



**ASSESSMENT OF QUALITY OF BOREHOLE WATER IN CHUKA SUB-COUNTY, KENYA**

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**ABSTRACT**

Groundwater from shallow aquifers is an important source of portable water in Chuka Sub-County. However, most shallow boreholes in Chuka Sub-County are undocumented and susceptible to contamination by both geogenic and anthropogenic activities. This study was conducted to evaluate the quality of shallow boreholes water in Chuka Sub-County. Samples were collected from twenty boreholes in Chuka Sub-County during the dry and wet seasons. The temperature, pH and conductivity were determined *in situ* using a meter. The concentration of cations was determined using ICP-MS. The concentrations of anions were determined using standard APHA analytical methods. Obtained data was analyzed using SAS software version 9.4. The temperatures and conductivities of borehole waters were within the limits set by KEBS and WHO. The pH of water in most boreholes during the wet season was within the limits set by KEBS and WHO. However, borehole water at Karandini (T15) was highly acidic (pH of 3.95) during the wet season. During the dry season, borehole waters were slightly acidic (4.42 - 6.44) except for the borehole at Ndagani market (T11), whose water was alkaline (pH = 8.75). The concentrations of macro-cations (Ca<sup>2+</sup> and Mg<sup>2+</sup>) were higher during the dry season. The concentrations of the trace and toxic cations differed significantly across sites and seasons but were within the limits set by KEBS and WHO. The concentrations of anions (NO<sup>-</sup>, SO<sup>2-</sup>, Cl<sup>-</sup> and PO<sup>3-</sup>) were within the limits set by

KEBS and WHO<sub>3</sub> for portable<sub>4</sub> water. However, the concentration of nitrate in several boreholes during the dry season was within the range that cause chronic health effects including colorectal, ovarian, thyroid, kidney and bladder cancers. Groundwater from most boreholes in Chuka Sub-County is generally safe for domestic uses but require regular monitoring for quality.

**Keywords:** Groundwater, borehole, contamination, geogenic, anthropogenic, heavy metals

**INTRODUCTION**

Sub-Saharan Africa suffers acute water shortage with 315 million people remaining without access to improved drinking water (Cobbing and Hiller, 2019). In Kenya, 43% of the population does not have access to clean water (Marshall, 2011). The country is tending toward chronic water scarcity because of increasing water demand due to rapid population growth, industrialization and expansion of irrigated agriculture (Mogaka *et al.*, 2009; Kithiia, 2012). The crisis is more severe in rural areas where almost half of the population does not have access to clean water and relies on raw water from rivers, lakes and dams (Marshall, 2011). Water scarcity will continue to be increase due to rapid population growth, urbanization, increasing per capita consumption rates, increasing average temperatures and climate change and pollution of surface water resources (Gizaw and Gan, 2017; Goulden *et al.*, 2009). In rural areas, shallow groundwater resources are increasingly being used for provision of domestic water supply to due to the ease of drilling and uplifting water from shallow hand-dug, hand-drilled and machine drilled shallow wells (Mumma *et al.*, 2011). These wells are therefore highly susceptible to contamination by both geogenic and anthropogenic sources because their siting does not require reconnaissance surveys and hydrogeological studies (RoK, 2006; Okotto-Okotto *et al.*, 2015).

In Chuka Sub-County of Tharaka-Nithi County, a significant part of the population obtains domestic water from shallow boreholes due to inadequate supplies by Nithi Water and Sanitation Company (NIWASCO). These boreholes are usually dug without hydrogeological studies because the government of Kenya does not regulate abstraction of groundwater from shallow wells (RoK, 2006). The population of Chuka Sub-County in Tharaka-Nithi County is increasing rapidly due to urbanization and establishment of several tertiary learning institutions in the Sub-county. Groundwater from shallow wells and boreholes is being used to bridge the deficit in supply from piped water resources in the county. These boreholes are

susceptible to pollution because their construction and operation is not regulated by the government. This study was aimed at evaluating the physico-chemical parameters of groundwater from shallow boreholes. The physico-chemical properties and the concentration of anions, cations and heavy metals in groundwater from several boreholes spread out throughout the Sub-County.

## MATERIAL AND METHODS

### Study Area

The area is located in the highest altitude of the county geographically, between latitude  $00^{\circ} 07'$  and  $00^{\circ} 26'$  South and between longitudes  $37^{\circ} 19'$  and  $37^{\circ} 46'$  East. Major towns in Tharaka Nithi County include Chuka which is highly populated with 45,882 residents and Chogoria with a lower population of 33,378 residents (KNBS, 2010). The area has deep red soils composed of volcanic ashes and weathered materials from the lahars.

### Sample Collection

Groundwater samples were collected from the boreholes during the dry and wet seasons using 250 ml sterilized PET bottles. The bottles were rinsed three times with respective borehole water prior to sampling. Samples were then collected from each borehole in triplicate and labelled T1 to T20. The pH, conductivity and temperature of the water samples were measured *in situ* using meters. The sampling site are given in table 1.

Table 1: Sampling sites with codes, longitudes and latitudes

Name of sampling site	Codes	Latitude	Longitude
Mungoni	T1	-0.3239489	37.6557212
Kibumbu	T2	-0.3335136	37.6437504
Ikuu Boys	T3	-0.3479525	37.6233826
Ndagani Slaughter	T4	-0.3367368	37.6499972
Kiandogo Village	T5	-0.3502179	37.6393124
Ndagani Marine	T6	-0.3086445	37.6743652
Njaina	T7	-0.30894876	37.6757678
Kirege	T8	-0.3479532	37.6233826
Iruma	T9	-0.3495257	37.6255826
Ndagani Tumaini	T10	-0.3343615	37.6740452
Ndagani Market	T11	-0.3365329	37.6451324
Kirigi Village	T12	-0.3485243	37.6244724
Kirubia	T13	-0.3349398	37.645954
Kangoro	T14	-0.3499825	37.6288856
Karandini	T15	-0.3602106	37.6341194
Kagumo	T16	-0.3452342	37.646274
Ikuu Market	T17	-0.3602106	37.6341194
Rukindu	T18	-0.3207712	37.6607199
Kathigirini Village	T19	-0.2491951	37.73082228
Karigini Village	T20	-0.3455232	37.6249728

### Analysis Of Samples

**Elemental Analysis:** Samples were filtered. Then 50 ml aliquot of each sample was transferred to a 100 ml beaker. 10 ml of 2.0M HNO<sub>3</sub> solution was added, evaporated, cooled and diluted to 50 ml mark in volumetric flask with ultrapure water. The commercially obtained standards, resultant samples and blank were then analyzed using ICP- MS following the standard calibration method. **Analysis of Chloride:** The concentration of chloride ions in the water samples was determined using the argentometric method (APHA Method 4500-Cl<sup>-</sup> B) described in the literature (APHA, 2017). The water sample was filtered; the pH adjusted to 7-10 with 2.0M NaOH and 2.0M of H<sub>2</sub>SO<sub>4</sub> and then titrated with 0.0141N AgNO<sub>3</sub> solution in the presence of potassium chromate indicator to a pink- yellow endpoint.

**Analysis of Nitrate:** The concentration of nitrate ions in the water samples was determined using a spectrophotometric method (APHA Method 4500-NO<sub>3</sub><sup>-</sup> B) described in the literature (APHA, 2017). A 50 ml aliquot of the filtered sample was transferred into a beaker then 1 ml of 1.0N HCl solution was added and the two mixed thoroughly. Standards were prepared through serial dilution of a 1000 ppm NaNO<sub>3</sub> stock solution. The blank (reagent water), the standards and the samples were then analyzed by measuring absorbance at 220 nm and 275 nm using UV-Visible Spectrophotometer. The standard calibration method was then used to determine the concentration of nitrate in the samples. **Analysis of Sulphate:** The concentration of sulphate ions in the water samples was determined using a turbidimetric method (APHA method

4500-SO<sub>4</sub><sup>2-</sup> E) described in the literature (APHA, 2017). Standard sulphate solutions were prepared by dissolving 0.1479g of anhydrous Na<sub>2</sub>SO<sub>4</sub> in distilled water and make up to 1 litre. A 1000 mL buffer solution was prepared by dissolving 30 g magnesium chloride (MgCl<sub>2</sub>. 6H<sub>2</sub>O), 5 g sodium acetate (CH<sub>3</sub>COONa .3H<sub>2</sub>O), 1.0 g potassium nitrate (KNO<sub>3</sub>) and 20 mL acetic acid (CH<sub>3</sub>COOH; 99% in 500 mL distilled water and made up to 1L. Then 50 mL of a standard solution was transferred into a 250 mL conical flask and thoroughly mixed with 10 mL of the aforementioned buffer solution using a magnetic stirrer. A spoonful of BaCl<sub>2</sub> crystals was then added while stirring and stirring continued at constant speed for about 60 s. The solution was then poured into an absorption cell, allowed to settle to about 5 min and its absorbance measured at 420 nm using UV-Visible spectrophotometer.

**Analysis of Phosphate:** The concentration of phosphate ions in the water samples was determined using the colorimetric method (APHA Method 4500-P E) described in the literature (APHA, 2017). A 100 mL combined reagent was prepared by mixing 50 mL 5.0 N H<sub>2</sub>SO<sub>4</sub>, 5.0 mL antimony potassium tartrate solution (prepared by dissolving 1.3715 g K(SbO)C<sub>4</sub>H<sub>4</sub>O<sub>6</sub>. ½ H<sub>2</sub>O in 400 mL distilled water in a 500 mL volumetric flask and topping to the mark with distilled water), 15 mL ammonium molybdate solution (prepared by dissolving 20 g (NH<sub>4</sub>)<sub>6</sub>Mo<sub>7</sub>O<sub>24</sub>. 4H<sub>2</sub>O in 500 mL distilled water), and 30 mL of 0.1 M ascorbic acid solution. A 50 mL filtered water sample was transferred into a 250 mL conical flask followed by 1 drop of phenolphthalein indicator and 8 mL of the combined reagent. The resultant solution was mixed thoroughly and allowed to stand for 10 min. The solution was then transferred into a quartz cuvette and its absorbance measured at 880 nm using UV-Visible spectrophotometer. The calibration blank (reagent water and combined reagent) and standard phosphate solutions (prepared using anhydrous KH<sub>2</sub>PO<sub>4</sub>) were also taken through the entire procedure.

## RESULTS AND DISCUSSION.

**Physico-Chemical Parameters:** The temperature, pH and conductivity of borehole waters during the wet and dry seasons are given in Table 2 During the wet season, the lowest and highest temperatures were recorded at the T1 (23.3°C) and T7 (29.0°C) sites, respectively. The mean temperature for the wet season was 25.75°C while the standard deviation was 1.84. Lowest and highest temperatures were at T17 (24.8°C) and T7 (32.1°C) during the dry season. The mean temperature and standard deviation for dry season were 29.1°C and 1.83, respectively.

**Table 2: Physico-Chemical Parameters of Borehole Waters**

Site	Physico-Chemical Parameters					
	Temperature (°C)		pH		Conductivity (µs/cm)	
	WS	DS	WS	DS	WS	DS
T1	23.3	27.3	8.52	5.44	37	34.1
T2	23.9	27.8	7.51	5.17	40.5	42.4
T3	23.3	29.1	8.08	4.98	36.9	37.7
T4	26.8	29.0	7.96	4.96	62.9	63.4
T5	26.3	29.4	7.0	4.77	57.8	55.2
T6	24.0	30.5	5.91	6.44	16	540
T7	29.0	32.1	6.61	4.8	31.3	22.5
T8	27.3	30.3	9.06	4.83	40.1	38.2
T9	26.8	30.7	8.1	5.15	53.5	52.9
T10	26.2	30.0	5.94	4.96	33.8	32.9
T11	27.7	31.4	7.49	8.75	1150	1208
T12	27.6	31.1	8.57	4.9	21.4	19.5
T13	27.4	30.6	5.96	5.3	100.8	39.9
T14	27.2	29.3	8.47	4.97	20.6	24
T15	27.2	29.3	3.95	4.72	30.5	27.1
T16	23.8	27.1	6.1	5.01	61	76.7
T17	24.1	24.8	5.89	4.42	60.9	59.4
T18	23.5	27.3	6.35	5.88	58.9	119.2
T19	23.7	26.8	9.3	5.18	63.8	58.8
T20	25.9	28.6	7.57	4.66	81.5	59.1
Mean	25.75	29.125	7.217	5.2645	102.96	130.55
Min	23.3	24.8	3.95	4.42	16	19.5
Max	29	32.1	9.3	8.75	1150	1208
St. dev	1.837189	1.830696	1.356536	0.933175	247.3636	277.3128

Note: DS= Dry Season; WS = Wet Season

Temperatures were significantly higher during dry season than during the wet season. The seasonal variation may be due to heavy rainfall and large quantity of fresh water in flow (Kumar and Prabhakar, 2012; Ombaka *et al.*, 2013). Moreover, temperature affects several factors that determine the odour and taste of water (Ombaka *et al.*, 2013; WHO, 2017). During the wet season, the lowest pH of 3.95 was recorded at site T15 while the highest pH of 9.3 was recorded at the T19 site. The mean pH and the standard deviation during the wet season were 7.2 and 1.36, respectively. However, the borehole water at site T15 (3.95) is highly acidic, this could be due to the geology of the site. During the dry season, the pH ranged from 4.42 to 8.75. The mean pH and the standard deviation were 5.3 and 0.93, respectively. The borehole waters were slightly acidic (4.42-6.44) except for site T11 (8.75), whose water was alkaline. The alkalinity is an indication of high amount of ions like  $\text{SO}_4^{2-}$  (Prasad *et al.*, 2014; Buridi and Gedala, 2014). The hydrogen ion are very few and are able to enter and disrupt mineral structures so that, they contribute to dissolved constituents. (Ombaka *et al.*, 2013). The pH of water is influenced by several factors including dissolved gases (e.g. carbon dioxide), volume of water and dissolved chemical species of both geogenic and anthropogenic origins (Murhekar, 2011; Thomas *et al.*, 2009; Buridi and Gedala, 2014; Kumar and Prabhakar, 2012). The final pH of the water is determined by the geology of the sampling site. Highly acidic water can cause adverse health effects such as irritation, gastro-intestinal disorders and redness of the eyes. Moreover, high acidity can lead to corrosion of several metals (Ombaka *et al.*, 2013). The electrical conductivity has a mean of 102.96 and a standard deviation of 247.36. During the dry season, the electrical conductivity has a mean of 130.55  $\mu\text{S}/\text{cm}$  and a standard deviation of 277.31. The borehole water at site T11 had remarkably higher conductivities than the other boreholes in the study area during both the wet (1150  $\mu\text{S}/\text{cm}$ ) and the dry (1208  $\mu\text{S}/\text{cm}$ ) seasons. Electrical conductivity signifies the amount of total dissolved salts. It is a tool to assess the purity of water. High electrical values at T11 indicate the presence of high amount of dissolved inorganic substances in ionized form. The values of electrical conductivity depend upon temperature, concentration and types of ions present. (Prasad *et al.*, 2014; Buridi and Gedala, 2014).

**Concentration of Macro-Cations in Borehole Waters:** The concentrations of macro-cations in borehole waters are shown in Table 3. In wet season, concentrations of  $^{44}\text{Ca}$  ranged from 0 to 797.72 ppb with a mean average of 89.58 ppb. Moreover, the concentration range for the dry season was zero to 3259.11 ppb with a mean of 339.25 ppb.

**Table 3: Concentrations of Macro-Cations in Borehole Waters**

Site	Ca 44(ppb)		Mg (ppb)		Ca 43 (ppb)	
	WS	DS	WS	DS	WS	DS
T1	61.49	32.29	270.56	174.10	47.11	24.80
T2	16.22	0.00	217.97	49.52	9.58	19.75
T3	106.36	161.36	256.59	287.86	83.83	85.16
T4	151.56	51.41	396.82	248.08	117.37	33.14
T5	166.63	416.27	410.77	381.15	97.41	215.56
T6	0.00	3259.11	53.76	4043.75	0.00	1511.29
T7	19.35	42.47	245.93	114.94	26.35	23.92
T8	0.00	0.00	168.37	224.29	0.00	15.58
T9	77.21	403.09	276.32	241.11	43.11	206.12
T10	7.25	0.00	165.69	162.16	42.32	0.00
T11	0.00	0.00	21.88	0.00	0.00	0.00
T12	77.15	0.00	238.03	0.00	61.48	0.00
T13	797.72	232.25	537.57	152.12	479.87	120.94
T14	41.25	0.00	311.10	126.11	36.73	14.05
T15	13.26	181.37	185.07	337.40	30.34	106.24
T16	16.38	392.67	565.74	800.46	14.37	190.97
T17	71.62	267.75	376.42	800.76	55.09	142.67
T18	101.99	1236.91	553.98	1145.57	52.69	609.71
T19	0.00	16.37	184.19	273.69	0.00	27.44
T20	66.19	91.72	1398.36	382.14	38.32	51.36
Mean	89.5815	339.252	341.756	497.2605	61.7985	169.935
Min	0.00	0.00	21.88	0.00	0.00	0.00
Max	797.72	3259.11	1398.36	4043.75	479.87	1511.29
St. dev	174.17	744.76	290.87	883.92	103.71	345.16

Note: DS= Dry Season; WS = Wet Season

The concentrations of  $^{43}\text{Ca}$  ranged zero to 479.87 ppb for the wet season and zero to 1511.29 ppb for the dry season. The mean concentrations were 61.80 and 169.94 ppb for the wet and dry seasons, respectively. The main source of magnesium

in the underground water sample may be attributed to the geological sources such as dolomites, biotite and pyroxene that are abundant in the basement rocks of the sampled area (Saana *et al.*, 2016). The mean concentrations for the wet and the dry seasons were 341.76 and 497.26 ppb, respectively. Concentration of the macro cations is higher during the dry season. The levels were higher during the dry season and lower during wet season for both calcium isotopes and magnesium. The higher concentration of macro cations is presumably due to the geology of the areas (Ombaka *et al.*, 2013). Low concentration of calcium observed could attribute to the absence of sulphate and phosphate containing rocks in the study area.

**Concentration of trace metals in borehole waters:** The concentrations of trace cations in borehole waters are shown in Table 4. The concentration of manganese in all boreholes was zero except T6 (13924.34 ppb), T14 (20.95 ppb) and T18 (1341.27 ppb). The concentrations of manganese during the wet season ranged from zero to 203.89 ppb with a mean concentration of 25.94 ppb. The concentrations in all boreholes were zero except T3 (15.03 ppb), T4 (58.64 ppb), T5 (7.49 ppb), T13 (203.89 ppb), T16 (196.33 ppb), T18 (33.45 ppb) and T20 (3.98 ppb). The concentration of manganese in all boreholes during both the dry and the wet season is significantly lower than the maximum allowed value of 0.1 mg/L set by the KEBS (KEBS, 2015) and the health-based value of 0.4 mg/L set by the WHO for portable water (WHO, 2017). In addition, the concentrations are lower than levels with potential to cause neurotoxicity in children (He *et al.*, 1994; Groschen *et al.*, 2009; Bouchard *et al.*, 2011). Manganese occurs naturally in ground waters sources and soils. Dissolution of manganese from minerals and rocks is favoured by low pH (< 7), anoxic conditions and micro-organisms that degrade organic carbon (Homoncik *et al.*, 2010).

The concentrations of iron during the dry season ranged from zero to 3368.8 ppb with a mean of 209.68 ppb while during the wet season, the concentrations ranged from zero to 715.17 ppb with a mean concentration of 35.76 ppb. These concentrations are lower than levels of 0.5 to 50 mg/L usually found in natural fresh waters and the 2 mg/L allocated to drinking water as part of the minimum daily dietary requirement for iron (WHO, 2017). The concentration of cobalt during the dry season ranged from zero to 14.77 ppb with a mean concentration of 1.73 ppb. The concentrations were within the range for naturally occurring cobalt in groundwater from geogenic sources (Hamilton, 1994). Cobalt is a constituent of several minerals including smeltite, cobaltite and linneite that are abundant in the nickel-bearing laterite deposits, sedimentary copper deposits and the nickel-copper sulphide deposits hosted in mafic and ultramafic rocks (Hamilton, 1994; Barceloux, 1999). The concentrations of copper during the dry season ranged from zero to 26.68 ppb with mean concentration of 2.15 ppb. During the wet season, the concentrations were between zero and 21.90 ppb with mean concentration of 1.18 ppb. These low levels further suggests that groundwater in the study area is not contaminated by copper from anthropogenic sources. The level of zinc during the dry season was zero in all samples. The concentrations during the wet season ranged from zero to 1166.13 ppb with a mean concentration of 88.26 ppb. The higher levels of zinc during the wet season are due to geochemical conditions than enhance mineralization from zinc bearing minerals (McPhail *et al.*, 2003).

**Concentration of toxic metals in borehole waters:** The concentrations of toxic metals in borehole waters are shown in Table 5. During the wet season, the concentrations ranged from zero to 6.45 ppb with a mean concentration of 0.32 ppb. Moreover, the concentrations of lead are two orders of magnitude lower the maximum concentration limit indicating that the groundwater is not contaminated with lead from anthropogenic sources. The concentrations of lead were generally higher during the dry season than in the wet season presumably due to enhanced solubilisation from lead-bearing minerals and rocks at low pH in the boreholes (Zheng *et al.*, 2009). The concentration of cadmium during the dry season was below the detection limit while concentrations during the wet season ranged from zero to 0.22 ppb with a mean concentration of 0.02 ppb. The concentration of mercury during the dry season ranged from zero to 0.1 ppb with a mean concentration of 0.01 ppb. The concentration during the wet season was below the detection limit. The concentrations of arsenic during the dry season ranged from zero to 1.4 ppb with a mean concentration of 0.07 ppb. In addition, the concentrations during the wet season ranged from zero to 0.43 ppb with a mean concentration of 0.02 ppb. These concentrations are significantly lower than the maximum concentration limit of 0.01 mg/L set by KEBS and the guideline value 0.01 mg/L set by the WHO (KEBS, 2015; WHO, 2017). The concentrations of boron in groundwaters ranged from zero to 75.59 ppb during the dry season and zero to 45.85 ppb during the wet season. The mean concentrations were 12.54 and 5.39 ppb during the dry and the wet season, respectively. The concentrations are within the guideline maximum value of 2.4 mg/L set by the WHO for portable water (WHO, 2017). The very low values also suggest that the boron in groundwaters is of geogenic origin presumably as a result of leaching from rocks and soils containing borates and borosilicates (WHO, 2017). The concentration of strontium during the dry season ranged from 1.56 to 240.01 ppb with mean concentration of 32.32 ppb. The concentrations during the wet season ranged from zero to 34.76 ppb with mean concentration of 12.73 ppb. The concentration of barium ranged from zero to 201.91 ppb during the dry season and zero to 37.11 ppb during the wet season. The mean concentrations were 10.10 and 1.86 ppb during the dry and the

wet season, respectively. These concentrations are all within the maximum concentration limit of 0.7 mg/L set by KEBS and the guideline value 1.3 mg/L set by the WHO (KEBS, 2015; WHO, 2017). The primary source of barium in groundwater is leaching from barium compounds in ore deposits and rocks (WHO, 2017).

**Table 4. Concentrations of Trace Cations in Borehole Waters**

Site	Concentration (ppb)									
	Mn		Fe		Co		Cu		Zn	
	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS
T1	0.00	0.00	0.00	0.00	0.15	32.85	0.00	0.00	0.00	1166.13
T2	0.00	0.00	0.00	0.00	1.13	2.90	0.00	0.00	0.00	0.00
T3	0.00	15.03	0.00	0.00	0.00	4.00	0.00	0.00	0.00	0.00
T4	0.00	58.64	0.00	0.00	0.06	2.37	0.00	0.00	0.00	51.06
T5	0.00	7.49	163.68	0.00	1.09	0.89	0.00	0.00	0.00	0.00
T6	13924.34	0.00	3368.82	0.00	9.88	26.93	0.00	0.00	0.00	114.20
T7	0.00	0.00	0.00	0.00	0.06	1.24	3.21	0.00	0.00	12.33
T8	0.00	0.00	0.00	0.00	0.00	1.84	0.00	0.00	0.00	19.25
T9	0.00	0.00	0.00	0.00	3.87	0.35	0.00	0.00	0.00	0.00
T10	0.00	0.00	0.00	0.00	2.49	5.08	0.00	21.90	0.00	0.00
T11	0.00	0.00	0.00	0.00	0.00	0.70	0.00	0.00	0.00	0.00
T12	0.00	0.00	0.00	0.00	0.40	2.07	26.68	1.79	0.00	77.24
T13	0.00	203.89	0.00	0.00	0.00	0.05	13.11	0.00	0.00	27.50
T14	20.95	0.00	0.00	0.00	0.00	2.42	0.00	0.00	0.00	62.90
T15	0.00	0.00	0.00	0.00	0.00	1.72	0.00	0.00	0.00	0.00
T16	0.00	196.33	0.00	0.00	14.77	37.94	0.00	0.00	0.00	47.73
T17	0.00	0.00	0.00	0.00	0.17	320.52	0.00	0.00	0.00	4.37
T18	1341.27	33.45	661.10	715.17	0.50	151.92	0.00	0.00	0.00	146.44
T19	0.00	0.00	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00
T20	0.00	3.98	0.00	0.00	0.00	1.89	0.00	0.00	0.00	36.12
Mean	764.33	25.9405	209.68	35.7585	1.7285	29.921	2.15	1.1845	0.00	88.2635
Min	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00
Max	13924.34	203.89	3368.82	715.17	14.77	320.52	26.68	21.90	0.00	1166.13
St. dev	3111.969614	61.350504	159.916874	758.581727	3.839707	76.513021	6.495134	6.495130	0.00	257.104001

21

Note: DS= Dry Season; WS = Wet Season

**Table 5. Concentrations of toxic elements in borehole waters**

Site	Concentration (ppb)													
	Pb		Cd		Hg		As		B		Sr		Ba	
	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS	WS	D	WS
T1	5.54	0.00	0.00	0.00	0.06	0.00	0.00	0.00	11.20	9.09	7.97	9.41	0.00	0.00
T2	0.00	0.00	0.00	0.22	0.02	0.00	0.00	0.00	7.00	0.00	14.50	11.33	0.00	0.00
T3	22.81	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	23.29	18.88	0.00	0.00
T4	62.80	0.00	0.00	0.00	0.03	0.00	0.00	0.00	11.10	0.00	23.01	26.78	0.00	0.00
T5	2.31	0.00	0.00	0.03	0.00	0.00	0.02	0.00	21.95	0.00	26.86	25.59	0.00	0.00
T6	0.00	0.00	0.00	0.02	0.00	0.00	1.40	0.00	3.43	0.00	240.01	0.00	201.91	0.00
T7	2.20	0.00	0.00	0.10	0.00	0.00	0.00	0.00	1.30	0.00	5.05	4.10	0.00	0.00
T8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.43	0.00	10.82	5.64	0.00	0.00
T9	15.58	0.00	0.00	0.00	0.00	0.00	0.05	0.00	8.43	0.00	14.97	9.22	0.00	0.00
T10	5.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.97	4.17	0.00	0.00
T11	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.43	75.59	45.85	12.57	9.36	0.00	0.00
T12	4.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.76	0.00	1.56	4.64	0.00	0.00
T13	0.00	6.46	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.00	12.67	34.76	0.00	0.00
T14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.40	2.07	13.32	12.39	0.00	0.00
T15	3.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.11	0.00	21.57	6.34	0.00	0.00
T16	108.30	0.00	0.00	0.02	0.00	0.00	0.00	0.00	17.51	0.00	53.02	18.71	0.00	37.11
T17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.08	0.00	40.66	23.07	0.00	0.00
T18	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	34.70	87.91	11.58	0.00	0.00
T19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.59	0.00	11.09	4.42	0.00	0.00
T20	2.52	0.00	0.00	0.03	0.00	0.00	0.00	0.00	37.79	16.11	18.65	14.21	0.00	0.00
Mean	11.79	0.32	0.00	0.02	0.01	0.00	0.07	0.02	12.54	5.39	32.32	12.73	10.10	1.86
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.56	0.00	0.00	0.00
Max	108.3	6.45	0.00	0.22	0.1	0.00	1.4	0.43	75.59	45.85	240.01	34.76	201.91	37.11
St. dev	26.92	1.44	0.00	0.05	0.03	0.00	0.31	0.10	17.46	12.71	52.72	9.19	45.15	8.30

Note: DS= Dry Season; WS = Wet Season

### Concentration of anions in borehole waters

The concentrations of anions in borehole waters are shown in Table 6. The concentration of nitrate is significantly higher during the wet season than the dry season in almost all boreholes. The higher nitrate concentrations during the wet season can be attributed to several factors including leaching of nitrate from agricultural fields, surface run-off into unprotected wells, sub-surface drainage into improperly cased wells and seepage of nitrate from latrines located close to boreholes.

**Table 6. Concentration of anions in borehole waters**

Site	Concentration of Anions (mg/L)							
	Nitrate (NO <sub>3</sub> <sup>-</sup> )		Phosphate (PO <sub>4</sub> <sup>3-</sup> )		Sulphate (SO <sub>4</sub> <sup>2-</sup> )		Chloride (Cl <sup>-</sup> )	
	DS	WS	DS	WS	DS	WS	DS	WS
T1	2.831	5.141	0.045	0.000	0.8887	0.370	0.720	1.000
T2	1.013	9.525	0.044	0.000	2.422	0.290	0.680	1.100
T3	0.299	3.412	0.068	0.050	7.019	0.230	0.640	1.000
T4	1.206	9.919	0.049	0.005	0.162	0.433	0.700	1.000
T5	1.396	10.855	0.049	0.004	0.218	0.407	0.720	1.100
T6	1.237	1.012	0.050	0.000	10.154	0.294	0.820	0.900
T7	0.754	5.521	0.043	0.000	0.918	0.094	0.840	1.050
T8	0.186	4.861	0.058	0.075	0.840	0.030	0.680	1.050
T9	0.571	4.714	0.062	0.112	2.428	0.019	0.680	1.650
T10	0.206	2.523	0.050	0.012	1.932	0.000	0.680	0.850
T11	0.306	2.422	0.150	0.139	8.339	14.335	1.240	1.750
T12	0.194	1.290	0.041	0.000	0.378	0.000	0.700	1.250
T13	0.196	1.152	0.043	0.018	0.362	0.000	0.660	1.250
T14	0.311	1.264	0.045	0.000	0.189	0.000	0.660	1.250
T15	0.347	2.427	0.043	0.000	0.278	3.000	0.680	1.000
T16	1.171	17.315	0.091	0.000	3.080	0.000	0.700	1.100
T17	1.954	19.555	0.043	0.000	0.3075	0.000	0.640	1.050
T18	0.418	4.378	0.052	0.020	9.101	12.906	0.660	0.950
T19	0.258	2.468	0.056	0.045	3.936	5.415	0.620	1.250
T20	1.026	3.578	0.056	0.090	5.332	3.615	0.740	1.150
Mean	0.794	5.667	0.057	0.029	2.914	2.072	0.723	1.135
Min	0.186	1.012	0.041	0.000	0.162	0.000	0.620	0.850
Max	2.831	19.555	0.150	0.139	10.154	14.335	1.240	1.750
St. dev	0.699	5.247	0.025	0.043	3.298	4.220	0.723	0.225

Note: DS= Dry Season; WS = Wet Season

The concentration of nitrate in all boreholes was within the WHO maximum acceptable limit of 50 mg/L for NO<sub>3</sub><sup>-</sup> in portable water (WHO, 2017). The water therefore does not pose adverse health effects (e.g. methaemoglobinaemia) associated with acute nitrate toxicity (WHO, 2017). However, the concentration of nitrate in several wells during the dry season is within the range that has been shown to cause chronic health effects including colorectal, ovarian, thyroid, kidney and bladder cancers (Jones *et al.*, 2016; Schullehner *et al.*, 2018; Temkin *et al.*, 2019).

The concentration of orthophosphate during the dry season ranged from 0.041 to 0.150 mg/L with a mean concentration of 0.057 mg/L. During the wet season, the concentration ranged from zero to 0.139 mg/L with a mean concentration of 0.029 mg/L. These concentrations are significantly lower than the 2.2 mg/L maximum concentration permissible in natural portable water in Kenya (KEBS, 2015). Thus, the concentration of PO<sub>4</sub><sup>3-</sup> in the groundwater does not pose any health or

were significantly lower during the wet season. This suggests that surface run-off and leachate from soils containing phosphatic fertilizers or manure was not the major source of orthophosphate in the groundwater. The orthophosphate in these volcanic soils can be immobilized and retained by several processes including precipitation or co-precipitation by multivalent cations (e.g. Ca<sup>2+</sup>) and adsorption by iron oxide minerals (Griffioen, 2006; Domagalski and Johnson, 2012). Thus, the background concentration of orthophosphate in the groundwater can be attributed to dissolution of phosphate-containing minerals in aquifer sediments. The concentration of orthophosphate in aquifers decreases as the pH of the groundwater decreases due to enhanced adsorption and retention by iron oxide minerals

in the sediments under acidic conditions (Griffioen, 2006; Domagalski and Johnson, 2012). The lower concentrations of  $\text{PO}_4^{3-}$  ions during the dry season are therefore consistent with the higher acidity of the groundwater during this period.

The concentration of sulphate during the dry season ranged from 0.162 to 10.154 mg/L with mean concentration of 2.914 mg/L. Moreover, the concentration was between zero and 14.335 mg/L with mean concentration of 2.072 mg/L during the wet season. The concentration of sulphate in all boreholes was significantly lower than the maximum permissible concentration of 400 mg/L in natural potable water set by the KEBS (KEBS, 2015). The concentrations of sulphate in groundwater in the study area do not pose any aesthetic or health hazards. Thus, the concentration of sulphate ions in groundwater during the wet season was significantly lower than corresponding concentrations during the dry season presumably due to dilution by external water that is abundant during this season. The lower concentration during the wet season suggests that the sulphate in groundwater is not anthropogenic but is derived from sulphate bearing minerals in the aquifers (WHO, 2017). The mean concentrations of chloride were 0.723 and 1.135 mg/L during the dry and the wet season, respectively. These concentrations are very low compared the maximum permissible concentration of 250 mg/L set by the KEBS (KEBS, 2015). The concentrations are also significantly lower than the 200-300 mg/L taste thresholds for the chloride anion (WHO, 2017). The concentrations of chloride in groundwater in the study area therefore do not pose any aesthetic or health hazards. The concentrations of chloride is considerably higher during the wet season. This suggests that agricultural run-off or leaching from soils is a possible source of chloride in addition to dissolution of chloride containing minerals. Concentration of Cl above 5mg/L could result to the irritation of the oesophagus, a burning sensation in the mouth and throat, spontaneous vomiting episodes of dermatitis and asthma can be triggered by exposure to chlorinated water.

## **CONCLUSION**

The water in most boreholes in Chuka Sub-County meet the permissible maximum limits set the WHO and KEBS for portable water. Therefore, the water in most boreholes is generally safe for human consumption and shows minimal contamination from anthropogenic sources, especially during the dry season. However, nitrates levels are higher there is indication of contamination from agricultural run-off during the wet season. The concentrations of nitrate in several boreholes is at levels that can cause chronic health effects. In addition, water in some boreholes is highly acidic, which increases the risk of geogenic contamination through dissolution of minerals from rocks.

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