria. After the last water sample of the day was collected, the samples were left for a minimum of 60 minutes before the DelAqua incubator was switched on to allow resuscitation of the Bacteria according to Oxfam - DelAqua Kit - User's manual (2012).

3.3 Laboratory analysis of water samples

3.3.1 Determination of different chemical parameters

Ammonium – Nitrogen (NH_4-N) was determined by colorimetric method using the reaction between Sodium salicylate solution and Hypochlorite solution (APHA, 2005). To 25 mL of filtered water sample, 2.5 mL of Sodium salicylate solution was added, followed immediately by addition of 2.5 mL of Hypochlorite solution. The sample was then placed in a water bath at a temperature of 25 °C in the dark for 90 minutes. Therefore, absorbance was determined at a wavelength of 655nm using GENESYS ^{TM} 10S UV-Vis spectrophotometer. Ammonium - Nitrogen concentrations was then calculated from linear equation generated from NH_4-N standard calibration curve (APHA, 2005).

Nitrate - Nitrogen (NO_3-N) was determined using sodium-salicylate method (APHA, 2005), where 20 mL of filtered water sample was put in an evaporation bottle. 1 mL of sodium salicylate solution freshly prepared was added to the sample. The bottles were put in the oven at 95 °C till dryness. The resulting residue were dissolved by adding 1 mL of conc. H_2SO_4 and the bottles swirled carefully while still warm. This was followed by addition of 40 mL distilled water and mixed carefully. Finally, 7 mL of potassium-sodium hydroxide-tartarate solution was added, mixed and the absorbance determined at a wavelength of 420 nm. The concentrations were then obtained from linear equation generated from NO_3-N standard curve of absorbance against concentration after absorbance readings were obtained using GENESYS ™ 10S UV-Vis spectrophotometer (APHA, 2005).

Nitrite - Nitrogen (NO_2-N) was determined by colorimetric method using the reaction between sulfanilamide and N-Naphthyl-(1)-ethylendiamine-dihydrochloride which gave an intense pink colour with presence of nitrite. Thus, to 25 mL of the filtered sample, 1 mL of Sulfanilamide solution was added. After 2 to 8 minutes, 1 mL of N-Naphthyl-(1)-ethylendiamine-dihydrochloride solution was added and gently mixed. The solution was left standing for about 10 minutes after which its absorbance was read from the spectrophotometer at a wavelength of 543 nm. The colour complex formed is normally stable for two hours. The Nitrite- Nitrogen concentrations was obtained from NO_2-N standard curve linear equation after absorbance readings are obtained using GENESYS ™ 10S UV-Vis spectrophotometer (APHA, 2005).

Fluoride was determined by SPADNS (Sulfanilic acid-azochromotrop. 1, 8-Dihydroxy-2-(4-sulfophenylazo) naphthalene-3, 6-disulfonic acid trisodium salt) colorimetric method using a spectrophotometer (APHA, 2005). In this method, 5mL of SPADNS reagent/solution and 5 mL of Zirconyl-acid reagent or 10mL acid-zirconyl-SPADNS reagent was added to 50 mL of the water sample then a portion of the mixture was put in a cuvette after which the absorbance was read using GENESYS ™ 10S UV-Vis spectrophotometer at a wavelength of 570 nm. The absorbance reading was converted to fluoride concentration by referencing the F^- standard curve linear equation (APHA, 2005).

Chloride (Cl^-) ions in water samples was determined by Argentometric method (also known as Mohr method) using silver nitrate as the titrant (APHA, 2005). 100mL of the water sample with a pH range of 7 to 10 was used in titration. Titration with standard $AgNO_3$ as a titrant was then done until a pink-yellow end point reached. The calculation for the determination of chloride ions was done as per Equation 2,

$$mg(Cl^{-})/L = \frac{(A-B) \times N \times 35\,450}{mL\ sample} \quad (1)$$

Where; A = mL titration for sample, B = mL titration for blank, N = Normality of $AgNO_3$ and mg NaCl/L = (mg Cl^-/L) X 1.65

Alkalinity was determined by acid titration methods (APHA, 2005), where titration of the water sample with 0.01N HCl was done using phenolphthalein and bromocresol green-methyl red indicator from Merck Indicators (APHA, 2005). 25 mL of filtered water sample was put in an Erlenmeyer flask. Five drops of phenolphthalein indicator were added. When the pink colour appeared, the sample was titrated against 0.01N HCl until the pink colour disappeared upon stirring to mark the endpoint for the carbonate alkalinity. Then three to four drops of mixed bromocresol green-methyl red (or methyl orange) were added to the water sample. Titration continued until a faint orange colour was formed, marking the endpoint. Total alkalinity was calculated using formula in Equation 2,

$$\text{Total alkalinity}\left(\frac{\text{meq}}{\text{L}}\right) = \frac{\text{volume of standard acid used (ml)} \times (\text{normality of acid} \times 10^3)}{\text{volume of the sample (mL)}}$$

(2)

Sulfate (SO_4^{2-}) were determined by Turbidimetric method (APHA, 2005) where 100mL of the water sample was placed into a 250mL Erlenmeyer flask. 20mL of the conditioning reagent/buffer solution was added while stirring. Then 20g of Barium Chloride ($BaCl_2$) was added while the solution was being stirred and timed for 1 minute. Immediately after the stirring, the solution was poured in the absorbance cell and turbidity (absorbance at a wavelength of 420nm) measured at 30 sec intervals for 4 minutes. Sulfate (SO_4^{2-}) ions concentration was calculated from linear equation generated from sulfate standard curve of absorbance against concentration after absorbance readings were obtained using GENESYS ™ 10S UV-Vis spectrophotometer (APHA, 2005).

Free Residual Chlorine (FRC) was analysed using Pool testers/comparator in the DelAqua water testing kit with standard colour scales indicating different concentrations of Free Residual Chorine (FRC) (Oxfam-DelAqua Kit - User's manual, 2012). The Pool tester/comparator cells were washed 3 times with the sample before its cells were filled with the water sample. One DPD (N, N-diethyl-p-phenylenediamine) No. 1 tablet was dropped at the right-hand cell (C12) of the pool tester. The comparator/pool tester was then sealed and inverted several times to allow the tablet to dissolve making sure air is not introduced. After the tablet had dissolved, free chlorine residual (mg/L) concentration was read holding the pool tester up against the light while matching the colour in the pool tester cells with the standard colour scales.

Total iron and lead were determined using Atomic Absorption Spectrophotometry (AAS) direct air - Acetylene method according to APHA (2005), by direct injection of the sample in the flame of an atomic absorption spectrophotometer. Thus, the water sample was digested through heating by adding 5 mL of concentrated HNO_3 in 150 mL of water sample in a hood. Boiling chips were added to help in boiling and minimize spatter. The sample was then brought to a slow boil and evaporated on a hot plate to the lowest volume possible (about 10 to 20 mL) before precipitation occurs. Heating continued and conc. HNO_3 was added until digestion was complete as shown by a light-coloured clear solution. The sample should not dry during digestion. The remaining digested sample was filtered and diluted in 100 mL flask to the mark and mixed thoroughly. Iron and lead were converted to the atomic state by thermal dissociation. The absorption of the atoms was measured in the beam path of the Flame Atomic Absorption Spectrophotometry (FAAS) at a wavelength of 248.3nm for both iron and lead. The concentrations were calculated using a calibration curve.

3.3.2 Determination of faecal coliforms

Microbiological analyses for faecal coliforms were done through the Membrane Filtration Technique (MFT) using the Oxfam - DelAqua water testing kit (Oxfam - DelAqua Kit - User's manual, 2012). Thus, 100mL of the water sample was filtered through a sterile membrane filter held on a membrane filtration unit. Any bacteria present in the water sample were caught in the gridded membrane filter (47mm Ø, pore size, 0.45µm). The membrane was then placed on an absorbent pad on a petri-dish, soaked in Lauryl sulphate broth (prepared before fieldwork). Lauryl sulphate broth is a selective growth medium which feeds coliform bacteria but inhibits the growth of any other bacteria caught in the filter. The membrane filter was then incubated at a temperature of 44°C (to allow growth of thermotolerant coliform bacteria only) in the DelAqua Kit incubator for 18 hours.

If the thermotolerant coliform bacteria are present in the water sample, it is expected they will grow and multiply during the incubation period to form colonies that can be seen with the naked eye. Thermotolerant coliform bacteria were then identified by their ability to produce a colour change (from pink/red to yellow) in Lauryl sulphate broth culture medium at 44°C (Plate 1). Yellow colonies were counted with the help of a colony counter or a hand magnifying lens available in the DelAqua Kit, and colony numbers were expressed as Colony Forming Units per 100mL (CFU/100mL) of the water sample. If no coliforms were observed, the coliform count was reported as <1 CFU/100mL (APHA, 2005). The procedure described above was selective and differential for *E. coli* and doesn't require further identification according to the standard DelAqua manual.

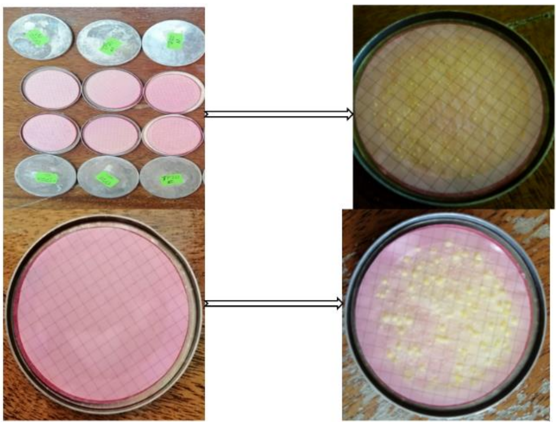

Plate 1: Faecal coliforms colour changes from pink/red to yellow after incubation for 24 hours

3.4 Consumers' perception of water safety in Lodwar town

A questionnaire (appendix IV) was administered across each supply chain to understand the perceptions of tanker owners, drivers and consumers on the safety of water they deliver or consume. Respondents who were educated filled the questionnaires while the researchers assisted those without education, where they were asked questions in the language they understood, and the researchers filled the responses in the questionnaire. Afterwards, the responses for each question were categorized and coded to make analysis easy and protect confidentiality.

To further check on the safety of water supplied in Lodwar town, all analysed water quality parameters values for all supply chains were compared against WHO Standards (2017) for drinking water quality to check for compliance. This was important in ascertaining the consumers' perceptions of water quality because public health risks could also occur as a result of other causes.

3.5 Determination of the prevalence of waterborne diseases

The retrospective assessment of waterborne and water-related diseases in Lodwar town from 2016 to 2020 was done with the help of outpatient secondary data that was obtained online from the Kenya District Health Information System (DHIS) aggregate, with permission. The DHIS is an open-source software for reporting, analysing and disseminating data for all health programs. The purpose of obtaining the data was to document all the routinely reported data in all public health facilities in Turkana County. The waterborne diseases outpatient data were accessed with the help of the Health Records Department at the Lodwar County and Referral Hospital. The data was downloaded in MS Excel format from the online system, filtered to pull out specific data for waterborne health conditions and finally transferred to SPSS for analysis.

The reported waterborne health conditions (diarrhoea, dysentery, cholera, amoebiasis, gastroenteritis, typhoid fever, hepatitis and bilharzia) case distributions were presented in percentage distribution per total reported cases annually over the period. Thus, if, for instance, typhoid fever was 80% in 2016, it means that typhoid fever cases constituted 80% of the total waterborne-related reported cases in 2016. The waterborne health conditions were reported in three categories (Wards, Municipality and County) according to the existing reporting procedure at Lodwar County and Referral Hospital (LCRH); Lodwar Township and Kanamkemer wards, Lodwar Municipality (Lodwar Township and Kanamkemer Wards combined) and Turkana County. In each of these categories, the data was reported in three sets; under 5 years (Form MOH 705A), above 5 years (Form MOH 705B) and a sum of all years; both <5 & > 5 years (forms MOH 705A plus form MOH 705B). The prevalence and trends of the above waterborne diseases were analysed for a period of five years from 2016 to 2020.

3.6 Data analysis

The data collected was recorded in the daily field reporting sheets (appendix II) and later transferred to/and processed using Microsoft Excel. Data analysis was done using Statistical Packages for Social Sciences (SPSS) at a significance level of $\alpha = 0.05$ since the water samples were above a threshold of 30, to qualify for any statistical analysis.

Normality test (using Shapiro–Wilk test) and homogeneity of variance test (using Levene's Test for Equality of Variances) were first done before the data were subjected to further analysis. This was to find out whether the data was normally distributed or not, and whether the distribution of variances of the data was equal or not. The two tests were followed by One-Way ANOVA test to determine any statistically significant differences between the means of values recorded at various sampling points across the water supply chains.

Hypotheses one and two were tested using One-Way ANOVA test which entailed testing for the significant differences in water quality parameters across all water supply chains. These included; (i) Tankers supply chain (Source [Borehole BH1B] → Standpipe (where tankers are refilled) → Tanker → Tanker's consumer storage tanks), (ii) Kiosks supply chain (Source [Borehole BH9] → Kiosks distribution tank → Kiosks → Kiosk's consumers storage tanks) and (iii) Piped water supply chain (Source [Borehole BH1A and BH1B] → Taps distribution tank → Taps → Tap's consumers storage tanks) - see Figure 3. Subsequently, post hoc tests (multiple means comparisons) using *Tukey HSD test* were performed to show which mean differences were significantly differing with one another among the sampling points across the supply chain. Pearson Correlation analysis test was used to test for the correlation between physico-chemical, heavy metals and microbiological parameters across the three supply chains.

The data for hypothesis three, secondary data of water borne diseases obtained online from the District Health Information System (DHIS) was presented in percentages and analysed by descriptive statistics to show the prevalence of waterborne diseases within the study period. The data failed the normality test and the homogeneity of variance tests making One-Way ANOVA analysis irrelevant to use. Therefore, an independent samples Kruskal-Wallis test was used to analyse the prevalence of waterborne health conditions across the 5-year study period.

The data collected using questionnaires across each water supply chain was analysed using mixed research approaches. These included coding and categorization, frequency distribution counts, content analysis of textual information using classification and tabulation, and thematic analysis techniques. This helped in categorizing responses and aligning them appropriately as anticipated in the study.

CHAPTER FOUR

RESULTS

4.1 Water quality dynamics across the water tankers supply chain

This section describes the *in-situ* water quality parameters like temperature, dissolved oxygen, conductivity, Free Residual Chlorine (FRC), salinity, total dissolved solids, turbidity and pH. It also includes nutrients (nitrates, nitrites and ammonium), chloride, fluoride, iron, lead and faecal coliform counts within the water tankers supply chain.

4.1.1 Temperature

The average temperature for the tankers' water supply chain over the sampling period ranged between 30.26 ± 0.35°C at the tankers, being the highest values recorded and 28.37 ± 0.32°C at the borehole, being the lowest values recorded (Table 2). Thus, the temperature increased from the borehole to the time the tankers delivered water to the consumer, with a slight decrease at the consumers' household storage tanks. There was a significant difference in the temperatures across the tankers' supply chain ($p=0.000$) (Table 2). Consequently, the post hoc test (Tukey HSD test at 0.05 significance level) revealed a significant difference in the means between borehole BH1B and Tankers ($p=0.011$). Additionally, the mean difference between the standpipe and tankers ($p=0.000$), and consumer storage tanks ($p=0.019$) was also significant (Table 2).

4.1.2 Turbidity

The distribution of turbidity across the water tanker supply chain over the sampling period increased from the lowest at the standpipe (2.04 ± 0.39 NTU) and highest at the consumer endpoint (8.01±2.04 NTU) (Table 2). The mean turbidity value at the consumers' storage tanks was above the WHO guideline for turbidity in drinking water of 5 NTU. However, the borehole recorded a similar low value at the standpipe. There was a significant difference in the distribution of the turbidity across the tankers' supply chain ($p=0.001$) at 0.05 significance level using the One-Way ANOVA test (Table 2). The mean differences between the sampling points were significantly different between standpipe and tanker ($p=0.040$), consumers–borehole ($p=0.016$), and consumers–standpipe ($p=0.001$) using the Tukey HSD test at 0.05 significance level (Table 2).

Table 2: Mean levels of physical parameters across the water tankers supply chain

Parameter	BH1B	Standpipe	Tanker	Consumer			
	Mean ±SD	**Mean ±SD**	**Mean ±SD**	**Mean ±SD**	**df**	**F value**	**P value**
Temperature (°C)	28.37 ± 0.64^{ac}	28.40 ± 0.51^{a}	30.26 ± 1.34^{b}	30.03 ± 0.78^{bc}	3, 31	8.993	**0.000**
Turbidity (NTU)	2.07±0.64 ^{a}	2.04±1.24 ^{a}	4.38±2.66 ^{ab}	8.01±2.04^{bc}	3, 27	7.072	**0.001**

Values are presented as mean ± Standard Deviation (SD), n =32.

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different, while the same superscripts are not significant, p< 0.05 using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-value is based on one-way ANOVA test at 0.05 significance level

4.1.3 Electrical conductivity (EC)

The distribution of electrical conductivity across the water tankers supply chain showed a slight increase from the borehole (271.33 ± 3.27 µS/cm) with a peak at the tankers (325.13 ± 36.18 µS/cm), at the point when water was being delivered to the consumer households (Table 3). The EC was slightly reduced at the consumer storage facilities (279.56 ± 7.44). However, the distribution of electrical conductivity across the supply chain was not significantly different (p=0.506) using One-Way ANOVA test at 0.05 significance level (Table 3).

4.1.4 Salinity

The Salinity average trends for the tankers' water supply chain over the sampling period indicate almost the same values at the boreholes, standpipe and consumer endpoints (0.05‰ [parts per a thousand]). There was a slight increase at the tankers when delivering water to the consumer households (0.06 ± 0.01‰) (Table 3). The distribution of salinity across the tankers' supply chain was not significantly different (p=0.571) using One-Way ANOVA test at 0.05 significance level (Table 3).

4.1.5 Dissolved oxygen

Dissolved oxygen values for tankers' water supply chain over the sampling period ranged between 7.27 ± 0.19 mg/L at the consumer storage tanks, the highest and lowest at the borehole (3.66 ± 0.49 mg/L) (Table 3). Thus, there was an increase in DO across the water tankers' supply chain. The dissolved oxygen levels across tankers supply chain were significantly different (p=0.000) at 0.05 significance level using one-way ANOVA test (Table 3). Moreover, the dissolved oxygen post hoc test (Tukey HSD Test) at 0.05 significance level revealed a significant mean difference between borehole BH1B and standpipe (p=0.031); tankers (p=0.000) and consumer storage tanks (p=0.000). As well, the means difference between standpipe and borehole 1B (p=0.031); tankers (p=0.000) and consumer storage tanks (p=0.000) were significantly different (Table 3). However, the mean difference between the tankers and consumer storage tanks was not significantly different (p=0.312) using Tukey HSD test at 0.05 significance level.

Table 3: Means of the *in-situ* chemical parameters across the water tankers supply chain

Parameter	BH1B	Standpipe	Tanker	Consumer			
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	df	F value	P value
DO (mg/L)	3.66 ± 0.98^{a}	4.94 ± 0.83^{b}	6.64 ± 0.69^{c}	7.27 ± 0.46^{cd}	3, 31	29.983	**0.000**
EC (µS/cm)	271.33 ± 6.54^{a}	274.63 ± 8.01^{a}	325.13 ± 140.13^{a}	279.56 ± 18.22^{a}	3, 31	0.795	0.506
Salinity (‰)	0.05^{a}	0.05^{a}	0.06 ± 0.03^{a}	0.05^{a}	3, 31	0.68	0.571
TDS (mg/L)	52.18 ± 0.94^{a}	53.68 ± 1.78^{a}	56.43 ± 14.70^{a}	53.96 ± 4.35^{a}	3, 30	0.275	0.843
pH (range)	$7.63\text{-}7.94^{a}$	$7.66\text{-}7.99^{a}$	$7.71\text{-}8.36^{ab}$	$7.78\text{-}8.65^{b}$	3, 31	4.108	**0.015**
FRC (mg/L)	0^{a}	0^{a}	0^{a}	0.19 ± 0.40^{b}			**0.002**

Values are presented as mean ± Standard Deviation (SD), n =32.

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different, while the same superscripts are not significant, $p < 0.05$ using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-value is based on one-way ANOVA test at 0.05 significance level, except for FRC, that based on Independent-Samples Kruskal-Wallis test.

4.1.6 Total dissolved solids (TDS)

The average distribution of total dissolved solids trends for the water tankers supply chain ranged between 52.18 ± 0.47mg/L at the borehole, being the lowest and 62.60 ± 7.18mg/L at the tankers, being the highest (Table 3). Thus, the TDS distribution increased from the borehole to the tankers during water delivery to the consumers, with a slight decrease at the consumer endpoint storage tanks. Nevertheless, the TDS across the water tankers supply chain was not significant (p=0.569) at 0.05 significance level using One-Way ANOVA test (Table 3).

4.1.7 Free residual chlorine (FRC)

Free Residual Chlorine (FRC) was not recorded at the borehole, standpipe and tankers when delivering water to the consumers. However, 0.19 ± 0.16 mg/L of FRC was recorded at the consumer household's storage tanks. This was recorded in three (3) out of six (6) consumers' storage tanks that were sampled during the study (Table 3). Nevertheless, the distribution of FRC across tankers supply chain was significantly different (p=0.002) using Independent-Samples Kruskal-Wallis test ($p<0.05$) (Table 3).

4.1.8 pH

The pH across the tankers water supply chain ranged between 7.63 at the borehole (lowest) and 8.65 at the consumer endpoints' storage tanks (highest) with a difference of 1.02 units (Table 3). There was a significant difference (p=0.015) in the distribution of pH across the water tankers supply chain, at a significance level of 0.05 using One-Way ANOVA test (Table 3). Consequently, there was a significant difference using Tukey HSD test at 0.05 significance level in the pH values recorded between borehole 1B and consumer storage tanks (p=0.038), and between the standpipe and the consumer storage tanks (p=0.018) respectively (Table 3).

4.1.9 Total alkalinity

The distribution of total alkalinity across the water tankers supply chain increased from the borehole to the tankers, with a slight decrease at the consumers' storage tanks. Borehole 1B recorded the lowest value (3.80 mEq/L) while tankers at the point of delivery (4.92 mEq/L) recorded the highest value over the study period, with a difference of 1.12 mEq/L (Table 4). However, the distribution of total alkalinity was not significantly different using One-Way ANOVA test (p=0.427) across the supply chain at 0.05 significance level (Table 4).

4.1.10 Nitrate – nitrogen

The distribution of nitrate across the water tankers' supply chain decreased from the borehole and the standpipe towards the consumers' households, although the values recorded at each sampling point differed slightly. The borehole (BH1B) and the standpipe both recorded a nitrate value of 0.058 mg/L, which was the highest, while the consumers endpoint recorded 0.055 mg/L, which was the lowest value, with a difference of 0.003 mg/L (Table 4). The nitrate concentrations across the tankers supply chain were not significant (p=0.659) using One-Way ANOVA test at 0.05 significance level (Table 4).

4.1.11 Nitrite – nitrogen

The distribution of nitrite across the water tankers' supply chain was the same, with an average value of 0.004 mg/L at all sampling points across the supply chain (Table 4). Thus, the nitrite levels across the supply chain could not be analysed as the values were the same.

4.1.12 Ammonium – nitrogen

The ammonium concentration across the water tankers' supply chain was the same, with an average value of 0.043 mg/L at all points, as shown in Table 4.

4.1.13 Sulfate

Sulfate levels across the water tankers supply chain ranged between 0.019 mg/L at the borehole (BH 1B), being the lowest, and 0.021 mg/L (highest) at both the tankers and consumer endpoints respectively (Table 4). Thus, sulfate levels increased slightly towards the consumers' endpoint. However, the distribution of sulfate across the water tankers supply chain was significantly different (p=0.001) at 0.05 significance level using One-Way ANOVA test (Table 4). Post hoc test between sampling points across the tankers supply chain using Tukey HSD test at 0.05 significance level revealed a significant difference in sulfate mean difference recorded at the borehole against other sampling points across the supply chain (Table 4).

4.1.14 Chloride

Chloride levels across the tankers supply chain ranged between 7.9 mg/L at the standpipe (lowest) and 17.5 ± 14.57 mg/L at the tankers (highest), as shown in Table 4. The chloride levels increased at the tankers but slightly decreased at the consumers' storage facilities. There was no significant difference (p=0.856) using One-Way ANOVA test at 0.05 significance level in the distribution of chloride levels across the water tankers supply chain (Table 4).

Table 4: Mean levels of various chemical parameters across the water tankers supply chain

Parameter	BH1B	Standpipe	Tanker	Consumer			
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	df	F value	P value
Total Alkalinity (mg/L)	3.80±0.35 [a]	4.23±0.68 [a]	4.92±1.86 [a]	4.23±0.67 [a]	3, 28	0.955	0.427
Nitrate (mg/L)	0.05782±0.005 [a]	0.05837±0.004 [a]	0.05590±0.007 [a]	0.05522±0.002 [a]	3, 28	0.54	0.659
Nitrite (mg/L)	0.00449±0.00001[a]	0.00442±0.00001a	0.00443±0.00001[a]	0.00443±0.00001[a]	3, 28	-	-
Ammonium (mg/L)	0.04259±0.00004[a]	0.04258±0.00002[a]	0.04259±0.00003[a]	0.04258±0.00004[a]	3, 28	-	-
Sulfate (mg/L)	0.0189±0.0001[a]	0.0204±0.0002[b]	0.0206±0.0001[b]	0.0207±0.0002[b]	3, 28	15.44	**0.001**
Chloride (mg/L)	12.9±4.24 [a]	7.9 [a]	17.5±14.57 [a]	12.4±3.54 [a]	3, 16	0.257	0.856
Fluoride (mg/L)	0.17±0.01 [a]	0.08 [a]	0.18±0.10 [a]	0.13±0.02 [a]	3, 16	0.495	0.691
Iron (mg/L)	<0.02 [a]	<0.02 [a]	<0.02 [a]	<0.02 [a]	-	-	-
Lead (mg/L)	<0.004 [a]	<0.004 [a]	<0.004	<0.004 [a]	-	-	-
Faecal Coliforms (CFUs/100mL)	6.40±1.41[a]	181.10±62.31[b]	242.05±163.56[b]	336.00±83.14[b]	3, 32	55.082	**0.001**

Values are presented as mean ± Standard Deviation (SD), n =29 (1-5), 17 (6-7), 32 (10).

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different, while the same superscripts are not significant, $p < 0.05$ using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-value is based on one-way ANOVA test at 0.05 significance level

4.1.15 Fluoride

The fluoride levels across the water tankers supply chain ranged from 0.08 mg/L at the standpipe (lowest) and 0.18 ± 0.10 mg/L at the tankers, being the highest, with a slight decrease at the household level (Table 4). There was no significant difference ($p=0.691$) in fluoride levels across the tankers' supply chain using One-Way ANOVA test at 0.05 significance (Table 5).

4.1.16 Iron and lead

Iron and Lead levels across the tankers supply chain were below detectable levels of 0.02 mg/L and 0.004 mg/L at all sampling points (Table 4).

4.1.17 Faecal coliform densities

The faecal coliform densities across water tankers' supply chain ranged between 336.00±83.14 CFUs/100mL at the tankers' (highest) during delivery and 6.4 ± 0.21 CFUs/100mL at the borehole (lowest) (Table 4). However, 181.10±62.31 CFUs/100mL faecal coliform densities were recorded at the standpipe from where the water tankers fetched the water. Thus, the mean values of the tanker supplies portray an increase in the faecal coliform densities across the supply chain from the borehole to the tankers' point of delivery. There was a slight decrease at the consumers' household storage facilities. Faecal coliform densities across the water tankers' supply chains were significantly different ($p=0.001$) using One-Way ANOVA test at 0.05 significance level (Table 4). Additionally, there was a significant difference in the mean difference of faecal coliforms recorded at the borehole and other sampling points ($p=0.001$) using Tukey HSD test at 0.05 significance level (Table 4).

4.1.18 The correlation among water quality parameters across the tanker supply chain

Pearson correlation analysis across the water tankers supply chain revealed significant correlation between faecal coliforms with DO, turbidity, nitrite, ammonium and sulfates at 0.05 significance level (Table 5). Temperature significantly correlated with nitrites, ammonium and chloride, while DO correlated significantly with faecal coliforms and turbidity. Electrical conductivity, salinity, TDS, chloride and total alkalinity correlated with pH, whereas fluoride significantly correlated with turbidity.

Table 5: Pearson correlation analysis of parameters across water tankers supply chain

	CFUs/100mL	Temperature (°C)	DO (mg/L)	EC (µS/cm)	FRC (mg/L)	Salinity (‰)	TDS (mg/L)	Turbidity (NTU)	pH	Nitrates (mg/L)	Nitrites (mg/L)	Ammonium (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Total Alkalinity
CFUs/100mL	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temperature (°C)	0.219	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dissolved Oxygen (mg/L)	**.371***	**.602****	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrical Conductivity (µS/cm)	0.292	**.575****	0.166	1	-	-	-	-	-	-	-	-	-	-	-	-
Free Residual Chlorine (mg/L)	0.292	0.024	0.212	0.028	1	-	-	-	-	-	-	-	-	-	-	-
Salinity (‰)	0.266	**.565****	0.165	**.993****	0.036	1	-	-	-	-	-	-	-	-	-	-
Total Dissolved Solids (mg/L)	0.280	**.554****	0.167	**.994****	0.040	**.995****	1	-	-	-	-	-	-	-	-	-
Turbidity (NTU)	**.337***	**.620****	**.406***	**.637****	0.277	**.606****	**.576****	1	-	-	-	-	-	-	-	-
pH	-0.048	**.512****	**.494****	**.355***	0.241	**.375***	**.396***	0.195	1	-	-	-	-	-	-	-
Nitrates (mg/L)	-0.181	0.053	-0.102	0.031	-0.065	0.067	0.028	0.070	-0.157	1	-	-	-	-	-	-
Nitrites (mg/L)	**-.352***	**-.360***	**-.686****	-0.109	-0.078	-0.106	-0.112	-0.242	-0.243	0.082	1	-	-	-	-	-
Ammonium (mg/L)	**.352***	**.360***	**.686****	0.109	0.078	0.106	0.112	0.242	0.243	-0.082	**-1.000****	1	-	-	-	-
Chloride (mg/L)	0.347	**.550***	0.181	**.939****	-0.113	**.924****	**.935****	**.663****	**.463***	0.047	-0.113	0.113	1	-	-	-
Fluoride (mg/L)	0.237	**.587****	0.051	**.957****	-0.139	**.962****	**.966****	**.572***	**.587****	0.022	0.030	-0.030	**.933****	1	-	-
Sulfate (mg/L)	**.400***	0.336	**.633****	0.220	0.139	0.245	0.238	0.284	0.322	-0.007	**-.771****	**.771****	0.258	0.241	1	-
Total Alkalinity (mEq/L)	0.248	**.564****	0.193	**.925****	0.113	**.933****	**.924****	**.594****	**.396***	-0.066	-0.193	0.193	**.848****	**.931****	0.289	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.2 Water quality parameters trends across the kiosks supply chain

4.2.1 Temperature

The mean water temperature recorded across kiosks' supply chains ranged from 32.46 °C at the consumers' storage facilities (highest) to 28.53 °C at the source (borehole), the lowest. Thus, an increase in the water temperature was recorded across the supply chain from the source to the consumer endpoint, as shown in Table 6. There was a significant difference ($p = 0.027$) in water temperature across kiosks' supply chains using One-Way ANOVA test at 0.05 significance level (Table 6). Further, there was a significant difference in the water temperature means recorded between the source and the consumers ($p=0.025$) using Turkey HSD test at 0.05 (Table 6).

4.2.2 Turbidity

The turbidity levels across the kiosks' supply chain decreased from the source to the kiosks, with an increase at the consumer households' endpoints. Therefore, the lowest value recorded across the supply chain was at the kiosks (3.05 NTU), with the highest at the consumers (5.74 NTU), as shown in Table 6. The turbidity recorded across the supply chain was not significantly different ($p=0.176$) using One-Way ANOVA test at 0.05 significance level (Table 6).

Table 6: Mean levels of physical parameters across the kiosks' supply chain

Parameter	BH9	Distribution tank	Kiosk	Consumer			
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	df	F value	P value
Temperature (°C)	28.61 ± 0.32^{a}	32.34 ± 2.06^{ab}	31.88 ± 0.60^{ab}	32.46 ± 2.95^{b}	3, 18	3.879	**0.027**
Turbidity (NTU)	4.09 ± 2.32^{a}	4.08 ± 2.50^{a}	3.05 ± 1.99^{a}	5.74 ± 2.06^{a}	3, 18	1.841	0.176

Values are presented as mean ± Standard Deviation (SD), n =19.

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different, while the same superscripts are not significant, $p < 0.05$ using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-value is based on one-way ANOVA test at 0.05 significance level

4.2.3 Electrical conductivity (EC)

Electrical conductivity increased across the kiosks' supply chain from the borehole towards the consumer endpoints. The borehole recorded the lowest EC values (301.67 μS/cm) while consumer endpoints recorded the highest (307.05 μS/cm) as shown in Table 7. However, there was no significant difference (p=0.417) in the distribution of EC across the kiosks' supply chain using One-Way ANOVA test at 0.05 significance level (Table 7).

4.2.4 Salinity

Salinity concentration across the kiosks' supply chain was almost the same in all sampling points, with very slight differences. Salinity ranged between 0.056‰ at the consumers, being the lowest value recorded, to 0.06‰ at the distribution tank, with the kiosks being the highest (Table 7). However, there were no significant differences (p=0.155) in the distribution of salinity across the kiosks' supply chain using One-Way ANOVA test at the 0.05 significance level (Table 7).

4.2.5 Dissolved oxygen (DO)

Dissolved oxygen concentrations across the kiosks supply chain were highest at the consumers (6.57 mg/L) and lowest at the source (4.48mg/L). The dissolved oxygen increased from the source towards the consumers' endpoint with a slight reduction at the kiosks (Table 7). There was a significant difference (p=0.005) using One-Way ANOVA test in the distribution of dissolved oxygen across the kiosks' supply chain at 0.05 significance level (Table 7). Consequently, the mean difference between the source and the consumers was significant (p=0.003) using Tukey HSD test at 0.05 significance level (Table 7).

4.2.6 Total dissolved solids (TDS)

There was a slight increase in Total Dissolved Solids (TDS) levels from the source to the kiosks, with a slight decrease at the consumers' household endpoints. The TDS values ranged between 58.59 mg/L at the kiosks (highest) and 55.89mg/L at the consumers, being the lowest (Table 7). However, there was no significant difference (p=0.589) in the distribution of TDS across the kiosks' supply chain using One-Way ANOVA test at 0.05 significance level (Table 7).

4.2.7 pH

The pH values recorded across the kiosks' supply chain ranged from 7.58 at the borehole (lowest) to 8.14 at the consumer households (highest), with a difference of 0.56 units across the supply chain (Table 7). The pH was significantly different (p=0.032) across the kiosks' supply chain using One-Way ANOVA test at 0.05 significant level (Table 7).

Table 7: Mean levels of *in-situ* chemical parameters across the kiosks' water supply chain

Parameter	BH9	Distribution tank	Kiosk	Consumer			
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	df	F value	P value
DO (mg/L)	4.48±0.87^{a}	5.72±1.31^{ab}	5.44±0.69^{ab}	6.57±0.62^{b}	3, 17	6.052	**0.005**
EC (µS/cm)	301.67±3.74	303.58±3.30	304.43±3.21^{a}	307.05±7.63^{a}	3, 18	0.996	0.417
Salinity (‰)	0.058±0.005^{a}	0.060^{a}	0.060^{a}	0.056±0.005^{a}	3, 18	1.968	0.156
TDS (mg/L)	57.42±4.07^{a}	57.83±1.82^{a}	58.59±1.85^{a}	55.89±5.19^{a}	3, 18	0.657	0.589
pH (range)	7.58-7.95^{a}	7.81-8.07^{a}	7.63-7.95^{a}	7.82-8.14^{a}	3, 18	3.674	**0.032**
FRC (mg/L)	0^{a}	0^{a}	0^{a}	0^{a}	-	-	-

Values are presented as mean ± Standard Deviation (SD), n =18 (1), 19 (2-4).

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different while same superscripts are not significant, p< 0.05 using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-value is based on one-way ANOVA test at 0.05 significance level

4.2.8 Free residual chlorine (FRC)

Free Residual Chlorine (FRC) was not detected at any of the sampling points across the kiosks' supply chain throughout the study period.

4.2.9 Total alkalinity

Total alkalinity across the water kiosks supply chain increased from the borehole towards the consumers' households. Borehole 1B recorded the lowest value (3.88 mEq/L) while the consumers' storage tanks (4.92 mEq/L) recorded the highest value, with a difference of 1.11 mEq/L (Table 8). The distribution of total alkalinity across the kiosks' supply chain was not significantly different (p=0.131) using One-Way ANOVA test at 0.05 significance level, as shown in Table 8.

4.2.10 Chloride

Chloride concentrations across the kiosks' supply chain decreased from the source towards the consumers over the sampling period. The highest value of 21.9 mg/L was recorded at the source (borehole), while the lowest value of 7.40 ± 7.78 mg/L was recorded at the consumers' endpoint (Table 8). Nevertheless, chloride distribution across the kiosks' supply chain was not significantly different (p=0.419) using One-Way ANOVA test at 0.05 significance level (Table 8).

4.2.11 Nitrate – nitrogen

The distribution of nitrate across the kiosks' supply chain increased from the source to the kiosks through the distribution tank, with a slight decrease at the consumers' households. The source (borehole) and the distribution tank both recorded the lowest values (0.052 mg/L each), with the highest value at the kiosk (0.056 mg/L), giving a difference of 0.004 mg/L (Table 8). There was a significant difference (p=0.020) in the distribution of nitrate across kiosks' supply chains using One-Way ANOVA test at 0.05 significance level (Table 8). Consequently, the nitrate means difference between the source and the kiosks was significantly different (p=0.030) across the supply chain using Tukey HSD test at 0.05 significance level (Table 8).

4.2.12 Nitrite – nitrogen

The nitrite levels across the kiosks' supply chain were almost similar at all the sampling points, recording a value of 0.004 mg/L over the period of study (Table 8).

Table 8: Mean levels of various chemical parameters across the kiosks' supply chain

Parameter	BH9	Distribution tank	Kiosk	Consumer			
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	df	F value	P value
Total Alkalinity (mg/L)	3.88±0.70 [a]	4.70±0.73 [a]	4.76±0.41 [a]	4.99±0.93 [a]	3, 18	2.135	0.131
Nitrate (mg/L)	0.052±0.001[a]	0.052±0.002[a]	0.056±0.002[b]	0.054±0.002[b]	3, 18	4.195	**0.061**
Nitrite (mg/L)	0.00449[a]	0.00448[a]	0.00446[a]	0.00447[a]	-	-	-
Ammonium (mg/L)	0.04261 [a]	0.04260 [a]	0.04256 [a]	0.04255 [a]	3, 18	0.024	0.995
Sulfate (mg/L)	0.0191 [a]	0.0194±0.001 [a]	0.0190 [a]	0.0189 [a]	3, 18	2.883	0.064
Chloride (mg/L)	21.9 [a]	13.9 [a]	10.40±2.12 [a]	7.40±7.78 [a]	3, 2	1.528	0.419
Fluoride (mg/L)	0.22 [a]	0.19 [a]	0.15±0.05 [a]	0.22±0.02 [a]	3, 2	1.588	0.409
Faecal Coliforms (0 CFUs/100mL)	2.83±2.02 [a]	20.50±15.59 [a]	27.83±12.66[a]	236.38±115.77[b]	3, 20	9.814	**0.003**
Iron (mg/L)	<0.02 [a]	<0.02 [a]	<0.02 [a]	<0.02 [a]	-	-	-
Lead (mg/L)	<0.004 [a]	<0.004 [a]	<0.004 [a]	<0.004 [a]	-	-	-

Values are presented as mean ± Standard Deviation (SD), n =19 (1-5), 3 (6-7), 21 (8).

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different, while the same superscripts are not significant, $p < 0.05$ using Tukey HSD test.

Bolded values: indicate significantly different p-values. P-value is based on one-way ANOVA test at 0.05 significance level

4.2.13 Ammonium – nitrogen

The mean ammonium value of 0.043 mg/L was recorded across the kiosks' supply chain. Thus, there were no significant differences ($p=0.995$) in the concentrations of ammonium across the kiosks' supply chains using Tukey HSD test at 0.05 significance level (Table 8).

4.2.14 Sulfate

The sulfate concentration across the kiosks' supply chain slightly increased from the source to the distribution tank, after which it decreased towards the consumers' households. However, the difference was minimal (0.0005 mg/L) between the lowest and highest values (Table 8). The consumers and the distribution tank recorded the lowest and the highest values respectively. There was no significant difference ($p=0.064$) in the distribution of sulfate across the kiosks supply chain using One-Way ANOVA test at 0.05 significance level (Table 8).

4.2.15 Fluoride

Fluoride levels across the kiosks supply chain over the sampling period decreased from the source to the kiosks, with an increase at the consumer endpoints. The highest value of 0.22 mg/L was recorded at the source and the consumers. The lowest value of 0.15 mg/L was recorded at the kiosks (Table 8). The concentration of fluoride across the kiosks' supply chain was not significantly different ($p=0.409$) using One-Way ANOVA test at 0.05 significance level (Table 8).

4.2.16 Iron and lead

Iron and Lead levels across the kiosks supply chain were below detectable levels of 0.02 mg/L and 0.004 mg/L at all sampling points over the study period (Table 8).

4.2.17 Faecal coliform densities

Faecal coliform densities across the kiosks' supply chain ranged between 236.38±115.77 CFUs/100mL at the consumers (highest) and 2.83±2.02 CFUs/100mL at the borehole (lowest) (Table 8). The faecal coliform densities increased significantly ($p=0.003$) across the supply chain using One-Way ANOVA test at 0.05 significance level (Table 8).

4.2.18 Correlation among water quality characteristics across the kiosks' supply chain

Pearson correlation analysis of all the parameters across the kiosks' supply chain indicated a significant correlation between faecal coliforms with DO and nitrates at 0.05 significance level. The pH correlated significantly with DO and ammonium, as shown in Table 9 below.

Table 9: Pearson correlation analysis of parameters across the kiosks' supply chain

	CFU per 100ml	Temperature (°C)	DO (mg/L)	EC (µS/cm)	Salinity (‰)	TDS (mg/L)	Turbidity (NTU)	FFRC (mg/L)	pH	Nitrates (mg/L)	Nitrites (mg/L)	Ammonium (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Total Alkalinity (mEq/L)
CFU per 100ml	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temperature (°C)	0.024	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dissolved Oxygen (mg/L)	**.493***	0.201	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Electrical Conductivity (µS/cm)	0.026	**.753****	0.078	1	-	-	-	-	-	-	-	-	-	-	-	-
Salinity (‰)	0.086	0.085	-0.267	0.149	1	-	-	-	-	-	-	-	-	-	-	-
Total Dissolved Solids (mg/L)	-0.086	0.247	-0.311	0.412	.713**	1	-	-	-	-	-	-	-	-	-	-
Turbidity (NTU)	0.396	-0.139	0.371	-0.100	-0.385	**-.689****	1	-	-	-	-	-	-	-	-	-
Free Residual Chlorine (mg/L)	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	-	-	-	-	-	-	-	-
pH	0.015	0.237	**.539***	0.298	-0.060	0.148	-0.092	.^{b}	1	-	-	-	-	-	-	-
Nitrates (mg/L)	**.514***	-0.082	0.315	-0.048	0.062	0.072	-0.013	.^{b}	-0.121	1	-	-	-	-	-	-
Nitrites (mg/L)	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	.^{b}	-	-	-	-	-
Ammonium (mg/L)	0.384	-0.178	-0.077	-0.044	0.029	-0.282	**.562****	.^{b}	**-.494***	0.076	.^{b}	1	-	-	-	-
Chloride (mg/L)	-0.561	-0.512	-0.596	-0.722	-0.075	0.027	-0.792	.^{b}	-0.465	-0.626	.^{b}	0.000	1	-	-	-
Fluoride (mg/L)	-0.211	-0.370	0.386	0.398	-0.165	-0.176	0.227	.^{b}	0.406	-0.482	.^{b}	0.000	0.010	1	-	-
Sulfate (mg/L)	0.047	-0.158	0.154	-0.248	0.187	0.081	-0.075	.^{b}	0.255	-0.237	.^{b}	-0.042	0.150	-0.024	1	-
Total Alkalinity (mEq/L)	-0.190	0.412	0.239	0.315	0.244	0.342	-0.225	.^{b}	0.265	0.095	.^{b}	-0.351	-0.267	-0.559	-0.178	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.3 Water quality characteristics across the piped water supply chain

4.3.1 Temperature

The distribution of temperature across the piped water supply chain over the sampling period was highest at the taps, ranging from 31.99°C ± 1.35 to 28.51°C ± 0.23 at borehole 1A (lowest). Thus, the temperature increased from the boreholes (average, 30.08°C) to the taps with a slight decrease at the consumer households' endpoints (Table 10). There was a significant difference ($p=0.000$) in the distribution of temperature across the piped water supply chain using One-Way ANOVA test at 0.05 significance level (Table 10). The temperature means differed between Borehole 1A and Borehole 1B ($p=0.009$), tap ($p=0.000$), and consumer endpoints ($p=0.016$) were significantly different using Tukey HSD test at 0.05 significance level (Table 10).

4.3.2 Turbidity

Turbidity across the piped tap water supply chain over the sampling period ranged from 3.21 ± 3.46 NTU (highest) at the consumer endpoints to 1.85 ± 0.73 NTU (lowest) at borehole 1B, as shown in Table 10. Though turbidity values recorded in every sampling site relatively varied, there were no significant differences ($p=0.881$) in concentrations across the supply chain using One-Way ANOVA test at 0.05 significance level (Table 10).

Table 10: Mean levels of physical parameters across the piped water supply chain

Parameter	BH1A	BH1B	Distribution tank	Tap	Consumer			
	Mean ±SD	**Mean ±SD**	**Mean ±SD**	**Mean ±SD**	**Mean ±SD**	**df**	**F value**	**P value**
Temperature (°C)	28.51±0.23 ^{a}	31.65±2.90 ^{bcd}	30.73±0.23 ^{acd}	31.99±1.35 ^{bcd}	30.95±1.20 ^{bcd}	4, 45	6.613	**0.000**
Turbidity (NTU)	2.91±3.04 ^{a}	1.85±0.73 ^{a}	2.71±3.61 ^{a}	2.37±2.42 ^{a}	3.21±3.46 ^{a}	4, 45	0.292	0.881

Note: Values are presented as mean ± Standard Deviation (SD), n =46.

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different, while the same superscripts are not significant, $p < 0.05$ using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-value is based on one-way ANOVA test at 0.05 significance level

4.3.3 Electrical conductivity (EC)

Electrical conductivity ranged from 266.47 ± 6.88 µS/cm at borehole 1A (lowest) to 272.13 ± 5.94 µS/cm at borehole 1B, being the highest (Table 11). However, the distribution of electrical conductivity was not significantly different (p=0.796) across the piped water supply chain using One-Way ANOVA test at 0.05 significance level (Table 11).

4.3.4 Salinity

The salinity concentration across the piped water supply chain was relatively similar in all the sampling sites, with a difference of 0.002‰. Borehole 1A, borehole 1B, distribution tank and taps all recorded a value of 0.050‰, with the consumer endpoints recording 0.052‰ (Table 11). There was no significant difference (p=0.214) in the distribution of salinity across the piped water supply chain at 0.05 level using One-Way ANOVA test (Table 11).

4.3.5 Dissolved oxygen (DO)

The dissolved oxygen trends increased from the boreholes (average: 4.49 mg/L) towards the consumer endpoints over the study period. Borehole 1B recorded the lowest value of 3.78 ± 0.90 mg/L, while the highest value of 7.50 ± 0.48 mg/L was recorded at the consumer endpoints (Table 11). The means of dissolved oxygen were significantly different (p=0.000) across the piped water supply chain using One-Way ANOVA test at 0.05 significance level (Table 11). On the other hand, there were significant differences in DO means between borehole 1A and borehole 1B (p=0.026), distribution tank (p=0.031), tap (p=0.000) and consumer endpoint (p=0.000) using Tukey HSD test at 0.05 significance level. Further, the mean differences between borehole 1B and distribution tank (p=0.000), tap (p=0.000) and consumer endpoint (p=0.000) were significantly different using Tukey HSD test at 0.05 significance level (Table 11).

4.3.6 Total dissolved solids (TDS)

The highest values of TDS across the piped water supply chain were recorded at borehole 1B (52.35 ± 0.91 mg/L), with the lowest recorded at borehole 1A (52.35 ± 1.18 mg/L). The distribution tank, taps and consumer endpoints recorded 51.75 ± 1.46 mg/L, 51.96 ± 1.32 mg/L and 51.85 ± 2.82 mg/L respectively (Table 11). However, there were no significant differences in the distribution of TDS across the supply chain (p=0.812) using One-Way ANOVA test at 0.05 significance level (Table 11).

Table 11: Mean levels of *In-situ* chemical parameters across the piped water supply chain

Parameter	**BH1A**	**BH1B**	**Distribution tank**	**Tap**	**Consumer**			
	Mean ±SD	**Mean ±SD**	**Mean ±SD**	**Mean ±SD**	**Mean ±SD**	**df**	**F value**	**P value**
DO (mg/L)	5.20±0.59 ^{a}	3.78±0.90 ^{b}	6.58±0.29 ^{c}	7.16±0.86 ^{d}	7.50±0.48 ^{e}	4, 45	32.068	**0.000**
EC (µS/cm)	266.47±6.88 ^{a}	272.13±5.94 ^{a}	266.73±5.86 ^{a}	268.92±7.84 ^{a}	268.77±9.38 ^{a}	4, 45	0.417	0.796
Salinity (‰)	0.050 ^{a}	0.050 ^{a}	0.050 ^{a}	0.050 ^{a}	0.052 ^{a}	4, 45	1.514	0.214
TDS (mg/L)	51.00±1.18 ^{a}	52.35±0.91 ^{a}	51.75±1.46 ^{a}	51.96±1.32 ^{a}	51.85±2.82 ^{a}	4, 45	0.394	0.812
pH (range)	7.72-8.06 ^{ac}	7.63-7.94 ^{ab}	7.68-8.07 ^{ab}	7.70-8.29 ^{abc}	7.93-8.38 ^{c}	4, 45	5.101	**0.002**
FRC (mg/L)	0 ^{a}	0 ^{a}	0 ^{a}	0.07±0.28 ^{a}	0 ^{a}	4, 45	0.441	0.779

Values are presented as mean ± Standard Deviation (SD), n =46.

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different while same superscripts are not significant, $p< 0.05$ using Tukey HSD test.

Bolded values: indicate significantly different p-values.

P-value is based on one-way ANOVA test at 0.05 significance level

4.3.7 pH

The pH values across the piped water supply chain increased from the boreholes towards the consumers. Borehole 1B recorded the lowest value of 7.63, while consumers recorded the highest value of 8.38, with a difference of 0.75 units (Table 11). Thus, the pH values across the piped water supply chain were significantly different (p=0.002) at 0.05 significance level using One-Way ANOVA test (Table 11). The pH levels recorded between the consumer endpoints and borehole 1B (p=0.002) and distribution tank (p=0.044) were significantly different using Tukey HSD test at 0.05 significance level (Table 11).

4.3.8 Free residual chlorine (FRC)

Free residual chlorine was only detected at the taps (0.07 ± 0.28 mg/L) across the supply chain over the sampling period. However, the distribution of FRC across the supply chain was not significantly different (p=0.779) at 0.05 level using One-Way ANOVA test (Table 11).

4.3.9 Total alkalinity

Total alkalinity concentration across the piped water supply chain slightly decreased at the distribution tank (3.58 mEq/L) from the boreholes (Average: 3.82 mEq/L). Consequently, there was an increase in the concentration at the tap level (4.51 mEq/L) and a slight decrease at the consumer endpoints (4.34 mEq/L), as shown in Table 12. Therefore, the distribution tank recorded the lowest value while the taps recorded the highest value over the study period, with a difference of 0.93 mEq/L. Total alkalinity concentration was significantly different (p=0.001) across the piped water supply chain at 0.05 significance level using One-Way ANOVA test (Table 12). Additionally, the post hoc test analysis for the mean difference across the supply chain indicated a significant difference between the taps and borehole 1A (p=0.048) and distribution tank (p=0.005) using Tukey HSD test at 0.05 significance level (Table 12).

4.3.10 Chloride

Chloride concentration across the piped water supply chain over the study period ranged from 7.40 ± 4.95 mg/L at the consumers' level (lowest) to the borehole 1B (12.90 ± 4.24 mg/L) and taps (12.90 ± 1.58 mg/L), both recording the highest value (Table 12). However, the chloride levels dropped at the distribution tank but increased at the taps, with a decrease at the consumers. The chloride levels across the piped water supply chain were not significantly different (p=0.183) at 0.05 significance level using One-Way ANOVA test (Table 12).

Table 12: Mean levels of various chemical parameters across the piped water supply chain

Parameter	BH1A	BH1B	Distribution tank	Tap	Consumer			
	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	Mean ±SD	df	F value	P value
Total Alkalinity (mg/L)	3.79±0.40 [a]	3.85±0.31 [ab]	3.58±0.35 [a]	4.51±0.55 [b]	4.34±0.58 [ab]	4, 44	5.478	**0.001**
Nitrate (mg/L)	0.068±0.012	0.057±0.004	0.065±0.004	0.066±0.006	0.067±0.01	4, 45	1.832	0.139
Nitrite (mg/L)	0.00450 [a]	0.00449 [a]	0.00447[a]	0.00443[b]	0.00444[b]	4, 45	-	**-**
Ammonium (mg/L)	0.043 [a]	0.043 [a]	0.043 [a]	0.043 [a]	0.043 [a]	4, 45	0	1.000
Sulfate (mg/L)	0.0189±0.0001[a]	0.0189±0.0001[a]	0.0192±0.0002[a]	0.0190±0.000[a]	0.0190±0.000[a]	4, 45	0	1.000
Chloride (mg/L)	10.90±1.41 [a]	12.90±4.24 [a]	9.40±0.71 [a]	12.90±1.58 [a]	7.40±4.95 [a]	4, 8	2.028	0.183
Fluoride (mg/L)	0.17±0.02 [a]	0.17±0.01 [a]	0.18±0.02 [a]	0.17±0.02 [a]	0.13±0.04 [a]	4, 8	1.787	0.225
Faecal Coliforms (0 CFUs/100mL)	6.17±2.02[a]	5.50.90±2.52 [a]	14.33±7.78 [a]	9.61±3.84[a]	74.80±19.79 [b]	4, 20	8.805	**0.001**
Iron (mg/L)	<0.02 [a]	<0.02 [a]	<0.02 [a]	<0.02 [a]	<0.02 [a]	-	-	-
Lead (mg/L)	<0.004 [a]	<0.004 [a]	<0.004 [a]	<0.004 [a]	<0.004 [a]	-	-	-

Values are presented as mean ± Standard Deviation (SD), n =45 (1), 46 (2-5), 9 (6-7), 81 (8).

Superscript letters across the rows represent post hoc test analysis.

Different superscript letters in a row are significantly different, while the same superscripts are not significant, $p < 0.05$ using Tukey HSD test.

Bolded values: indicate significantly different p-values. P-value is based on one-way ANOVA test at 0.05 significance level

4.3.11 Nitrate – nitrogen

Nitrate – nitrogen slightly varied across the supply chain. Borehole 1A recorded the highest value of 0.068 mg/L, while Borehole 1B had the lowest value of 0.057 mg/L, with a difference of 0.011 mg/L. The nitrate slightly increased from the distribution tank towards the consumers (Table 12). However, nitrate concentrations across the piped water supply chain were not significantly different (p=0.139) at 0.05 significance level using One-Way ANOVA test (Table 12).

4.3.12 Nitrite – nitrogen

Nitrite values obtained across the supply chain were the same at all sampling sites, with an average value of 0.004 mg/L (Table 12).

4.3.13 Ammonium – nitrogen

Ammonium concentration across the piped water supply chain was the same. A value of 0.043 mg/L was recorded in all sampling points across the supply chain. Therefore, the distribution of ammonium across the piped water supply was not significantly different (p=1.000) at 0.05 significance level using One-Way ANOVA test (Table 12).

4.3.14 Sulfate

Sulfate concentration across the piped water supply chain was relatively similar in all the sampling points, with minimal variance. The lowest values were recorded in boreholes 1A and 1B (0.0189 mg/L), while the highest value was recorded at the distribution tank (0.0192 mg/L) (Table 12). Hence, sulfate levels slightly increased from the boreholes 1A and 1B to the distribution tank, after which they decreased towards the consumer endpoints. However, the distribution of sulfate across the piped water supply chain was not significantly different (p=1.000) at 0.05 significance level using One-Way ANOVA test (Table 12).

4.3.15 Iron and lead

Iron and Lead concentrations across the piped water supply chain were below detectable levels of 0.02 mg/L and 0.004 mg/L, at all sampling points over the study period (Table 12).

4.3.16 Fluoride

Fluoride levels across the piped water supply chain decreased from the distribution tank towards the consumer household endpoints over the study period. The highest and lowest values were recorded at the distribution tank (0.18 ± 0.02 mg/L) and the consumer households (0.13 ± 0.04 mg/L), respectively (Table 12). However, boreholes 1A & 1B and the tap levels recorded similar values. Fluoride concentrations were not significantly different (p=0.225) across the piped water supply chain at 0.05 significance level using One-Way ANOVA test (Table 12).

4.3.17 Faecal coliform densities

The faecal coliform densities across the piped water supply chain ranged from 5.50.90±2.52 CFUs/100mL at Borehole 1B (lowest) to 74.80±19.79 CFUs/100mL at the consumer endpoints (highest) (Table 12). The distribution tank was fed by two boreholes: Borehole 1A (6.17±2.02 CFUs/100mL) and Borehole 1B (5.50.90±2.52 CFUs/100mL. There was an increase in the faecal coliform densities at the distribution tank (14.33±7.78 CFUs/100mL). The faecal coliform densities obtained at different sampling points were significantly different across the piped water supply chain ($p = 0.001$) using One-Way ANOVA test at 0.05 significance level (Table 12). Notably, the mean difference of faecal coliform densities between consumer households and all other sampling points: Boreholes BH1A ($p = 0.022$) and BH1B ($p = 0.001$), distribution tank ($p = 0.035$) and taps ($p = 0.001$), were significantly different at 0.05 significance level using Tukey HSD test as indicated in Table 12.

4.3.18 Correlation among water quality parameters across the piped water supply chain

FRC and turbidity positively correlated with EC. The water pH negatively correlated with FRC and turbidity at 0.05 significance level using Pearson correlation test. Nitrite negatively correlated with total alkalinity, as fluoride correlated significantly with turbidity (negative) and chloride (positive) (Table 13).

Table 13: Correlation assessed parameters across the piped water supply chain

	CFU per 100ml	Temperature (°C)	DO (mg/L)	EC (µS/cm)	FRC (mg/L)	Salinity (‰)	TDS (mg/L)	Turbidity (NTU)	pH	Nitrate (mg/L)	Nitrite (mg/L)	Ammonium (mg/L)	Chloride (mg/L)	Fluoride (mg/L)	Sulfate (mg/L)	Total Alkalinity (mEq/L)
CFU per 100ml	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temperature (°C)	-0.054	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DO (mg/L)	0.044	0.001	1	-	-	-	-	-	-	-	-	-	-	-	-	-
EC (µS/cm)	-0.084	0.115	-0.006	1	-	-	-	-	-	-	-	-	-	-	-	-
FRC (mg/L)	-0.097	-0.074	0.164	**.353***	1	-	-	-	-	-	-	-	-	-	-	-
Salinity (‰)	0.200	-0.028	0.115	.488**	-0.035	1	-	-	-	-	-	-	-	-	-	-
TDS (mg/L)	-0.239	0.043	0.067	.573**	-0.004	.561**	1	-	-	-	-	-	-	-	-	-
Turbidity (NTU)	0.259	0.091	0.055	**.301***	0.144	-0.143	-.478**	1	-	-	-	-	-	-	-	-
pH	0.090	-0.099	.607**	-0.135	**-.291***	0.228	0.219	**-.282***	1	-	-	-	-	-	-	-
Nitrate (mg/L)	0.063	-0.115	0.191	-0.062	-0.031	-0.024	-0.109	-0.021	0.157	1	-	-	-	-	-	-
Nitrite (mg/L)	0.071	-0.259	-.374**	-0.227	-0.104	-0.124	-0.124	-0.148	-0.220	-0.069	1	-	-	-	-	-
Ammonium (mg/L)	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	-	-	-	-
Chloride (mg/L)	-0.221	0.262	-0.003	0.398	0.410	.[a]	0.214	-0.365	-0.231	0.192	-0.145	.[a]	1	-	-	-
Fluoride (mg/L)	-0.276	-0.107	-0.436	0.245	0.218	.[a]	0.230	**-.655***	-0.453	0.220	0.097	.[a]	**.572***	1	-	-
Sulfate (mg/L)	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	.[a]	-
Total Alkalinity (mEq/L)	-0.183	0.141	.424**	0.114	-0.220	0.246	.404**	-0.211	.438**	0.109	**-.283***	.[a]	0.293	0.293	.[a]	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Bolded: Significantly different values

a. Cannot be computed because at least one of the variables was constant.

4.4 Waterborne diseases retrospective study in Lodwar Town (2016 – 2020)

Waterborne health risks were reported in three categories (County, Municipality and Ward levels), including Lodwar Township and Kanamkemer wards separately, Lodwar Municipality (Lodwar Township and Kanamkemer Wards combined) and Turkana County. In each of these categories, the data was reported in three sets: under 5 years, above 5 years and a sum of all years (both under 5 and above 5 years).

4.4.1 Results for Lodwar Township Ward

The District Health Information System (DHIS) waterborne diseases data for Lodwar Township Ward for outpatients under 5 years children showed that diarrhoea (966 cases), gastroenteritis (153 cases), and amoebiasis (78 cases) were reported in 2020, while Hepatitis was only reported in 2016 (1 case) and 2017 (3 cases) respectively. Cholera was not reported over the five years. However, dysentery, typhoid fever and bilharzia were reported every year. The cases of dysentery ranged between 69 (2017) and 198 in 2019. Typhoid fever cases ranged between 52 (2016) and 392 (2020), while Bilharzia had 1 case (2016, 2020) and 16 cases (2018). The prevalence of dysentery, typhoid fever and bilharzia cases over the five years from 2016 to 2020 showed no significant difference ($p = 0.406$) at 0.05 significance level using Independent-Samples Kruskal-Wallis test. Thus, typhoid fever and dysentery were the most reported waterborne diseases among outpatient children under 5 years between 2016 and 2020, except for 2020, where diarrhoea came first with typhoid fever, gastroenteritis and dysentery coming second, third and fourth respectively (Figure 4).

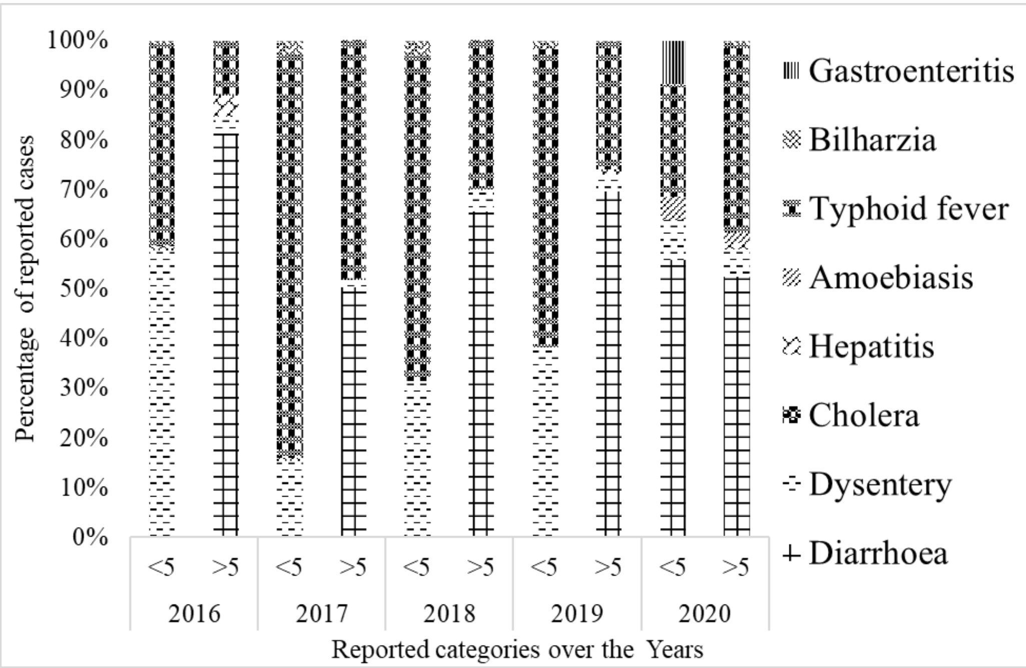

Figure 4: Percentage of waterborne disease outpatient cases in Lodwar Township Ward

The outpatient cases for individuals above 5 years reported in Lodwar Township Ward for the study period indicated that diarrhoea, dysentery, hepatitis, typhoid fever and bilharzia were reported every year except bilharzia, which was not reported in 2016. Diarrhoea ranged between 3520 cases (2019) and 2041 (2020). Dysentery ranged between 71 cases (2017) and 215 (2018, 2020), and hepatitis ranged between 5 cases (2017) and 114 (2016). Typhoid fever cases were lowest in 2016 (296 cases) and highest in 2017 (2261 cases), while bilharzia reported no cases in 2016 (lowest) and 32 cases in 2020 (highest). Amoebiasis was only reported in 2020, with 84 cases. No cases of cholera were reported throughout the study period. The distribution of diarrhoea ($p= 0.406$), dysentery ($p= 0.406$), hepatitis ($p= 0.406$), typhoid fever ($p= 0.406$) and bilharzia ($p= 0.392$) at 0.05 significance level using Independent – Samples Kruskal-Wallis test was not significantly different across the study period. Therefore, diarrhoea → typhoid fever, and → dysentery were the first, second and third most reported waterborne disease cases among outpatient individuals above 5 years in Lodwar Township ward (Figure 4).

By summing up the total cases (both <5 years and >5 years) of the reported waterborne health conditions for Lodwar Township ward, it was notable that cases of diarrhoea, dysentery, hepatitis, typhoid fever and bilharzia were reported throughout the study period. However, cases of amoebiasis (162 cases) and gastroenteritis (153 cases) were only reported in 2020, while no cases of Cholera were reported over the study period of 5 years. The number of cases reported for diarrhoea was from 2,173 (2016) to 3,520 (2019). Dysentery was from 140 (2017) to 387 (2018) cases, with 8 (2017) to 115 (2016) for hepatitis cases. Typhoid fever recorded between 348 (2016) and 2,626 (2017) cases, while bilharzia had 1 case in 2016 (lowest) and 33 cases in 2020 (highest). There was no significant difference in the prevalence of diarrhoea ($p=0.406$), dysentery ($p=0.406$), hepatitis ($p=0.406$), typhoid fever ($p=0.406$), and bilharzia ($p=0.406$) across the five years at 0.05 significance level using Independent – Samples Kruskal-Wallis test. As such, the sum of under 5 years and above 5 years cases in Lodwar township ward portrayed diarrhoea → typhoid fever → and dysentery as the three most reported waterborne health conditions (Figure 5).

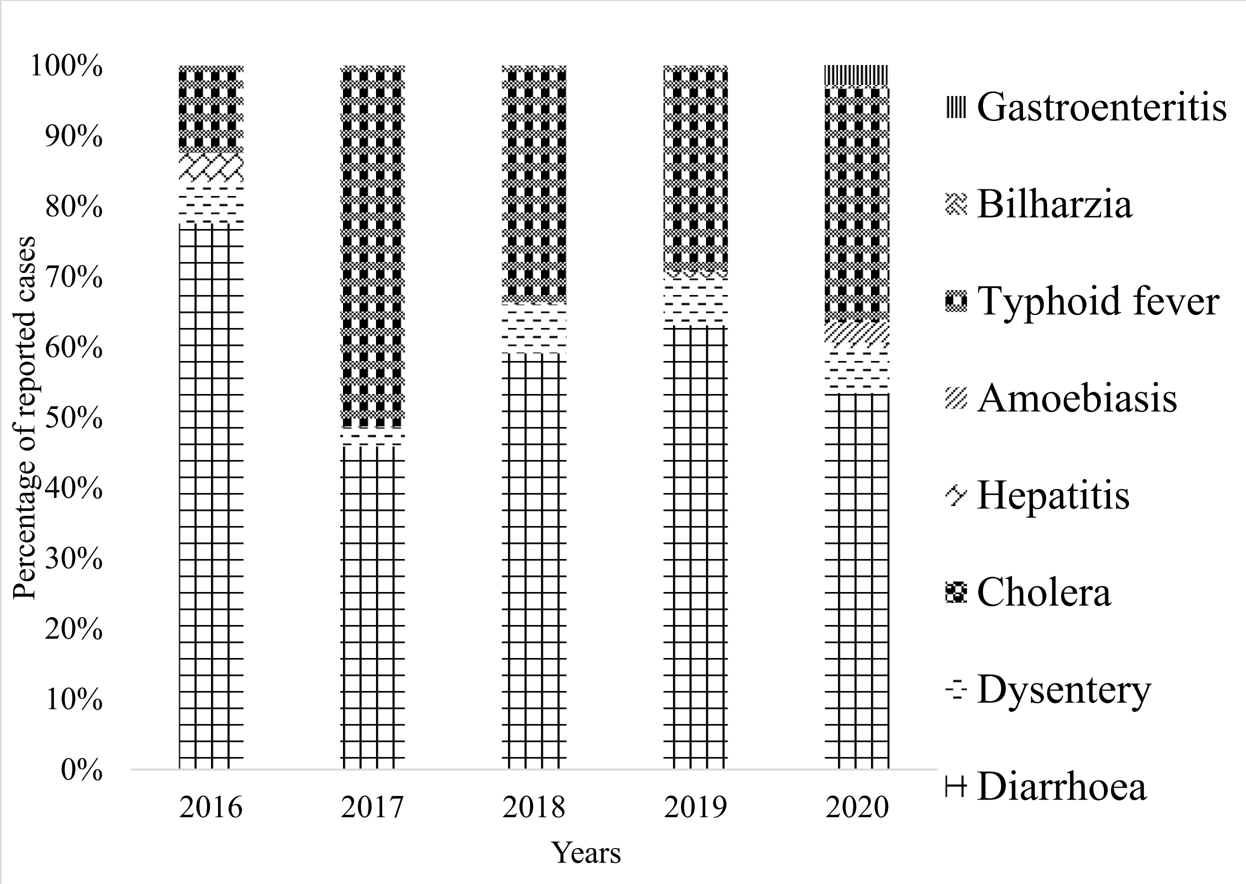

Figure 5: Prevalence of reported waterborne health conditions in Lodwar Township Ward

4.4.2 Waterborne diseases in Kanamkemer Ward

The DHIS data for Kanamkemer Ward for the outpatient children under 5 years pointed out that diarrhoea (490 cases), amoebiasis (51 cases), hepatitis (28 cases) and gastroenteritis (3 cases) were only reported in 2020. Bilharzia was reported in 2017 (37 cases) and 2018 (2 cases). No cases of cholera were reported over the study period. Dysentery and typhoid fever were reported throughout the study period. Dysentery cases ranged between 6 (2019) and 109 (2016). Typhoid fever was reported between 5 (2018, 2020) and 48 cases (2017). The prevalence of dysentery ($p=0.284$) and typhoid fever ($p=0.368$) from 2016 to 2020 revealed no significant difference at 0.05 significance level using Independent – Samples Kruskal-Wallis test. Therefore, the most reported waterborne health risks among children under 5 years were dysentery → and typhoid fever (Figure 6).

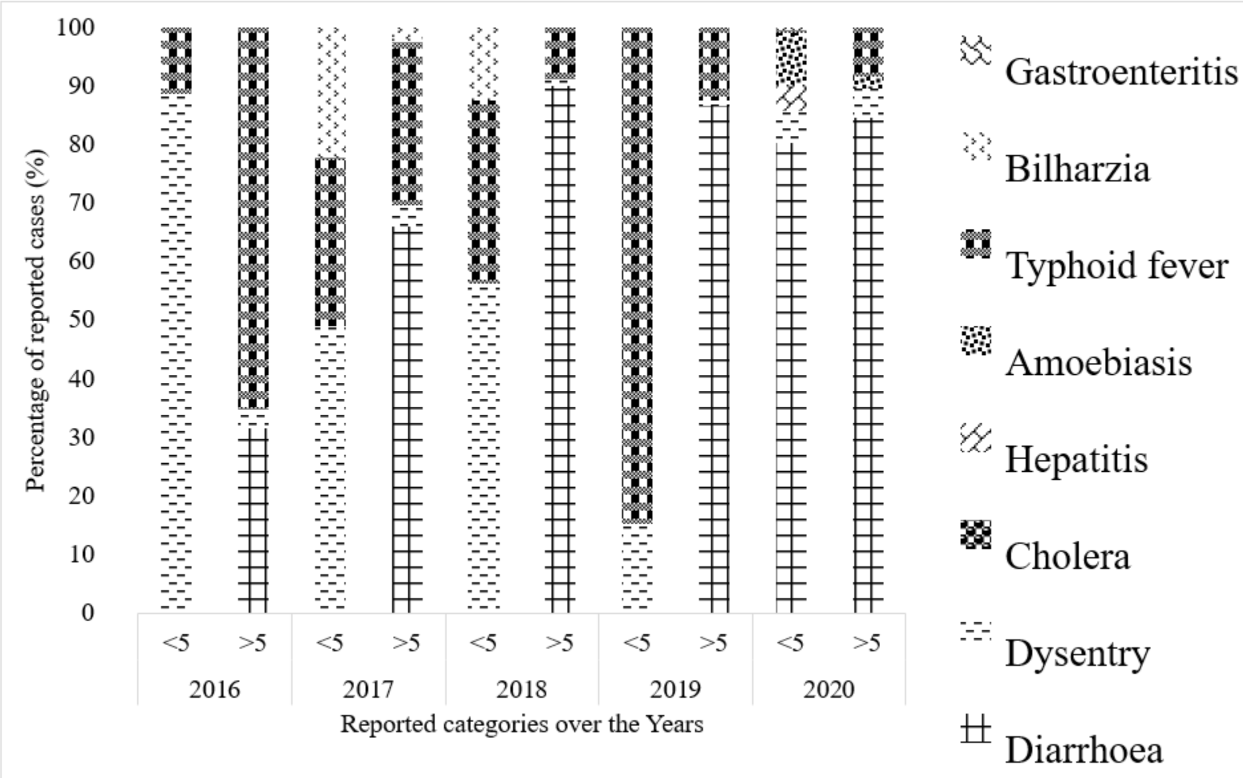

Figure 6: Percentage of reported waterborne diseases in Kanamkemer Ward

The above 5 years' outpatient cases reported in Kanamkemer Ward during the study period revealed that diarrhoea, dysentery and typhoid fever were reported throughout the five years. The cases of diarrhoea were lowest in 2016 (903 cases) and highest in 2019 (1956 cases). Dysentery cases were between 14 (2018) and 80 (2020). Typhoid fever cases were 121 (2018) and 1867 (2016). Hepatitis (1 case in 2019 and 3 cases in 2020), amoebiasis (31 cases in 2020) and bilharzia (34 cases in 2017) were either reported once or twice respectively. However, no cases of cholera were reported over the study period. The prevalence of diarrhoea ($p= 0.406$), dysentery ($p= 0.406$) and typhoid fever ($p= 0.406$) across the five years was not significantly different at 0.05 significance level using Independent – Samples Kruskal-Wallis test. Accordingly, diarrhoea →, dysentery → and typhoid fever were the first, second and third commonly reported cases of waterborne health conditions among residents above 5 years in Kanamkemer ward (Figure 6).

The total outpatient cases (<5 years and >5 years) for Kanamkemer ward indicated that diarrhoea, dysentery and typhoid fever occurred throughout the assessment period. Further, amoebiasis had 82 cases (2020), bilharzia 71 cases (2017) and 2 cases (2018), hepatitis 1 case (2019) and 31 cases (2020) and gastroenteritis 3 cases (2020). Nevertheless, no cholera cases were reported in the ward over the 5 years. Diarrhoea recorded between 903 (2016) and 1,956 (2019) cases, dysentery between 23 (2018) and 202 (2016) cases, while typhoid fever had between 126 (2018) and 1,881 (2019) cases (Figure 7). There was no significant difference in the prevalence of diarrhoea (p=0.406), dysentery (p=0.406), hepatitis (p=0.317), typhoid fever (p=0.406), and bilharzia (p=0.317) at 0.05 significance level using Independent – Samples Kruskal-Wallis test between 2016 and 2020.

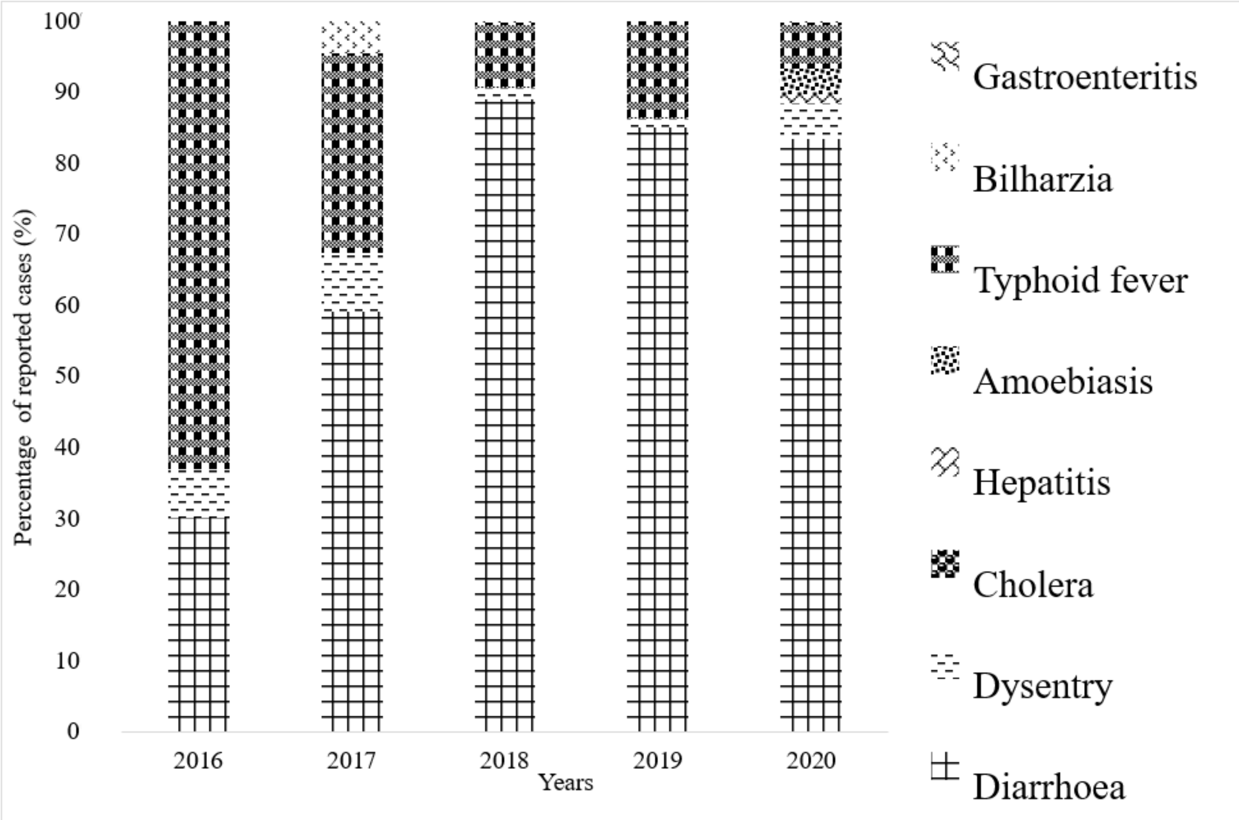

Figure 7: Prevalence of waterborne conditions in Kanamkemer Ward from 2016 to 2020

4.4.3 Lodwar Municipality waterborne diseases retrospective assessment

The reported outpatient cases for children under 5 years within Lodwar municipality, covering the two Wards of Lodwar Township and Kanamkemer revealed that dysentery, hepatitis, typhoid fever and bilharzia were reported over the 5 years, except for hepatitis, which had no cases reported in 2018 and 2019. Dysentery cases were between 151 (2017) and 204 (2019). Hepatitis had no cases in 2018 and 2019, with 28 cases in 2020. Typhoid fever recorded between 66 (2016) and 413 (2017) cases, while bilharzia had between 1 (2016, 2020) and 50 (2017) cases (Figure 8). On the other hand, cases of diarrhoea (1,456), gastroenteritis (156) and amoebiasis (129) were reported only in 2020, with no cases of cholera reported throughout the 5 years. There were no significant differences in the prevalence of dysentery (p=0.406), hepatitis (p=0.368), typhoid fever (p=0.406), and bilharzia (p=0.406) at 0.05 significance level using Independent – Samples Kruskal-Wallis test across the assessment period.

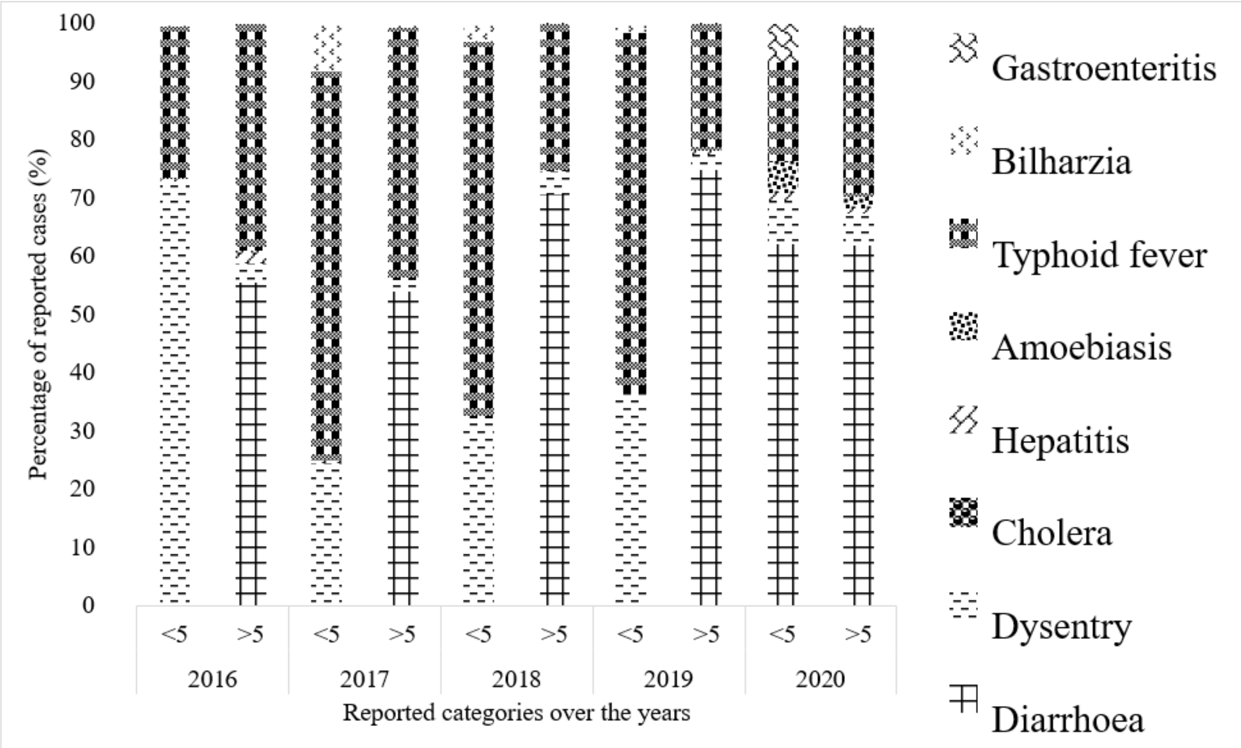

Figure 8: Distribution of waterborne health risks in Lodwar municipality

Outpatient cases for people above 5 years reported within Lodwar municipality across the study period revealed that Amoebiasis (115 cases) was only reported in 2020, and no cases of cholera and gastroenteritis were reported throughout the 5 years. Cases of diarrhoea, dysentery, hepatitis, typhoid fever and Bilharzia were reported throughout the assessment period. Diarrhoea cases ranged between 3,076 (2016) and 5,476 (2019), dysentery between 121 (2017) and 295 (2020) cases. Hepatitis ranged between 5 (2017) and 114 (2016) cases, and typhoid fever varied between 1,588 (2019) and 2,661 (2017) cases. Bilharzia reported between no cases in 2016 and 40 cases in 2017 (Figure 8). The prevalence of diarrhoea (p=0.406), dysentery (p=0.406), hepatitis (p=0.406), typhoid fever (p=0.406), and bilharzia (p=0.392) between 2016 and 2020 was not significantly different using Independent – Samples Kruskal-Wallis test at 0.05 significance level.

Summing up all the cases (under 5 years and above 5 years) in Lodwar Municipality, amoebiasis (244 cases) and gastroenteritis (156 cases) were only reported in 2020. No cases of cholera were reported throughout the study period within Lodwar Municipality. However, cases of diarrhoea, dysentery, hepatitis, typhoid fever and bilharzia were reported throughout the 5 years within the Municipality (Figure 9). Diarrhoea cases varied between 3,076 (2016) and 5,476 (2019), with dysentery between 272 (2017) and 470 (2020). Hepatitis cases ranged between 8 (2017) and 115 (2016), and typhoid fever cases ranged between 1,931 (2019) and 3,074 (2017) cases. Bilharzia ranged between 1 (2016) and 90 (2017) cases. There were no significant differences in the prevalence of diarrhoea (p=0.406), dysentery (p=0.406), hepatitis (p=0.406), typhoid fever (p=0.406), and bilharzia (p=0.406) at 0.05 significance level using Independent – Samples Kruskal-Wallis test from 2016 to 2020.

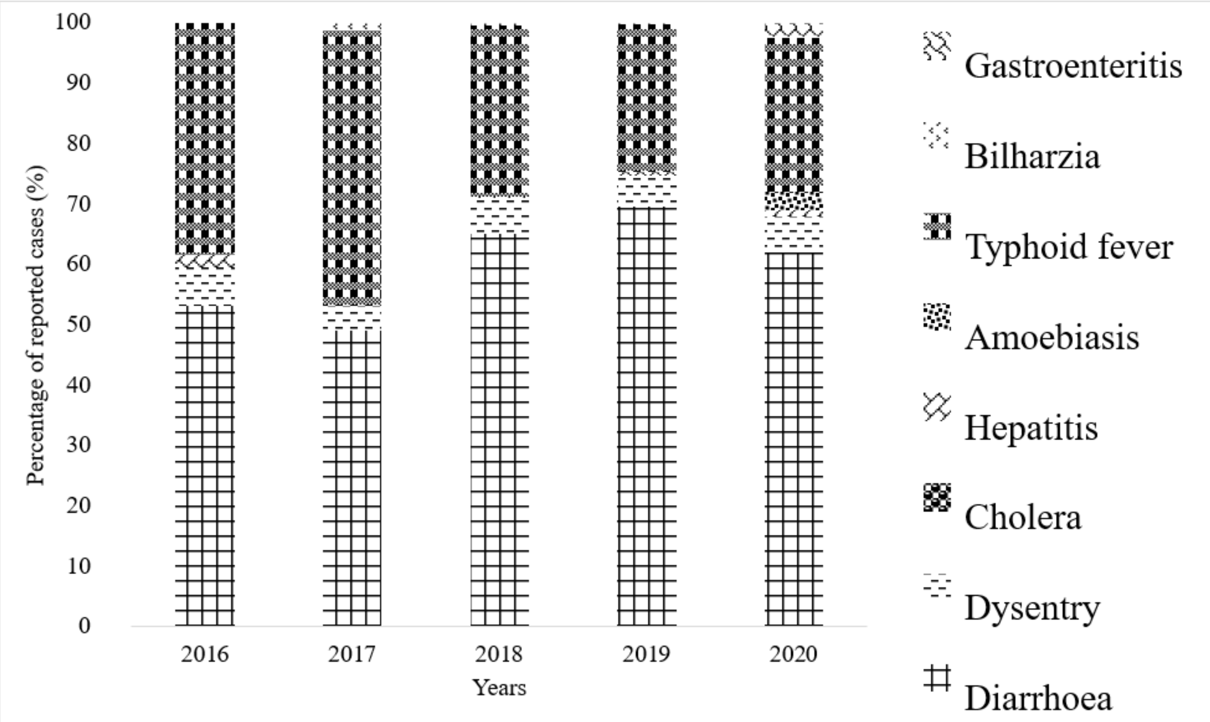

Figure 9: Prevalence of waterborne health conditions in Lodwar town from 2016 to 2020

4.4.4 Turkana County waterborne diseases retrospective assessment from 2016 to 2020

The reported outpatient cases for children under 5 years for the entire Turkana County pointed out that dysentery, cholera, hepatitis, typhoid fever and bilharzia were reported over the 5 years, except for cholera, which had no cases reported in 2016 and 2017 (Figure 10). Dysentery ranged between 930 cases (2020) and 3,468 (2017). Cholera had no cases in 2016 and 2017, with 77 cases in 2020. Hepatitis cases ranged between 3 (2018, 2019) and 124 (2020). Typhoid fever had between 464 (2016) and 583 (2019) cases, while bilharzia ranged between 2 (2020) and 72 (2018) cases. On the other hand, cases of diarrhoea (14,923), gastroenteritis (1,380) and amoebiasis (179) were reported in 2020. Independent – Samples Kruskal – Wallis test at a significance level of 0.05 revealed no significant differences in the prevalence of cholera (p= 0.368), dysentery (p= 0.406), hepatitis (p= 0.406), typhoid fever (p= 0.406) and bilharzia (p= 0.406) from 2016 to 2020.

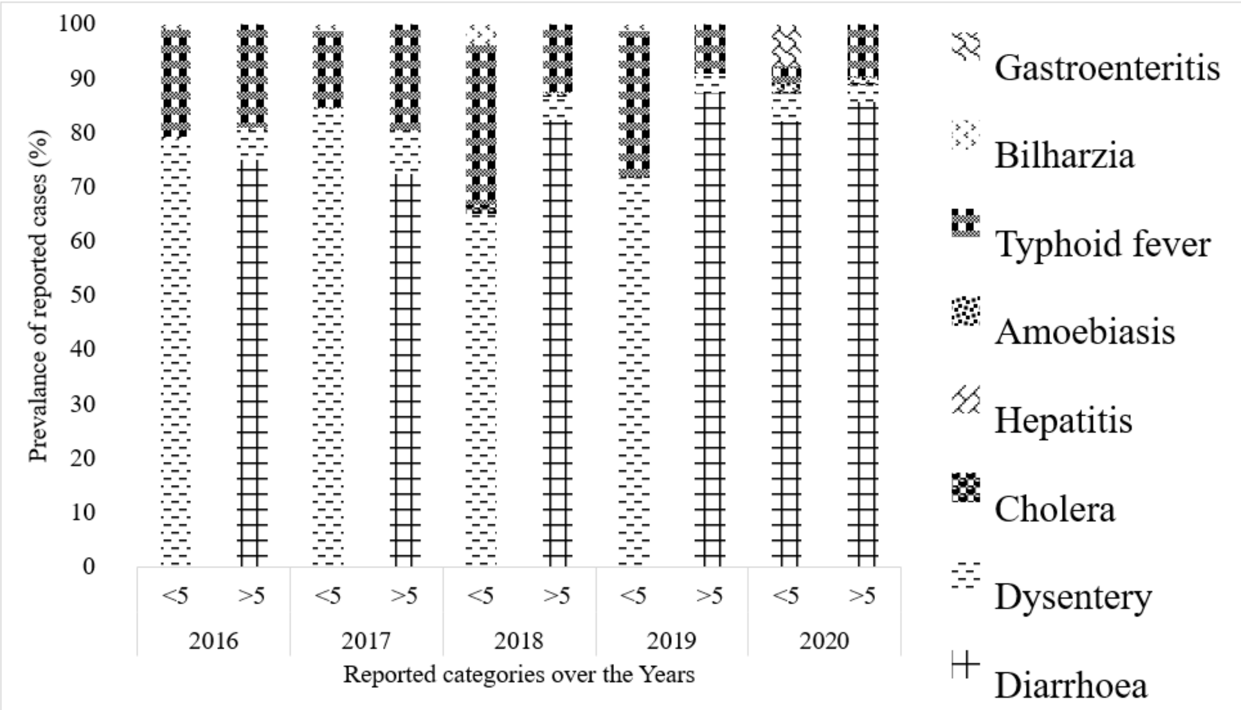

Figure 10: Distribution of waterborne outpatient cases in Turkana County

The above 5 years outpatients cases reported within Turkana County for the study period indicated that amoebiasis cases (292) were only reported in 2020, while cases of cholera were reported in 2018 (180), 2019 (75) and 2020 (227) respectively. Cases of diarrhoea, dysentery, hepatitis, typhoid fever and bilharzia were reported throughout the study period (Figure 10). Diarrhoea cases varied between 33,939 (2017) and 53,774 (2019), dysentery between 1,737 (2020) and 3,719 (2017) cases, and hepatitis between 77 (2017) and 280 (2020) cases. Typhoid fever had between 5,275 (2020) and 9,007 (2016) cases, while bilharzia had a range between 25 (2016) and 61 (2017) cases. The prevalence of the health conditions across the study period using Independent – Samples Kruskal – Wallis test at 0.05 significance level revealed no significant differences in the prevalence of diarrhoea (p= 0.406), cholera (p= 0.368), dysentery (p= 0.406), hepatitis (p= 0.406), typhoid fever (p= 0.406) and bilharzia (p= 0.406) between 2016 to 20220.

The waterborne health conditions cases considered for Turkana County revealed that amoebiasis (471 cases) and gastroenteritis (1,380 cases) were only reported in 2020. Cholera cases were reported in 2018 (208), 2019 (80) and 2020 (304). However, cases of diarrhoea, dysentery, hepatitis, typhoid and bilharzia were reported throughout the assessment period. Diarrhoea cases ranged between 33,939 (2017) and 61,756 (2020), dysentery between 2,667 (2020) and 7,187 (2017) cases. Hepatitis had between 94 (2017) and 404 (2020) cases, typhoid between 5,824 (2020) and 9,579 (2017) cases, with bilharzia ranging between 45 (2020) and 126 (2018) cases (

Figure **11**). Cholera (p= 0.368), dysentery (p= 0.406), hepatitis (p= 0.406), typhoid fever (p= 0.406) and bilharzia (p= 0.406) across the 5 years showed no significant differences using Independent – Samples Kruskal – Wallis test at 0.05 significance level.

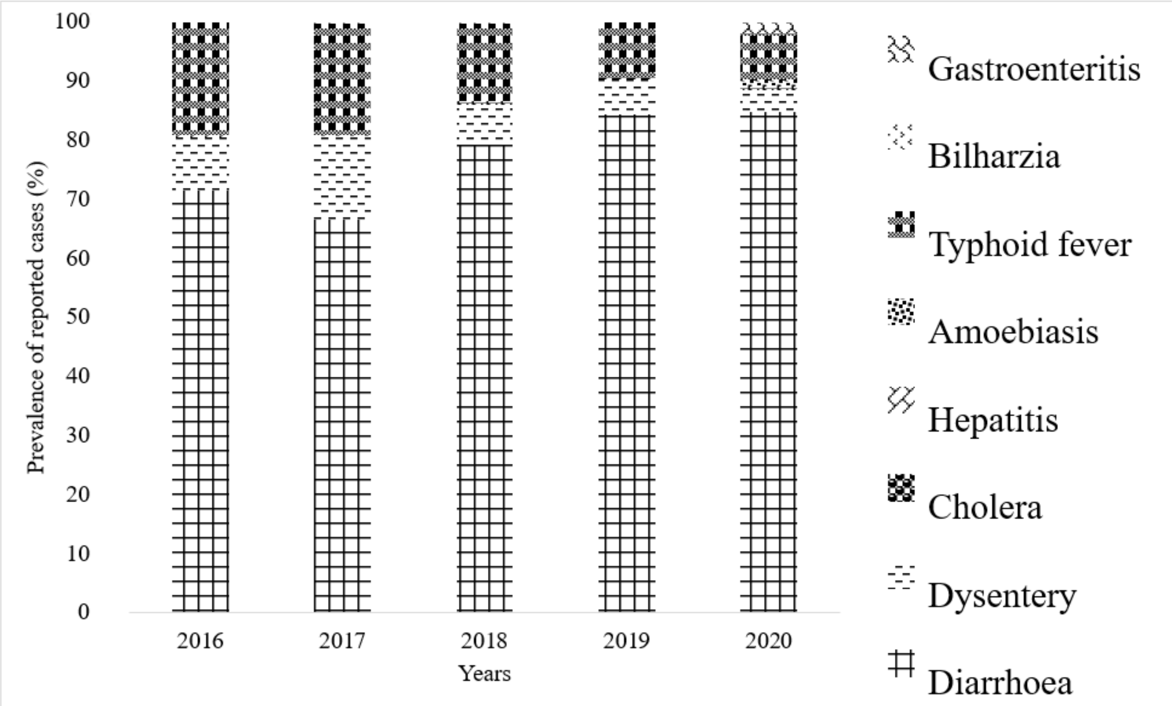

Figure 11: Distribution of waterborne conditions for Turkana County from 2016 to 2022

4.5 Consumers and tanker drivers' perceptions of vendors' water quality in Lodwar town

Questionnaires were administered to get consumers' views on vendors' water at the point of use for the three supply chains. The tanker drivers also gave their opinion on the quality of water they deliver.

4.5.1 Tanker drivers' perceptions of vendors' water quality

Ten (10) out of fifteen (15) representing 66.7% of tanker drivers sampled were interviewed. All the tanker drivers (100%) reported that they used LOWASCO's *Moi Garden* water supply as the main source of water they supplied. Other water sources mentioned to be occasionally used by the water tankers include Loborot borehole (30%), Chinese borehole at KEFRI (10%), private boreholes (10%) and boreholes in Lokichar, Lokori, Nakukulas and Nawoiyaragae (10%) (Figure 12 A). On the other hand, 40% of the interviewed tanker drivers mentioned that they had no other water source apart from the *Moi Garden* supply. All water tanker drivers (100%) reported that they did not deliver river water to their customers.

When asked how often they cleaned the tankers, the drivers gave varied responses. 50% of drivers mentioned they rarely cleaned their tankers. Others noted that they did so weekly (10%), after 1 month (20%), after 2 months (10%) and after 2 years (10%) respectively (Figure 12 B). 90% of the interviewed tanker drivers noted that the main supply water was safe, while 10% reported that they were not sure if the main supply water was safe (Figure 12 C).

The tanker drivers were also asked how often water quality monitoring for the tanker supply chain was monitored. Eighty percent (80%) noted that monitoring of water quality was done occasionally, or they had not interacted with those who were supposed to undertake the water monitoring. On the other hand, 20% of the tanker drivers reported that water quality monitoring of their tankers was done once in a month (Figure 12 D). 90% of the tanker drivers reported that they do not think the water utility, or any other relevant authority, was doing much to protect consumers from any risks that can come from vended water (Figure 12 E).

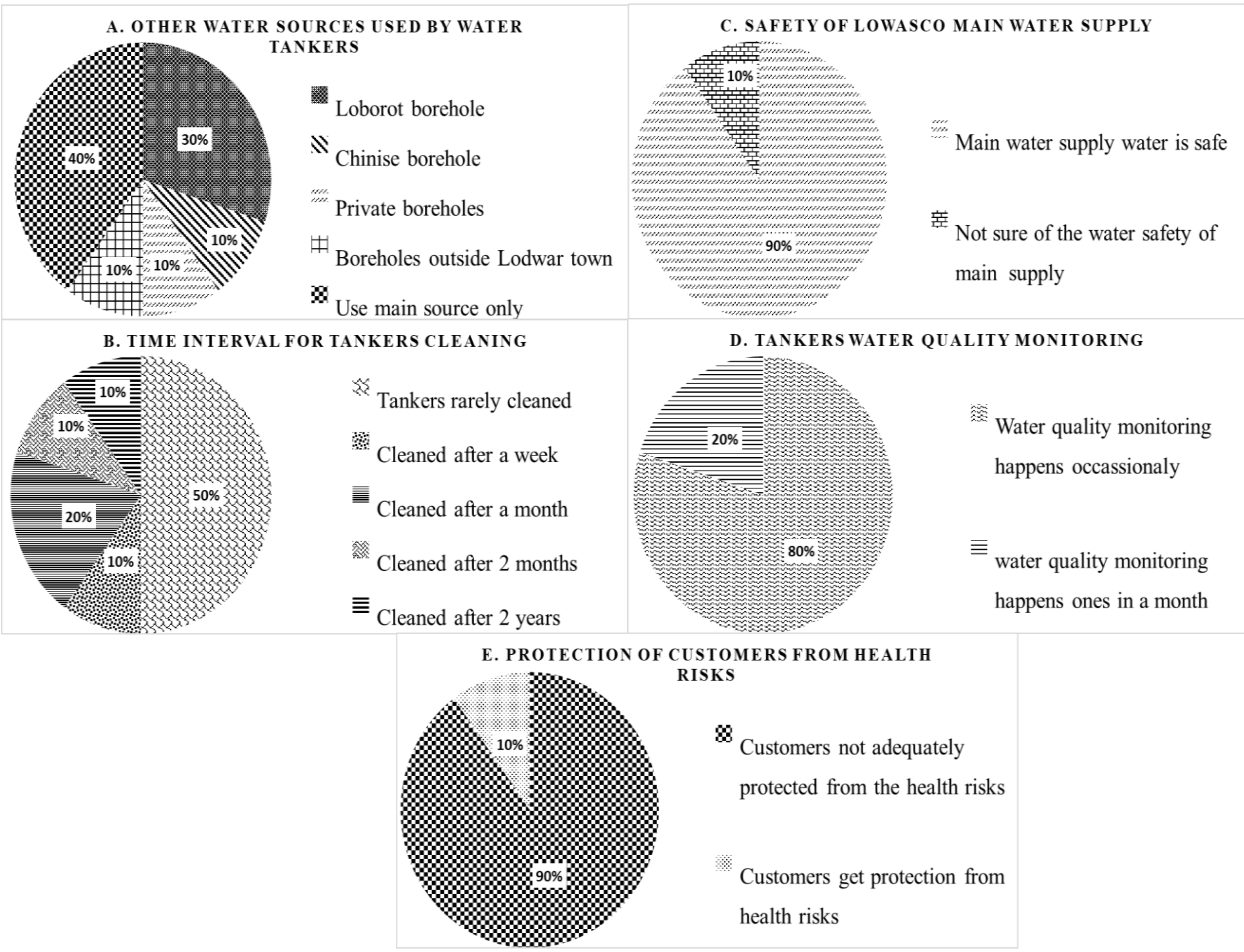

Figure 12: Tanker drivers' perceptions of water quality in Lodwar town

4.5.2 Consumers' perception of vended water quality from water tankers

Most of the water tanker's consumer households interviewed were not connected to LOWASCO piped water. Out of the six (6) interviewed households, only one (1), representing

16.7% was connected while five (5), representing 83.3% were not connected to the LOWASCO supply (Figure 16 A). All of them (100%) reported using water tankers as their main source of water supply. Asked whether they relied on other water sources apart from the water tanker, 66.7% of consumers noted that they had no other water source. 16.7% reported using a household tap from a nearby estate, which was connected to the utility supply (Figure 13 B). Fifty per cent (50%) of the water tankers consumers reported treating water at the household. On the other hand, 50% of them were not treating water after the tankers' delivery (Figure 13 C).

When asked how often they cleaned their water storage facilities, 33.4% of the tanker consumers reported cleaning their storage facilities whenever the water was depleted (Figure 13 D). Some tanker consumers cleaned their water storage facilities after 3 months (16.7%) while others cleaned after 2 weeks (16.7%). However, 16.7% of the water tankers' consumers mentioned that it was not possible to clean their water storage tanks. This was due to the way they were installed or constructed.

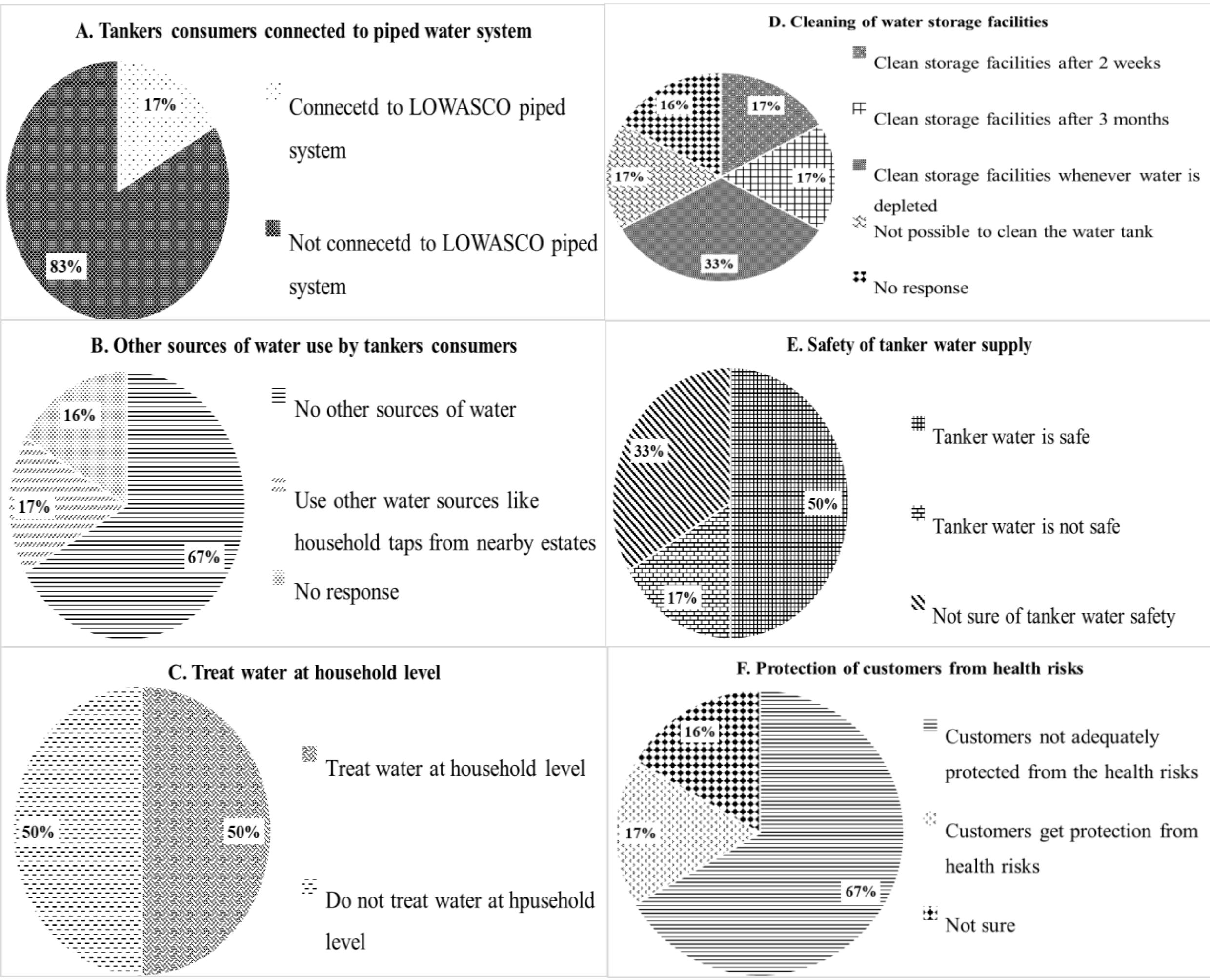

Figure 13: Tanker consumers' perceptions of water quality in Lodwar town

Fifty per cent (50%) of the tanker consumers noted that they believed tanker water was safe. 33.3% reported that they were not sure of the tankers' water safety, while 16.7% mentioned that it was not safe (Figure 13 E). Some of the interviewed tanker consumer households (16.7%) reported typhoid fever as a common waterborne disease they experienced (Table 14). Inadequate hygiene, inadequate or negligence to treat water, unreliable or lack of utility supply and inadequate finances to buy disinfectants were mentioned as some of the challenges the water consumers thought hindered safe water delivery in Lodwar town. On the other hand, 66.7% of the tanker consumers reported that they did not believe that the relevant authorities were doing much to protect consumers from water-related risks. 16.7% of consumers believed authorities were taking necessary actions to protect the consumers from risks (Figure 13 F).

Table 14: Waterborne health risks perceived by consumers in Lodwar town

Water tankers consumers	Kiosks consumers	Piped water consumers
Typhoid	Diarrhoea Typhoid Stomach ache	Diarrhoea Typhoid

4.5.3 Kiosk consumers' perceptions of vended water quality

Eleven (11) households that used the kiosks' water supply were interviewed during the study. The kiosks supplied water mainly to the Internally Displaced Persons (IDP) village commonly known as "*Kanaan*". The households reported that they were not connected to a piped water supply. They fetched water from public kiosks established at different locations in the village. When the water was not in the kiosks, the households mentioned they looked for water at nearby villages, including tap water resold at households, car washes, Loborot borehole, Moi Garden supply and even River Turkwel water for some villages. Hence, the consumers had to hire motorbikes or handcarts and other means to transport water to their residences. Out of the households interviewed, 72.7% reported that they did not treat water, while 27.3% of the households mentioned that they treated water (Figure 14 A).

The respondents gave varied responses on the cleaning of water storage facilities. Some reported to clean their storage facilities weekly (27.3%), occasionally (9.1%), or when the water was depleted (18.2%) (Figure 14 B). The kiosks' consumers expressed confidence that the kiosks' water was safe (81.8%), while 18.2% were not sure if the water was safe (Figure 14 C). Typhoid and stomach-ache were reported as diseases associated with the consumption of kiosks' water (Table 14). Some of the kiosk's consumers (36.4%) confirmed they had confidence that the relevant authorities were taking necessary actions in protecting them from water-related risks. On the other hand, 54.5% of the kiosk water consumers reported that relevant authorities were not responsive in protecting them from waterborne health risks. However, 9.1% of kiosk water consumers were not even sure whether responsible government authorities were taking necessary steps to protect them from waterborne health risks (Figure 14 D).

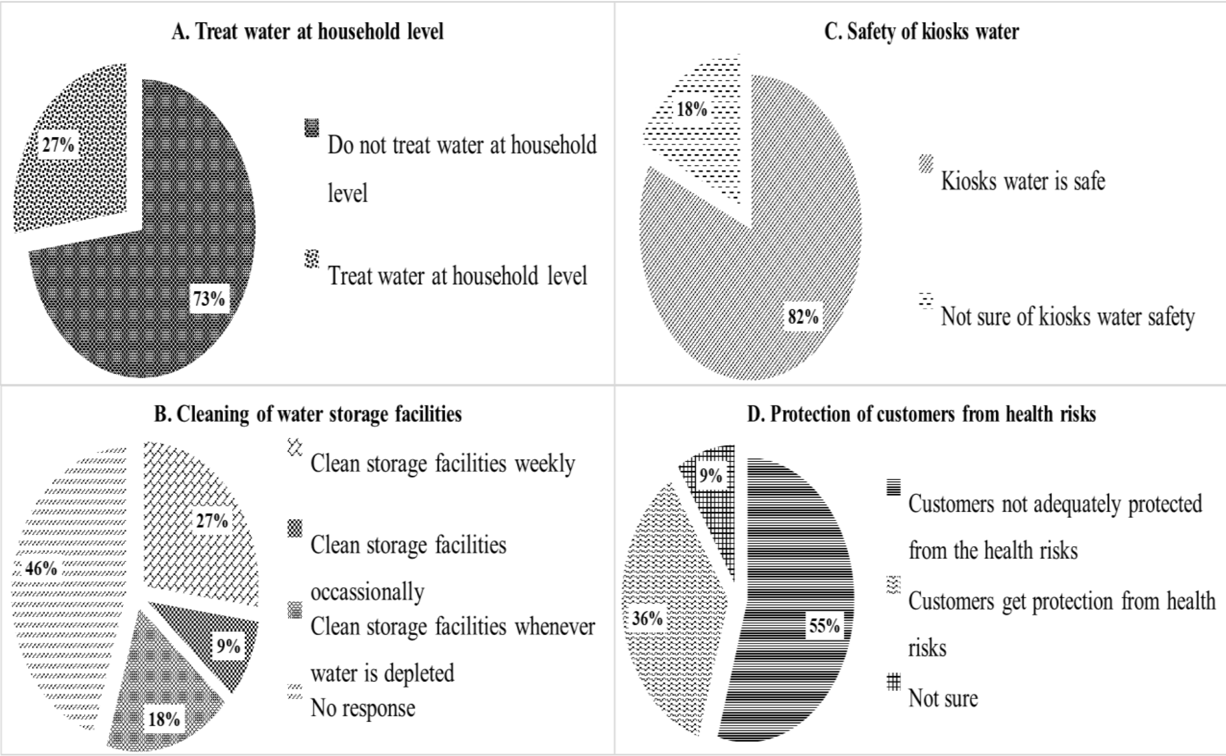

Figure 14: Kiosks consumers' perceptions of water quality in Lodwar town

4.5.4 Piped water consumers' perceptions of vended water quality

Thirteen (13) households connected to the utility's tap water were interviewed in different villages served by LOWASCO's main water supply. The households reported using other water sources whenever the tap water supply was disrupted. This forced them to fetch water from storage tanks meant for car washes in town, the Moi Garden outlet tap used by handcart vendors, a hand pump at the showground and nearby villages, and places with storage tanks like St. Augustine church and the division Mosque. Alternatively, they rely on water vendors such as tankers, motorbikes and handcarts for those who can afford. Most piped water consumers' households did not treat water (84.6%), while 7.7% reported treating water using chlorine disinfectants or boiling (Figure 15 A).

A few households with piped water (7.7%) reported washing their water storage facilities. 7.7% mentioned they never washed their water storage containers (Figure 15 B). Some households with taps (76.9%) were confident the utility's water was safe. 15.4% of the piped water households expressed concerns that the water was unsafe (Figure 15 C). Diarrhoea and typhoid were associated with the consumption of piped water by the interviewed households (Table 14). Some piped water consumers (53.8%) expressed confidence that the relevant authorities were taking necessary actions to protect them from water-related risks. 30.8% were not satisfied with the services of mandated authorities in protecting them as consumers from waterborne risks (Figure 15 D).

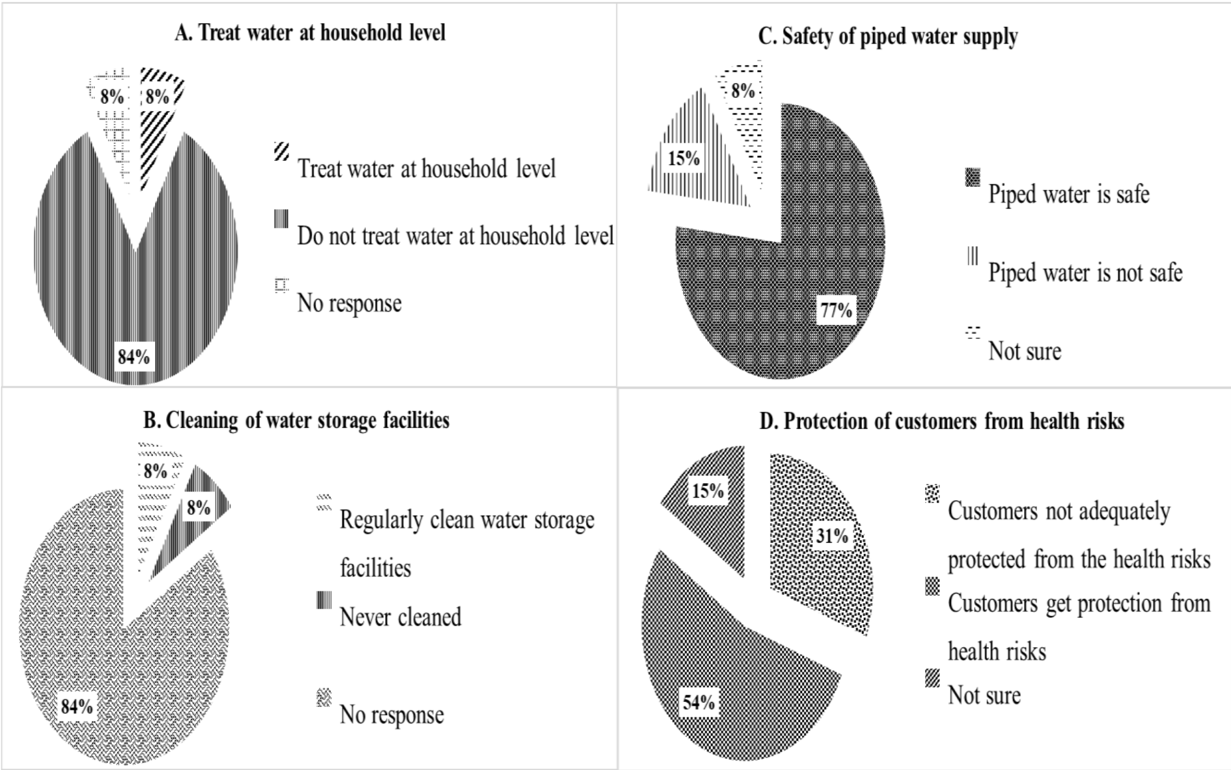

Figure 15: Piped water consumers' perceptions of water quality in Lodwar town

CHAPTER FIVE

DISCUSSION

5.1 Physical–chemical and nutrient characteristics of water across supply chains

This study clearly shows that Lodwar town utilises three main water supply chains to provide water to its residents. These water supply chains are water tankers, kiosks and piped water supply.

5.1.1 Physical characteristics of water across supply chains

5.1.1.1 Temperature

Across all water supply chains, temperature varied significantly from the sources (boreholes) to the consumers' point of use, indicating that various factors influenced water temperature. The water sources for all the supply chains recorded the lowest temperature values due to the cold nature of underground water, which has been reported to be naturally cold in other studies (Hoko, 2008; Salehi, 2022). Further, the boreholes and standpipes were sampled before other sampling points across the supply chains (distribution tanks, tankers, kiosks and consumers' storage tanks), which were sampled later. Therefore, the change in temperature across the supply chains was influenced by the time of sampling, distance, ambient temperature of the surroundings and the nature of storage tanks material as reported by Hoko (2008) in Bindura District, Zimbabwe and in a review by Salehi (2022).

The water tankers' supply chain recorded higher temperature values at the tankers compared to the source and consumers' storage tanks. This could be because of different sampling times, the distance travelled, the surrounding temperature and the nature of tanks used by tankers, which were made of steel, providing an ideal scenario for water to heat up during transportation. The tankers heat up by absorbing sunlight, hence the higher temperature obtained. These results are similar to observations by Salehi (2022) in a global review of water shortage and potable water safety. The slight decrease in temperature at the consumer households could be because most consumers' storage tanks were stationed under a shade, resulting in lower water temperature. This finding compares to the observation made by Slavik *et al.* (2020) in a global review of water quality aspects related to domestic drinking water storage tanks. In this study, a correlation was noted between temperature and nitrite, ammonium and chloride across the tankers' supply chain. This might be due to oxidation of nitrogen compounds from increased temperature, which was reported by Rantanen *et al.* (2018) to be one of the drivers of nitrite seasonality.

The temperature at the utility's kiosks' distribution tank was slightly higher compared to the kiosks' taps and the source. This was attributed to the fact that the distribution tank was exposed to the sun's radiation. Hence, it was heated, influencing the temperature of the stored water, providing a conducive environment for the growth of contaminating microbes as identified in other studies (Hoko, 2008; Salehi, 2022). The significant difference in the temperature recorded across the kiosks' supply chain, especially the mean difference between the source and consumers, indicated that various factors influenced water temperature across the supply chain, as explained above. The increased water temperature observed at the consumers' point of use could have resulted from storage options at the household level. The storage options may have exposed some storage containers to sun radiation, as most of them were internally displaced persons (IDPs) with inadequately established household structures. Peter and Routledge (2018) observed that higher temperatures favoured microbial growth and biofilm formation in water storage facilities in London, England, which compares with the findings of this study, as faecal coliforms and temperature increased from the source to the consumers.

Across the piped water supply chain, the temperature varied significantly from the borehole to the taps, with a slight decrease at the consumers' point of use. The high temperature recorded at the taps may be due to ambient temperature and sun radiation that may have heated the laid pipeline as observed in Bindura District, Zimbabwe and across the globe (Hoko, 2008; Salehi, 2022). As the water was being piped to the households, the distribution tanks and the utility's pipeline network were exposed to sun radiation. Hence, the hot surrounding temperatures influenced the water temperature. At the consumers' level, the water temperature decreased as the water was mostly stored in containers under shades or inside the houses. Slavik *et al.* (2020) noted that shading reduces storage tanks' exposure to direct sunlight, reducing the potential for microbial growth. They further asserted that increased temperature in water storage tanks may increase microbial growth in water, similar to observations by Salehi (2022) in a global review of water shortage and potable water safety.

The temperature values recorded across all the water supply chains were reflective of the surrounding temperatures of 30.5 °C, according to the Turkana CIDP (2018). This variance in water temperature was significant among the sampling points from the boreholes to the consumers. Thus, the water temperature recorded across the supply chains was above the findings of Chalchisa *et al*. (2017) in water storage tanks in Jimma town, Ethiopia ranging from 21.3 to 23.1°C. High water temperatures in a study conducted in Osun state, Nigeria were reported to affect chemical reactions in water. This influenced other water quality parameters such as DO, pH, NH_3, and NH_4^+ as the maximum rate of nitrification was reported at 30 to 35°C water temperatures (Olajire and Imeokparia, 2001; Sallenave, 2019). This is consistent with the result of this study as temperature positively correlated with nitrites, ammonium and chloride across tankers' supply chain.

5.1.1.2 Turbidity

The water tankers and consumer households recorded increased values of turbidity across the water tankers' supply chain. Turbidity levels significantly varied across the sampling sites from the source to the consumers due to the unhygienic conditions of tankers and consumer storage tanks. A clear indicator was the field observation of a lack of regular cleaning or prolonged water storage at the household level, as similarly reported by Hoko (2008) in Bindura District, Zimbabwe. This could increase total suspended solids (TSS) from inorganic matter (sediments, dust, silt), organic matter (algae and biofilm) and oxide of iron in the tanks, changing the mineral content of water. As the water was transported to the consumers, dust and airborne substances might have entered the tankers/tanks, as some tankers/tanks were not lidded. This contributed to increased turbidity observed during field work both at the tankers and consumers' storage facilities.

The turbidity of water varied across the kiosks' supply chain, with the highest value recorded at the consumers' storage facilities, which could be associated with improper water handling (collection, transfer, use of unclean dips) or unclean storage containers at the households. At homesteads, the water was scooped from the storage containers, which could have caused resuspension of particles in water, hence increasing turbidity. These results are similar to those reported by Hoko (2008) in Bindura district, Zimbabwe. Sorlini *et al*. (2013) findings in a study in Logone Valley, Chad-Cameroon, asserted that the presence of inorganic particulate matter in water could influence its turbidity and may play host to microorganisms, hence indirectly posing a health risk. This assertion could apply in this study as there was a possibility of water exposure to inorganic particulate matter like dust, pollen and unhygienic conditions of storage facilities at the households, including lack of frequent cleaning of water containers. Further, a study in Cochabamba, Bolivia, by Schafer (2010) associated high turbidity levels at the customers' point of use with high presence of bacteria and algal growth in the storage facilities due to poor hygienic conditions and prolonged storage. On the other hand, the decreased turbidity at the kiosks could be attributed to sedimentation at the distribution tank, although its variance across the supply chain was not significant.

The turbidity levels obtained across piped water supply chain slightly varied at all sampling points. However, the values recorded in this study were below WHO recommended guideline of below 5 NTU (WHO, 2017) for drinking water. This implies that water was safe for use, similar to the findings of Chalchisa *et al*. (2017) in storage tanks in Jimma town, Ethiopia. Nevertheless, the slightly high turbidity value recorded at the consumers could be attributed to the presence of inorganic particulate matter such as dust, as similarly observed by Sorlini *et al*. (2013) in Logone Valley, Chad-Cameroon. It could also be due to the hygiene conditions of the storage facilities at the households as reported by Schafer (2010) in Cochabamba, Bolivia. Moreover, a study by Kothari *et al*. (2021) in Uttarakhand, India underpinned that turbidity levels in water occurred due to the presence of soil, organic and inorganic matter, plankton, and other microscopic organisms. These assertions could apply to this study, considering hygiene conditions, water handling and storage observed at the household levels.

Across all water supply chains, turbidity values were within WHO recommended levels of 5 NTU (WHO, 2017) except at the tankers and kiosks consumers' storage tanks, which recorded a slightly higher value of 5.90 NTU. This implied that the water was unsafe for drinking at the point of use for the two chains unless filtration was done. The high turbidity levels recorded at the tankers and kiosks' consumers were beyond the accepted guideline of 5 NTU in drinking water, as similarly reported in Cape Coast Metropolis, Ghana, to favour high levels of *E. coli* counts (Awere & Anornu, 2016). Further, high levels of disease-causing organisms such as pathogenic bacteria have been associated with high turbidity in Ghana (Schafer *et al*., 2009) and Logone Valley, Chad-Cameroon (Sorlini *et al*., 2013). The result from these previous studies agrees with the findings of this study, as they reveal a similar relationship of a positive correlation between turbidity and faecal coliform densities, potentially impacting the health of the residents of Lodwar town.

5.1.2 Chemical properties of water across supply chains

5.1.2.1 Dissolved oxygen (DO)

Dissolved oxygen concentrations varied significantly across all water supply chains. That suggests that DO was influenced by various activities between the source and consumers, such as filling of tankers, transportation, hygiene of storage facilities, transfer to other storage facilities and storage. The boreholes recorded the lowest DO values, consistent with the result of other studies that underground water is low in DO. Factors such as the depth of the borehole, groundwater temperatures, and oxidation-reduction potential influenced DO concentrations, as similarly reported in Hong Kong, China (Zan *et al*., 2019). Depletion of dissolved oxygen in water supplies was reported to encourage microbial reduction of nitrate to nitrite and sulfate to sulfide. This was reported to cause an increase in the concentration of ferrous iron, with subsequent discolouration at the tap when the water is aerated (WHO, 2017). This assertion agrees with the results of this study, as nitrate concentrations were low at the boreholes, as were DO concentrations.

Across the water tankers' supply chain, the consumers' storage facilities recorded the highest DO value. The dissolved oxygen progressively increased as the water was being transported to consumers from the borehole, due to mixing and aeration as it interacted with atmospheric oxygen. Some tankers were not well covered during transportation, as observed during fieldwork. A report by WHO (2017) similarly noted that dissolved oxygen content of water was influenced by the source, raw water temperature, treatment, and chemical or biological processes taking place in the distribution system. Low concentrations of DO were recorded at the boreholes (low temperature), while high levels of DO were recorded at the consumers (high temperature) in this study. These results were contrary to the findings of Zan *et al*. (2019) in Hong Kong, China, where cold water had higher levels of DO, whereas warm water had a lower level. It is imperative to note that very high levels of dissolved oxygen may exacerbate corrosion of metal pipes or tanks, according to WHO (2017). This is a risk that water tankers (those made of steel) in Lodwar town may be exposed to. Nevertheless, no health-based guideline value has been recommended for DO in drinking water based on the WHO (2017) standards. DO correlated significantly with faecal coliforms in this study, similar to the findings of Shamsudin *et al*. (2016) in Shah Alam, Malaysia, where high concentration of DO was reported to increase microbial inactivation in water, hence inversely correlated. However, this observation was contrary to the findings of this study, as dissolved oxygen increased as faecal coliforms increased. That was attributed to the effects of relatively high surrounding temperatures, which accelerate microbial activity as explained above.

Kiosks' distribution tank and consumers' storage tanks recorded higher Dissolved oxygen (DO) concentrations compared to the borehole and kiosk levels. At the distribution tanks, increased DO could be due to aeration, as it was observed that the tanks were not lidded, and the photosynthetic effect of algae was also witnessed in the tanks. The DO levels decreased from the kiosk's level across the kiosks' supply chain. This may be ascribed to water piping from the distribution tank to the kiosks and the surrounding high temperature, which decreases the dissolution of oxygen in water. In a study conducted by Wang *et al.* (2022), long hydraulic retention time of water in pipes was noted to cause a decrease in DO concentrations, potentially deteriorating water quality. Moreover, DO concentration in water was reported to be influenced by the source, water temperature, treatment, and chemical or biological processes taking place in the distribution system (WHO, 2017). These factors may be responsible for the significant variance of DO across the kiosks' supply chain in Lodwar town. They include increased DO levels at the consumers, which could be attributed to aeration during storage, use and transfer of water to other storage containers.

The DO concentrations increased across the piped water supply chain, with the highest value being at the consumers. This was contrary to the findings of Lukubye and Andama (2017) in Mbarara Municipality, Uganda, where a decrease in DO was reported when the temperature increases. Similar trend observed in this study across the supply chain. Further, DO was expected to decrease with high retention time of water in the pipeline (Wang *et al*., 2022), which was not the case in this study, as the DO increased across the supply chain. This could be related to broken pipes witnessed across the piped system during field work, which could have provided pathways for aeration of the system. Additionally, increased DO concentrations at the consumers could be attributed to re-aeration and mixing of water when using and transferring to other vessels at consumers' storage tanks.

5.1.2.2 pH

The increased pH recorded at the tankers and consumers may be attributed to increased hydroxide ions (OH^-) from dissolved minerals such as iron, manganese, and calcium in the tankers during transportation to consumers. Consequently, the pH values recorded at all sampling points varied significantly across the supply chain, with tankers (7.71-8.36) and consumers (7.78-8.65) recording high ranges. Thus, an indicator of the significant influence of water pH from oxidation processes during transportation due to leachates and aeration in the tanks. The presence of dissolved substances like carbonates, dust, TDS and leachates from corrosion of tanks at the tankers or household storage facilities is implied by increased TDS, alkalinity and EC levels at the tankers in this study. A study conducted by Meride and Ayenew (2016) in Wondo Genet campus, Ethiopia, noted that the pH levels in water were mainly determined by the amount of dissolved carbon dioxide in water, which forms carbonic acid. However, pH levels recorded in this study were alkaline in all sampling sites, suggesting the addition of hydroxide ions. Further, other studies have reported several factors influencing water pH including water sources, water storage tanks or vessel materials, temperature, mineral absorption, dust, level of bacterial activity in a vessel, and duration of water storage before use (Packiyam *et al*., 2016) and in a systematic review of literature (Manga *et al*., 2021). These suggestions may explain the increased pH at the tankers and consumers in this study. Thus, the tanker water across the supply chain was slightly alkaline as the pH recorded in all sampling points was above 7, falling within WHO recommended range of 6.5 – 8.5. This compares with the findings obtained earlier in Bengaluru, India, where pH was within acceptable standards in tanker water (Joseph & Sibi, 2020).

The pH of water across the kiosks' supply chain significantly varied, with a slight increase at the distribution tank and consumers' levels. This was attributed to possible contamination of water at the distribution tank due to dissolved ions, storage time and unhygienic conditions of storage facilities. As observed in the field, the kiosks' distribution tanks were made of plastic, open and birds' waste and algae were seen in and on top of the tanks. The presence of organic matter and other dissolved substances such as carbonates, bicarbonates and hydroxides was reported to influence water pH in a study conducted in Wondo Genet campus, Ethiopia (Meride & Ayenew, 2016). As well, airborne contaminants like dust or algae, when they grow in the storage facilities, produce weak carbonic acid, lowering the pH of water as reported in Bindura district, Zimbabwe (Hoko, 2008). This was contrary to the result obtained at the kiosks' distribution tank in this study.

Across the piped water supply chain, the water pH varied significantly, attributed to the diluting effect of the two boreholes at the concrete main distribution tank, periodic addition of chlorine at the tank, and storage at various sampling sites. For instance, cleaning the main distribution tank at the resource centre was not regularly done, pointing to the presence of leachate and biofilm formation in the tank. Concrete has been reported to be of high pH in nature because calcium hydroxide is produced as a byproduct of cement hydration, and concrete paste leaching increases calcium carbonate content (Neville, 2001; Nwoke *et al*., 2019). This could have led to conversion of carbon derivatives such as carbonates, bicarbonates and carbon dioxide concentrations affecting pH within the piping system. Presence of dissolved ions in piped water was also reported in Wondo Genet campus, Ethiopia, to influence water pH (Meride & Ayenew, 2016). The water pH was considerably higher at the consumer storage facilities compared to other sampling sites. This could be due to prolonged storage, which was reported to increase water pH in Al-Karak province, Jordan (Ziadat, 2005) and Jimma, Ethiopia (Chalchisa *et al*., 2017).

Across all the supply chains, the water pH significantly varied in all sampling points. This implies that different factors, as explained above, influenced water pH. However, the pH levels recorded across the supply chains were within WHO recommended guidelines of 6.5 – 8.5 for drinking water (WHO, 2017). Notably, all sample sites recorded pH values above 7, implying that the water was slightly alkaline but safe for drinking.

5.1.2.3 Total alkalinity

The recorded increased total alkalinity levels across the water tankers supply chain, with a slight decrease at the consumer storage tanks, could be attributed to vendors' water handling during filling, transportation or transfer between the source and consumers' households, although it was not significantly different. At the tankers, the high alkalinity concentration could be a result of dissolved ions that contain carbonate, bicarbonate and hydroxide ions, coupled with rusting of metal tanks forming iron oxide (Fe_2O_3). Similar observation was reported in Zamora, Mexico (Reyes-Toscano *et al*., 2020), where increased alkalinity in water was associated with environmental factors or presence of contaminants that contained carbonate, bicarbonate and hydroxide compounds. This could explain alkalinity trends in this study because sampling points were possible recontamination pathways across the supply chain. The presence of carbonate, bicarbonate and hydroxide ions in water influenced its buffering capacity to neutralize acids and bases, impacting the stability of pH levels. This was further witnessed in increased levels of TDS, pH, temperature, EC and salinity in this study. Similar findings were reported in Tamil Nadu, India, where an increase in carbonates, bicarbonates and hydroxide ions positively influenced total alkalinity in water (Jothivenkatachalam *et al*., 2010). The slight decrease of total alkalinity at the tankers' consumers could be associated with mixing of water from different sources, as witnessed during field work.

The concentration of total alkalinity across the kiosks' supply chain slightly varied from the source to the consumers. This variance was attributed to the presence of salts or compounds containing carbonates, bicarbonates and hydroxide ions, which increases total alkalinity in water as observed by Jothivenkatachalam *et al*. (2010) in Tamil Nadu, India. The associated compounds could include leachate at the storage tanks or from dust, organic matter and biofilm observed at the kiosk distribution tank. At the consumers' storage tanks, the slight increase in the concentration of total alkalinity could be due to several factors which also influenced water pH. These factors include the presence of dissolved contaminants from sediments during storage, formation of biofilm due to lack of cleaning, long storage time or mixing water from different sources. This observation compares with the high pH range obtained at the consumers' level in this study. Thus, contaminants containing carbonate, bicarbonate and hydroxide compounds at the consumers increased alkalinity levels, as observed in Zamora, Mexico (Reyes-Toscano *et al.*, 2020).

The distribution tank recorded the lowest levels of total alkalinity across the piped water supply chain. This may be due to the dilution effect as the two-source boreholes supplied water to it. On the other hand, the taps level recorded the highest total alkalinity levels across the piped water supply chain. Increased concentrations recorded at the taps could be from the effect of water supply disruptions and broken pipes, as witnessed immediately after the distribution tank, which could lead to oxidation and recontamination of water along the way. Similar to increasing pH trends across the supply chain, it revealed contaminants such as bicarbonate and hydroxide compounds were present in water, comparing to results obtained in Tamil Nadu, India by Reyes-Toscano *et al*., (2020). Across the supply chain, the concentrations of alkalinity were significantly different, especially the mean differences between the taps and borehole 1A and the distribution tank, related to the discussion above. However, the recorded values were within permissible WHO guidelines of 600 mg/L for drinking water, similar to results obtained in another study in West Bengal, India (Mitra *et al*., 2018).

The total alkalinity concentrations recorded across all the supply chains were within acceptable WHO guidelines for drinking water. This implied the water in Lodwar town was safe for drinking. This speaks to the stability of water pH due to the buffering capacity of total alkalinity as pH levels recorded across the supply chains were above 7.

5.1.2.4 Electrical conductivity (EC)

The electrical conductivity (EC) across the three supply chains slightly varied among sampling sites but was not significantly different. The EC values recorded in all the sampling points were below the WHO acceptable guideline of 400 µS/cm (WHO, 2017) for drinking water. This suggests that the water supplied in Lodwar town was safe for drinking. Further, it infers that vendors' activities across the supply chain had minimal influence on water EC during transportation from the source to the consumers. However, some boreholes' water in Turkana was reported in other studies to exceed the WHO acceptable EC guidelines of 400 µS/cm (Rusiniak *et al*., 2021; WHO, 2017). A study conducted by Meride and Ayenew (2016) in Wondo Genet campus, Ethiopia, observed that water with low EC levels was less ionized due to the presence of low concentrations of dissolved solids. This could explain the low EC and TDS concentration recorded at the boreholes in this study. The tankers recorded the highest EC values across the supply chain compared to other sampling sites. This points to the presence of dissolved ions leachates in the tanks favoured by high temperature and pH, responsible for chemical activity at the tankers. It is further supported by the higher concentration of TDS recorded at the tankers in this study. These results agree with assertions that EC increases as temperature and pH increase, similar to observations by Hoko (2008) in Bindura District, Zimbabwe. Further, he also reported that EC had a linear relationship with TDS and could be used to measure salinity in water. This explains the findings in this study, as EC correlated positively with TDS and salinity at the 0.01 significance level using the Pearson correlation analysis test.

The increased EC concentrations across the kiosks' supply chain may be an indication of progressive presence of dissolved substances in water, as observed in the increasing trend of TDS from the source to the consumer. Similar trends of a positive relationship between EC and TDS have been reported in other studies (Hoko, 2008). However, the observed EC variance across the supply chain was within the acceptable WHO standard for drinking water. This suggests dissolved ions in the water were minimal to influence water EC, similar to the observation at Wondo Genet campus, Ethiopia, by Meride and Ayenew (2016). Despite that, the increased EC values were observed at the consumer households compared to other sampling sites. This indicates increased dissolved ions in the consumers' stored water, probably due to poor tank handling, cleaning, transfer to other containers, prolonged storage or mixing of water from other sources with different quality, similar to results reported for Bindura District, Zimbabwe (Hoko, 2008).

Electrical conductivity recorded relatively varied across the piped water supply chain but was not significantly different. This suggests that very few dissolved solids were added to the system across the supply chain to cause ionization of water to influence water EC as reported in other studies (Meride & Ayenew, 2016). The EC values decreased at the distribution tank with a slight increase at the taps and consumers compared to the high value at borehole 1B. The values recorded at the distribution tank could be attributed to the fact that the tank received water from two boreholes. Thus, the dilution effect contributed to the low EC values recorded at the tank, similar to the results of Salehi (2022) that blending water from different sources could alter its water chemistry. Nevertheless, the high EC values at borehole 1B could be due to increased TDS from ions leached from geological processes at the borehole, pointing to the presence of dissolved ions like carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, and organic ions in water. Similar results were reported in some groundwater sources in Mbarara municipality, Uganda (Lukubye & Andama, 2017).

5.1.2.5 Salinity

The concentration of salinity slightly increased across the tankers ' supply chain, which was attributed to leachates from the tanks or other dissolved substances. That could be an indicator of some level of corrosion in the tankers. This was evident through increased concentrations of TDS, EC and chloride across the supply chain, similar to results documented by Hoko (2008) in Bindura District, Zimbabwe. Further, an increase in these values may also be due to the mixing of water from various sources with different characteristics. This was a common practice among water tankers in Lodwar. Other times, some of these tankers ferried water for construction whose sources could be rich in suspended and dissolved solids. The positive correlation between EC and salinity infers that EC could be used to measure salinity in water.

The kiosks' distribution tank and taps recorded salinity levels slightly above the borehole and consumer storage tanks, although not significantly different across the supply chain. This could be due to increased TDS concentrations at the two sampling points. The results of this study compare with the findings of other studies conducted in Bindura District, Zimbabwe, which reported a positive relationship between salinity and TDS in water (Hoko, 2008). The water salinity slightly reduced at the consumers, which could be attributed to possible households' water handling practices like filtration, as suggested by Shammi *et al.* (2019) in Bangladesh.

Water salinity levels were relatively similar at the boreholes, distribution tank and taps, with a slight increase at the consumers', although not significantly different across the piped water supply chain. This implies that water handling (collection or treatment) and storage at the sampling points had minimal influence on water salinity. The slight increase in salinity at consumers could be associated with households' water handling, storage and use. There is a possibility that consumers were mixing water from several sources with different characteristics, as observed by Salehi (2022). He further reported that this practice could lead to the addition of dissolved salts in water, although this was not reflected in the patterns of EC and TDS in this study. A study conducted in Bindura District, Zimbabwe, recommended that EC could be a good measure of water salinity because of their close relationship, which influences the taste of water (Hoko, 2008).

Salinity levels across all water supply chains in Lodwar town slightly differed, but not significantly different. This revealed that vendors' activities, transportation, water handling and storage had minimal influence on water salinity.

5.1.2.6 Total dissolved solids (TDS)

Higher TDS levels were recorded at the tankers compared to other sampling sites across the water tankers' supply chain. This was associated with corrosion and leachates from the tankers or biofilm formation observed in some tankers. The leachates in tankers may include organic and inorganic substances, including dissolved and suspended solids, heavy metals, various chemicals and pathogens associated with the fact that most tankers were not regularly cleaned as observed in the field. The TDS levels at the tankers aligned with increased sulfate, chloride, fluoride, EC, salinity and pH at the tankers. Further, high temperatures recorded at the tankers could have increased the dissolution of ions at the tankers. Similar findings were reported by Lukubye and Andama (2017) in Mbarara Municipality, Uganda. Reduced TDS at the tanker consumers could be due to mixing of water from other sources, as observed at some consumers' households.

The slight increased TDS at the kiosks' level could be due to dust, silt, dissolved salts & minerals, and birds' wastes. It was witnessed that the distribution tank was sometimes left open. Similar findings were obtained by Lukubye and Andama (2017) in Mbarara Municipality, Uganda, where carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, and organic ions were reported to influence water quality. Further, the TDS levels at the kiosks' level could have been influenced by biofilm formation in the pipe system, which could have formed during supply disruptions witnessed during field work. Among the consumers, the slight decrease in TDS could be related to the dilution effect from mixing water from different sources, as widely practised by consumers in Lodwar town.

Across the piped waters supply chain, the observed TDS variance at the sampling points was relatively similar after the distribution tank. This could be explained by the dilution effect brought by mixing water from the two different boreholes at the distribution tank. This compares with the findings of Salehi (2022) in a global review that mixing water from several sources influences its water chemistry. The increased TDS concentrations at borehole 1B could be attributed to the geology of the area and presence of dissolved ions such as calcium, magnesium, potassium, sodium, bicarbonates, chloride and sulfate in groundwater. This was further revealed by the increased EC concentration of the borehole water. This agrees with the findings of Lukubye and Andama (2017) of water sources in Mbarara municipality, Uganda. The TDS trend observed in this study related to the EC concentrations across the supply chain, which was affected by dissolved ions in water as reported in Uttarakhand, India, by Kothari *et al*. (2021). Similarly, they underpinned that TDS obtained in drinking water from Uttarakhand, India, directly correlated with turbidity, hardness, alkalinity and conductivity.

The total dissolved solids (TDS) concentration across all water supply chains was not significantly different, although it varied at the sampling sites. This implies that vendors' activities, transportation, and storage from the source to consumers had minimal influence on the water TDS. The TDS concentrations recorded across all the supply chains were way below the WHO and WASREB acceptable standards of 600 mg/L and 1500 mg/L respectively (WASREB, 2008; WHO, 2017). This implies the water was safe for drinking. Drinking water with TDS levels above 1000 mg/L was considered unpalatable water and could result in excessive scaling in water pipes, heaters, boilers, and household appliances, according to WHO (2022).

5.1.2.7 Sulfate

Although sulfate concentration in drinking water is not of health concerns (WHO, 2017), it was important to identify their concentrations as high levels make water taste bitter. The slight increase in sulfate concentrations across the water tankers' supply chain could be attributed to the fact that aerated or chlorinated water could oxidize possible present sulfide to sulfate, as reported by WHO (WHO, 2017). This becomes a concern since borehole water was found to have low dissolved oxygen, which was aerated during transportation to consumers, as observed in this study. Further, the significant variance of sulfate concentration at the sampling points, especially between the borehole and all the other sampling points, may be due to the presence of mineral deposits from storage tank leachates or re-suspended sediments resulting in bad taste as observed in Uttarakhand, India by Kothari *et al*. (2021). Hence, the likelihood that vendors' water handling during collection, transportation and transfer to customers' storage tanks between the source and the consumers could have influenced sulfate concentrations in water. That notwithstanding, the sulfate levels recorded in this study were way below WHO recommended value of not more than 250 mg/L for drinking water safety. This was an indication that water delivered by tankers was safe, which compares to results reported in Molo Town, Kenya (Chebet *et al*., 2010).

The sulfate concentrations across the kiosks' supply chain slightly increased at the distribution tank and later decreased at the consumer households. The slight increase of sulfate at the distribution tank could be due to mineral deposits from the borehole's underground rocks or storage tank sediments and leachates, as similarly suggested by Kothari *et al*. (2021) in Uttarakhand, India. The sulfate levels were not significantly different in all sampling points, an indication that water storage at the distribution tank and consumers had minimal influence on it. The sulfate values recorded in all sampling sites were extremely low compared to the WHO and WASREB permissible values of 250 mg/L and 400 mg/L for drinking water respectively (WASREB 2008; WHO, 2017).

The sulfate concentrations across the piped water supply chain were below WHO and WASREB permissible values of 250 mg/L and 400 mg/L for drinking water (WASREB, 2008; WHO, 2017). This observation infers that the water was fit for human consumption, similar to results obtained in Molo Town, Kenya (Chebet *et al*., 2020). According to Kothari *et al*. (2021), sulfate in water could result from infiltration of industrial effluents or mineral deposits from underground rocks, and its high levels impart a bad taste in water. This may explain the slightly increased sulfate levels at the storage distribution tank made of concrete, which may harbour mineral deposits.

Sulfate levels across all the supply chains were below the WHO and WASREB recommended standards, as explained above. This infers that the water was safe for drinking, and vendors' activities across the supply chains had minimal influence on water sulfate.

5.1.2.8 Chloride

The presence of chloride in water has been reported to increase the EC of water, hence increasing its corrosivity and bad taste (WHO, 2017). This scenario may be true in this study as both EC and chloride increased at the tankers' level, hence the possibility of exacerbating corrosion in tankers. However, there was no significant influence of water handling processes on the levels of chloride ions across the supply chain. The public drinking water standards require the chloride level not to exceed 250 mg/L (Kumar & Puri, 2012; WASREB, 2008; WHO, 2017). The results obtained in this study were within permissible guidelines, agreeing with Okoko and Idise's (2014) observations at Delta State University, Nigeria, where chloride was within permissible standards in pipe-borne water. The higher levels of chloride at the tankers may be associated with corrosion of metals due to rust, similar to the results of tanker water in Bengaluru, India (Joseph & Sibi, 2020). Further, 18% of the water samples they collected from tankers in Bengaluru, India, had higher chloride content, hence did not qualify for drinking water purposes, unlike this study.

The chloride concentrations across the kiosks' supply chain decreased from the borehole towards consumer households. The high chloride levels at the borehole could be attributed to underground soil characteristics as well as the weathering processes, leaching of sedimentary rocks and soil, and domestic and municipal effluents, as reported in another research in Kumasi, Ghana (Boadi *et al*., 2020). However, chloride concentration across the kiosks' supply chain was not significantly different and was below the WHO/WASREB permissible guideline value of 250 mg/L in drinking water (WASREB, 2008). Thus, an indication that water handling and vendors' activities, including storage between the source and consumers, had minimal influence on water chloride levels. Chloride has been reported to increase the EC of water, hence increasing its corrosivity (WHO, 2017). This could affect other parameters influencing water chemistry.

Chloride concentrations across the piped water supply chain decreased at the distribution tank. This was attributed to dilution influence since the distribution tank received water from two boreholes, agreeing with the findings of Salehi (2022) in a global review, where dilution influenced water quality. At the tap level, there was a slight increase in chloride and

EC across the piped water supply chain, which could have resulted from leachates and possible corrosion.

The chloride concentrations recorded in all sampling points across the three supply chains were within permissible levels of 250 mg/L maximum as set by WASREB (2008) for drinking water. This implies the water in Lodwar town was safe for drinking, similar to results obtained in Delta State University, Nigeria, where chloride levels were within permissible standards in pipe-borne water (Okoko & Idise, 2014).

5.1.2.9 Fluoride

The fluoride levels across the tankers' supply chain differed at the sampling points but were not significantly different. Fluoride concentration was slightly higher at the boreholes compared to the standpipe, though they were within the WHO acceptable guideline value of 1.5 mg/L for drinking water (WHO, 2017). The presence of fluoride at the boreholes was associated with chemical weathering of minerals containing fluorine in parts of Turkana (Rusiniak *et al*., 2021) and volcanic rocks in crystalline basement aquifers in Marathon County, Wisconsin (Ozsvath, 2006). Thus, vendors' activities (filling at the standpipes, transportation, cleaning of tankers and transfer to consumer tanks) across the supply chain did not contribute significantly to fluoride level fluctuations in water. Abdurahman and Zewdie (2018) reported that fluoride levels in water depend on the geology of the area and the depth of the borehole, as observed in Hawassa city, Ethiopia. Further, Alarco´n-Herrera *et al*. (2013) suggested that fluoride concentrations were influenced by alkalinity, bicarbonate concentrations and electrical conductivity in groundwater, especially in semi-arid regions in Latin America. In the case of Turkana, a previous study observed that some boreholes/wells had fluoride concentrations (range of 0.15–5.87 mg/L) exceeding WHO recommended levels of 1.5mg/L, contrary to the findings of this study (Rusiniak *et al*., 2021). Further, they noted that high fluoride levels in drinking water caused health-related risks like dental or skeletal fluorosis or hypocalcaemia when calcium fluoride (CaF_2) precipitates in human tissues.

The highest levels of fluoride across the kiosks' water supply chain were recorded at the borehole, and consumers with the lowest level recorded at the kiosks' level. At the borehole, the presence of fluoride could be related to the fact that fluoride occurs naturally in groundwater. Similarly, other studies have associated high fluoride levels at the borehole to chemical weathering of minerals containing fluorine and volcanic rocks in crystalline basement aquifers in studies conducted in Turkana County, Kenya and Marathon County, Wisconsin (Ozsvath, 2006; Rusiniak *et al*., 2021). These findings could explain fluoride concentration variance across the supply chain. Further, it has been reported that fluoride concentrations are influenced by alkalinity, bicarbonate concentrations and electrical conductivity, which explains the varying total alkalinity and EC concentration in all sampling sites in this study (Abdurahman & Zewdie, 2018; Alarco´n-Herrera *et al*., 2013). The level of fluoride at the kiosks' consumers could be a consequence of mixing water from different water sources, as commonly practised in Lodwar town, coupled with other factors explained above.

Fluoride levels across the piped water supply chain decreased from the distribution tank towards the consumer endpoints. This was a clear indication that dilution due to mixing water from the two boreholes at the distribution tank plays a role in influencing its subsequent water quality, including fluoride. This is further supported by the findings of other studies, as explained in the previous section, where fluoride concentrations in water were influenced by EC and total alkalinity concentrations (Abdurahman & Zewdie, 2018; Alarco´n-Herrera *et al*., 2013). It has been reported in other studies that fluoride in drinking water had a significant influence on teeth and bones because it strengthens enamel and bones by replacing hydroxide ions from hydroxyapatite, $Ca_5(PO_4)_3OH$, an essential mineral of teeth, according to Woldu (2020). This fact underpins the importance of fluoride in drinking water.

The fluoride concentrations recorded across all the water supply chains in Lodwar town were within the acceptable fluoride value of 1.5 mg/L for drinking water quality according to WASREB (2008) and WHO (2017) guidelines. The result of this study compares with the findings of Sukumaran *et al*. (2015) in groundwater in Bihar, India, where fluoride levels were within acceptable guidelines. However, a previous study in Turkana suggested that fluoride levels in some boreholes were above recommended acceptable guidelines (Rusiniak *et al*., 2021), suggesting water in parts of Turkana may not be fit for drinking.

5.1.2.10 Lead and iron

Lead (Pb) ions could damage the adult nervous system, digestive system, lead to children's growth retardation, loss of appetite, walking inconvenience, lack of concentration and mental retardation according to Yu *et al*. (2020). On the other hand, Porter and Rawla (2017) suggested that iron (Fe) ions overload or high levels in the human body may lead to a genetic disorder called *Haemochromatosis,* which could damage parts of the body such as the liver, joints, pancreas and heart. The above effect on humans makes the two ions important to measure in drinking water.

The concentrations of iron and lead ions in this study were below detectable levels across the water tankers, kiosks and piped water supply chains. This infers that the parameters were within permissible WHO guideline values of 0.03 mg/L for iron and 0.01 mg/L for lead (WHO, 2017). The results obtained in this study agree with the findings of Kothari *et al*. (2021)

in Uttarakhand, India, who reported similar results. However, the findings of this study are contrary to the observations of Awere and Anornu (2016) in Cape Coast Metropolis, Ghana, where higher levels of iron were associated with rust in water tankers. Therefore, the result of this study suggests that water tankers in Lodwar town had minimal rust since iron concentrations were below detectable levels. The major source of lead in drinking water is mainly reported in plumbing materials, coupled with alkalinity and pH influence on lead and iron in water, as observed by Lasheen *et al*. (2008) in drinking water pipes in Egypt.

5.1.2.11 Free residual chlorine (FRC)

There was no Free Residual Chlorine (FRC) detected at the borehole, standpipe and tankers, implying there was no chlorination/treatment of water undertaken at the sampling sites, exposing water to possible contamination across the tankers' supply chain. Kothari *et al*. (2021) reported similar results for borehole water in Uttarakhand, India. However, during this study, FRC of 0.19±0.40 mg/L was detected at the consumers' level, indicating possible water treatment at the household level. This could be attributed to an observation in the field where some tanker customers added chlorine disinfectants like Aqua tabs, Water Guard or P&G purifier of water (formerly PUR) in the stored water before consumption. The values recorded at the consumers' households were within recommended FRC acceptable levels of 0.02 mg/L (WHO, 2017), effective to protect water against microbial reinfection from the point of chlorination to the point of use (WASREB, 2008).

Free Residual Chlorine across the kiosks' supply chain was not detected at any of the sampling points. This reveals that the water was not treated before being supplied to the consumers at the household level. The findings of this study compare with results obtained by Kothari *et al*. (2021) in all water samples tested in Uttarakhand, India, where chlorination was not detected. This creates a high risk of water contamination across the supply chain, exposing consumers to waterborne disease risks.

Across the piped water supply chain, FRC was only detected once in two taps out of 22 taps over the study period. In all other sampling sites across the supply chain, FRC was not detected. This finding was contrary to information given by the water utility that the water was treated at the distribution tank twice a week. The fact that FRC was only detected once at the taps implies that the treatment of water, as claimed by the water utility, was not regular, or chlorine dosing was insufficient. Thus, the water was not well protected against microbial reinfection, posing waterborne diseases among the consumers. Therefore, the partial detection of FRC across the piped water supply chain in this study could be attributed to insufficient chlorine dosing, long residence time of water at the distribution tank and presence of dead zones in storage tanks as observed in La Sirena, Cali, Colombia by Araya and Sanchez (2018). Inadequate residual chlorine or lack of water treatment could lead to possible contamination of water that may be a public health threat to the consumers unless treatment is done at the consumption level, as reported in borehole water in Uttarakhand district, India (Kothari *et al*., 2021).

The observation from the field during this study indicated that no treatment of water happened at the boreholes. However, the water utility claimed to add chlorine twice a week at the distribution tanks (for piped and kiosks supply chains), which could not be verified when measured during field work, except the one incident at the two taps. This observation agrees with the findings of high faecal coliforms in this study, which indicates microbial contamination of water. Such water, as explained above, is unsafe for drinking unless treated before consumption.

5.1.3 Nitrogen derivatives across water supply chains

The nitrogen derivatives (NO_3, NH_4 and NO_2) across the tankers' supply chain recorded relatively the same values at the sampling points. Hence, not significantly different across the supply chains. Temperature correlated significantly with ammonium and nitrite across the tankers' supply chain, favouring oxidization of ammonia to nitrite. This reveals an existence of microbial activity that favoured nitrification in water, similar to findings by Rantanen *et al*. (2018) for the drinking water distribution system in the Helsinki Metropolitan area, Finland. Ammonium (NH_4-N) levels across the water tankers supply chain slightly differed in all sampling points, with the borehole levels of 0.04259 mg/L agreeing with the WHO report that ammonia in most cases was below 0.2 mg/L in groundwater sources. Consequently, high ammonium concentrations in water could indicate bacterial, sewage and animal waste pollution (WHO, 2022). High ammonium in water could react with chlorine to reduce free chlorine, leading to the formation of carcinogenic chloramines, exposing consumers to a health risk (WHO, 2022). Rantanen *et al*. (2018) asserted that free ammonia enhances nitrification in water, leading to an increase in nitrite levels, which are further oxidized to nitrate in the presence of oxygen.

Nitrite concentrations slightly differed between the standpipe and the borehole, suggesting a possibility of nitrification at the standpipe. This could further be related to dissolved oxygen increasing trends across the supply chain observed in this study, favouring nitrification. This was expected due to low oxygen concentration at the borehole. Thereafter, the concentration reduced due to conversion to nitrate as oxygen levels increased, as per the result above. A previous study on nitrite levels in groundwater in Turkana suggested that nitrite levels exceeded WHO standards for potable water of 3mg/L in 28.51% of water samples they assessed, contrary to this study (Rusiniak *et al*., 2021). Also, nitrite levels in water were influenced by microbial action, which reduces nitrate to nitrite in reduced oxygen conditions, attributed to its significant distribution across the supply chain (WHO, 2017). However, the nitrite levels obtained in this study were within WHO and WASREB permissible levels of less than 3 mg/L and 0.5mg/L in drinking water, an indication of safe water.

Nitrate (NO_3-N) concentrations across the tankers' supply chain were not significantly different, although it was recorded at all sampling sites. This implied that vendors' activities like filling of water, transportation, transfer and storage at the consumers had minimal influence on nitrate concentration. Further, it points to low oxidation potential and less interaction among nitrogen derivatives in water, which, in the presence of favourable temperature and sufficient alkalinity, enhance nitrification processes such that ammonia is oxidized to nitrite, and then nitrate. The nitrate levels recorded across the supply chain were within WHO permissible levels of less than 50 mg/L in drinking water, agreeing with the findings of Adimalla and Qian (2019) in Telangana, India. Similar results were reported by Meride and Ayenew (2016) in a water supply in Wondo Genet campus, Ethiopia. Contrary to this study, Rusiniak *et al*. (2021) reported that some boreholes' water in Turkana exceeded WHO permissible standards for nitrate, which may lead to health risks such as *methaemoglobinaemia* and thyroid effects (WHO, 2017).

Across the kiosks' supply chain, the concentrations of ammonium and nitrite were within the WHO permissible standards of 3 mg/L and 0.5 mg/L for nitrite and ammonium in drinking water (WHO, 2017). The two parameters recorded similar trends across the supply chain, agreeing with the finding of Rantanen *et al*. (2018), who suggested that free ammonia encourages nitrification in water, leading to an increase in nitrite levels. The increased nitrate concentrations at the kiosks may be attributed to organic pollution at the distribution tank due to the presence of birds' droppings observed at the top of the distribution tank during field work. This was an indication that water could easily get contaminated with these organic materials. Nitrate significantly varied across the kiosks' supply chain, a clear indication that vendors' water handling, storage and hygiene of the storage tanks/containers influenced the distribution of nitrate. Nevertheless, nitrate levels were within the WHO permissible limit of less than 50 mg/L for drinking water (WHO, 2017). This study result concurs with the findings of other studies in Telangana, India (Adimalla & Qian, 2019) and Wondo Genet campus, Ethiopia (Meride & Ayenew, 2016), where nitrate was within permissible levels in drinking water. This was contrary to the observation of Rusiniak *et al*. (2021) for borehole water in Turkana, where nitrate concentrations exceeded WHO permissible standards.

The concentrations of Ammonium across the piped water supply chain were within the WHO permissible value of 0.5 mg/L for safe drinking water. This implies that water handling and storage at the sampling points had less influence on its levels (WHO, 2017). Other studies have reported that free ammonia may increase nitrite concentrations in water as a result of the nitrification process, as observed in a drinking water distribution system in the Helsinki Metropolitan area, Finland (Rantanen *et al*., 2018). Nitrite concentrations slightly decreased from the boreholes to the tap level, with a slight increase at the consumers' households. This could relate to mixing two borehole waters at the distribution tanks and the nitrification process, where nitrite is converted to nitrate. This is further revealed by increasing dissolved oxygen trend observed in this study.

The nitrite levels across the piped water supply chain were within the WHO accepted guideline of 3 mg/L in drinking water, indicating safe water (WHO, 2017). This observation varies with the findings of Rusiniak *et al*. (2021), where nitrite levels in some groundwater samples in Turkana exceeded WHO standards for potable water. The nitrate concentrations slightly varied across the piped water supply chain, but the values detected at various sampling points were not significantly different. This means that water handling and storage from the source to the consumers had less influence on its levels, which were within the WHO acceptable guideline of 50 mg/L for drinking water, similar to the findings of a groundwater study in Bihar, India (Adimalla & Qian, 2019; Sukumaran *et al*., 2015).

The nitrogen derivatives across all water supply chains in Lodwar town were within acceptable WHO (2017) guidelines for drinking water. This implies that the water supplied in Lodwar town was safe for human consumption as it met recommended standards. However, the results of this study were contrary to those of other studies in different parts of Turkana, as explained above.

5.2 Faecal coliform densities across water supply chains

5.2.1 Water tankers supply chain

Contamination of water across the tankers' supply chain could occur at the sampling points, either at the borehole, standpipe, tankers during transportation or at the consumers' storage tanks. Groundwater sources (boreholes) were expected to be of better water quality as reported for borehole water in Benin metropolis, Edo State, by Onajite *et al*. (2018) and Kumasi, Ghana, by Boadi *et al*. (2020). For this reason, boreholes are commonly used as drinking water sources in many places, including in Lodwar town. The low levels of faecal coliform densities at the borehole water could be attributed to inhibition of bacterial growth due to its cold temperatures, similar to the findings of Stoler *et al*. (2014) in Accra, Ghana. Contamination at the standpipe may have resulted from poor handling and contaminated filling pipes.

Across the supply chain, the faecal coliform densities increased from the borehole to tankers, with a slight decrease at the consumers' storage tanks. This pointed to increased contamination of water across the supply chain. These results compare with the findings of Opryszko *et al.* (2013) in rural Ghana, who suggested that vended water quality degrades during transportation and storage. Hence, it is observed in this study that subsequent sampling points after the borehole, including the consumers' level, had high faecal coliform densities. This is due to recontamination by suspended solids, poor handling or inadequate residual protection that may exist across the transportation chain, as portrayed by increased faecal coliforms in tankers. Consequently, other studies have reported that bacterial contamination in tanker water may be due to inadequate water disinfection, similar to results reported in Makkah Al-Mokarama, Saudi Arabia, by Mihdhdir (2009) and Bengaluru, India, by Joseph and Sibi (2020). This assertion may apply to Lodwar town since the water supplied to water tankers and subsequently delivered to the consumers' households was neither treated at the source nor by water tanker vendors.

In Kenya, fixed point water suppliers such as public taps and water kiosks were classified in a report by UNDP as safer and more affordable compared to mobile water vendors such as pushcarts and tankers since vendors obtain water from several unverified sources (UNDP, 2011). Contrary, Whittington *et al*. (1989) in Ukunda, Kenya, reported that consumers perceived water tankers as of good water quality, though no water quality testing of the vended water was done. In Cape Coast Metropolis, Ghana, tanker water was associated with outbreaks of diarrhoeal diseases in a study conducted by Awere and Anornu (2016).

The high faecal coliforms in tanker water have been associated with improper tank cleaning coupled with increased temperature, which may support microbial growth as noted in Bindura District, Zimbabwe (Hoko, 2008). This study's findings agree with the results obtained by Awere and Anornu (2016) in Cape Coast Metropolis, Ghana, that water from tankers had poor quality when measured against the WHO guidelines of zero (0) CFU/100mL, as it failed in bacteriological characteristics. This was attributed to poor management, including improper cleaning and lack of disinfection. Similar to the results of this study, increased levels of *E. coli* in water supplied by tankers and other mobile vendors were reported in Cape Coast, Ghana and Njoro, Kenya (Macharia *et al*., 2015; Obeng *et al*., 2010).

On the other hand, contamination at the consumer household's tanks occurred because the tanks were not regularly cleaned, encouraging biofilm formation or due to improper handling, like transferring water to different containers, as documented by Awere and Anornu (2016). The slight decline of faecal coliform densities recorded at the consumers' may be due to household-level water treatment. This is because some consumers were observed during field work to practice household-level water treatment methods such as boiling or the addition of chlorine purifiers like Water Guard, Aqua Tabs, P&G Purifier or filtration. These practices reduce faecal coliforms as they kill parasites, bacteria and viruses in water. However, the recorded presence of faecal coliforms in water at the consumer level poses a public health threat as suggested by Elimelech (2006) in a global review and studies conducted in Naivasha and Njoro in Kenya (Donde *et al*., 2013; Macharia *et al*., 2015).

Similar to the result of this study, faecal contamination of water at consumers' storage facilities compared to the taps, standpipes and borehole water was reported in Kenya and Ethiopia by Ayalew *et al*. (2014). Kwami and Sawyerr (2018) noted that vendors' activities, such as filling of tankers, transportation, and transfer of water to consumers' tanks, favoured microbial and faecal coliform contamination of water due to lack of proper cleaning and poor sanitation. The faecal coliforms obtained between the borehole and tankers were significantly different. This was attributed to vendors handling activities such as unhygienic handling at the standpipe and improper covering of tanks during transportation, which played a critical role in faecal contamination of water as observed by Gizachew *et al*. (2020) in Boloso Sore Woreda, Wolaita Zone, Ethiopia. Therefore, lack of treatment, poor hygiene, and sanitation at the source, either by the water utility and tanker operators, were identified as possible causes of poor quality of water delivered by tankers to residents of Lodwar town, similar to Obeng *et al.* (2010) observation in Cape Coast Metropolis, Ghana.

5.2.2 Kiosks supply chain

Across the kiosks' supply chain, the faecal coliform densities increased from the borehole to the consumer point of use, pointing to recontamination of water at all sampling points. The borehole recorded less faecal coliforms. This was attributed to the fact that the water source was groundwater with less contamination compared to other exposed sampling points, as suggested by Onajite *et al*. (2018) in Benin metropolis, Edo State and Boadi *et al.* (2020) in Kumasi, Ghana. Increased faecal coliform densities across the supply chain may also be due to water quality degradation at the households' storage, resulting in faecal contamination as reported in other studies (Macharia *et al*., 2015; Opryszko *et al.,* 2013). The contamination of water at the consumer households may have resulted from dirty hands during fetching or transfer to other containers, or the storage/transfer containers were not clean, as was observed in a study conducted by Gizachew *et al*. (2020) in Boloso Sore Woreda, Ethiopia.

According to WHO guidelines, drinking water sources are expected to be free from faecal contamination (WHO, 2017). In line with the current study, contamination at the source was attributed to the effects of floods, which destroyed boreholes, filling them with flash flood water observed during field work (personal communication from LOWASCO field staff) and also reported in research conducted in Anambra state, Nigeria and South Eastern Nigeria (Nwaiwu *et al*., 2020; Onuorah *et al.,* 2019). In such a situation, flushing by pumping out flood water and disinfection using sand filtration and high-strength calcium hypochlorite (HSCH) or calcium hypochlorite as high-test hypochlorite (HTH) was suggested by Godfrey and Ball (2003) in Kuito, Angola. Obeng *et al.* (2010), in a study conducted in Cape Coast, Ghana, asserted that poor management at the source was the cause of poor quality of water supplied to customers.

Contamination at the kiosks' distribution tanks may be due to inadequate treatment, similar to the observation of Gizachew *et al*. (2020) in Boloso Sore Woreda, Ethiopia. Birds' droppings were seen on the top of the kiosks' distribution tanks. Occasionally, the tanks were not well covered, indicating the likelihood of contamination from the birds, resulting in increased faecal coliform densities at the distribution tanks. At the kiosks' level, the water was received directly from the distribution tanks. Thus, contamination was directly related to the quality of the water at the distribution tanks and the hygienic condition of the outlet taps. Therefore, treatment of water at the distribution tanks and careful handling at the taps and consumer storage tanks could greatly improve water quality and reduce contamination risks. Similar results were reported in Luanda, Angola and Kathmandu, Nepal, where handling of water along the supply chain was identified as a major challenge to bacteriological water quality in a study conducted by Cain (2018). To address this, vendors in Luanda, Angola and Kathmandu, Nepal, used chlorination and reverse osmosis processes to treat water before delivering it to the consumers to improve its quality. Similar treatment processes should be adopted by vendors in Lodwar town and other areas where informal water supply plays a key role in water provision.

Water contamination at the consumer households' level was attributed to lack of/or inadequate treatment, poor hygiene conditions and contaminated storage facilities. Similar results were obtained in a study conducted in Gombe Metropolis, Nigeria (Kwami & Sawyerr, 2018). Howard and Bartram (2003) observed that consumption of poor-quality water by households was a key pathway for the transmission of infectious diarrhoeal diseases. The result obtained during this study agrees with the findings of Opryszko *et al.* (2013) in rural Ghana. The study suggested that recontamination pathways across the supply chain may have resulted due to unclean hands contact with stored water, mixing water from multiple sources, collection and storage vessels, transfer of water from one container to another, and source contamination (contamination at the borehole, kiosks or distribution tanks). These factors were also suggested in studies conducted in Kenya (Donde *et al*., 2013; Macharia *et al*., 2015).

5.2.3 Piped water supply chain

The faecal coliform densities were higher at the consumer households' level compared to the distribution tank. It was expected that the faecal coliforms would be eliminated because chlorination was done at the main distribution tank, and quality was maintained by residual chlorine in the distribution system before the water was supplied to the households. Consequently, contamination at the households' level may be because of lack of regular cleaning of the storage containers or tanks, broken pipes, poor handling (e.g., use of unsanitary dips) and unhygienic conditions such as lack of hand washing after visiting the toilets or before handling the water or inefficient treatment at the distribution tank, similarly reported by Gwibi *et al.* (2019) in Mohale Basin, Lesotho. The latter applied in this study since it was observed that there was no water treatment at the source, while treatment at the distribution tank was not regular. The results obtained in this study are consistent with the findings of Kwami and Sawyerr (2018) in Gombe Metropolis, Nigeria, where water storage facilities favoured microbial and faecal coliforms growth. This was due to lack of regular cleaning of such containers and storage facilities, coupled with lack of basic household treatment of drinking water and/or low levels of FRC in the system, resulting in faecal contamination. Opryszko *et al.* (2013), in a study conducted in Ghana, noted that water quality degrades during household storage, including faecal contamination. This explains the increased faecal coliform densities at the household level obtained in this study.

The presence of faecal coliforms at the water source (boreholes) observed in this study agrees with results reported by Sukumaran *et al*. (2015) in Bihar, India, where high concentrations of total and faecal coliforms were detected in groundwater associated with human activities. In this study, borehole 1A was recently drilled and therefore may not have stabilized or may have been contaminated during drilling, as per personal communication from LOWASCO staff. Malard *et al*. (2005) observed that subsurface sediment contamination occurred during borehole drilling using air percussion drilling methods in Lyon, France, which may explain the results obtained in this study. Nyakundi *et al*. (2020) also recorded high faecal coliforms at the boreholes in Umoja Innercore estate in Nairobi, which they attributed to the proximity of the boreholes to shallow septic tanks.

In Lodwar, the observed borehole contamination could be due to destruction of boreholes by floods and other factors, as reported for Anambra state, Nigeria and Southeastern Nigeria in studies conducted by Nwaiwu *et al*. (2020) and Onuorah *et al.* (2019) respectively. The result by Obeng *et al.* (2010) in Cape Coast, Ghana, that poor management at the source may be a cause of poor quality of water supplied to customers, could explain the presence of faecal coliform at borehole 1A. Gwibi *et al.* (2019) in a study conducted in Mohale Basin, Lesotho, observed a significant relationship between *E. coli* counts in water samples from areas lacking water source protection, high prevalence of open defecation, unhygienic practices, presence of livestock faeces and latrines built within the proximity of water sources. These factors may have played a role in the presence of faecal coliforms at the water sources in Lodwar town.

The higher faecal coliform densities at household taps compared to the densities at the distribution tank may be due to under-chlorination treatment, resulting in low or lack of Free Residual Chlorine (FRC) in water. This compromises the water quality as it exposes the water to recontamination across the supply chain. Similar findings were suggested by Sheikhi *et al*. (2014), that disinfected water may still be polluted if the residual chlorine is low. Thus, it is important to have an effective and efficient water quality monitoring plan at selected points within the water distribution system. Consumption of poor-quality water at households is an important route for transmission of infectious diarrhoeal diseases, a primary component of water-related disease burden observed in WHO reports (Howard & Bartram, 2003; WHO/UNICEF, 2017). Thus, the dynamism in the distribution of faecal coliform densities obtained across the piped water supply chain was influenced by different factors compared with the findings of Opryszko *et al.* (2013) in rural Ghana. The factors include lack of treatment, irregular storage tank cleaning, broken pipes, biofilm formation and long storage time. The researchers further suggested that the potability of drinking water at the point of use was influenced by hygiene, collection, treatment and storage systems.

5.3 Residents' perceptions of vendors' water quality in Lodwar town

5.3.1. Tanker drivers

Almost all tankers used LOWASCO's main water supply at Moi Garden because it was the only water source recommended by the water utility for tanker supply and preferred by most customers as a clean water source. This agrees with the findings of Ayalew *et al*. (2014) in Kenya and Ethiopia that perceived good quality of vended water is one of the key drivers of its demand by the consumers. However, some tankers may have used other unapproved water sources when the main supply broke or due to high prices, which may have compromised water quality, according to the consumers. Additionally, some customers may have directed tanker drivers to deliver water from a specific water source according to their preferences. Some tankers, especially those owned by the county government or those contracted during drought emergencies, may be forced to use other sources far away from Lodwar town, depending on the location they deliver water. This influences the quality of water delivered.

According to tanker drivers, the hygienic conditions of tankers depended on the effort of individual drivers because there was no standard period in which tankers were supposed to be cleaned. On the other hand, their approval of the utility's main source water safety was entirely based on physical factors such as colour, taste and customers' approval of the same source (perceived good water quality), as similarly reported in a global review (Garrick *et al*., 2019). Additionally, drivers mentioned that customers had no complaints since the water utility used to chlorinate borehole water before the floods destroyed the chlorine facility. Nevertheless, some drivers pointed out the presence of black rubbers, particles and white stones in borehole water, especially in the newly drilled borehole 1A. This was attributed to substances used during drilling. According to the drivers, vendors' water quality monitoring was not given the required attention in Lodwar town by responsible institutions like the public health department. This is because there is inadequate institutional capacity in terms of personnel or required infrastructure, like a water quality laboratory in the County to support water quality monitoring.

These factors, among others, contributed to tanker drivers having little confidence in the impact of government authorities mandated to provide water services in the county, which they said were not proactive in protecting consumers from waterborne health risks. High prices and poor management, presence of only one filling standpipe, high revenue which they suggested should be charged per day and not per trip as currently done, lack of chlorine, limited operation hours, unreliable power supply, poor roads and poor drainage were some of the reasons the tanker drivers were not satisfied by the effort of relevant authorities. Further, sharing of borehole used by tankers with piped system, presence of dry taps in parts of town, poor utility staff coordination and inability of LOWASCO to support independent supply of water were other reasons the tanker drivers had no faith in institutions in charge of water services in Turkana County. As a result, they resolved to use other unapproved water sources with unverified water quality, which they said influenced the quality of water they deliver to consumers.

5.3.2 Water tankers consumers

The households using water tankers as their main source of water supply were either not served by the water utility or had connections without a water supply. Half of the interviewed tanker customers expressed satisfaction with the water supplied by tankers as safe because they believed it was treated at the utility source, similar to the perception reported in Ukunda, Kenya (Whittington *et al.,* 1989). On the other hand, the other half noted that they treated water at the household level because sometimes the water was dirty and was stored for long periods. The hygienic conditions at the households' water storage tanks depended on individual customers' efforts since they gave varying timelines, with most of them indicating that they cleaned their tanks after the water was depleted.

The customers had varied opinions on tanker water safety; half of them indicated that tanker water was safe, while others had a contrary opinion, noting that they could not ascertain tanker water quality. This was because they were sometimes supplied with dirty water, which agrees with the findings of Stoler *et al*. (2014) in Greater Accra, Ghana, that some customers perceived the quality of water supplied by the vendors as good. Contrary to that assertion, the quality of water vendors came under criticism by some customers, similar to reports from Cape Coast Metropolis, Ghana (Awere & Anornu, 2016). Most customers had no faith in institutions managing water services in Lodwar town because the water utility was not able to supply them with water as they desired. Dirty substances were present in the water, indicating lack of treatment, since most parts of the town were not supplied with piped water. However, some expressed that the institutions have at least improved recently compared to previous years, indicating the positive impact of devolution on water supply in the town.

5.3.3 Kiosk water consumers

The functional kiosks in Lodwar town supplied water to areas mainly inhabited by Internally Displaced Persons (IDPs) of the 2007 post-election violence. This was because the water supply was not enough for everyone to have a tap, according to the water utility. Most kiosk water consumers noted that they did not treat water because they assumed the utility did so. They reported the presence of high chlorine levels in the water occasionally. Some households that reported treating water did so because they were not sure if the water utility treated water. Further, they noted that they were sensitized about treating water at home using disinfectants like Aqua Tabs, Water PUR, and Water Guard or boiling it. However, most kiosk consumers were satisfied that the water was safe.

The consumers' satisfaction was based on the presence of chlorine in the water, the assumption that the water utility treats the water, the water was not salty, the distribution tank was regularly washed, and the fact that it was used by many people. This observation agreed with the findings of other studies in Ukunda, Kenya and Tanzania, that consumers perceived some forms of vended water to be of good quality, influencing their willingness to pay for the vended water (Bayliss & Tukai, 2011; Whittington *et al*., 1989). The majority of kiosk consumers had no faith or were not satisfied with the water service-providing institutions, citing their failure to provide satisfactory services. Inadequate water kiosk ATM tokens in each household, unreliable kiosk water supply, lack of individual households' taps, overcrowding at the kiosks, uncertain kiosk water quality and wastage at the distribution tank where water can overflow for even more than two hours were mentioned as some of the reasons why the residents had no faith in the relevant institutions. Nevertheless, some households affirmed that the water utility had improved in the recent past since they sometimes treated water and did repairs of broken pipes.

5.3.4 Piped water consumers

The majority of households interviewed with piped water did not treat water, as they believed the water utility did chlorination before distribution to consumers. As a result, these households were confident that the tap water was safe for consumption, as reported in other studies (Stoler *et al*., 2014). Some of the reasons given by consumers for water utility's approval included water treatment, regular supply, good customer relationship, few waterborne disease cases reported, repair of broken pipes and cleaning of distribution tanks. On the other hand, some consumers were not happy with the water utility services because of high chlorine in water sometimes, high bills, abrupt water supply cut off without customers' knowledge and delay in repairing leaking or broken pipes.

5.4 Waterborne disease patterns and prevalence in Turkana County (2016 to 2020)

This section evaluates selected waterborne disease cases in a retrospective assessment for 5 years from 2016 to 2020 in both Lodwar town and the entire Turkana County. Eight (8) waterborne health conditions were considered for this study: diarrhoea, dysentery, cholera, amoebiasis, gastroenteritis, typhoid fever, hepatitis and bilharzia. These diseases are known to be contracted from consumption of contaminated drinking water with human urine or faeces, except for Bilharzia, which is caused by parasitic blood flukes (*schistosomes*) from infected animals (Nwabor *et al*., 2016; WHO, 2017). A quick observation revealed that gastroenteritis was only reported among children of 5 years and below, pointing to the presence of rotaviruses. This was reported by Banyai *et al*. (2018) as primarily affecting young children and accounting for almost 40% of hospital admissions for diarrhoea and 200,000 deaths worldwide. Again, all assessed waterborne health conditions were reported in 2020 compared to previous years, which could be an improvement in reporting or a possibility that the diseases occurred more in 2020. Over the study period, flash floods were reported across Turkana County in May, 2016 (Daily nation, May 2016); March, 2017; April, 2018; October, 2019 (UNICEF, December 2019) and 2020 (April, May, August and October) (Daily nation, May 2020) hence influencing occurrence of the assessed waterborne diseases.

According to a review of waterborne disease risks by Manetu and Karanja (2021), waterborne diseases were linked to morbidity and mortality among children below 5 years in less developed countries, a finding which could be true for Lodwar town, according to reported data. Similar to observations in this study in Lodwar, unavailability of piped water, use of surface water, poor hygienic practices and inadequate sanitation were mentioned as some of the causes of waterborne diseases in a review conducted by Nwabor *et al*. (2016).

5.4.1 Lodwar township ward

The common waterborne diseases reported among children under 5 years in Lodwar township ward for the period of study were dysentery (bloody diarrhoea), typhoid fever and bilharzia (*Schistosomiasis*), although there was a slight difference from one year to another. There was no significant difference in the distribution of cases reported over the 5 years, revealing the occurrence of reported diseases over the study period. Thus, it implies that the public health risks associated with reported diseases were spread throughout the five years considered under this study. The presence of these diseases was similarly reported in this study to indicate consumption of unsafe water, poor hygienic practices and inadequate sanitation among consumers' households, according to a review by Manetu and Karanja (2021). These factors could make the diseases endemic if water treatment measures are not put in place to improve water quality. On the other hand, inaccurate reporting, failure to visit a health facility or delay of information to reach health facilities may also contribute to poor data on the occurrence of waterborne disease cases across the 5 years under review.

Typhoid fever and dysentery were the first and second highest reported conditions in all the years, except for 2016 and 2020, where dysentery and diarrhoea were reported first and second highest respectively. This trend could be attributed to the fact that typhoid fever, dysentery and diarrhoea were among the first waterborne health conditions to be detected whenever an individual consumes contaminated water, according to a review conducted by Nath *et al*. (2006). Thus, the fact that these waterborne health conditions were reported throughout the study period indicates the residents of Lodwar township ward are exposed to contaminated drinking water. Similar suggestions were identified in a review of water and waterborne diseases by other researchers (Nwabor *et al*., 2016). Further, this was in agreement with the findings of the WHO and UNICEF progress report on drinking water, sanitation and hygiene that consumption of contaminated drinking water exposed users to public health risks like typhoid, cholera, infectious hepatitis, dysentery, diarrhoea, among others (WHO/UNICEF, 2017). Additionally, Elimelech (2006) and Nath *et al*. (2006) reported that 80% of all diseases and over one-third of deaths in developing countries, with about 90% being children under the age of 5 years, were caused by consumption of contaminated water due to a weaker immune system and inability to take precautions.

Diarrhoea, dysentery, typhoid fever, hepatitis and bilharzia were the commonly reported waterborne health conditions for individuals above 5 years in Lodwar township ward. However, Diarrhoea and typhoid fever were the first two reported waterborne health conditions among the residents of Lodwar township ward. There were no significant differences in the distribution of reported waterborne health conditions in Lodwar township ward, even though there was a slight variance in cases reported over the years. This infers that residents were consuming contaminated water throughout the 5 years. The presence of waterborne health risks can be attributed to the consumption of poor water quality, which has been reported to be a transmission route for infectious diarrhoeal diseases according to a WHO report (Howard & Bartram, 2003).

Putting together all the reported (<5 & > 5 years) waterborne health conditions cases over the 5 years, it was clear that diarrhoea, typhoid fever and dysentery were the first, second and third highest conditions reported. This implies that the three waterborne diseases were the major conditions that residents of Lodwar township ward suffered from consumption of contaminated water. These findings agree with WHO and UNICEF reports that such diseases result from the consumption of contaminated water (WHO/UNICEF, 2017). There was no significant difference in the distribution of reported waterborne health conditions over the 5 years; hence, the slight differences observed across the years had minimal influence on the number of cases reported. Notably, there were no cases of cholera reported over the 5 years, and consequently, there was no outbreak of cholera in Lodwar township ward during the study period. Moreover, the cases of amoebiasis and gastroenteritis were only reported in 2020, which could indicate that the two health conditions were reported for the first time or maybe they occurred previously but were not reported. Amoebiasis is a parasitic disease caused by *Entamoeba histolytica* and mainly affects people from developing countries because of drinking contaminated water and inadequate hygiene conditions, according to another study (Carrero *et al*., 2020).

5.4.2 Kanamkemer ward

The major waterborne diseases reported among children under 5 years in Kanamkemer ward were dysentery (bloody diarrhoea) and typhoid fever. This observation agrees with the findings of Leting *et al*. (2022) in Lodwar town that *Salmonella* and *Shigella* were the common contributors of diarrhoea among children less than five years. There were no significant differences in the distribution of dysentery (bloody diarrhoea) and typhoid fever reported cases over the 5 years. Thus, revealing that storage and water handling at the consumer households had minimal influence on the number of reported cases across the study period, although slight differences were observed over the years. However, this was an indicator that residents of Kanamkemer ward were exposed to contaminated water throughout the 5 years of study, similar to reports in other studies (Nwabor *et al*., 2016).

Typhoid fever, dysentery and diarrhoea were reported among the first waterborne health conditions to be detected whenever an individual consumes contaminated water, according to other researchers in Lodwar town (Leting *et al*., 2022). Again, the presence of these waterborne health conditions among the residents of Kanamkemer ward was an indication that residents were exposed to contaminated drinking water, as per the WHO/UNICEF (2017) report. The reported cases of diarrhoea and typhoid fever among children under 5 years in Kanamkemer Ward were lower compared to the number of reported cases in Lodwar township ward. This was attributed to the fact that many estates in the Lodwar township ward were not connected to utility water, compared to the Kanamkemer ward. Many parts of Lodwar township Ward, like Kawalase, Lokaparaparae and Napetet, depend on River Kawalase as their water source. For example, in 2018 and 2019, cases of diarrhoea and typhoid fever in Kanamkemer Ward were less than 10 compared to Lodwar Township, which recorded over 100 cases attributed to the impact of floods that were experienced in 2018 and 2019, majorly affecting Lodwar Township.

Diarrhoea, dysentery and typhoid fever were reported among individuals above 5 years in Kanamkemer ward. This observation infers that the residents of Kanamkemer ward mostly suffered from the three waterborne conditions because of contaminated water use. This concurs with the findings of other studies that waterborne health risks were associated with consumption of contaminated water (Howard & Bartram, 2003; WHO/UNICEF, 2017). The cases of waterborne health risks reported in Lodwar Township Ward for individuals above 5 years were higher over the study period compared to those reported in Kanamkemer Ward. This was explained by the fact that Lodwar township ward had a slightly higher population of 49,020 compared to 44,960 for Kanamakemer ward (KPHC, 2019), and more health facilities, making reporting easy, coupled with inadequate water supply. Additionally, cases of hepatitis and bilharzia were consistently reported among the residents of Lodwar Township over the five years under study. On the other hand, hepatitis and bilharzia were reported twice and once, respectively in Kanamkemer ward. Both hepatitis A and E reported were associated with poor sanitation and ingestion of faecal contaminated water according to the progress report on drinking water, sanitation and hygiene (WHO/UNICEF, 2017).

Summing up (under 5 years and above 5 years) cases revealed that the most occurring waterborne health conditions in Kanamkemer ward were diarrhoea, typhoid fever and dysentery in that order, except for 2016 when typhoid fever was the highest reported, with diarrhoea being second. This implies that the residents of Kanamkemer ward were exposed to these waterborne health risks from drinking contaminated water. Moreover, cases of hepatitis and bilharzia were only reported twice over the study period in Kanamkemer. Similarly, in Kanamkemer ward, no cholera cases were reported during the study period, just like in Lodwar township ward. Gastroenteritis was only reported once in 2020 among children under 5 years over the study period. This was attributed to improved vaccination efforts against rotaviruses and noroviruses, the leading causes of gastroenteritis among children according to Banyai *et al*. (2018) and Hartman *et al*. (2019).

5.4.3 Lodwar Municipality (Lodwar Township and Kanamkemer wards combined)

The data for Lodwar municipality includes the sum of reported cases data for the two wards, namely, Lodwar township ward and Kanamkemer ward. Typhoid fever, dysentery and bilharzia were commonly reported waterborne diseases among children under 5 years, except in 2020, where diarrhoea, typhoid fever and dysentery were the first, second and third highest conditions reported. This suggests that these are the main waterborne health conditions children under 5 years of age within Lodwar town suffer from when drinking contaminated water. In 2020, cases of amoebiasis and gastroenteritis were reported, with amoebiasis being reportedly caused by consumption of contaminated water or food among other causes, while gastroenteritis was associated with consumption of water contaminated with human faeces (Hartman *et al*., 2019). The result of this study identifies the presence of waterborne health risks among the residents of Lodwar town throughout the study, which the WHO and UNICEF relate to unsafe water consumption (WHO/UNICEF, 2017).

On the other hand, diarrhoea, typhoid fever and dysentery were the common outpatient waterborne health conditions reported among individuals above 5 years of age in Lodwar town. These diseases were associated with unsafe water consumption and open defecation according to studies conducted in Turkana (Beesley *et al*., 2016; Ong'ech *et al*., 2021). Muya (2013) noted that waterborne disease outbreaks contributed to students missing lessons in Turkana County. Thus, water plays a critical role in influencing the health and wellbeing of the residents of Lodwar town. Although there was a slight variance in the number of cases reported over the study period, the distribution of diarrhoea, dysentery, hepatitis, typhoid fever, and bilharzia across the study period was not significantly different, pointing to the persistent waterborne health risks among residents of Lodwar town.

In general, considering all the reported waterborne disease cases for under 5 years and above 5 years in Lodwar town, diarrhoea, typhoid fever, dysentery, hepatitis, and bilharzia were the common reported water-related diseases in Lodwar town. Amoebiasis and gastroenteritis were additionally reported in 2020. The results obtained in this study compare with the findings of other studies where the same health conditions were reported in Turkana, associated with the consumption of contaminated water. Other causes reported are contaminated food or poor hygiene and sanitation (Leting *et al*., 2022; Ong'ech *et al*., 2021). The most widespread diseases over the study period were diarrhoea, typhoid fever and dysentery. However, the distribution of these waterborne health conditions was not significantly different across the years. This implies that the health risks persisted over the study period, or interventions put in place, either by the government or community, had minimal influence on their distribution patterns.

5.4.3.1 Prevalent waterborne health conditions in Lodwar town from 2016 to 2020

This section gives a summarized view of prevalent waterborne health conditions in Lodwar town. In the context of this study, disease prevalence means waterborne diseases commonly reported throughout the study period. Hence, the distribution percentages of the total number of individual cases reported per disease in a particular year were used to define prevalence. For example, if in 2016 half of the cases reported were for typhoid fever, then that amounts to 50% prevalence of typhoid fever in that year compared to other reported diseases. Table 15, summarised the first three (3) prevalent waterborne health risks among children under 5 years and individuals above 5 years in Lowar town and Turkana County over the study period.

Table 15: Prevalent waterborne health risks in Lodwar town

Under 5 years	Above 5 years	Total (<5+>5) years
Dysentery (bloody diarrhoea)	Diarrhoea	Diarrhoea
Typhoid fever	Typhoid fever	Typhoid fever
Bilharzia (*Schistosomiasis*)	Dysentery	Dysentery

Diarrhoea, typhoid fever and dysentery were the most prevalent waterborne health risks in Lodwar town and Turkana County, according to the findings of this study. This agrees with the findings of other studies in Kenya and sub-Saharan Africa. Iijima *et al*. (2017) noted that diarrheagenic *Escherichia coli* (DEC) was an agent of endemic and epidemic diarrhoea globally, especially in developing nations. Their findings detected diarrheagenic *Escherichia coli* (DEC) in 55.9% of children with diarrhoea and 9% in healthy adults in Kenya, linked to consumption of contaminated water and food. Further, Jiang *et al*. (2002) observed enterotoxigenic *Escherichia coli* (ETEC) as the prevalent enteric pathogen (25%) identified among international travellers with diarrhoea acquired in Mombasa (Kenya), Goa (India) and Montego Bay (Jamaica). On the other hand, Plant-Paris *et al*. (2019) found that *Clostridium difficile* was more prevalent in children with diarrhoea than Rotavirus in Kenya. Compared to the findings in this study and observations from other studies, it gives a similar situation in Lodwar town and Turkana County, since they highlighted the same key issues affecting consumers.

The prevalence of these waterborne health risks in Lodwar town was associated with inadequate water supply, contaminated water, poor hygiene and sanitation systems as observed in many sub-Saharan African countries (Kariuki, 2008). Similar to the observation in this study, Osienmo *et al*. (2019) affirmed that all drinking water at the abstraction and point of use for Marigat residents was microbiologically contaminated, posing public health risks to consumers of such water. According to Khoubfekr *et al*. (2022), genus *Shigella* and *E. coli* were identified as causes of dysentery in South Khorasan Province, Iran, which could be similar in the case of Lodwar town, according to observations of this study. Waterborne health risks such as typhoid, cholera, and invasive nontyphoidal *Salmonella* were reported to be among the key enteric infections endemic in most parts of sub-Saharan Africa, particularly in informal settlements, emergencies and displaced populations. These conditions are similar in Lodwar town, as water is scarce, with many informal settlements not having access to safe water (Kariuki *et al*., 2021).

5.4.4 Waterborne health risks in Turkana County from 2016 to 2020

The assessment of waterborne health conditions in Turkana County was meant to understand the widespread of the considered waterborne health conditions in the County over the 5 years. It gives a comparison of risks within the residents of Lodwar town and the rest of the County. Dysentery, typhoid fever, hepatitis and bilharzia were commonly reported diseases among children under 5 years of age in Turkana County. Dysentery, typhoid fever and bilharzia were rated first, second and third between 2016 and 2019, similar to the findings of other studies conducted in Lodwar town (Leting *et al*., 2022). According to Kiptum and Moraa

(2021), waterborne disease incidences mostly occurred in Turkana Central during the onset of the rainy season, concurring with observations in this study since Lodwar town is situated in Turkana Central. Nevertheless, cholera was notably reported between 2018 and 2020 in the County, unlike in Lodwar town. This implies that floods may have been experienced in other parts of the county, with 2020 and 2018 reporting the highest cases compared to 2019. These observations agree with the results of other studies, suggesting that floods could lead to outbreaks of cholera (Kiptum & Moraa, 2021; Loharikar *et al*., 2013).

During heavy rainfall, flood damages water sources and carry faecal matter to water sources, leading to microbial contamination of drinking water. Thus, pointing out the fact that the associated unsafe water risks were widespread throughout the study period, leading to reported cases, as similarly suggested in another study in Turkana (Beesley *et al*, 2016). Consequently, a different trend was observed in 2020, where cases of diarrhoea and gastroenteritis were highly reported, attributed to the effects of floods experienced in 2020. This includes the effects of increased water levels in Lake Turkana linked to impacts of climate change, according to other reports (Ngara-Muraya, 2020; The Star, 8th September 2020). Therefore, just as was reported in Lodwar Township and Kanamkemer wards, the presence of waterborne health conditions reported in Turkana County still points to the fact that such health risks occurred from unsafe water consumption as noted in a global joint monitoring report (WHO/UNICEF, 2017).

Among individuals above 5 years of age in Turkana County, diarrhoea, typhoid fever and dysentery were highly reported cases across the study period. Ngara-Muraya (2020), in a study conducted in Kenya, associated these waterborne health conditions with drought and floods, due to consumption of untreated water and poor hygiene conditions similar to conditions in Turkana County. This may be true because destructive floods were experienced in the County in 2016, 2018 and 2020, which even destroyed boreholes and other water sources according to Daily Nation and UNICEF reports (Daily Nation, May 2016 and 2020; UNICEF, December 2019). Again, there was an increase in the water levels in Lake Turkana, which posed public health risks among the people living along the lake, especially for cholera, diarrhoea, dysentery and typhoid fever. Additionally, cases of amoebiasis were reported in 2020 among the residents of Turkana County, according to the Star newspaper on 8th September 2020.

Generally, when summing up both under 5 years and above 5 years reported waterborne health conditions from 2016 to 2020 in Turkana County, it was clear that diarrhoea, dysentery, typhoid fever, cholera, hepatitis and bilharzia were commonly reported waterborne diseases in

Turkana County similar to observations in other studies (Hartman *et al*., 2019; Leting *et al*., 2022; Loharikar *et al*., 2013). This was an indication that unsafe water consumption risks coupled with poor sanitation and hygiene played a role in the occurrence of these health conditions, as reported in the progress on drinking water, sanitation and hygiene report (WHO/UNICEF, 2017).

Over the study period (2018 to 2020), cholera cases were reported in Turkana County. Other studies attributed it to flash floods, poor hygiene and increased water levels in Lake Turkana (Loharikar *et al*., 2013; Ngara-Muraya, 2020). However, no cases of cholera were reported in Lodwar town (both in Lodwar Township and Kanamkemer wards), which may be because piped water was supplied to some residents of Lodwar town or accessibility to households' treatment options, like the use of chlorine disinfectants or boiling, compared to other parts of the County. Consequently, cases of gastroenteritis were only reported among children under 5 years of age and only in 2020. The occurrence of this health condition could be due to unsafe water consumption, poor hygiene and sanitation, which are mostly witnessed among young children according to other studies (Banyai *et al*., 2018; Hartman *et al*., 2019).

In general, the presence of waterborne health conditions among the residents of Lodwar town and Turkana County infers that the residents were exposed to waterborne health risks. These risks could be due to unsafe water consumption, poor hygiene and sanitation among other factors, as suggested in other studies (Ong'ech *et al*., 2021; WHO/UNICEF, 2017). Thus, although not directly verifiable, there is a likelihood that vended water use in Lodwar town also contributed to the occurrence of these health conditions. This is because faecal coliforms were present in all water samples tested across all water supply chains in this study. Other factors that may have influenced the number of reported cases of waterborne health conditions are improved reporting, additional health facilities, delays in reporting or lack of reporting, among many others.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The physical and chemical parameters assessed across the three water supply chains in Lodwar town significantly differed from the source to the consumers. The temperature, dissolved oxygen and pH significantly varied across water tankers, kiosks and piped water supply chains. On the other hand, FRC and nitrite varied significantly across water tankers and piped water supply chains. Turbidity, ammonium, and sulfate were significantly different across the water tankers supply chain, as nitrate significantly differed across the kiosks supply chain. The variance in the water parameters levels across the supply chains was attributed to the vendors' activities, including water handling and hygiene, transportation and storage between the source and the consumers, which influenced changes in the levels of parameters assessed. These parameters varied with distance across the supply chains, with lower values at the borehole/source and increased towards the consumers.

There was inadequate treatment of water witnessed at the source, distribution tanks, storage facilities at the consumers', or the tankers during transportation by the water vendors. Only a few cases of water treatment were witnessed at the consumers', depending on the ability and affordability of the individual household. This study revealed gaps in water treatment and water handling processes by the water utility, vendors and consumers across the supply chains. For instance, turbidity at the tankers and kiosks' consumers exceeded the WHO permissible limits for drinking water. This implies a public health risk exposure to waterborne diseases to the consumers, especially when water is not treated before consumption, as is the case in Lodwar town. Thus, the hypothesis that there was no significant difference in selected physical-chemical parameters of vended water across water tankers, kiosks and piped water supply chains from the water source to the consumer point of use in Lodwar town was rejected.

A water quality monitoring system should be developed by County departments of Public Health, Water Services and TUWASCO to monitor the quality of water supplied to the residents of Lodwar town. This is crucial since water quality is affected by many factors, both at the source, during piping and transportation, including human activities and environmental factors like climate change. The monitoring system should incorporate aspects such as seasonal variability and the influence of climate change on informal vendors' water quality. This will help understand the changing water quality during wet and dry seasons, and emergencies, especially at times of drought and humanitarian crisis. Spatial analysis of changing water quality from the source to consumers is also important to understand the factors influencing water quality changes over time and distance during transportation to the consumers. This is key as some vendors in this study transported water to far-flung areas, even more than 50 Kilometres from the source.

Faecal coliform densities were recorded in all sampling points across both tankers, piped water and kiosks supply chains, implying the water was unsafe for drinking. The faecal coliform densities were significantly different across the water tankers, kiosks and piped water supply chains during the study period in Lodwar town. The presence of faecal coliforms across all water supply chains in Lodwar Town revealed a gap in the water treatment process and handling by the water utility, vendors and consumers. This poses a public health risk, especially waterborne diseases, to the consumers and residents of Lodwar town if further treatment is not done at the household level before consumption. Therefore, the hypothesis that there was no significant difference in the densities of faecal coliforms recorded across the water supply chains from the water source to the consumers' endpoint in Lodwar town is rejected.

TUWASCO should therefore prioritise treating water at the source or distribution tanks before supplying to the consumers. Doing so will minimize exposure to waterborne health risks associated with water contamination. This will help avert waterborne diseases like typhoid, diarrhoea and dysentery as reported among residents of Lodwar town in this study. It should also include an appeal to all partners and other well-wishers to pay more attention to safe water supply and delivery in Lodwar town and Turkana County. Additionally, there is a need to sensitize both informal vendors and consumers on the importance of regular water disinfection and basic Water, Sanitation and Hygiene (WASH) best practices to promote safe water consumption among the consumers. This includes the need for water vendors to regularly treat water before they deliver it to the consumers. The consumers should be able to verify water quality at the household level or treat water before use.

Diarrhoea, typhoid fever and dysentery were the most prevalent waterborne health risks in Lodwar town and Turkana County over the 5 years under study, according to the findings of this study. However, the prevalence of these waterborne diseases among residents of Lodwar town from 2016 to 2020 was not significantly different over the 5 years of study. This implied that the recorded prevalence rates and actual cases over the study revealed a consistent trend. It was also possible that some people who got sick and didn't go to the hospital were not captured during this period. Thus, the hypothesis that there was no significant prevalence of waterborne diseases among the residents of Lodwar town from 2016 to 2020 was not rejected. Nevertheless, the presence of the recorded eight (8) waterborne and water-related diseases among the residents (both children under 5 years and individuals above 5 years of age) of

Lodwar town and Turkana County at large was an issue of public health concern requiring urgent action.

The direct nexus between vended water quality and public health risks needs to be explored. This will help in understanding if there is a direct link between vended water delivered to the consumers and the waterborne health risks among the consumers. It was not possible to directly link the reported waterborne health risks identified from the data obtained from the health records department of LCRH because such activity would need long-term purposeful research.

6.2 Conclusions

i. The physical and chemical parameters varied with distance across all the supply chains but within WHO recommended standards for drinking water. Only turbidity at the tankers (8.01±2.04) and kiosks' (5.74±2.06) consumers exceeded the WHO permissible limits, implying the water was unsafe at the point of use unless treated at the household level. Thus, the hypothesis that there was no significant difference in selected physical-chemical parameters of vended water across water tankers, kiosks and piped water supply chains from the water source to the consumers' point of use in Lodwar town was rejected.

ii. Faecal coliform densities (2.83 – 336.00 CFUs/100 mL) were recorded at all sampling points across all supply chains, implying the water was unsafe for drinking unless treated before use. Therefore, the hypothesis that there was no significant difference in the densities of faecal coliforms recorded across the water supply chains from the water source to the consumers' endpoint in Lodwar town was rejected.

iii. Diarrhoea, Typhoid fever and Dysentery were the most prevalent waterborne health risks in Lodwar town and Turkana County over the 5 years under study. Thus, the hypothesis that there was no significant prevalence of waterborne diseases among the residents of Lodwar town from 2016 to 2020 was not rejected.

6.3 Recommendations

More time is required to monitor vended water quality throughout the year across all seasons in Lodwar town. The study therefore recommends the following interventions for improvement of vendors' water quality in Lodwar town.

i. TUWASCO should adopt a regular water quality monitoring system in collaboration with the Public Health Department to ascertain the quality of water supplied to the residents of Lodwar town.

ii. The water should be treated at the source or distribution tanks before being supplied to consumers to avoid exposure to waterborne health risks associated with water contamination.
iii. Community sensitization on water, sanitation and hygiene (WASH) should be a priority for consumers in Lodwar town to verify water quality at the household level or treat water before use to avoid waterborne health risks.

6.3 Suggestions for further studies

More studies are required to fully understand the dynamics around water vendors water quality, has vendors play an important role in water supply. In view of this study findings, the following studies are suggested to enhance vended water quality understanding.

i. Assess seasonal variability and the influence of climate change on informal vendors' water quality.
ii. Undertake spatial analysis of vendors' water quality from the source to consumers to understand water quality changes over time and distance during transportation to the consumers.
iii. Understand the link between vended water quality consumption and waterborne health risks reported in Lodwar Municipality.

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APPENDICES

I. NACOSTI research permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **785294**

Date of Issue: **13/September/2021**

RESEARCH LICENSE

This is to Certify that Mr.. Paul Eyanae Ekwar of Egerton University, has been licensed to conduct research in Turkana on the topic: Assessment of vended water quality: A case study of water Tankers and Kiosks in Lodwar Township, Turkana County, Kenya for the period ending : 13/September/2022.

License No: **NACOSTI/P/21/12872**

785294

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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II. Water tankers census tool

S/No	Registration No.	Type	Tanker owner	Driver	Capacity (L)	Daily trips	Contact	Ownership type
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								

III. Daily field reporting form

Sampling point ID:					
Parameter	**Reading 1**	**Reading 2**	**Reading 3**	**Average**	**Remarks**
Temperature					
EC					
pH					
DO					
Turbidity					
TDS					
FRC					
GPS location:					
Sampling point ID:					
Parameter	**Reading 1**	**Reading 2**	**Reading 3**	**Average**	**Remarks**
Temperature					
EC					
pH					
DO					
Turbidity					
TDS					
FRC					
GPS location:					

IV. Questionnaire for water supply chain endpoint consumers

ASSESSMENT OF VENDED WATER QUALITY: A CASE STUDY OF WATER TANKERS AND KIOSKS IN LODWAR, TURKANA COUNTY, KENYA

INTRODUCTION

My name is Paul Ekwar, I am a postgraduate student at Egerton University, Kenya. I am conducting a survey on the perception of household consumers of vended water quality. The aim of this study is to analyse the selected water quality parameters of vended water along the water tankers and kiosks supply chains from the source to consumer end point in Lodwar town in Turkana County, Kenya. I would like to request for 10 minutes of your time so that you can respond to the following questions. The information you give will be kept confidential and shall be used solely for academic purposes in accordance to the ethical approval by Bioethics committee of Egerton University. Many thanks.

SECTION 1: IDENTIFICATION

101 Place of Residence:

102 Respondent gender:

103 Interview date:

104 GPS location of Household:

SECTION 2: HOUSEHOLD WATER USE

201 Are you connected to LOWASCO piped water supply?

202 Water is your main source of water?

203 Apart from the source mentioned above, which other sources of water do you use?

204 What factors prompt you to use vendors' water? (*Why do you prefer vended what?)*

205 How many times in a month do you order vended water?

206 What is the capacity of your storage tank?

207 How long does it take to empty the water tank?

SECTION 3: WATER QUALITY

301 Do you normally subject vendors' water to any treatment before use? *(Probe why)*

302 How often you do you clean your storage facility? *(Confirm: Underground or Elevated tank)*

303 Do you think the water delivered by the water vendors is safe? *Explain why*?

304 What are the common water related diseases experienced in your household?

SECTION 4: GENERAL QUESTIONS ON WATER PROVISION IN LODWAR TOWN

401 What main challenges do you think hinder safe delivery of water by the vendors?

402 What best practices do you think can improve the quality of vended water? *(Probe both from the source, vendors and consumer)*

403 What other comments can you make in regards to vendors' water quality and safety in Lodwar town?

404 Do you think much is being done by the County Government to protect consumers from any risks that can come from vended water? *(Probe why)*

V. Analysis details and relevant raw data

Table 16: Lauryl sulphate broth composition

Lauryl sulphate broth composition	
Description	**Quantity**
Tryptose	(20.000 gm/L)
Lactose	(5.000 gm/L)
Sodium chloride	(5.000 gm/L)
Dipotassium hydrogen phosphate	(2.750 gm/L)
Potassium dihydrogen phosphate	(2.750 gm/L)
Sodium lauryl sulphate (SLS)	(0.100 gm/L)
Final pH at 25°C	(6.8 ± 0.2)

Table 17: WHO and WASREB guidelines for drinking water quality

Parameter	**WHO standard (2017)**	**WASREB (2008)**
EC (µS/cm)	400	
TDS (mg/L)	600	1500
Turbidity (NTU)	5	5
pH	6.5 to 8.5	6.5 to 8.5
FRC (mg/L)	0.02	0.2 ± 0.5
Nitrate (mg/L)	50	10
Nitrites (mg/L)	3	
Ammonia (mg/L)	0.5	0.5
Sulfate (mg/L)	250	400
Chloride (mg/L)	250	250
Fluoride (mg/L)	1.5	1.5
Iron (mg/L)	0.03	0.3
Lead (mg/L)	0.01	0.05
Faecal coliforms (CFUs/100 mg/L)	0	0

VI. Abstract of publication in a refereed journal

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Journal of
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 Journal of Water, Sanitation and Hygiene for Development Vol 15 No 5, 398 doi: 10.2166/washdev.2025.301

Research Paper

Physiochemical and bacteriological quality of tanker vended water supply chain in Lodwar Town, Kenya

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ABSTRACT

Informal water vendors emerge in many sub-Saharan African countries like Kenya to fill water supply gaps caused by inefficiency of water utilities to meet water supply demand. Quality of water delivered by vendors is of concern owing to uncertainty of transportation/storage tanks' hygiene and water sources used. This study assessed water quality parameters of tankers in Lodwar Town, from the source to consumers. Standard methods for determining water quality were used to measure parameter concentrations. Key findings: temperature (28.27–32.26 °C), turbidity (2.04–5.90 mg/L), dissolved oxygen (3.66–7.27 mg/L), pH (7.63–8.65), free residual chlorine (0–0.19 mg/L), nitrite (0.004 mg/L), ammonium (0.0425–0.0426 mg/L), sulphate (0.019–0.021 mg/L), and faecal coliforms (6.40–199.40 CFUs/100 mL). The study revealed significant differences ($p < 0.05$) across tankers' supply chains using one-way ANOVA testing. Turbidity surpassed WHO limits of 5.0 NTU at the consumers. Faecal coliforms were detected at all sampling points, implying faecal/microbial contamination of water, making it unsafe for drinking. The contributing factors were inadequate water treatment, poor hygiene, improper handling, and lack of monitoring and regulation. These findings highlight the status of tanker vendors' water quality and the need for stringent monitoring and regulation of water vendors in Lodwar Town.

Key words: faecal coliforms, informal water vendors, supply chains, water quality, water tankers

HIGHLIGHTS

- Determination of tankers' water quality across the supply chain from the source to the consumers.
- Identification of contamination pathways across tankers' water supply chains.
- Provide tanker vendors with water quality status to inform monitoring and regulation.