



## Quality Characteristics of Drinking Water from Selected Boreholes in Lodwar Municipality, Turkana County, Kenya

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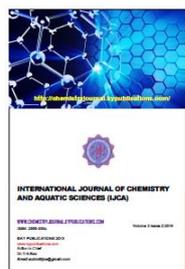
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### ABSTRACT

The quality of drinking water from boreholes is of public health importance. The study investigated the quality of drinking water randomly sampled in triplicates from six boreholes in Lodwar municipality namely: Moi Garden 1D, Moi Garden 1B, Napuu 7, Nabulon 5, Nabulon 6 and Nabulon 8 during the dry season. Physico-chemical parameters were determined in situ using multiparameter electrode (Hann-HI98129).  $K^+$  and  $Na^+$  were determined using flame photometry while  $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Pb^{2+}$  and  $Cd^{2+}$  using Atomic Absorption Spectroscopy (iCE3300 AA System).  $Cl^-$ ,  $SO_4^{2-}$ ,  $CO_3^{2-}$  and  $HCO_3^-$  were determined using titrimetric technique,  $F^-$  using HACH ISE fluoride (HQ44Odmulti) while  $NO_3^-$  analysis used UV/Vis spectrophotometric technique (Vis 130 Spectrophotometer). pH ranged:  $7.4\pm 0.00$ - $7.933\pm 0.03$ , temperature:  $33.57\pm 0.03$ - $34.8\pm 0.00$  °C, turbidity:  $0.19\pm 0.00$ - $0.73\pm 0.00$  NTU, EC:  $259.3\pm 0.33$ - $688.3\pm 0.33$   $\mu S/cm$  and TDS:  $130.1\pm 0.06$ - $341.1\pm 0.67$  ppm and all except EC levels in Napuu 7 and Nabulon 8 fall within WHO limits.  $F^-$  ranged:  $0.7473\pm 0.00$ - $2.087\pm 0.00$   $mgL^{-1}$ ,  $Cl^-$ :  $0.6\pm 0.00$ - $2.1\pm 0.06$   $mgL^{-1}$ ,  $NO_3^-$ :  $0.1033\pm 0.1$ - $0.1733\pm 0.00$   $mgL^{-1}$  and  $HCO_3^-$ :  $2.48\pm 0.00$ - $5.440\pm 0.00$   $mgL^{-1}$  with all parameters complying with WHO standard except  $F^-$  reading in Napuu 7.  $SO_4^{2-}$  ranged:  $0.0303\pm 0.00$ - $2.081\pm 0.00$   $mgL^{-1}$  and  $CO_3^{2-}$  in trace levels with all levels complying with WHO limits.  $K^+$  and  $Na^+$  ranged:  $0.633$ - $5.117$   $mgL^{-1}$  and  $0.0933$ - $0.4367$   $mgL^{-1}$ , respectively and fall within WHO standards.  $Ca^{2+}$ ,  $Mg^{2+}$  ranged  $0.2323$ - $0.9133$   $mgL^{-1}$  and  $1.083$ - $1.423$   $mgL^{-1}$ , respectively and complied with WHO limits. Both  $Pb^{2+}$  and  $Cd^{2+}$  were recorded at trace levels complying with WHO standards. The groundwater quality indices (GWQI) for Moi Garden 1D, Moi Garden 1B, Nabulon 5 and Nabulon 6 fall below 50 confirming the water as safe for consumption. This calls for measures to monitor the elevated  $F^-$  and removal in drinking water from Napuu 7.

Key words: Water Quality, Boreholes, Lodwar Municipality, Chemical Parameters and WHO Limits

## 1. Introduction

Water scarcity due to population growth and climate change is a concern globally. Groundwater use is on increase as an alternative resource (UN, 2022). Turkana County is one of the arid and semi-arid lands (ASALs) of Kenya where groundwater is the primary source of freshwater for drinking, domestic and livestock use (Rusiniak *et al.*, 2021). Water consumption in the county is intensive in urban centers such as Lodwar municipality with an estimated population of 185, 305 people (Ewoton *et al.*, 2023). Previous studies report that groundwater supply in Lodwar municipality is entirely from boreholes especially along Turkwel River (Makokha *et al.*, 2024). However, the borehole water is vulnerable to pollution mainly from geogenic sources since the boreholes are located in areas with low industrial and agricultural activities. Pastoralism is the dominant anthropogenic activity in the county (Makokha *et al.*, 2024). Geogenic pollution of groundwater could be aggravated by human activities such as pumping and mining (UN, 2022) given the geological formation of Turkana County is mainly crystalline basement rocks of volcanic origin (Rusiniak *et al.*, 2021). The municipal borehole water quality and distribution system is managed by Turkana Water and Sewerage Company (TUWASCO).

In some cases, water passes the physical parameters by being transparent, odorless and tasteless but contamination risk is still high with chemical pollutants that are only determinable through appropriate analytical techniques. Such pollutants include divalent heavy metals such as lead ( $Pb^{2+}$ ) and cadmium ( $Cd^{2+}$ ), monovalent anions such as fluoride ( $F^-$ ), divalent anions such as sulphates ( $SO_4^{2-}$ ) and monovalent elements such as sodium ( $Na^+$ ) that could be detrimental to human health when consumed in drinking water beyond WHO allowable limits (WHO, 2022). Heavy metals such as hexavalent chromium ( $Cr^{6+}$ ) are carcinogenic based on International Agency for Research on Cancer's (IARC) standards while fluoride ( $F^-$ ) has been widely reported to cause dental and skeletal fluorosis among other systemic disorders when levels exceed WHO limits of 1.5 mg/L (Akafu *et al.*, 2019; Santhi *et al.*, 2024).

Water treatment technology is ever-evolving with the existing conventional water treatment technologies such as membrane processes (electrodialysis, reverse osmosis and nanofiltration), ion exchange (Sun *et al.*, 2023), coagulation (Sun *et al.*, 2023), electrocoagulation (Grzegorzec *et al.*, 2020) and adsorption process (Patnaik *et al.*, 2016; Garba *et al.*, 2019; Hgde *et al.*, 2020; Tazik *et al.*, 2023) being relatively efficient and but high cost. Adsorption process is preferred due to simplicity, safety, lower cost and ability to remove a wider spectrum of pollutants from water (Tazik *et al.*, 2023). Due to high cost of water purification systems, small scale purified water vendors have emerged in Lodwar municipality but the purified water is expensive. Consequently, a high number of fluorosis cases have been reported in the county (Rusiniak *et al.*, 2021).

Current research has embarked on generating efficient, safe, stable, selective and low cost water treatment technologies for sustainable healthy living. Machine learning approaches have also emerged that can predict water quality trends (Yavuz, 2025). The current study aimed at conducting chemical analysis on water from selected boreholes in Lodwar municipality in order to inform evidence-based policy interventions by the government as well as foster research and development of advantage-dominant water purification systems.

## 2. Materials and Methods

### 2.1 Study Area

Lodwar town is located in Turkana, the second largest county in the north-western region of Kenya covering approximately 77,000 km<sup>2</sup>.

Turkana County is located in ASALs region of Kenya with mean annual rainfall and temperature of 210 mm and 24-30°C, respectively (Munene *et al.*, 2023). Precipitation is unpredictable throughout the year. The county is located within East African Rift Valley whose unique geological formation contributes to higher fluoride levels in groundwater (Hosseini *et al.*, 2024). The geology of the county is mainly composed of crystalline basement rocks of volcanic origin. The study focused on Lodwar town municipality, Global Positioning System (GPS) coordinates: 3° 07' 8.80" N, 35° 35' 50.17" E with an estimated population of 185, 305 people. Lodwar town's water supply depends mainly on boreholes located along Turkwel River (Makokha *et al.*, 2024) under the administration of TUWASCO.

Turkwel River runs through Lodwar town and forms part of the trio feeding Lake Turkana, namely: Turkwel, Omo and Kerio River (Munene *et al.*, 2023). The GPS study map of sampling sites in Lodwar municipality is presented in figure 1.

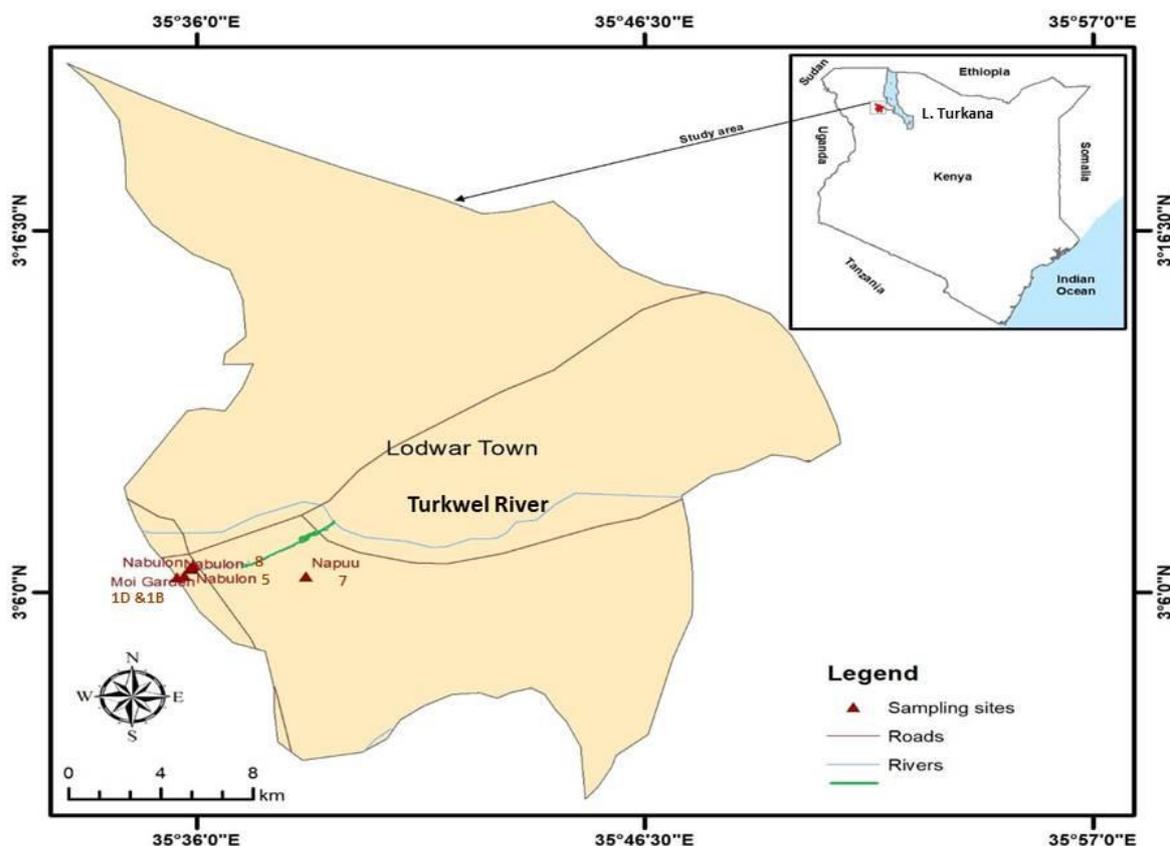


Fig 1: GPS map of sampling sites in Lodwar Municipality

## 2.2 Sampling and Analysis

During the dry season, 1.0 L of water was collected in clean, sterilized, transparent bottles with lids from the six random boreholes in triplicates. The sample size was determined using Yamane's formula (Ying and Idrakisyah (2024) as presented in equation (1).

$$n = \frac{N}{1 + (N \times e^2)} \quad (1)$$

Where n is the sample size, N is the target population and e is the margin of error, in this case, 5% for 95% confidence level.

Physico-chemical parameters; pH, temperature, turbidity, electrical conductivity (EC) and total suspended solids (TDS) were measured in situ using a pre-calibrated portable multiparameter electrode (Hann-HI98129).

Water samples for nitrate ( $\text{NO}_3^-$ ), fluorides ( $\text{F}^-$ ), chlorides ( $\text{Cl}^-$ ), sulphates ( $\text{SO}_4^{2-}$ ), carbonates ( $\text{CO}_3^{2-}$ ) and bicarbonates ( $\text{HCO}_3^-$ ) analysis were ice preserved while for potassium ions ( $\text{K}^+$ ), sodium ions ( $\text{Na}^+$ ), calcium ions ( $\text{Ca}^{2+}$ ), magnesium ions ( $\text{Mg}^{2+}$ ), lead ions ( $\text{Pb}^{2+}$ ) and cadmium ions ( $\text{Cd}^{2+}$ ) acid preserved and transported to the laboratory for analyses. Levels of  $\text{K}^+$  and  $\text{Na}^+$  were determined using flame photometry while  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{Pb}^{2+}$  and  $\text{Cd}^{2+}$  using Atomic Absorption Spectrophotometry (iCE3300 AA System). Titrimetric technique was used to determine the concentration of  $\text{Cl}^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{CO}_3^{2-}$  and  $\text{HCO}_3^-$  in the water sample. Analysis of  $\text{F}^-$  used HACH ISE fluoride (HQ44Odmulti) while  $\text{NO}_3^-$  analysis by color development used UV/Vis spectrophotometry (Vis 130 Spectrophotometer).

### 1.3 Calculation of Groundwater Quality Index (GWQI)

The GWQI for individual boreholes was calculated using the method by Dhakad *et al.*, 2008 and Boadi *et al.*, 2020). The quality rating/sub index  $Q_i$  is given by equation (2).

$$Q_i = \sum_{i=1}^n \left( \frac{M_i - I_i}{S_i - I_i} \right) \times 100 \quad (2)$$

Where  $M_i$  is the average value of the laboratory parameter,  $S_i$  is the standard guideline value of the  $i^{\text{th}}$  parameter and  $I_i$  is the ideal value of the  $i^{\text{th}}$  parameter, taken as zero except for  $\text{PH}=7$ ,  $\text{DO}=14.6$  and fluorides=1.0. The unit weight,  $W_i$  is taken as the reciprocal of  $S_i$ . The GWQI was obtained from the  $\sum Q_i W_i$  divided by  $\sum W_i$  as presented in equation (3).

$$GWQI = \frac{\sum_{i=1}^n Q_i W_i}{\sum_{i=1}^n W_i} \quad (3)$$

The quality parameters considered for computing GWQI for consumable water were PH, Cl<sup>-</sup>, F<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, TDS, total hardness and turbidity (Dhakad *et al.*, 2008). The water quality was classified as per table 1.

**Table 1. Classification of GWQI values**

| GWQI   | Status                  |
|--------|-------------------------|
| 0-25   | Excellent               |
| 26-50  | Good                    |
| 51-75  | Poor                    |
| 76-100 | Very poor               |
| >100   | Unsuitable for drinking |

### 2.3 Data Analysis

Data was recorded and expressed as Mean  $\pm$  Standard Error of Mean. Levels of physico-chemical parameters and other chemical species were compared to WHO drinking water standards.

## 3. Results and Discussion

### 3.1 Physicochemical Parameters:

The mean physicochemical water quality parameters of boreholes in Lodwar municipality are summarized in table 2.

**pH:** From table 2, pH ranged:  $7.4\pm 0.00$ - $7.933\pm 0.03$  and fall within the safe WHO permissible limit of 6.5-8.5. PH < 7 indicates acidic water with higher hydrogen ion ( $H^+$ ) concentration while PH > 7 indicates alkaline water with a higher hydroxyl ion ( $OH^-$ ) concentration.

Pure water has neutral pH of 7 and the concentration of  $H^+$  and  $OH^-$  is equal (Lila *et al.*, 2023). The higher  $H^+$  in acidic pH competes for ligands with metal ions (Zhao *et al.*, 2024) hence promoting solubility of metals ions (Ibe *et al.*, 2025) and release in groundwater from the basement rocks.

**Table 2: Mean physicochemical quality parameters**

| Parameter            | Moi Garden 1D   | Moi Garden 1B     | Napuu 7           | Nabulon 5       | Nabulon 6       | Nabulon 8         | WHO          |
|----------------------|-----------------|-------------------|-------------------|-----------------|-----------------|-------------------|--------------|
| PH                   | $7.633\pm 0.03$ | $7.767\pm 0.03$   | $7.8\pm 0.00$     | $7.633\pm 0.03$ | $7.4\pm 0.00$   | $7.933\pm 0.03$   | 6.5-8.5      |
| Temp ( $^{\circ}C$ ) | $34.53\pm 0.03$ | $33.57\pm 0.03$   | $34.8\pm 0.00$    | $34.47\pm 0.03$ | $34.7\pm 0.00$  | $34.33\pm 0.03$   | -            |
| Turbidity (NTU)      | $0.49\pm 0.00$  | $0.6333\pm 0.003$ | $0.4467\pm 0.003$ | $0.19\pm 0.00$  | $0.73\pm 0.00$  | $0.4667\pm 0.003$ | 15           |
| EC ( $\mu S/cm$ )    | $259.3\pm 0.33$ | $334.0\pm 0.00$   | $588.7\pm 0.33$   | $321.3\pm 0.33$ | $317.3\pm 0.33$ | $688.3\pm 0.33$   | 400.0        |
| TDS (ppm)            | $130.1\pm 0.06$ | $168.0\pm 0.00$   | $294.3\pm 0.33$   | $161.3\pm 0.33$ | $158.3\pm 0.33$ | $341.1\pm 0.67$   | $\leq 600.0$ |

Highly acidic or alkaline water is corrosive, hence unsafe for drinking. The findings were consistent with the study by Rusiniak *et al.* (2021) in Turkana County. Kithure & Mbae, 2022 also found PH ranging  $6.47\pm 0.31$  to  $7.47\pm 0.42$  in borehole water from selected sites within Nairobi County.

**Temperature:** Table 2 also showed that temperature ranged:  $33.57\pm 0.03$ - $34.8\pm 0.00$   $^{\circ}C$ . The recorded higher groundwater temperature could be influenced by higher land surface temperature of the ASALs region and climate change (UN, 2022). Higher water temperature may promote easier desorption of metallic ions from rock particles since adsorption process is exothermic (decreases with temperature increase), hence increasing their release into groundwater (Zhao *et al.*, 2024). Higher water temperature also lowers dissolved oxygen due to decreased oxygen solubility and initially increases biochemical oxygen demand indicating increased microbial activities (Yavus, 2025). Water temperature influences drinking water quality aspects such as odour and taste. The observed results were in line with findings by Mbugua *et al.* (2022) in Lokichar Basin in Turkana County.

**Turbidity:** The turbidity levels ranged:  $0.19\pm 0.00$ - $0.73\pm 0.00$  NTU and complied with WHO limits of 15 NTU. Turbidity is a measure of water transparency indicating the amount of light scattered by substances suspended in water such as clay, silt, inorganic and organic matter and microorganisms, when light is illuminated on the sample. Higher turbidity may not be harmful on its own but it is an indicator of pollution, for instance with disease-causing pathogenic microorganisms (Ibe *et al.*, 2025). The findings compared well with study by Boadi *et al.* (2020) in Kumasi metropolis in Ghana.

**Electrical Conductivity (EC):** The observed EC levels ranged:  $259.3\pm 0.33$ - $688.3\pm 0.33$   $\mu S/cm$  and exceeded WHO limits of 400  $\mu S/cm$  in water from two boreholes: Napuu 7 and Nabulon 8. Higher EC is caused by ionic contaminants such as  $F^-$  present in water and is an indicator of pollution (Sharma and Tiwari, 2018). Rusiniak *et al.* (2021) reported lower EC ranging 0.281-47.000  $\mu S/cm$  in Turkana County.

**Total Dissolved Solids (TDS):** TDS ranged: 130.1±0.06-341.1±0.67 ppm and fall within the WHO limits of < 600 ppm. TDS is a measure of organic and inorganic substances dissolved in water such as salts, minerals and metals (Ibe *et al.*, 2025).

Calcium and magnesium are associated with elevated TDS and are the cause for water hardness. The results were coherent with study by Kithure & Mbae, 2022 in Nairobi County.

### 3.2 Anions

**Monovalent anions:** The mean of selected monovalent anions analyzed in the study is presented in table 3.

**Table 3: Mean monovalent anion levels**

| Parameter (mgL <sup>-1</sup> ) | Moi Garden 1D | Moi Garden 1B | Napuu 7     | Nabulon 5   | Nabulon 6   | Nabulon 8   | WHO  |
|--------------------------------|---------------|---------------|-------------|-------------|-------------|-------------|------|
| F <sup>-</sup>                 | 0.8253±0.00   | 0.7843±0.00   | 2.087±0.00  | 0.8333±0.00 | 0.7473±0.00 | 1.483±0.00  | 1.5  |
| Cl <sup>-</sup>                | 0.68±0.00     | 1.263±0.00    | 1.733±0.03  | 0.6±0.00    | 0.8433±0.00 | 2.1±0.06    | 250  |
| NO <sub>3</sub> <sup>-</sup>   | 0.1433±0.00   | 0.12±0.00     | 0.1733±0.00 | 0.1067±0.11 | 0.1033±0.1  | 0.1167±0.12 | 50.0 |
| HCO <sub>3</sub> <sup>-</sup>  | 2.48±0.00     | 2.733±0.00    | 5.340±0.00  | 3.489±0.00  | 3.341±0.00  | 5.440±0.00  | -    |

From table 3, F<sup>-</sup> ranged: 0.7473±0.00-2.087±0.00 mgL<sup>-1</sup> and was elevated beyond WHO limits of 1.5 mgL<sup>-1</sup> in Napuu 7. The observed fluoride enrichment in Napuu 7 could be attributed to dissolution of fluoride-bearing minerals in volcanic rocks (Rusiniak *et al.*, 2021) since agricultural and industrial pollution are unlikely in Lodwar town (Makokha *et al.*, 2024). Natural weathering of fluorite releases fluoride in groundwater as per equation (4).



F<sup>-</sup> levels below WHO limits prevent dental caries, while levels beyond WHO limits not only cause dental and skeletal fluorosis but also cardiovascular, neurological, reproductive, genetic and endocrine disorders (Magroliya & Trivedi, 2017; Akafu *et al.*, 2019; Santhi *et al.*, 2024). The F<sup>-</sup> levels were consistent with findings by Rusiniak *et al.* (2021) ranging 0.15-5.87 mg/L in selected boreholes from the same county.

The Cl<sup>-</sup> levels ranged: 0.6±0.00-2.1±0.06 mgL<sup>-1</sup> and fall within the acceptable range. Acceptable Cl<sup>-</sup> level is not harmful on its own and is used in water treatment but levels beyond 250 mgL<sup>-1</sup> may lead to undesirable taste. Furthermore, elevated Cl<sup>-</sup> levels have been linked to hypertension and kidney stones (Boadi *et al.*, 2020). The recorded chloride levels could be linked to geogenic sources.

NO<sub>3</sub><sup>-</sup> levels ranged: 0.1033±0.1-0.1733±0.00 mgL<sup>-1</sup> and complied with WHO limit of 50 mgL<sup>-1</sup>. Detrimental health effects of nitrates include methaemoglobinaemia. In Turkana, nitrate pollution in groundwater could be linked to anthropogenic and not geogenic sources with reported open defecation and cattle breeding likely to accelerate nitrate enrichment of groundwater (Boadi *et al.*, 2020; Rusiniak *et al.*, 2021).

The level of HCO<sub>3</sub><sup>-</sup> ranged: 2.48±0.00-5.440±0.00 mgL<sup>-1</sup>. The bicarbonates give water a pleasant odor and presents no adverse health effects to human (Benaabidate *et al.*, 2021). Increase in bicarbonates concentration raises alkalinity of groundwater (Rusiniak *et al.*, 2021). The anions followed the following hierarchy of concentration: HCO<sub>3</sub><sup>-</sup> > Cl<sup>-</sup> > F<sup>-</sup> > NO<sub>3</sub><sup>-</sup>

**Divalent Anions:** The mean of selected divalent anions analyzed in the study is presented in table 4.

**Table 4: Mean divalent anion levels**

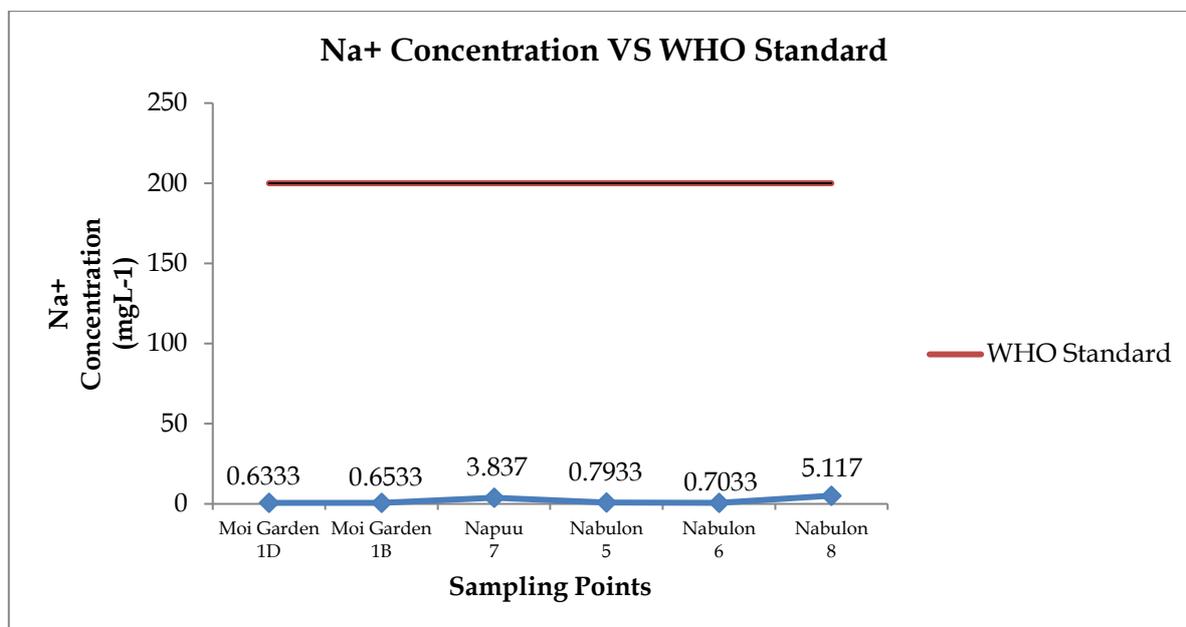
| Parameter (mgL <sup>-1</sup> ) | Moi Garden 1D | Moi Garden 1B | Napuu 7    | Nabulon 5  | Nabulon 6   | Nabulon 8  | WHO |
|--------------------------------|---------------|---------------|------------|------------|-------------|------------|-----|
| SO <sub>4</sub> <sup>2-</sup>  | 0.1523±0.00   | 0.1507±0.00   | 1.052±0.00 | 0.171±0.00 | 0.0303±0.00 | 2.081±0.00 | 250 |
| CO <sub>3</sub> <sup>2-</sup>  | Trace         | Trace         | Trace      | Trace      | Trace       | Trace      |     |

From table 4, the SO<sub>4</sub><sup>2-</sup> levels ranged: 0.0303±0.00-2.081±0.00 mgL<sup>-1</sup> and fall within WHO standard of 250 mgL<sup>-1</sup>.

SO<sub>4</sub><sup>2-</sup> levels are determined by anthropogenic activities as well as microbial activities in the aquifer (Makokha *et al.*, 2024). Excessive sulphates in drinking water may cause diarrhea in human. CO<sub>3</sub><sup>2-</sup> were detected in trace levels, presenting no health threat.

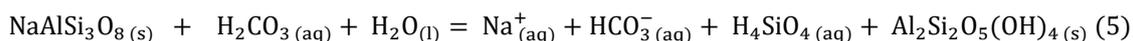
### 3.3 Cations

**Monovalent Cations:** The mean of selected monovalent cations analyzed in the study is presented in figure 2 and 3



**Fig 2: Na<sup>+</sup> levels in Lodwar municipality's borehole water**

From figure 2, Na<sup>+</sup> levels ranged 0.633-5.117 mgL<sup>-1</sup> and complied with WHO standard of 200 mgL<sup>-1</sup>. The chemical weathering process of Na-feldspar yields high Na<sup>+</sup> concentration and HCO<sub>3</sub><sup>-</sup> (Rusiniak *et al.*, 2021) in groundwater as per equation (5).



Na<sup>+</sup> is an essential electrolyte in the human body. However, sodium poisoning may cause nausea, vomiting and convulsion (Lila *et al.*, 2023). The previous studies by Rusiniak *et al.* (2021) recorded higher Na<sup>+</sup> levels.

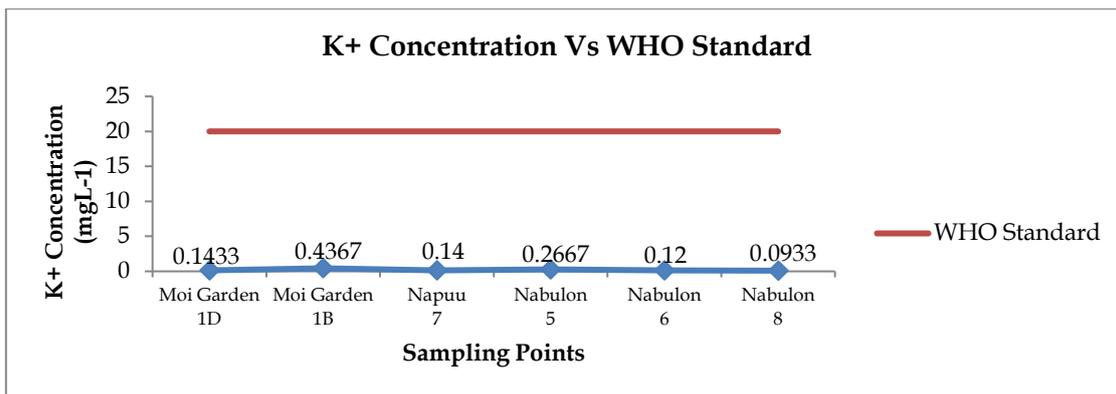


Fig 3: K<sup>+</sup> levels in Lodwar municipality’s borehole water

From figure 3, K<sup>+</sup> levels ranged: 0.0933-0.4367 mgL<sup>-1</sup> and fall within WHO limits of 20 mgL<sup>-1</sup>. Like Na<sup>+</sup>, K<sup>+</sup> is an essential electrolyte in human body. K<sup>+</sup> in drinking water may be elevated by potassium-based water treatment solutions causing health effects to vulnerable people with preexisting cardiovascular and renal diseases (Lila *et al.*, 2023). Increase in Na<sup>+</sup> and K<sup>+</sup> concentration increases water salinity (Boadi *et al.*, 2020). Similarly, the previous studies by Rusiniak *et al.* (2021) recorded higher Na<sup>+</sup> levels.

**Divalent Cations:** The mean of selected divalent cations analyzed in the study is presented in figure 4 and 5.

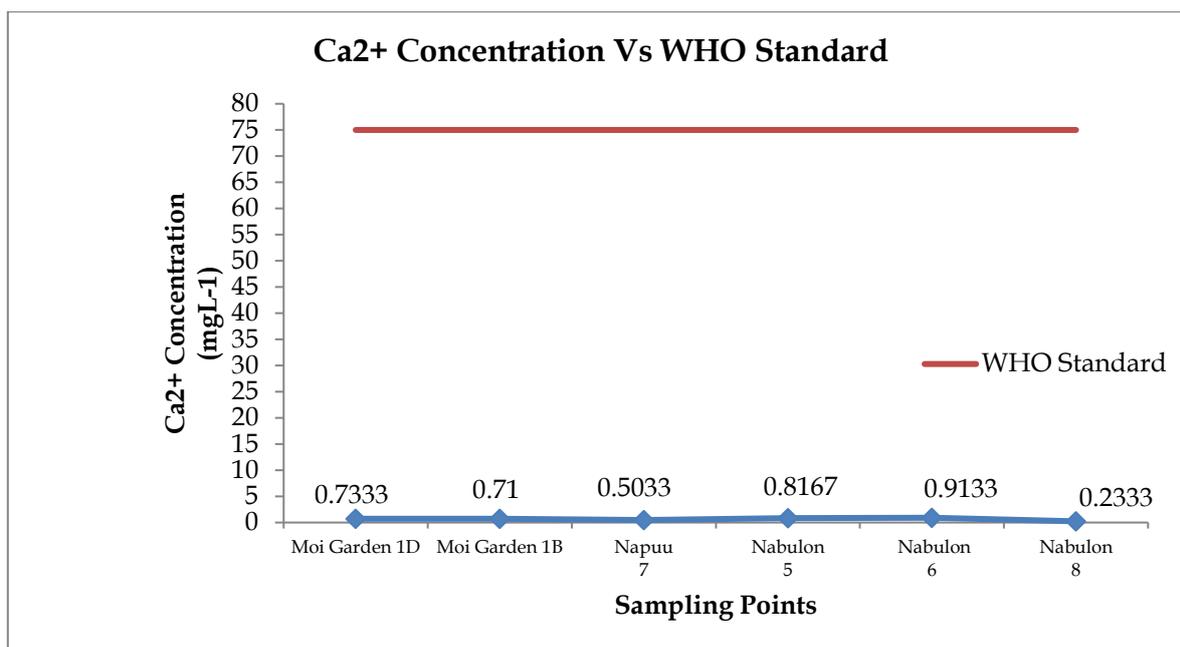


Fig 4: Ca<sup>2+</sup> levels in Lodwar municipality’s borehole water

From figure 4, Ca<sup>2+</sup> ranged: 0.2323-0.9133 mgL<sup>-1</sup> and fall within WHO maximum allowable limits of 75.0 mgL<sup>-1</sup>. The detected Ca<sup>2+</sup> has links to geogenic sources and is cause for water hardness. Calcium is essential for stronger bones and teeth (Boadi *et al.*, 2020). The results were lower than findings by Boadi *et al.* (2020) in Kumasi in Ghana and Rusiniak *et al.* (2021) in Turkana County.

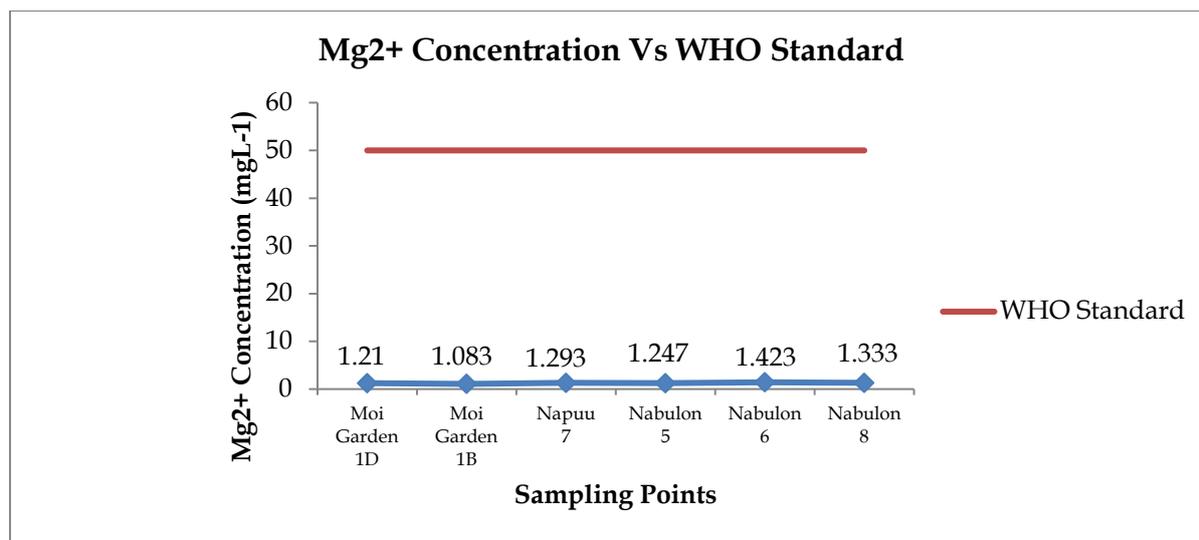


Fig 5: Mg<sup>2+</sup> levels in Lodwar municipality's borehole water

The observed Mg<sup>2+</sup> levels ranged: 1.083-1.423 mgL<sup>-1</sup> and complied with WHO standard of 50.0 mgL<sup>-1</sup>. The detected Mg<sup>2+</sup> is influenced by natural processes and is a contributor to water hardness. Magnesium is an essential element in human body (Boadi *et al.*, 2020). However, magnesium poisoning may be manifested through fatigue, nausea and cardiac arrest (Lila *et al.*, 2023). The results were consistent with findings by Boadi *et al.* (2020) in Kumasi metropolis in Ghana and lower compared to study by Rusiniak *et al.* (2021) in Turkana County.

### 3.4 Heavy Metals

Heavy metal pollution remains a global public health concern. Heavy metals are highly toxic metallic elements whose density is relatively higher than that of water (Tchounwou *et al.*, 2012). The metallic toxins could be released from weathering of the bedrock as well as anthropogenic activities such as agriculture and industrial production (Yang *et al.*, 2018; Githaiga *et al.*, 2021). Lead and cadmium being carcinogenic, were analyzed in the borehole water and their mean levels presented in table 5.

Table 5: Mean heavy metal levels

| Parameter (mgL <sup>-1</sup> ) | Moi Garden 1D | Moi Garden 1B | Napuu 7 | Nabulon 5 | Nabulon 6 | Nabulon 8 | WHO   |
|--------------------------------|---------------|---------------|---------|-----------|-----------|-----------|-------|
| Pb <sup>2+</sup>               | Trace         | Trace         | Trace   | Trace     | Trace     | Trace     | 0.01  |
| Cd <sup>2+</sup>               | Trace         | Trace         | Trace   | Trace     | Trace     | Trace     | 0.003 |

**Lead:** From table 5, Pb<sup>2+</sup> was detected in very small quantities within WHO standards of 0.01 mgL<sup>-1</sup>, presenting no health threat. Lead is not essential in human body and is among the most toxic heavy metals. Acute lead poisoning may lead to neurological, cardiovascular, reproductive and kidney problems (Shikha & Tanu, 2016) while chronic exposure is manifested by memory loss, lack of coordination, anemia, slurred speech, numbness and tingling. Lead poisoning may also cause non-developmental problems in children (WHO, 2022). The results were consistent with findings by Kithure & Mbae, 2022 in Nairobi County.

**Cadmium:** Cd<sup>2+</sup> was detected in very small quantities within WHO standards of 0.003 mgL<sup>-1</sup>, presenting no health threat. Cadmium is not essential in human body. Cadmium poisoning may cause cardiovascular diseases, osteotoxicity and infertility among other problems such as diarrhea, diabetes and neurological disorders (Sharma *et al.*, 2015). Similarly, the results compared well with findings by Kithure & Mbae, 2022 in Nairobi County.

#### 4. Groundwater Quality Index

The GWQI at individual boreholes is presented in table 6.

**Table 6: GWQI for individual boreholes**

| Sampling Site | $\sum_{i=1}^n Q_i W_i$ | $\sum_{i=1}^n W_i$ | $GWQI = \frac{\sum_{i=1}^n Q_i W_i}{\sum_{i=1}^n W_i}$ |
|---------------|------------------------|--------------------|--|
| Moi Garden 1D | 18.03                  | 0.885              | 20.37  |
| Moi Garden 1B | 22.4                   | 0.885              | 25.31  |
| Napuu 7       | 151.6                  | 0.885              | 171.3  |
| Nabulon 5     | 17.15                  | 0.885              | 19.38  |
| Nabulon 6     | 30.17                  | 0.885              | 34.09  |
| Nabulon 8     | 72.06                  | 0.885              | 81.42  |

From table 6, the water quality indices for Moi Garden 1D, Moi Garden 1B, Nabulon 5 and Nabulon 6 fall below 50, indicating that the water was fit for consumption. However, the quality of water in Napuu 7 and Nabulon 8 was poor for human consumption. Boadi *et al.*, 2020 obtained WQI of 54.25, which indicated that borehole water from Kumasi metropolis in Ghana was unsafe for drinking.

#### 5. Conclusion

The tested borehole water quality parameters complied with WHO limits except one fluoride reading in Napuu 7 and EC values in Napuu 7 and Nabulon 8, confirming that the water from the five boreholes was fit for drinking. This was also affirmed by GWQI values below 50. The dominant ions in Napuu 7 and Nabulon 8 were  $\text{Na}^+$  and  $\text{HCO}_3^-$  confirming them as  $\text{Na}^+\text{-HCO}_3^-$  hydrogeochemical type.

##### 5.1 Recommendations

The fluoride levels in Napuu 7 and EC in Napuu 7 and Nabulon 8 were elevated and this necessitates continuous monitoring of the fluorides and removal before drinking. Further analysis of other chemical parameters is highly recommended.

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