Research Paper

Physico-chemical quality of drinking water in the Njoro sub-county in Kenya

Philip Ruciaka Kirianki, Edward Muchiri and Natasha Potgieter

ABSTRACT

Njoro sub-county in Kenya suffers from constant water shortages causing the residents to rely on both improved and unimproved water sources in the area. The households in the sub-county also use different household storage containers to store drinking water in times when water is not readily available. This study was therefore undertaken to assess selective physico-chemical parameters of water used by the population for drinking purposes using standard assessment methods. A total of 372 water source samples and 162 storage container water samples were tested over a period of three months. Turbidity (0.70–273.85 NTU), iron (0.7–2.10 mg/L), fluoride (0.15–4.01 mg/L), manganese (0.01–0.37 mg/L), and nitrate (0.09–27.90 mg/L) levels in water samples were generally higher than the Kenya Bureau of Standards (KEBS) and/or the World Health Organization (WHO) water quality recommendations for safe drinkable water. The results from this study support the need for continuous monitoring and treating drinking water at the points of collection and of consumption to minimize the long-term health effects on communities consuming this water.

Key words | Kenya, physico-chemical parameters, public health, water quality

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INTRODUCTION

In Kenya, many people lack access to potable water, mostly due to recurrent droughts, poor management of water sources, and the arid and semi-arid climate of some regions (Kalungu *et al.* 2014). Although the government spends a great deal of money to improve access to potable water, many rural households do not have access to sufficient volumes for their basic daily needs (Shadrack 2012). Several studies have assessed the quality of different water sources in Kenya (Mwaura 2003; Shivoga *et al.* 2007; Yillia *et al.* 2008; Kiruki *et al.* 2011; Donde *et al.* 2013). However, this is done intermittently and the majority of studies usually did a snap shot (due to cost and time factors) of the water quality. The WHO recommendations for drinking water quality encourage water testing on a regular basis to verify its quality (WHO 2011). These recommendations provide a framework for achieving safe drinking water through the implementation of health-based targets, creation of water safety plans, and the maintenance of water surveillance. In the Njoro sub-county of Kenya, drinking water is obtained mostly from harvested rain water, boreholes, springs, wells, dams, and rivers. These sources are polluted through contamination from sewage leakages, agricultural run offs and livestock wastes (Shadrack 2012). As a result, it is

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necessary to perform frequent assessments of water at the points of collection and of consumption to determine the suitability of the water for domestic use. Physico-chemical components of drinking water have an ability to cause adverse health effects after prolonged periods of exposure, especially chemicals that have toxic properties, such as metals and substances that are carcinogenic (Moturi *et al.* 2002). The aim of this study was, therefore, to assess specific physico-chemical parameters of improved and unimproved water sources and water stored inside various households in the Njoro sub-county of Kenya to determine the quality of drinking water used by rural and peri-urban communities.

MATERIALS AND METHODS

Study site

Njoro sub-county (Figure 1) is located at an elevation of 1,600 to 2,000 m above sea level and about 20 km southwest of Nakuru town in the Kenyan Rift Valley Province (Mainuri & Owino 2013).

The region is classified as semi-arid. It has a total annual rainfall that ranges from 500 mm in the lowlands to 1,800 mm in the highlands and occurs in two seasons, namely, the long rains from March to April and the short

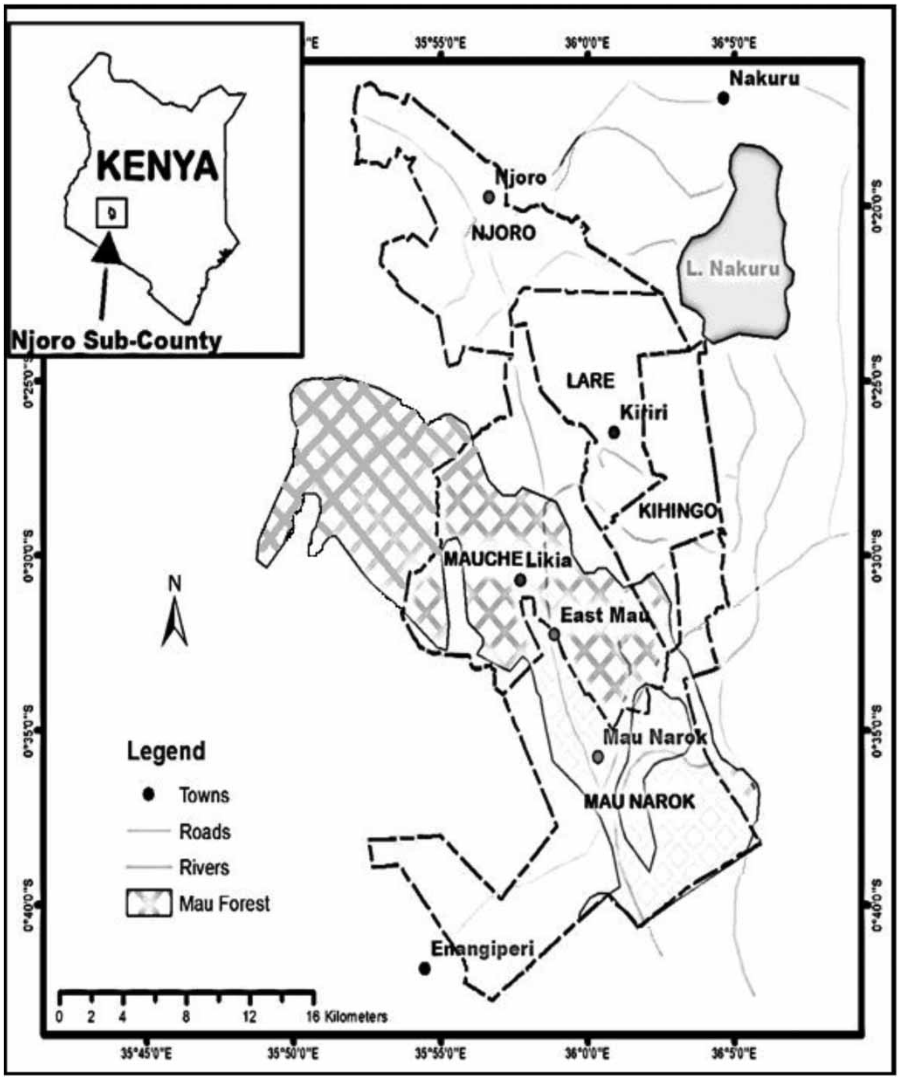

Figure 1 | Map of Njoro sub-county, Kenya.

rains from October to December. The Njoro River is the major source of water but its volume reduces during dry seasons. The salty Lake Nakuru is the nearest lake to the sub-county (Shivoga *et al.* 2007; Yillia *et al.* 2008). The sub-county is divided into five administrative divisions: Njoro, Lare, Kihingo, Maunarok, and Mauche with a total population of approximately 188,124 people (KNSB 2009, 2013). The mainstay of the economy in this area is agri-based industries including vegetable and milk processing, large-scale maize, wheat, and barley farming, and light manufacturing industries such as timber milling, canning, and quarrying (WHO 2011). Due to rapid urbanization, Njoro sub-county has experienced a high population growth (Shivoga *et al.* 2007; Yillia *et al.* 2008). This has led to the generation of more industrial, household, fecal, and agricultural wastes which find their way into water bodies during the raining season (Razif & Persada 2015) where it affects the physico-chemical and microbiological quality of drinking water.

Sample collection

Simple random sampling was used to select the participating villages in this study. The sample size of this study was calculated using the formula $n = z^2 p.q/d^2$ where n = desired sample size; z = standard normal deviation at 1.96 (obtained from a two-tailed normal table); $q = 1 - p$; $d^2 = 0.05^2$, and p = prevalence of the condition under study (Kiruki *et al.* 2011). A total of 372 water samples were collected from 124 water sources and 162 samples from 54 household storage containers (Table 1).

Water sources in the study area were categorized as improved and unimproved sources according to the WHO criteria. An improved water source is defined as a source which as a result of a construction or intervention program is protected from external sources of contamination, while an unimproved water source is not protected in any way from external contaminants like fecal matter (WHO 2011). Sterile 500 mL plastic bottles were used for all water sample collections and all samples were transported immediately after collection on ice to the laboratory for further analysis within 6 hours of collection. Three samples were taken from each source and container type. Household water from storage containers were collected by visiting the homesteads and requesting consent from the home owner before taking a sample. A sterile collection bottle was used to collect a water sample from any domestic storage container that had water used for drinking and other household purposes. Water samples from water sources were collected from all sources used by the study communities as points of water collection. Wells were purged for

Table 1 | Water sources and household water storage containers assessed in Njoro sub-county

Water source and container		***n* (%)**	**Kihingo**	**Njoro**	**Lare**	**Mauche**	**Maunarok**
Unimproved source	River	5 (38.46%)	–	4	–	1	–
	Spring	1 (7.96%)	–	1	–	–	–
	Well	5 (38.46%)	3	1	–	–	1
	Dam	2 (15.38%)	–	–	–	1	1
Improved source	Spring	6 (5.41%)	–	1	–	2	3
	Tap/piped water	28 (25.23%)	2	11	5	9	1
	Tank	45 (40.45%)	14	12	2	6	11
	Borehole	24 (21.62%)	2	17	2	2	1
	Well	8 (7.21%)	5	–	–	–	3
Household container	Sufuria	2 (3.70%)	–	1	–	1	–
	Cup	2 (3.70%)	–	–	1	1	–
	Jug	2 (3.70%)	–	1	–	1	–
	Clay pot	2 (3.70%)	–	1	–	1	–
	Jerry can	40 (74.07%)	9	10	4	7	10
	Bucket	2 (3.70%)	–	1	1	–	–
	Gallon	4 (7.41%)	3	–	1	–	–

–, No samples collected because source type/container type not available to test.

at least 3 minutes to flush out any standing water from the bottom while taps were allowed to run for 2 minutes before sampling. The sample bottle was then rinsed with the water sample three times before taking the sample.

Sample analysis

Physico-chemical parameters used in this assessment included temperature, total dissolved solids (TDS), electrical conductivity (EC), pH, turbidity, dissolved oxygen (DO), biological oxygen demand (BOD), nitrate, manganese, fluoride, and iron. All measurements were based on standard procedures (APHA 1998). All water sample readings were taken in triplicate and averages entered into MS Excel.

Portable meters were used according to the manufacturer's instructions. Temperature, TDS, EC, and pH were measured at the point of sample collection using a multimeter (Combo, Hanna Instruments, USA) according to the manufacturer's instructions. The bulb end of the multi-meter was rinsed in sterile distilled water and carefully placed into the water sample, allowed to stabilize, and each of the readings taken after 2 minutes. The electrode of the pH meter was first calibrated against a pH buffer of 7, 9, and 12, respectively, at room temperature to adjust to the response of the glass electrode. DO was measured at the point of sample collection using a portable DO meter (Hach HQ 40d, USA). The probe was rinsed in distilled water and immersed into the water sample. The reading displayed on the screen was read and recorded in mg/L (KEBS 2010). Turbidity was measured in the laboratory using a turbidity meter (Hach 2100Q, USA). A total of 25 mL of the sample was gently agitated until all air bubbles disappeared. The sample was added to a sample cell and the turbidity read directly from the instrument display screen and recorded in nephelometric turbidity units (NTU). Five days BOD was determined using standard procedures. In brief, the samples were put in the aluminum foil-covered BOD bottle and incubated in the dark for 5 days at 20 °C. Readings were recorded in mg/L (Himedia, USA).

The water samples were not filtered so the mean concentrations of chemical water quality (nitrate, iron, manganese, and fluoride) are total dissolved constituents. Fluoride was assayed using the USEPA SPADNS method. The method involves the reaction between fluoride and a red zirconium dye solution. Fluoride combines with part of the zicornium to form a colorless complex that bleaches the red color in an amount proportional to the fluoride concentration. In brief, a pipette was used to draw approximately 10 mL of the water sample into a dry sample cell and 10 mL of deionized water (control) was drawn into another sample cell to serve as the control. A volume of 2 mL of SPADNS 2 reagent was added to each cell and swirled to mix the contents. Samples were read at 580 nm against the control using a spectrophotometer (Hach DR-3900) and results recorded. Nitrate was assayed using cadmium reduction method. Cadmium metal reduces nitrate in the water sample to nitrite which reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt. The salt couples with gentisic acid to form an amber colored solution. In brief, the sample cell was filled with 10 mL of the sample followed by the addition of nitraVer 5 nitrate reagent powder (cadmium). The contents were swirled for 1 minute to obtain a uniform mixture. An amber color read at 500 nm using a spectrophotometer (Hach DR-3900) was indicative of the presence of nitrate. Manganese was analyzed using the periodate oxidation method. If manganese is present in the water sample, it is oxidized to the purple permanganate compound by the sodium periodate upon buffering with citrate. The intensity of the purple color is directly proportional to the manganese concentration in the respective water sample. In brief, 10 mL of the water sample and distilled water were added into separate sample cells and the citrate powder pillow followed by sodium periodate powder pillow poured into each of the cells. The samples were read at a wavelength of 525 nm using a spectrophotometer (Hach DR-3900) against the control. Iron was analyzed using the FerroVer method. In the case where iron is present in the water sample, the FerroVer reagent converts all the iron into soluble ferrous iron. The 1,10-phenanthroline indicator contained in the powder forms an orange color in proportion to the amount of iron present. Briefly, 10 mL of the sample was put in a sample cell followed by addition of the contents of the FerroVer iron reagent pillows. After dissolvement, the sample was read on a spectrophotometer at a wavelength of 510 nm using a spectrophotometer (Hach DR-3900) against the control.

Data analyses

The physico-chemical quality of drinking water was measured using the WHO water quality recommendations (WHO 2011) and the Kenya Bureau of Standards (KEBS) (KEBS 2010) as shown in Table 2. All the data generated during the study were coded and entered into MS Excel 2010 for cleaning, editing, and then imported into Statistical Analysis System (SAS) version 9.1 for analysis. The means and standard errors were determined and recorded. One-way analysis of variance (ANOVA) was carried out to test the significance differences and the level of significance was determined using the least significant design (LSD) at $\alpha = 0.05$. The LSD method separates means by use of small letters (e.g., a,b,c). If the means within a column are followed by the same letter, they are not statistically different. Means followed by different letters in the same column indicates that the said variable level significantly affects the parameter(s) being analyzed.

Table 2 | Drinking water recommendations used for assessment of quality of water samples

Parameters tested	World Health Organization (WHO) (WHO 2011)	Kenya Bureau (KEBS) (KEBS 2010)
Temperature	Not specified	Not specified
pH	6.5–8.5	6.5–8.5
Electrical conductivity (EC)	Not specified	Not specified
Dissolved oxygen (DO)	Not specified	6 mg/L
Turbidity	5 NTU	5 NTU
Biological oxygen demand (BOD)	Not specified	30 mg/L
Total dissolved solids (TDS)	600 mg/L	1,200 mg/L
Nitrate-NO3	50 mg/L (brief exposure)	10 mg/L
Dissolved manganese	Not specified	0.1 mg/L
Dissolved iron	Not specified	0.3 mg/L
Fluoride	1.5 mg/L	1.5 mg/L

RESULTS AND DISCUSSION

This study assessed the physico-chemical parameters of improved and unimproved water sources and water stored within different household containers in Njoro sub-county in Kenya. Improved drinking water sources were the primary sources of drinking water for the population constituting 89.52% ($n = 111$) while unimproved sources formed 10.48% ($n = 13$). Improved drinking sources in this study included: taps/piped water (25.23%), tanks (40.54%), boreholes (21.62%), protected wells (7.21%), and protected springs (5.41%). Unimproved water sources in this study included: rivers (38.46%), unprotected wells (38.46%), dams (15.38%), and unprotected springs (7.69%). Several different household water storage containers were used in the study area ($n = 54$) and included: jugs (3.70%), cups (3.70%), plastic 5-liter gallons (7.41%), sufurias (silver in color and made of aluminum) (3.07%), jerry cans (74.07%), ceramic pots (3.70%), and buckets (3.70%) (Table 1).

Table 3 provides an overview of all chemical analyses in the study. The nitrate levels for the majority of unimproved water sources and springs in the Mauche region were above the KEBS recommendation limit (KEBS 2010). In this study, nitrate varied between 0.09 and 27.90 mg/L in the unimproved water sources, between 0.90 and 85 mg/L in the improved water sources, and between 0.25 and 9.25 mg/L in the water storage containers. Based on WHO guidelines, nitrate levels in protected springs were high (85 mg/L). Nitrates were above the recommended levels in various water sources: 27.90 mg/L in rivers in Mauche; 13.30 mg/L in unprotected springs in Njoro; 25.80 mg/L in dams in Mauche; and 85.00 mg/L in protected springs in Mauche (Table 3). This could be due to extensive agricultural activities carried out in these regions and hence excessive application of inorganic nitrogenous fertilizers, waste water treatment, and oxidation of human excreta (Khazenzi *et al.* 2014). Findings of a previous study on groundwater in Langas, Kenya had mean nitrate levels above 10 mg/L (Khazenzi *et al.* 2014) attributed to the leakage of nitrates from the pit latrines through the soil into water bodies. Nitrates are highly leachable and can find their way into surface as well as underground water sources leading to contamination (Maghanga *et al.* 2012).

Table 3 | Chemical parameters for improved and unimproved water sources and household storage containers used in Njoro sub-county (mean ± standard error)

Water source and container		Sub-county	*n*	Nitrate (mg/L)	Manganese (mg/L)	Iron (mg/L)	Fluoride (mg/L)
Unimproved water source	River	Mauche	3	27.90 ± 0.29b	0.03 ± 0.01a	0.87 ± 0.23a	2.42 ± 0.64a
		Njoro	12	9.23 ± 1.38ab	0.27 ± 0.04a	0.89 ± 0.05a	0.88 ± 0.30b
	Spring	Njoro	3	13.30 ± 1.38a	0.10 ± 0.02a	0.53 ± 0.19a	1.59 ± 0.12b
	Well	Kihingo	9	5.13 ± 0.70a	0.08 ± 0.03a	0.77 ± 0.32a	0.84 ± 0.25a
		Maunarok	3	0.09 ± 0.02 b	0.08 ± 0.01a	0.07 ± 0.02a	1.25 ± 0.10a
		Njoro	3	2.00 ± 0.01b	0.10 ± 0.03a	0.16 ± 0.07a	4.01 ± 1.29a
	Dam	Mauche	3	8.20 ± 0.21c	0.03 ± 0.01a	0.53 ± 0.23a	2.54 ± 0.17a
		Maunarok	3	25.80 ± 3.89a	0.08 ± 0.03a	0.31 ± 0.13a	1.44 ± 0.11a
Improved water source	Spring	Mauche	6	85.00 ± 5.00a	0.31 ± 0.05a	1.12 ± 0.02a	2.99 ± 0.17a
		Maunarok	9	4.27 ± 0.60b	0.04 ± 0.01a	0.34 ± 0.15a	2.28 ± 0.32a
		Njoro	3	8.60 ± 0.39b	0.07 ± 0.02a	0.54 ± 0.15a	2.75 ± 1.01ab
	Tap/piped water	Kihingo	6	1.09 ± 0.11a	0.05 ± 0.01a	0.25 ± 0.04a	1.71 ± 0.32a
		Lare	15	4.77 ± 0.58a	0.20 ± 0.05a	0.55 ± 0.05a	2.37 ± 0.57a
		Mauche	27	3.90 ± 1.86c	0.11 ± 0.05a	0.54 ± 0.16a	2.11 ± 0.49a
		Maunarok	3	1.20 ± 0.03b	0.05 ± 0.01a	0.25 ± 0.11a	1.89 ± 0.04a
		Njoro	33	2.74 ± 1.00b	0.20 ± 0.05a	0.64 ± 0.20a	1.80 ± 0.37b
	Tank	Kihingo	42	3.09 ± 1.29a	0.24 ± 0.05a	0.53 ± 0.09a	1.73 ± 0.27a
		Lare	6	1.23 ± 0.44a	0.19 ± 0.03a	0.87 ± 0.34a	2.80 ± 0.10a
		Mauche	18	3.42 ± 1.40c	0.29 ± 0.13a	0.64 ± 0.17a	2.20 ± 0.59a
		Maunarok	33	1.70 ± 0.52b	0.07 ± 0.02a	0.30 ± 0.06a	0.80 ± 0.31a
		Njoro	36	3.58 ± 1.30b	0.26 ± 0.06a	0.83 ± 0.18a	0.99 ± 0.21b
	Borehole	Kihingo	6	6.40 ± 0.78a	0.36 ± 0.07a	0.67 ± 0.22a	1.62 ± 0.49a
		Lare	6	6.12 ± 0.84a	0.19 ± 0.03a	0.58 ± 0.09a	1.18 ± 0.23a
		Mauche	6	1.45 ± 0.15c	0.03 ± 0.01a	0.65 ± 0.08a	2.61 ± 0.31a
		Maunarok	3	0.90 ± 0.21b	0.05 ± 0.01a	0.18 ± 0.03a	0.15 ± 0.04a
		Njoro	51	2.32 ± 0.50b	0.06 ± 0.02a	0.40 ± 0.12a	1.86 ± 0.28b
	Well	Kihingo	15	6.86 ± 0.70a	0.37 ± 0.14a	0.52 ± 0.13a	1.05 ± 0.47a
		Maunarok	9	2.42 ± 0.21b	0.09 ± 0.03a	0.25 ± 0.03a	1.84 ± 0.59a
Container	Gallon	Kihingo	9	5.31 ± 0.97a	0.1 ± 0.01a	0.25 ± 0.03a	1.29 ± 0.46a
		Lare	3	2.69 ± 0.09a	0.04 ± 0.01a	0.26 ± 0.05a	2.43 ± 1.01a
	Jug	Mauche	3	1.85 ± 0.38a	0.32 ± 0.08a	0.53 ± 0.17a	3.39 ± 0.14a
		Njoro	3	5.63 ± 0.39a	0.03 ± 0.01a	1.56 ± 0.35ab	0.42 ± 0.16a
	Cup/mug	Lare	3	4.21 ± 0.91a	0.06 ± 0.02a	0.04 ± 0.01a	1.80 ± 0.33a
		Mauche	3	0.65 ± 0.19a	0.05 ± 0.02a	1.05 ± 0.02a	0.23 ± 0.10b
	Jerry can	Kihingo	27	3.49 ± 1.33a	0.30 ± 0.10a	0.55 ± 0.13a	2.04 ± 0.37a
		Lare	12	7.20 ± 1.88a	0.17 ± 0.02a	1.61 ± 0.47a	1.67 ± 0.16a
		Mauche	21	4.60 ± 0.48a	0.20 ± 0.02a	0.83 ± 0.16a	3.19 ± 0.23a
		Maunarok	30	3.82 ± 0.36	0.13 ± 0.04	0.34 ± 0.09	1.2 0 ± 0.33
		Njoro	30	2.56 ± 0.77a	0.17 ± 0.04a	0.43 ± 0.11b	1.34 ± 0.06a
	Clay pot	Mauche	3	0.25 ± 0.08a	0.15 ± 0.03a	0.39 ± 0.17a	3.11 ± 0.13a
		Njoro	3	0.96 ± 0.22a	0.05 ± 0.02a	1.15 ± 0.02b	3.12 ± 1.05a
	Bucket	Lare	3	9.25 ± 1.28a	0.04 ± 0.01a	1.06 ± 0.01a	1.63 ± 0.19a
		Njoro	3	0.33 ± 0.11a	0.04 ± 0.01a	0.89 ± 0.29b	1.87 ± 0.04a
	Sufuria	Mauche	3	0.88 ± 0.21a	0.04 ± 0.01a	0.24 ± 0.06a	0.44 ± 0.17b
		Njoro	3	8.12 ± 3.11a	0.03 ± 0.01a	2.10 ± 0.17a	1.73 ± 0.08a

Manganese results in this assessment varied between 0.03 and 0.27 mg/L in the unimproved water sources, between 0.03 and 0.37 mg/L in the improved water sources, and between 0.03 and 0.32 mg/L in the water storage containers. Manganese concentrations in river (Njoro), spring (Mauche), tap water (Lare and Njoro), tank water (Kihingo, Lare, Mauche, and Njoro), borehole water (Kihingo), protected wells (Kihingo), gallons (Kihingo), jugs (Mauche), jerry cans (Kihingo, Lare, Mauche, Maunarok, and Njoro), and clay pots (Mauche) are shown in Table 3. Dissolved manganese occurs naturally in the ground rocks and can come into contact with underground and surface drinking water (Perlman 2014). Manganese alters the esthetic properties of drinking water, and, in very high concentrations, and for prolonged periods of time, can cause intellectual impairment (Bouchard *et al.* 2011).

Iron levels in unimproved water sources varied between 0.07 and 0.89 mg/L, between 0.18 and 1.12 mg/L in the improved water sources, and between 0.04 and 2.10 mg/L in the water storage containers. Iron measurements were higher than KEBS guidelines apart from unprotected wells (Maunarok and Njoro), tap water (Kihingo and Maunarok), borehole water (Maunarok), and protected wells (Maunarok) (Table 3). Dissolved iron is an abundant mineral in the Earth's crust and when it enters into water, it forms an insoluble precipitate of ferric iron (Wendt *et al.* 2016). The findings of this study are similar to a study in Ota, Nigeria reporting high iron levels in drinking water and groundwater (Anake *et al.* 2014). The high levels of iron containers across the locations could be due to infiltration of iron from soil and pipes into the water supplies before collection (Wendt *et al.* 2016).

Fluoride levels varied between 0.84 and 4.01 mg/L in the unimproved water sources, between 0.15 and 2.99 mg/L in the improved water sources, and between 0.23 and 3.39 mg/L in the water storage containers. The highest mean fluoride measurement in unimproved sources was 4.01 mg/L (unprotected wells in Njoro), in improved sources the highest measurement was 2.99 mg/L (protected springs in Mauche), and at households the highest measurement was 3.39 mg/L (jug water in Mauche) (Meenaksi & Maheshwari 2006; KEBS 2010) (Table 3). Fluoride is a mineral found on the Earth's crust and can find its way into underground drinking water sources (Njenga *et al.* 2005). In levels above 1.5 mg/L, fluoride causes dental fluorosis characterized by brown teeth whereby fluoride replaces the hydroxyl group on the enamel with the hydroxyapatite (Moturi *et al.* 2002). High fluoride is due to the location of Njoro sub-county in the East African Great Rift Valley whereby the underground water from aquifers interacts with the fluoride-bearing rocks (Meenaksi & Maheshwari 2006).

The physical assessment in this study is shown in Tables 4 and 5. The mean temperatures in this study ranged from 16.35 to 24.7 °C in unimproved water sources. The mean temperature in improved water sources ranged from 19.16 to 27.55 °C and in household storage containers ranged from 14.10 to 27.20 °C. Water stored in buckets in Lare had the highest temperature. The high temperatures in rivers could be a result of discharge of human, agricultural, and industrial effluents (Shivoga *et al.* 2007). Water may have a higher temperature because the suspended and dissolved materials can absorb heat from the sun (Munoz *et al.* 2015). Higher water temperatures are less pleasing to consumers and warm water encourages microorganism growth (Shivoga *et al.* 2007; Yillia *et al.* 2008).

The mean pH readings varied between 6.65 and 8.17 in the unimproved water sources, 7.10 and 8.73 in the improved water sources, and 7.13 and 8.67 in the storage containers (Tables 4 and 5). The mean pH in water sources and domestic containers was above the WHO and KEBS recommended values of 6.5 to 8.5 in tap water in Maunarok (8.73), 8.65 (cups/mugs in Lare), and 8.67 (clay pots in Njoro). The pH of water is measured on a scale ranging from 0 to 14 and a pH of less than 7 is acidic whereas more than 7 is alkaline. The pH is important in the effectiveness of disinfection and impacts corrosion of pipes (KEBS 2010). The observed levels for pH indicated that the majority of samples are neutral and slightly alkaline.

EC varied between 180 and 3,360 μS/cm in the unimproved water sources, 60 to 880 μS/cm in the improved water sources, and 20 to 530 μS/cm in the water storage containers (Tables 4 and 5). EC is a measure of the capacity of water to carry electric charge and indicates the amount of TDS. Although there are no WHO and KEBS guidelines on EC, high levels make drinking water increasingly unpleasant. The EC is affected by motion, total concentration, mobility, temperature, and valence of the solution of ions (Morrison *et al.* 2001).

The mean DO varied from 2.59 to 7.27 mg/L in unimproved water sources, 2.67 to 7.04 mg/L in improved water sources, and between 4.59 to 7.10 mg/L in domestic storage containers (Tables 4 and 5). DO forms an important aspect of humans, animals, and water bodies like fish for

Table 4 | Physico-chemical parameters for improved and unimproved water sources in Njoro sub-county (mean ± standard error)

Water source		**Sub-county**	***n***	**Temp (°C)**	**pH**	**EC (μS/cm)**	**DO (mg/L)**	**Turb (NTU)**	**BOD (mg/L)**	**TDS (mg/L)**
Unimproved source	River	Mauche	3	24.70 ± 1.87a	7.51 ± 0.34ab	310 ± 0.06a	5.83 ± 1.46a	44.70 ± 2.87b	0.30 ± 0.06a	150 ± 0.02a
		Njoro	12	16.35 ± 1.09b	8.17 ± 0.09a	3,360 ± 0.64a	7.27 ± 0.16a	94.53 ± 22.80a	0.87 ± 0.23a	70 ± 0.01b
	Spring	Njoro	3	24.00 ± 1.64a	6.74 ± 0.71b	340 ± 0.02a	6.81 ± 0.39a	72.40 ± 10.31ab	0.50 ± 0.19a	170 ± 0.04b
	Well	Kihingo	9	22.23 ± 0.75a	7.56 ± 0.11a	760 ± 0.19a	3.23 ± 0.23b	1.80 ± 0.21a	0.82 ± 0.07b	370 ± 0.11a
		Maunarok	3	22.00 ± 0.31a	7.67 ± 1.84a	180 ± 0.06ab	6.71 ± 1.56a	9.50 ± 2.31b	0.63 ± 0.01ab	90 ± 0.03ab
		Njoro	3	18.00 ± 2.81b	6.65 ± 0.15b	210 ± 0.03a	2.59 ± 0.06b	36.70 ± 9.59c	1.82 ± 0.12a	100 ± 0.03b
	Dam	Mauche	3	19.00 ± 2.83a	7.89 ± 0.32a	270 ± 0.04a	6.93 ± 1.83a	20.30 ± 2.81b	1.49 ± 0.07a	140 ± 0.03a
		Maunarok	3	22.50 ± 1.73a	7.81 ± 0.41a	210 ± 0.04a	6.25 ± 1.24a	59.70 ± 3.62a	0.17 ± 0.02b	100 ± 0.03a
Improved source	Spring	Mauche	6	25.20 ± 7.50a	7.34 ± 0.52a	350 ± 0.03a	6.27 ± 0.66a	273.85 ± 52.85a	1.94 ± 0.21a	180 ± 0.08a
		Maunarok	9	19.43 ± 0.34a	7.10 ± 0.32a	160 ± 0.01b	6.47 ± 0.18a	11.70 ± 1.14b	0.26 ± 0.04b	70 ± 0.01b
		Njor	3	22.10 ± 1.07b	7.12 ± 0.06b	880 ± 0.19a	6.84 ± 1.31a	37.90 ± 2.87bc	0.47 ± 0.11a	440 ± 0.03a
	Tap/piped water	Kihingo	6	21.55 ± 0.25a	7.91 ± 0.66a	680 ± 0.07a	5.41 ± 1.56a	0.55 ± 0.05a	2.16 ± 0.23a	340 ± 0.04a
		Lare	15	21.88 ± 0.75a	7.85 ± 0.24a	170 ± 0.06a	4.48 ± 0.89a	21.92 ± 4.14a	1.01 ± 0.37a	80 ± 0.01a
		Mauche	27	21.21 ± 0.70a	7.78 ± 0.14a	250 ± 0.05a	5.65 ± 0.35a	5.79 ± 1.12b	1.02 ± 0.20a	120 ± 0.03a
		Maunarok	3	21.20 ± 0.37a	8.73 ± 0.28a	190 ± 0.01a	7.04 ± 1.39a	0.30 ± 0.08b	0.91 ± 0.06a	100 ± 0.01a
		Njoro	33	22.28 ± 0.72ab	8.36 ± 0.15a	320 ± 0.03a	6.20 ± 0.28a	4.96 ± 0.59c	1.10 ± 0.36a	160 ± 0.01b
	Tank	Kihingo	42	20.73 ± 0.59a	8.05 ± 0.17a	150 ± 0.05b	6.31 ± 0.29a	4.99 ± 1.90a	0.94 ± 0.16b	80 ± 0.03b
		Lare	6	23.35 ± 3.55a	7.83 ± 0.27a	250 ± 0.05a	5.93 ± 0.74a	1.50 ± 0.20a	0.81 ± 0.06a	130 ± 0.02a
		Mauche	18	20.82 ± 0.60a	7.60 ± 0.08a	350 ± 0.04a	6.16 ± 0.18a	4.38 ± 1.25b	1.61 ± 0.34a	180 ± 0.02a
		Maunarok	33	19.16 ± 0.92a	7.79 ± 0.13a	60 ± 0.02b	5.90 ± 0.26a	3.83 ± 0.81b	0.92 ± 0.07a	30 ± 0.01b
		Njoro	36	20.51 ± 0.75b	7.60 ± 0.19b	100 ± 0.04a	5.27 ± 0.34a	2.90 ± 0.77c	1.02 ± 0.15a	50 ± 0.01b
	Borehole	Kihingo	6	23.85 ± 0.05a	8.09 ± 0.06a	510 ± 0.04ab	6.05 ± 0.30a	0.40 ± 0.08a	0.35 ± 0.10b	250 ± 0.02 ab
		Lare	6	27.55 ± 0.55a	8.42 ± 0.06a	470 ± 0.03a	6.21 ± 0.30a	6.70 ± 1.28a	1.12 ± 0.07a	240 ± 0.02a
		Mauche	6	23.70 ± 0.90a	7.53 ± 0.02a	180 ± 0.02a	6.85 ± 0.01a	7.90 ± 0.60b	0.61 ± 0.08a	90 ± 0.01a
		Maunarok	3	19.80 ± 2.57a	8.24 ± 1.33a	190 ± 0.02a	6.41 ± 1.39a	0.20 ± 0.08b	0.17 ± 0.06b	100 ± 0.02a
		Njoro	51	24.22 ± 0.52a	7.67 ± 0.14b	370 ± 0.03a	6.39 ± 0.33a	5.99 ± 0.70c	0.84 ± 0.10a	190 ± 0.01b
	Well	Kihingo	15	20.86 ± 0.49a	7.42 ± 0.15a	860 ± 0.13a	2.67 ± 0.46b	13.26 ± 1.14a	0.76 ± 0.23b	390 ± 0.04a
		Maunarok	9	22.97 ± 1.10a	7.73 ± 0.32a	220 ± 0.01a	6.30 ± 0.18a	11.70 ± 1.14b	0.26 ± 0.04a	110 ± 0.01a

Table 5 | Physico-chemical parameters for water in household storage containers in Njoro sub-county (mean ± standard error)

Container	Sub-county	*n*	Temp (°C)	pH	EC (μS/cm)	DO (mg/L)	Turb (NTU)	BOD (mg/L)	TDS (mg/L)
Gallon	Kihingo	9	23.90 ± 0.75a	8.10 ± 0.08a	530 ± 0.05a	5.13 ± 0.98a	7.87 ± 1.42a	0.62 ± 0.05a	260 ± 0.03a
	Lare	3	18.50 ± 1.14a	8.09 ± 0.08a	110 ± 0.03a	7.05 ± 1.12a	2.70 ± 0.10a	0.73 ± 0.21a	50 ± 0.01a
Jug	Mauche	3	19.00 ± 1.18a	7.13 ± 0.42a	30 ± 0.01a	5.32 ± 0.13a	0.80 ± 0.10a	3.08 ± 0.02a	40 ± 0.01a
	Njoro	3	24.20 ± 0.43a	8.21 ± 0.89a	320 ± 0.11a	6.03 ± 0.34a	1.50 ± 0.08a	0.58 ± 0.15b	160 ± 0.01a
Cup or mug	Lare	3	20.90 ± 1.19a	8.65 ± 1.12a	440 ± 0.11a	6.64 ± 1.81a	0.70 ± 0.02a	2.31 ± 0.31a	220 ± 0.02a
	Mauche	3	21.00 ± 0.63a	8.35 ± 0.27a	180 ± 0.04a	6.83 ± 0.76a	7.10 ± 1.59a	3.08 ± 0.04a	90 ± 0.03a
Jerrycan	Kihingo	27	21.14 ± 0.61b	7.97 ± 0.16a	280 ± 0.09a	6.12 ± 0.41a	6.74 ± 0.67a	0.87 ± 0.28a	140 ± 0.05a
	Lare	12	23.78 ± 1.00a	7.90 ± 0.18a	400 ± 0.04a	4.59 ± 0.38a	12.88 ± 2.40	1.47 ± 0.42	200 ± 0.02a
	Mauche	21	21.14 ± 1.08a	7.87 ± 0.10a	160 ± 0.02a	7.10 ± 0.70a	4.74 ± 0.65	2.59 ± 0.58	80 ± 0.01a
	Maunarok	30	19.01 ± 1.06	7.84 ± 0.14	130 ± 0.04	6.24 ± 0.31	3.62 ± 0.9	0.63 ± 0.0	70 ± 0.02
	Njoro	30	21.51 ± 0.81a	7.97 ± 0.14a	370 ± 0.05a	5.86 ± 0.28a	2.33 ± 0.94a	0.85 ± 0.26b	180 ± 0.03a
Claypot	Mauche	3	14.10 ± 0.30a	7.76 ± 0.82a	190 ± 0.03a	5.66 ± 0.34a	4.20 ± 1.39a	2.19 ± 0.11a	90 ± 0.03a
	Njoro	3	21.70 ± 0.83a	8.67 ± 0.49a	350 ± 0.13a	5.91 ± 0.89a	8.80 ± 2.34a	1.06 ± 0.02b	180 ± 0.07a
Bucket	Lare	3	27.20 ± 1.94a	7.18 ± 0.33a	30 ± 0.01a	6.16 ± 0.86a	3.00 ± 0.39a	2.00 ± 0.16a	40 ± 0.01a
	Njoro	3	20.60 ± 1.21a	8.04 ± 0.54a	90 ± 0.03a	5.77 ± 0.48a	6.80 ± 1.38a	5.62 ± 0.11a	50 ± 0.01a
Sufuria	Mauche	3	16.10 ± 2.32a	8.04 ± 0.12a	190 ± 0.09a	6.22 ± 0.11a	3.70 ± 1.41a	3.45 ± 0.14a	100 ± 0.03a
	Njoro	3	17.30 ± 0.92a	8.12 ± 0.59a	70 ± 0.02a	6.89 ± 0.79a	2.00 ± 0.41a	0.73 ± 0.28b	30 ± 0.01a

respiration (Munoz *et al.* 2015). Low DO is caused by sewage leakage, run off from fertilizers, and inorganic wastes from industrial and domestic activities. Although DO enters water by photosynthesis and diffusion from air, for diffusion to occur, temperature and the solubility nature of oxygen are critical (Zhang *et al.* 2015).

The turbidity in unimproved water sources ranged from 1.80 to 94.53 mg/L, between 0.20 and 273.85 mg/L in the improved water sources, and between 0.70 and 12.88 mg/L in the water storage containers. The highest turbidity in improved water sources was recorded in protected springs in Mauche (273.85 mg/L), in unimproved sources was in river samples (94.53 mg/L), and in household containers was in jerry cans in Lare (12.88 mg/L) (Tables 4 and 5). Turbidity is a measure of light transmission through water which is influenced by the organic and inorganic particles suspended in the water (Muthuraman & Sasikala 2014). This parameter indicates microbial contamination as microorganisms prefer to attach to these particles (Yillia *et al.* 2008). The results from this assessment showed that turbidity levels in the majority of sources and container stored water were higher than the recommended WHO and KEBS guidelines (KEBS 2010; WHO 2011). High turbidity levels are caused by suspended and colloidal materials such as inorganic materials, clay, and silt (Juntunen *et al.* 2013; Perlman 2014). The high turbidity levels in various drinking water sources and water in household storage containers in this assessment indicated that the esthetic properties of the drinking water such as color and taste were greatly affected (Muthuraman & Sasikala 2014; Perlman 2014).

The measurements from this study for BOD varied between 0.17 and 1.82 mg/L in the unimproved water sources, between 0.17 and 1.94 mg/L in the improved water sources, and between 0.58 and 5.62 mg/L in the water storage containers (Tables 4 and 5). BOD is the amount of oxygen that is required to break down organic matter in water through aerobic processes by microorganisms (Razif & Persada 2015). Another study in the Njoro district to determine the extent of organic pollution of River Njoro reported that the 5-day BOD was in the range of 2.00 to 44 mg/L (Kiruki *et al.* 2011).

TDS in this study varied between 70 and 370 mg/L in the unimproved water sources, between 30 and 440 mg/L in the improved water sources, and between 10 and

260 mg/L in the water storage containers (Tables 4 and 5). The TDS levels were within the WHO and KEBS guidelines of 600 and 1,200 mg/L, respectively. TDS impact on the palatability of drinking water and constitute the dissolved inorganic anions and cations in water. High TDS is caused by sewage spillage, runoffs, chemicals used in water treatment, and the nature of materials used in the piping systems of drinking water (Ahmad & Chand 2015).

CONCLUSIONS

The quality of drinking water available to communities must be of a prescribed recommendation standard for physico-chemical quality. This study showed a variation in parameters tested across sampling points and between different water source types and between different storage container types. Although this study only undertook a one-off assessment of available water sources and water from household storage containers in a specific region in Kenya, the results from this study add to the growing set of data available for quality assessment on water used for domestic purposes in Kenya. The high levels of turbidity, iron, fluoride, manganese, and nitrate detected in the drinking water sample is worrying and a potential health risk to vulnerable individuals. Therefore, more frequent monitoring is needed to investigate specific contributing sources of pollution to water sources and household stored water. In order to achieve universal drinking water access for all by 2030, people must take ownership of their water sources and how they store water at the household level. There should also be adequate training of communities on water storage, handling, and treatment to ensure improvement in water quality in Njoro sub-county.

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