Water Quality Assessment of Tap And Kiosks Supply Systems in Lodwar Town in Turkana County, Kenya

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Abstract

Growing urban areas in developing countries face water access challenges from inadequate urban water supply systems against growing water demand. Water utilities like in Lodwar establish kiosks supplies to fill water supply gaps especially in peri-urban areas and informal settlements. However, the quality of many urban water supply systems is uncertain due to several factors that need to be established. This study assessed selected physical-chemical parameters and biological (faecal coliform densities) in water across piped and kiosks supply chains from the source to consumers in Lodwar town. Electrical Conductivity (EC), pH, temperature, 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. Nitrate-Nitrogen (NO_3-N), was determined by calorimetric method using light spectrophotometer (420nm wavelength). Free Residual Chlorine (FRC) was analysed using Pool tester with standard colour scales for different FRC concentrations. Faecal coliforms were determined by Membrane Filtration Technique (MFT) using Oxfam - DelAqua water testing kit. Temperature (28.51-32.46°C), DO (3.78-7.50mg/L) and pH (7.58-8.38) were significantly different ($p<0.05$) across all supply chains while, faecal coliforms (6.40-340.79CFUs/100mL) were significantly different ($p<0.05$) across piped water supply chain using one-way ANOVA test (F value = 7.693; df=4, 80; p=0.000). Nitrate (0.052-0.068mg/L) was significantly different ($p<0.05$) across kiosks supply chain using one-way ANOVA test (F value = 4.195; df=3, 18; p=0.020). The faecal coliforms in all supply chains recorded higher values than WHO standards (0 CFUs/100mL) for drinking water hence showing that the water was contaminated. Inadequate water treatment, poor hygiene, improper water handling, lack of water quality monitoring and poor maintenance of piped system influenced water quality in Lodwar town. Faecal coliforms increased across all supply chains hence grossly contaminated and posing waterborne health risks to consumers. Regular water quality monitoring and treatment at the source and storage tanks are required to improve its quality.

Key words: faecal coliform, monitoring, supply chain, water quality

Introduction

Globally, by 2022, 2.2 billion people still lacked safely managed drinking water; including 1.5 billion with basic services, 292 million with limited services, 296 million with unimproved and 115 million drinking surface water (WHO and UNICEF, 2023). However, since 2015, coverage of safely managed drinking water has increased from 69% to 73%; rising from 56% to 62% in rural areas and from 80% to 81% in urban areas according to joint monitoring report by WHO and UNICEF (2023). Further, the report indicates that water quality was the most common limiting factor for safely managed drinking water services, a concern that motivated this study in Lodwar town. It is reported that if there are no interventions for improvement of water quality management by 2030, only 81% of 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 were reported to lose productivity to water and sanitation related diseases spending up to 5% of their Gross Domestic Product (GDP) (WHO, 2012). Additionally, economic losses were attributed to time wasted when fetching water from distant areas. Further, UNICEF in 2021 reported that 700 children under the age of five die every day from diarrhoeal diseases due to unsafe drinking water or poor sanitation and hygiene (UNICEF, 2021).

There exist formal (piped) and informal systems (vendors like kiosks) in water service provision in most urban centres especially in developing countries. In Lodwar town, these systems are managed by Lodwar Water and Sanitation Company (LOWASCO). The informal systems of water supply exist to provide water to households not served by LOWASCO or have intermittent utility water supply. This may be due to infrastructural challenges or finite water resources as suggested by other researchers (Awere and Anornu, 2016; Garrick *et al*., 2019). 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 to languishing of formal systems compared to informal water systems which have thrived due to high demand for water supply (Garrick *et al*., 2019). The cost to supply water to the estimated 10 billion people globally by 2050 was projected to be $60 trillion (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 Kenya, 45% of the population has no access to piped water within easy reach (WASREB, 2019), thus creating a conducive environment for water vendors to bridge the gap. 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 making human right to water untenable (UNDP, 2011). 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 more reliable means of water provision. 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).

Lodwar town was the best candidate for this study due to inadequate water access, water scarcity and stress associated to arid and semi-arid lands (ASAL) climatic conditions within the Sahel region. The 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 exists a water supply gap. That notwithstanding, the quality of water supplied to residents of Lodwar town is of concern as the existing water supply gap creates an opportunity for water vending to thrive. This poses waterborne disease risks like cholera, typhoid, and dysentery to households living in Lodwar town as previously reported in the area as a result of compromised water quality (WHO, 2008; IFRC, 2020). It is against this outstanding gap that this study seeks to assess physical – chemical and bacteriological quality of water supply systems in Lodwar town focusing on piped water and kiosks supply chains.

Materials and Methods

Study area

This study was conducted in Lodwar town in Turkana County, Kenya. Lodwar is located 35.62°E and 3.14°N (Figure 13) at an altitude of 477 metres above sea level (Olango, 2019). The temperature in Turkana ranges from 20 to 41^{o}C with an average of 30.5^{o}C (Turkana County CIDP, 2018). The mean annual rainfall received in the area is 217 mm (Opiyo *et al*., 2014; Olango, 2019) with prolonged dry periods in January, February and September.

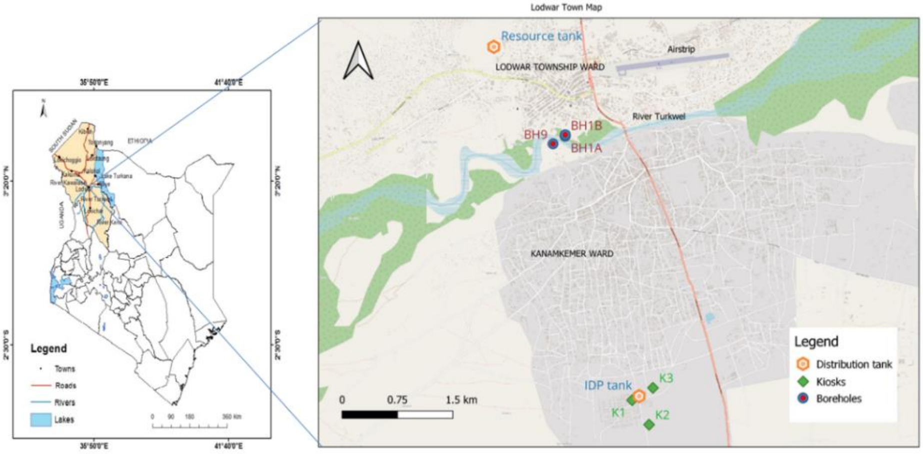

Figure 13: A map of Lodwar town showing geographical position of water sources

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

Sampling points

Selected physical-chemical and bacteriological water quality parameters across piped water and kiosks supply chains were assessed at different days within a period of 7 weeks between May and July 2021. Water samples for analyses were collected at different sampling sites (Figure 14). BH9, BH1A and BH1B are water sources (boreholes).

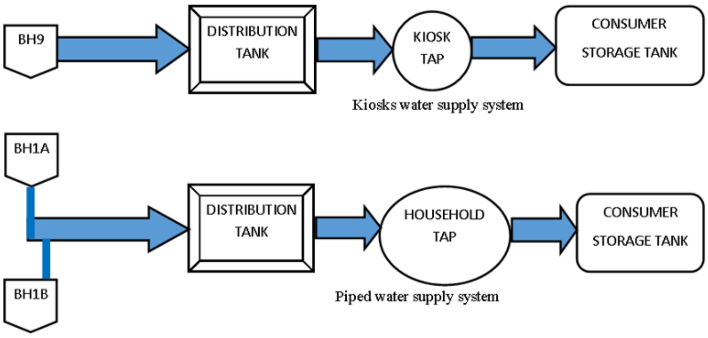

Figure 14: A flow diagram showing sampling points along supply chains in Lodwar town

A total of 72 samples for physical-chemical and bacteriological characteristics analyses were collected across the supply chains with two replicates each totalling to 144 samples (**Table 26**). All the samples were analysed in triplicates.

Table 26: Number of samples collected across water supply chains in Lodwar town

Kiosks supply chain sampling points	**Number of samples analysed for physical - chemical and bacteriological parameters**	**Piped water supply chain sampling points**	**Number of samples analysed for physical - chemical and bacteriological parameters**
Borehole 9	4	Borehole 1A	5
		Borehole 1B	5
Distribution tank	4	Distribution tank	5
Kiosks	7	Taps	22
Consumer households	7	Consumer households	13
Total	**22x2 = 44 replicates**	Total	**50x2 = 100 replicates**

Water sample collection and sampling procedures

Prior to sampling, all glassware and sampling bottles intended for physical-chemical parameter analyses were thoroughly pre-washed with acid water and then rinsed with distilled water before use for water samples collection. In addition, for microbiological analyses, during sampling; the outlet taps for boreholes and kiosks were wiped with a 70% alcohol-soaked tissue paper, and a significant amount of water flushed out before sample collection to avoid contamination as was suggested by Awere and Anornu (2016). Water samples were collected using 1000 mL plastic bottles for chemical analysis and 500 mL for microbial analysis. For sampling points without outlet taps, the samples were collected using a pre-cleaned bucket/jug then transferred to plastic bottles. Samples for *in-situ* measurements (Temperature, pH, EC, DO, TDS and Turbidity) along the supply chain were collected in a small bucket thoroughly pre-washed and rinsed with the sample to minimize interference of the parameters. The readings were taken in triplicates from the field using respective Hach Multimeters (HACH HQ 40d for EC, pH, temperature and TDS; HACH HQ 30d for DO, and HACH HQ 11d for turbidity) calibrated prior to avoid errors as recommended in the manufacturer's instructions.
The samples were preserved in cool boxes in the field and transported to Turkana University laboratory where bacteriological tests were done within 24 hours after collection. Samples for chemical analysis were kept in the refrigerator at 4°C until analyses at Egerton University water quality laboratory. FRC was analyzed *in-situ* using pool tester available in the DelAqua water testing kit by dropping one DPD (N, N-diethyl-p-phenylenediamine) No. 1 tablet at the right-hand cell (C12) of the pool tester. The sample was shaken until the tablet dissolved in the sample which were then compared through matching the colour with the pool tester standard colours representing difference residual chlorine concentrations. Nitrate - Nitrogen (NO_3-N) was analysed using Sodium-salicylate method at Egerton University water quality laboratory. All these parameters were analysed using standard methods according to APHA (2005).

Bacteriological tests to determine faecal coliform densities in water samples was done through Membrane Filtration Technique (MFT) using Oxfam-DelAqua water testing kit manufacturer's manual (Oxfam-Delagua, 2012). An aliquot of 100mL of the water sample was filtered through a sterile membrane filter paper (GFC, 47mm Ø, pour size, 0.45µm) held on a membrane filtration unit. The membrane filter paper with the bacteria retained was placed on an absorbent pad right side up on a petri-dish soaked in approximately 2.5mL of Lauryl sulphate broth, a growth medium that feeds coliform bacteria and inhibits the growth of other bacteria in the filter. The filter was incubated at 44^{o}C to allow the growth of thermotolerant faecal coliform bacteria colonies for 18-24 hours. The faecal coliforms bacteria were identified by their ability to produce a colour change (from Red to Yellow) in Lauryl sulphate broth culture medium at 44°C. The yellow colonies were counted with the help of a hand magnifying lens available in the DelAqua Kit and colonies numbers expressed as colony forming units per 100mL (CFU/100mL). This procedure is differential and selective for *E. coli* and according to the standard manual doesn't require further identification.

The data was processed using Microsoft Excel and Statistical Packages for Social Sciences (SPSS) for analysis at a significance level of 0.05. One-Way ANOVA test was used to test for the relationships in the water quality parameters across the supply chain. FRC across piped water supply chain was analysed using Independent-Samples Kruskal-Wallis test at 0.05 significance level. Subsequently, multiple means comparisons across the supply chains using Tukey HSD tests were performed to show mean differences among the sampling.

Results

Across piped water supply chain, temperature (df=4, 45; f=6.613; p=0.000), dissolved oxygen (df=4, 45; f=32.068; p=0.000), pH (df=4, 45; f=5.101; p=0.002) and faecal coliform densities (df=4, 80; f=7.693; p=0.000) were significantly different using ANOVA test ($p<0.05$). see Table 27 below. All the parameters recorded highest values at the consumers storage facilities except for temperature which highest values were recorded at the taps, with the boreholes recording lowest values.

Temperature (df=3, 18; f=3.879; p=0.027), dissolved oxygen (df=3, 17; f=6.052; p=0.005), pH (df=3, 18; f=3.674; p=0.032) and nitrate (df=3, 18; f=4.195; p=0.020) were significantly different across kiosks supply chain using ANOVA test as shown in **Table 30.** As well, the highest values for all parameters were recorded at the consumers except for nitrate which highest value were recorded at the kiosks level.

Across both piped and kiosks water supply chains, temperature, dissolved oxygen and pH varied significantly. Further, the highest values for all these parameters were recorded at the consumers and lowest values recorded at the boreholes, giving an implication that the water quality degraded from the source towards the consumer households.

Table 27: Summarized results and analysis across piped water supply chain in Lodwar town

Note: Values are presented as mean ± Standard Deviation (SD), n =46 (1-8); n =81 (9).

	Parameter	**BH1A Mean ±SD**	**BH1B Mean ±SD**	**Distribution tank Mean ±SD**	**Tap Mean ±SD**	**Consumer Mean ±SD**	**df**	**F value**	**P value**
1	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**
2	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
3	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**
4	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
5	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
6	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**
7	FRC (mg/L)	0 ^{a}	0 ^{a}	0 ^{a}	0.07±0.28 ^{a}	0 ^{a}	4, 45	0.441	0.779
8	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
9	Faecal Coliforms (0 CFUs/100mL)	34.70±82.73 ^{a}	13.90±39.52 ^{a}	11.50±10.74 ^{a}	31.55±74.95 ^{a}	151.04±144.74 ^{b}	4, 80	7.693	**0.000**

Superscript letters across the rows represents 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-values are based on one-way ANOVA test at 0.05 significance level except for FRC that based on Independent-Samples Kruskal-Wallis test.

Table 28: *Summarized results and analysis across water kiosks supply chain in Lodwar town*

Note: Values are presented as mean ± Standard Deviation (SD), n =19 (1-2,4-6, 8); n =21 (9).

	Parameter	**BH9 Mean ±SD**	**Distribution tank Mean ±SD**	**Kiosk Mean ±SD**	**Consumer Mean ±SD**	**df**	**F value**	**P value**
1	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**
2	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
3	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**
4	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
5	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
6	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**
7	FRC (mg/L)	0^{a}	0^{a}	0^{a}	0^{a}	-	-	-
8	Nitrate (mg/L)	0.052±0.001^{a}	0.052±0.002^{ab}	0.056±0.002^{b}	0.054±0.002^{ab}	3, 18	4.195	**0.020**
9	Faecal Coliforms (0 CFUs/100mL)	88.10±127.38^{a}	185.10±303.96^{a}	284.79±312.99^{a}	340.79±199.49^{a}	3, 20	1.14	0.357

Superscript letters across the rows represents 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-values are based on one-way ANOVA test at 0.05 significance level except for FRC that based on Independent-Samples Kruskal-Wallis test.

Discussion

Physical-chemical characteristics of water across water supply chains

Across all water supply chains, temperature varied significantly from the source to the consumers indicating that various factors influenced water temperature. The temperature across piped water system increased from boreholes to the taps with a slight decrease at the consumers' point of use. On the other hand, temperature across kiosks supply chain increased at the consumers' level. The change in temperature across the supply chains was influenced by the time of sampling, ambient temperature of the surroundings and nature of storage tank material as suggested by Hoko (2008) in Bindura District, Zimbabwe and in a review by Salehi (2022). As the water was being piped to households and kiosks, storage tanks and pipes were exposed to the sun hence hot temperatures influencing water temperature. At the taps consumers, the temperature of water 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 hence reducing potential for microbial growth. Increased temperature in water storage tanks was reported in other studies to increase microbial growth in water (Salehi, 2022). Contrary, increased water temperature was recorded at the kiosks consumers attributed to storage options at the households' level which may have exposed storage containers to sun radiations as most of them were internally displaced persons (IDPs) with inadequate established households' structures. Peter and Routledge (2018) observed that higher temperatures favoured microbial growth and biofilm formation in water storage facilities in London, UK agreeing with the findings of this study as faecal coliforms and temperature increased from the source to consumers. Notably, temperature at the kiosks distribution tank was slightly higher compared to the kiosks and the source. This was attributed to the fact that the distribution tank was exposed to sun radiations and therefore was heated, influencing the temperature of water it stores and growth of contaminating microbes similar to findings of other researchers (Hoko, 2008; Salehi, 2022). Further, high temperature was reported to affect chemical reactions in water hence influencing other water quality parameters in Osun state, Nigeria (Olajire and Imeokparia, 2001).

Turbidity levels slightly varied across all supply chains with values obtained at all sampling points complying with WHO recommended value of below 5 NTU for drinking water except at the kiosks consumers level which recorded higher value (WHO, 2017). This was an indication that tap water was safe for use compared to kiosks water similar to the findings of Chalchisa *et al*. (2017) in storage tanks in Jimma town, Ethiopia. Nevertheless, the slightly high turbidity values recorded at the kiosks consumers could be attributed to the presence of particulate matter such as dust and pollen grains as reported in Logone Valley, Chad-Cameroon (Sorlini *et al*., 2013) or hygiene conditions of storage facilities at the households reported in Cochabamba, Bolivia (Schafer, 2010). Moreover, a study by Kothari *et al*. (2021) in Uttarakhand, India underpinned that the turbidity levels in water occurred due to the presence of soil, organic and inorganic matter, plankton, and other microscopic organisms, assertions that could apply to this study. As water was used, storage containers were constantly agitated allowing resuspension of particles in water hence increased turbidity similar to the findings of Hoko (2008) in Bindura district, Zimbabwe. 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 higher turbidity levels recorded at the kiosks consumers (5.74±2.06 NTU) were above WHO recommended levels of 5 NTU for drinking water (WHO, 2017). This was an indication that the water was not desirable for drinking purposes, pointing to the need for households' treatment before consumption.

Electrical conductivity recorded relatively varied values across piped water and kiosks supply chains but were not significantly different. This infers that there were very little dissolved solids like carbonates and bicarbonates added to the water across the supply chains which could have caused ionization of the water to influence the EC just as it was noted in Wondo genet campus, Ethiopia (Meride and Ayenew, 2016).The EC values decreased at the piped system distribution tank with a slight increase at the taps and the consumers compared to high value at borehole 1B. This trend could be attributed to the fact that water from the two boreholes filled the same distribution tank which may have neutralize the two boreholes' EC values, as it was also reported by Salehi (2022) that blending water from different sources could alter its water chemistry. Nevertheless, the relatively high EC values at borehole 1B could be due to increased TDS and temperature at the borehole pointing to presence of dissolved ions like carbonate, bicarbonate, chloride, sulfate, phosphate, nitrate, calcium, magnesium, sodium, and organic ions in water just as was reported by Lukubye and Andama (2017) in some water sources in Mbarara municipality, Uganda. On the other hand, the increased EC concentrations across kiosks supply chain may be an indication of presence of dissolved substances in water as noted above and observed in the increasing trend of TDS from the source to the consumers. However, increased EC values at the consumer households compared to other samplings sites may be due to presence of dissolved ions due to poor handling or improper storage as observed in Bindura District, Zimbabwe by Hoko (2008). The EC values recorded across the supply chains were below WHO acceptable guideline of 400 µS/cm for drinking water suggesting the water was safe for domestic use (WHO, 2017). This assertion was contrary to the findings of Rusiniak *et al*. (2021) who found some boreholes water in Turkana exceeding WHO acceptable EC guidelines of 400 µS/cm.

Dissolved oxygen concentrations varied significantly across all the water supply chains suggesting that DO was significantly influenced by several factors between the source and consumers. The boreholes recorded lowest DO values attributed to the fact the underground water are low in DO and factors such as depth of the borehole, groundwater temperatures and oxidation - reduction potential influenced its concentrations as similarly reported by Zan *et al*. (2019) in Hong Kong, China. Depletion of dissolved oxygen in water supplies was reported to encourage microbial reduction of nitrate to nitrite and sulfate to sulphide, and could cause an increase in the concentration of ferrous iron, with subsequent discoloration at the tap when the water is aerated (WHO, 2017). This assertion could agree with the results of this study as nitrate concentrations were low at the boreholes just as was the concentrations of DO. The increased concentration of DO across piped water supply chain and highest at the consumers, was contrary to the findings of other researchers that a decrease in DO is expected when the temperature increases as observed by Lukubye and Andama (2017) in Mbarara Municipality, Uganda. Wang *et al*. (2022) further suggested that DO is expected to decrease with high retention time of water in the pipeline. Therefore, the increase of DO concentrations across the supply chain could be attributed to re-aeration at the sampling points (distribution tank, tap and consumer storage tanks) hence explaining why DO levels were high at the consumer level. The decrease in DO at the kiosks level can be due to water piping from the distribution tank to kiosks as was suggested by Wang *et al.* (2022) that long hydraulic retention time of water in the pipes could cause a decrease in DO concentrations, potentially deteriorating water quality. 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 DO variance across the supply chains in Lodwar town including increased levels at the consumers attributed to aeration during storage.

The water pH varied significantly across all water supply chains, attributed to handling and storage at various sampling sites similar to observations of Meride and Ayenew (2016) in Wondo genet campus, Ethiopia. Further, several factors have been reported to influence pH of water including; water sources, water storage tanks or vessel materials, temperature, mineral absorption, dust, the level of bacterial activity in a vessel, and duration of water storage before use (Packiyam *et al*., 2016; Manga *et al*., 2021). The water pH was considerably high at the consumers storage facilities compared to other sampling sites agreeing with findings of other studies in Al-Karak province, Jordan by Ziadat (2005) and Chalchisa *et al*. (2017) in Jimma, Ethiopia that water pH increased upon storage. As well, airborne contaminants like dust or algae when it grows in the storage facilities produces weak carbonic acid lowering the pH of water as was suggested in Bindura district, Zimbabwe by Hoko (2008). Nevertheless, the pH values recorded across the supply chains suggested that the water was alkaline as all values recorded were above the pH of 7 although within WHO acceptable values of 6.5 – 8.5 hence water was safe for drinking (WHO, 2017). In another study in Bindura district, Zimbabwe, Hoko (2008) noted that pH tend to influence taste in water and therefore could have aesthetic implications.

Free residual chlorine was only detected once at the tap level across piped water supply chain implying inadequate water treatment which could be due to chlorine dosing, 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). In all other sampling sites across piped water supply chain, FRC was not detected contrary to the information given by the water utility that the water was treated twice in a week. FRC across kiosks supply chain was not detected at all sampling points, revealing that the water inadequately or was not treated before being supplied to consumers and at the household level. The findings of the study compares with results obtained by Kothari *et al*. (2021) in all water samples tested in Uttarakhand, India where chlorination was not detected hence a high risk of water contamination across the supply chain exposing consumers to waterborne disease risks.

The nitrate concentrations slightly varied across piped water supply chain but the values detected at various sampling points were not significantly different. This points out 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, which are again oxidized to nitrate according to Rantanen *et al*. (2018). The increased nitrate concentrations at the kiosks may be attributed to organic pollution at the distribution tank due to 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 kiosk supply chain, a clear indication that vendors' water handling and hygienic conditions at the sampling points had influence in the distribution of nitrate. Nevertheless, nitrate levels were within WHO permissible limit of less than 50 mg/L in drinking water across all supply chains (WHO, 2017). The result obtained in this study concur with the findings of other researchers in Bihar and Telangana, India and Wondo Genet campus, Ethiopia that nitrate were within permissible levels in drinking water (Sukumaran *et al*., 2015; Meride and Ayenew, 2016; Adimalla and Qian, 2019). However, these findings were contrary to what was reported by other researchers in some boreholes water in Turkana that nitrate concentrations exceeded WHO permissible standards which may lead to health risks such as methaemoglobinaemia and thyroid (WHO, 2017; Rusiniak *et al*., 2021).

Faecal coliforms densities across piped water and kiosks supply chain

Across the supply chains, faecal coliforms densities increased from the borehole to consumer point of use pointing to recontamination of water at all sampling points. The boreholes recorded less faecal coliforms attributed to the fact that water sources were groundwater with less contamination compared to other exposed sampling points as was similarly 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 chains may be due to water quality degradation during households storage if not well managed, resulting to faecal contamination as reported by Opryszko *et al.* (2013) in Ghana. In respect to this study, the faecal coliforms detected at the source could be attributed to the effects of floods which destroyed boreholes, filling them with flash floods water. This was observed during field work (personal communication from LOWASCO field staff) and also reported in studies conducted in Anambra state, Nigeria and South Eastern Nigeria (Onuorah *et al.,* 2019; Nwaiwu *et al*., 2020). In such situations, 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 (lack of regular cleaning and disinfection) at the source could be a cause of poor quality of water supplied to customers. The findings of this study agrees with the results of other studies that observed faecal coliforms in boreholes and ground water due to factors such as human activities in Bihar, India (Sukumaran *et al*., 2015); subsurface sediments contamination during borehole drilling using air percussion drilling methods in Lyon, France (Malard *et al*., 2005); proximity of the boreholes to shallow septic tanks in Umoja Innercore estate, Nairobi (Nyakundi *et al*., 2020) and destruction by floods observed in Anambra state, Nigeria and South Eastern Nigeria (Onuorah *et al.,* 2019; Nwaiwu *et al*., 2020). Gwibi *et al.* (2019) in a study conducted in Mohale Basin, Lesotho observed a significant relationship between *E. coli* counts in water sources samples and lack of water source protection, high prevalence of open defecation, unhygienic practices, presence of livestock faeces and latrines within the proximity of water sources. These factors may probably played part in the presence of faecal coliforms at the water sources in Lodwar.

Contamination at the households level may be explained by lack of regular cleaning of 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 toilets or before handling the water as well as inefficient treatment at the distribution tanks similar to observation of Gwibi *et al.* (2019) in Mohale Basin, Lesotho. The latter applied in this study since it was observed that there was no treatment of water at the source and treatment at the distribution tanks was not regular. The results obtained in this study are consistent to the findings of Kwami and Sawyerr (2018) in Gombe Metropolis, Nigeria that water storage facilities favoured microbial and faecal coliforms due to lack of cleaning and proper sanitation of such containers and storage facilities coupled with lack of basic households treatment of drinking water and/or low levels of FRC resulting to faecal contamination. Opryszko *et al.* (2013) in a study conducted in Ghana noted that water quality degrades during household storage including faecal contamination which may explain increased faecal coliform densities at the households' level obtained in this study. Gizachew *et al*. (2020) affirmed that contamination of water at the consumer households may result from mishandling during storage or the storage containers may not be hygienic as was observed in their in Boloso Sore Woreda, Ethiopia. Further, water contamination at the consumers just as observed in this study was attributed to lack of/or inadequate treatment, poor hygiene conditions and contaminated storage facilities in a research conducted in Gombe Metropolis, Nigeria (Kwami and Sawyerr, 2018). Howard and Bartram (2003) observed that consumption of poor-quality water by households was a key pathway for transmission of infectious diarrhoeal diseases. The result of this study agrees with the findings of Opryszko *et al.* (2013) in rural Ghana who suggested that recontamination pathways across the supply chain may be as a result of unclean hands contact with stored water, mixing water from multiple sources, collection and storage vessels contamination, transfer of water from one container to the other, and source contamination (contamination at the borehole, kiosks or distribution tanks). According to WHO guidelines, drinking water sources are expected to be free from faecal contamination (WHO, 2017). This is contrary to the findings of this study as faecal coliforms are present in all sampling points across all supply chains an indication the water was not safe for drinking hence a waterborne health risk to the consumers. This calls for household end point of use treatment methods like chlorination, filtration, boiling or solarization to improve water quality.

Conclusion and Recommendations

Several factors including inadequate water treatment, poor hygiene, improper handling of water, lack of monitoring and regulation influenced water quality across all supply chains in Lodwar town. Faecal coliforms were recorded in all sampling points across both piped water and kiosks supply chains while turbidity at the kiosks consumers exceeded WHO standards for drinking water quality implying the water was not safe for drinking. The free residual chlorine (FRC) was detected only once at the taps along piped system while it was not completely detected across kiosks supply chain over the period of study, which poses waterborne health risks to the consumers. This was evident through faecal coliforms contamination observed in all sampling points across the supply chains hence the water was not safe for drinking unless it is treated at the households' level before use. In view of this, we recommend as follows; a) water treatment should be done at the source or distribution tanks before the water is supplied to the consumers to avoid exposure to waterborne health risks associated with water contamination, b) regular water quality monitoring should be adopted by LOWASCO in collaboration with the Public health department to ascertain quality of water supplied to the residents of Lodwar town, and c) community sensitization on water, sanitation and hygiene (WASH) should be a priority to consumers in Lodwar town so that they are able to verify water quality at households' level or treat water before use.

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