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UNDERGROUND WATER IN KENYA: ABSTRACTION, POLLUTION AND SOCIETAL DEMAND; A CASE STUDY OF WELLS IN THREE PERI-URBAN AREAS OF ELDORET TOWN IS USED TO ILLUSTRATE THIS SCENARIO

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AUTHORS' CONTRIBUTIONS
This work was carried out in collaboration between all authors. Author PW designed the study, wrote the protocol and interpreted the data. Authors PW, HT and JM anchored the field study, gathered the initial data. Authors PW, HT and JM performed preliminary data analysis. Authors PW, MW and JM managed the literature searches and produced the initial draft. All authors read and approved the final manuscript.

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ABSTRACT

The quality of water from different sources is a concern raised by the Sustainable Development Goals. Rapid urbanization has forced most urban dwellers to live in crowded slums that are characterized by poor sanitation and inadequate supply of clean water. They rely on water wells that are often close to sources of pollution. The aim of this study was to analyze the quality of water in wells in three peri-urban centers of Eldoret Municipality. Six wells were randomly selected in each center, and their distances from pit latrines and garbage dumpsites determined by a tape measure. Two other water wells located at the recommended 30 m or above from a pollution source, served as controls. Biochemical oxygen demand (BOD), pH, turbidity, water temperature, nitrogen and phosphorous for each water sample collected two times during the dry season (January to March 2015) and two times during wet season (April to May 2015) were determined using standard methods and procedures. The findings were then compared to the Kenya National Water Quality Standards (KNWQS). In all the centers', the average distance from water wells to pit latrines (12.9 m) and garbage dumpsites (16.8 m) were below the desirable KNWQS limit, an indication that contaminants could leach from pollution sources into the water wells. The mean temperature, pH (wet season), BOD, phosphorous and nitrogen in each water well were within the permissible limits of 19-30°C, 6.5-8.5, 0.8-5 mg/l, <0.05 mg/l and <0-1 ppm, respectively. However, the mean, pH (dry season) and turbidity in each water well exceeded the permissible limits of, 6.5-8.5, <0.03 g/l, <5 NTU respectively. Analysis of variance (ANOVA) was used to analyze statistical differences in the variables among the water samples. This revealed that there was a significant variation in water pH in Langas, (ANOVA: $F_{3, 39}$=15.73; p<0.0001), while in Huruma the variations were not significant (ANOVA: $F_{3, 39}$=15.73; p=0.6420) in the dry season, at 0.05 level of significance. This study concludes that topography is a key influence on proximity of water wells to pit latrines and garbage dumpsites in the study areas, thus affecting the levels of pH, Turbidity and TSS in ground water. This study recommends the construction and use of standard communal water wells, review of the 30 m location distance of water wells and other water abstraction points from pollution sources and regular monitoring of ground water quality.

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Keywords: Underground water; abstraction; pollution; water budget; sustainable development.

1. INTRODUCTION

The use of groundwater has spurred growth in agriculture across the world. Among the top worldwide groundwater abstracting countries are India, the United States of America and China [1]. These three countries account for over 50 percent (about 442 km^3) of global groundwater abstraction of an estimated 840 km^3 per year [2]. The value of India's agricultural output rose from $28.3 to $49.9 billion from 1970 to 1993. At the start of this period, groundwater contributed only 4.4 percent of this value, while by the mid-1990s it contributed 14.5 percent [2].

In 2005, the Kenya National Water Services Strategy revealed that the water sanitation situation was poor [3]. Sustainable access to safe water was around 60 percent in the urban setting and dropped to as low as 20 percent in the settlements of the urban poor where half of the urban population lived [4]. In urban areas, large populations living in informal settlements within the towns and cities have no access to safe water. In rural areas, there are large disparities between geographic areas for instance in North Eastern and Eastern parts of Kenya, less than 30 percent of the poor people have access to safe water compared to approximately 60 percent in Western parts of Kenya [5].

1.1 Area of Study

This study was carried out in Eldoret Municipality, Uasin Gishu County, Kenya (Fig. 1), Uasin Gishu County covers an area of 2,955.30 Km^2, and is located at 0° 31' N (Latitude) 35° 17'E (Longitude). The County governance is divided into 3 Constituencies and 13 wards. There are three peri-urban areas that lie within different Constituencies; Huruma in Eldoret North, Munyaka in Eldoret East and Langas in Eldoret South. The area receives annual rainfall that range between 900 and 1,200 mm. Annual temperatures range between 8 and 27°C. Eldoret Municipality has an estimated population of 289,380 people [6]. Economic activities include; horticulture, dairy farming, wheat and maize farming, sports and tourism.

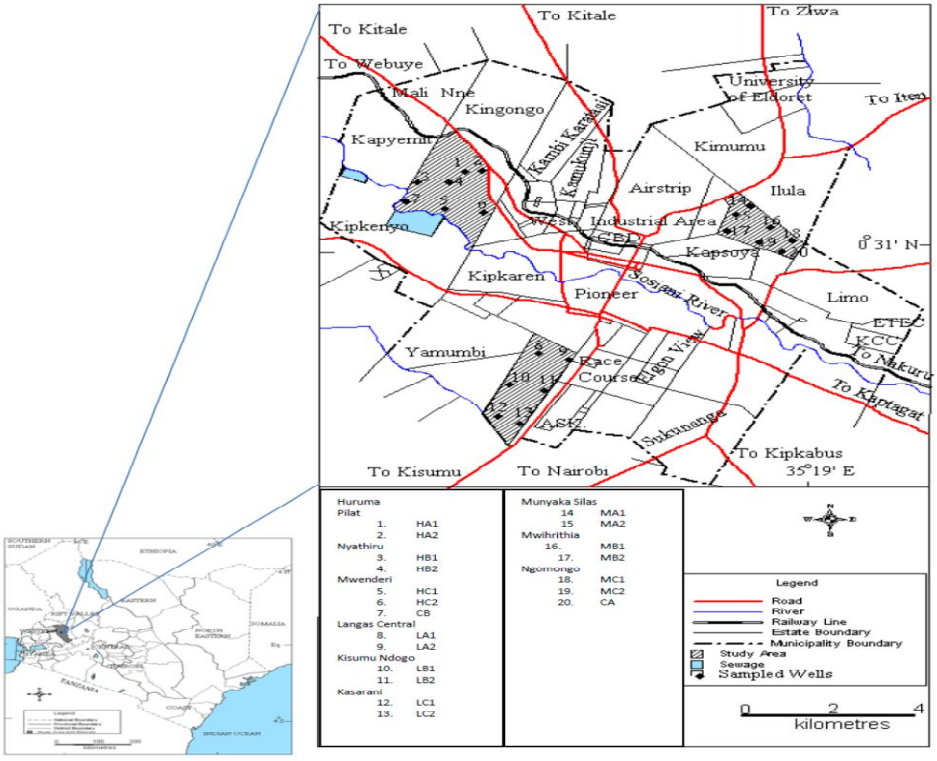

Fig. 1. Map of Eldoret Municipality showing the distribution of the wells sampled (dots in shaded areas) in Langas, Munyaka and Huruma. (Courtesy of L. Kanda, School of Arts and Social Sciences; Moi University, 2015)

1.2 Statement of the Problem

Close to 70 percent of diseases in developing countries are water borne, causing approximately three million deaths per annum [7]. Cross-country research shows that communicable diseases cause 56 percent of deaths among the poorest 20 percent of the population compared with 8 percent among the richest 20 percent [7]. Over 50 percent of Kenya's households do not have access to safe drinking water and the proportion is higher among the poor. In urban areas, large populations living in informal settlements within the towns and cities have no access to safe water [5]. In many peri-urban areas of Kenya, potable piped water hardly exists and where it does exist, it is unreliable [8]. In such areas, residents often rely on groundwater sources for their day to day activities. According to a study done in Langas, if the distance between wells and pit latrines is not adequate, microorganisms can migrate from the latrine to the water in the well [9]. The present study was carried out due to increasing concern on the quality and safety of drinking water in slum areas of Kenya as indicated by increase in waterborne disease outbreak [10].

2. METHODOLOGY AND DATA ANALYSIS

2.1 Research Design

Formal experimental design was used, specifically; two-group simple randomized design. First of all the population was defined and then from the population a sample was randomly selected. Further random selection of the population was done, and assigned to the experimental and control groups. Thus, the design yielded two groups as representatives of the population. The two groups (experimental and control groups) of the design were given different treatments of the independent variable (Proximity to water wells). Distance of proximity of water wells to pit latrines and landfills was determined by direct measurement using a tape measure. This was followed by collection of water samples and laboratory analysis of water samples collected from randomly selected water wells.

2.2 Selection of Sampling Points

Three peri-urban areas (Langas, Munyaka and Huruma) were purposefully chosen in Eldoret Town. Each of the three areas was divided into three distinct study zones; Langas- LA (Central), LB (Kisumu Ndogo) and LC (Kasarani); Munyaka- MA (Silas), MB (Mwitirithia) and MC (Ngomongo); Huruma- HA (Pilot), HB (Nyathiru), and HC (Mwenderi). Zoning was based on the geographical/political boundaries and divisions of the area. Ten water wells of proximity above 31 m from garbage dumpsites and pit latrines were purposely selected and were assigned distinct numbers that were individually written on slips of paper one to ten. Two (2) control wells were then randomly chosen by lottery from the ten water wells. Control point A was located Munyaka area and Control point B was located in Huruma. A total of 40 samples were collected in duplicates during the dry season (January and March 2015) and a further 40 samples were collected in duplicates during the wet season (April and May 2015). Water samples were collected half a meter deep from the surface of the water using dip sampling method. The water samples were then transported to the laboratory in one liter plastic bottles. All samples were analyzed using standard analytical procedures.

2.3 Proximity of Selected Water Wells to Sources of Pollution

All the selected water wells were located below 30 m from pit latrines or garbage dumpsite (Fig. 2). The selected water wells were located between 6 to 20 m from a pit latrine and 5 to 25 m from a garbage dumpsite. Controls A and B (CA and CB) were located at 31 and 35 m respectively from pit latrines and 34 and 35 m respectively from garbage dumpsites (Fig. 2).

2.4 Determination of Biochemical Oxygen Demand (BOD_5)

The depletion of dissolved oxygen in the water samples by microorganisms as they oxidize organic matter in a given sample was determined in-situ and ex-situ using an automatic Dissolved Oxygen (DO) Multimeter (Model, HANNA-HI 9142, USA), whose multimeter probe screen was set to DO mg/l. Calibration was performed with HI 7040 zero oxygen solution. The HI 7040 zero solution was stirred gently for 2-3 minutes. From each study zone, a pair of 250 mL BOD bottles were filled with water samples from each selected water well and left to stand for 15 minutes or until the air bubbles disappeared. Determination of BOD consisted of initial and final readings. The DO of the two dilution water blanks and a pair of each sample were determined immediately after collection of the samples and recorded on a data sheet. This was done by immersing the multimetre probe into the water samples and allowing the water temperature to stabilize. This was done three times for each sample and the mean value recorded [11]. Water sample in the second BOD bottle was incubated in the dark at 20± 0.5°C in an incubator (Mrc; model number: DFI-150) for 5 days. Water seals were filled

with dilution water and cap to reduce evaporation from seals and were checked daily. If necessary, dilution water was added, after which the final readings of the DO were taken at the end of 5 days following a similar procedure as for taking the initial readings. BOD was then calculated by subtracting the final DO from the initial DO (Eq. 1).

2.5 Calculation of BOD_5

$$BOD\ mg/l = (Initial\ DO - DO_5) \times Dilution\ Factor \quad (1)$$

Where;

DO = Dissolved oxygen before incubation
DO_5 = Dissolved oxygen after 5 days of incubation

$$Dilution\ Factor = \frac{Bottle\ Volume\ (x\ ML)}{Sample\ Volume}$$

2.6 Determination of Water pH

The pH of the water samples was measured ex-situ using the standard protocols and methods of [11]. This was done in the laboratory by direct reading on a pH meter (Labtech, Model pH-Pro12, Serial. No.-1530, India). The pH meter calibration was done according to the manufacturer`s specifications, before recording the measurements. Standard buffer solutions of pH 4 and pH 7 were used for calibration. Fresh buffer solutions of pH 4 and 7 were prepared and then dispensed separately in clean 250 mL glass beakers, and the pH meter electrode immersed in the solution one at a time, to a depth of 2 cm. Calibration was done at both pH 4 and pH 7 by pressing the calibration knob. Another 250 mL beaker was filled with the water from one well. The pH value of the sample was recorded from the digital display after submerging the pH probe in the water sample and holding for 5 minutes to achieve a stabilized reading. After the measurement of each sample, the probe was rinsed with deionized water [11], and the procedure was repeated for all the water samples. Three replicate samples were measured and the mean value recorded [11].

2.7 Determination of Total Phosphorus

2.7.1 Preparation of sulphuric acid, 5N H_2SO_4,

A 500 mL clean beaker was placed in cold water in a sink. Then 250 mL distilled water was poured into it and 74 mL concentrated Sulphuric acid was added slowly while stirring and then diluted to 500 mL with distilled water.

2.7.2 Preparation of murphriley solution

Six grams ammonium molybdate ($[NH_4]_6Mo_7O_{24}.4H_2O$) was dissolved in 125 mL of warm (50°C) distilled water. Separately, 0.15 g antimony potassium tartarate ($KSb\ C_4H_4O_6$) was dissolved in 50 mL distilled water. Both solutions were added to 500 mL of 5N H_2SO_4. It was mixed thoroughly and then diluted to 1000 mL with distilled water. It was then transferred to a reagent bottle and kept in a dark cool place for 24 hours, before it was used for analysis.

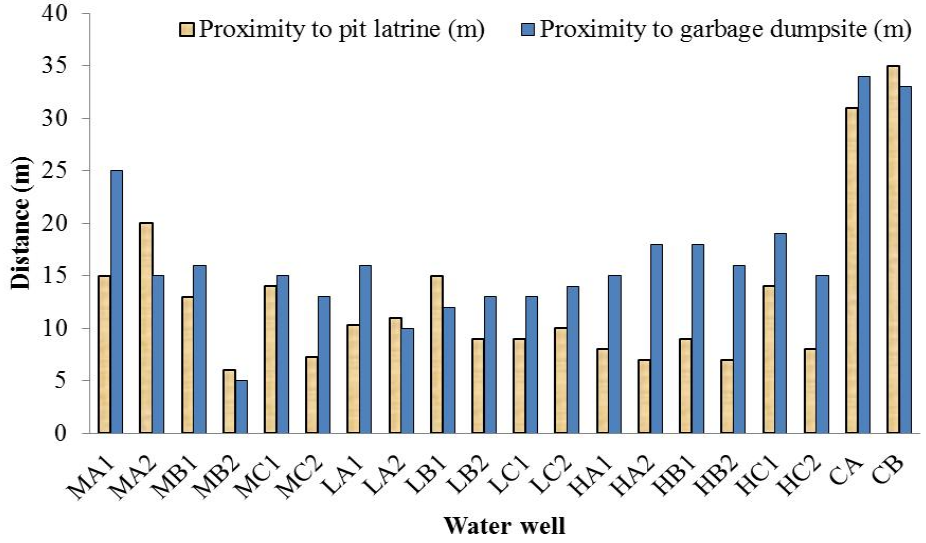

Fig. 2. Distance of selected water wells to pit latrines and garbage dumpsites

2.7.3 Preparation of ascorbic acid reducing agent

Ascorbic acid ($C_6H_8O_6$) (1.581 g) was dissolved in 300 mL murphriley solution and mixed well and kept in dark for 24 hours.

2.7.4 Calibration of the spectrometer

Standard phosphorous dilution series of; 0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2 and 1.4 mg/l were prepared and were used for calibration of the spectrometer. Fifty milliliters of the sample was pipetted into an acid dry-cleaned 125 mL Erlenmeyer flask. One drop of phenolphthalein indicator solution was added. A red colour developed and 5N H_2SO_4 was added until the colour disappeared. Eight milliliters of combined reagent was added and mixed thoroughly. It was then heated for 30 minutes in an autoclave at 121°C (20 psi) for colour development and left to cool to room temperature.

2.7.5 Colorimetric procedure for phosphorus

Five milliliters of the supernatant clear wet-ashed digest solution was pipetted into 50 mL volumetric flask. Twenty milliliters of distilled water was added to each flask followed by adding 10 mL of ascorbic acid as reducing agent. The solution was then left to stand for 1 hour to permit full colour development.

A graph of absorbance against concentration of standards was plotted (Fig. 3), to aid in getting the value of m, (y = mc). Where y = absorbance of each sample – absorbance of blank. y/m = c and c is the corrected concentration. A 2 mL digest aliquot and a 50 mL final dilution was used for colour intensity measurement and the sample concentration determined from the graph using the formula (2):

$$Y = 0.7874x$$

$$\text{Phoshorous concentration}\frac{\text{mg}}{\text{l}} = \frac{\text{Absorbance}}{\text{X}} \quad (2)$$

2.8 Determination of Nitrogen

Kjeldel method [12] was used. Ten grams of catalyst was added in a dry Kjeldel flask. Two hundred milliliters of the water sample was poured in Kjeldel flasks in duplicate. Twenty milliliters of concentrated H_2SO_4 was added to each of the solutions. These solutions were heated and then cooled to room temperature. The digest were then transferred into a micro-Kjeldel distillation unit to which 10 mL of 50 percent sodium hydroxide solution and 10 mL of distilled water were added followed by 3 to 4 drops of 1 percent w/v phenolphthalein indicator solution. The latter was placed under a condenser so that the tip of the outlet of the condenser was dipped into the contents of the conical flask. 5 mL of 0.05 N H_2SO_4 solution was placed into a 250 mL receiving conical flask. It was then topped up with 10 mL of distilled water. The boiling flask was heated and the steam passed into the sample. The distillation was continued for about 10 minutes. The conical flask was removed and the boiling flask cooled so that all wastes were sucked and removed through a tap. This process was repeated for the duplicate sample and the distillates were subsequently titrated against 0.05 N sodium hydroxide. The turning of pink colour to yellow was considered the end point. An average value was calculated and recorded. Distilled water blank was digested concurrently using this method (Eq. 3) [12].

Net Alkali Titer, mL=Net blank 0.05 N NaOH Titer, mL-Sample 0.05 N NaOH Titer, mL

Calculation

$$\text{Nitrogen, ppm (W/V)} = \frac{\text{Net Alkali Titer,mL} \times 0.05\text{N NaOH} \times 0.014 \times 1{,}000{,}000}{\text{Sample Volume mL}} \quad (3)$$

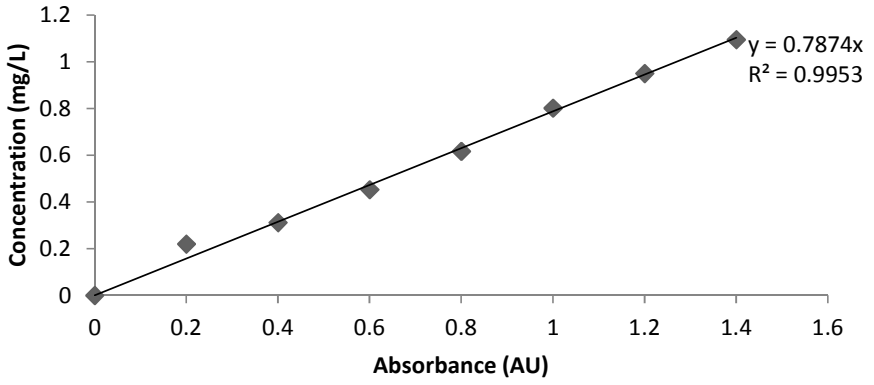

Fig. 3. Standard calibration curve of phosphorus

3. RESULTS AND DATA ANALYSIS

Quantitative analysis was done for the numerical data obtained from the field. Descriptive and inferential statistics were used to analyze the data. Means, standards deviations, one way ANOVA, one-Sample t-Test and Pearson's correlation analysis were used to analyze the relationship between variables in relation to seasons. This was done using JMP (version 12) statistical software. For solids and nutrients, one way ANOVA was used to analyze mean differences among the study samples and the control samples over the two seasons. Pairwise correlation was also used to analyze the relationship between variables. Tukey test was used to analyze the significant differences between the test values and the control samples over the two seasons.

3.1 Results

Biochemical Oxygen Demand levels in samples collected from water wells in the three centres during the dry and wet seasons was varied. In both seasons, BOD levels in all test samples from the three centres were within the KNWQS optimum limits of 0.8 - 5mg/l, BOD in control samples was also within the acceptable range (Table 1).

3.2 One way ANOVA: Tukey Test

However, BOD in control samples was not significantly different from that of Langas (ANOVA: dry season $F_{3, 39}$=6.10; p=0.3246; wet season $F_{3, 39}$=4.57; p=0.4210), but was significantly lower than that of Munyaka (ANOVA: dry season $F_{3, 39}$=6.10; p=0.0196; wet season $F_{3, 39}$=4.57; p=0.0191) and Huruma (ANOVA: dry season $F_{3, 39}$=6.10; p=0.0033; wet season $F_{3, 39}$=4.57; p=0.0251) (Figs. 4 and 5).

Table 1. Mean (±SEM) levels of BOD (mg/l) in samples from different water wells in three centers during dry and wet seasons

	Dry season		Wet season	
	n	BOD (mg/l)	n	BOD (mg/l)
Control	4	0.20±0.04 c	4	0.23±0.05 b
Munyaka	12	1.93±0.39 ab	12	2.56±0.48 a
Huruma	12	2.30±0.28 a	12	2.48±0.44 a
Langas	12	1.17±0.17 bc	12	1.40±0.20 ab

In both the dry and wet seasons, the water pH of samples from in the three centers and control ranged from 5.89 to 7.42 over the dry season, where some values were below the required KNWQS limits of 6.5-8.5 and 6.38 to 8.33 over the wet season and were within the KNWQS optimum limits of 6.5-8.5 (Table 2). In all the three study areas, pH showed an increasing trend from the dry to wet season. However there was higher variation in pH over the dry season as compared to the wet season (Table 2). There was significant different in pH among test samples and pH over the dry season as compared to the wet season where there was no significant difference in pH (Figs. 6 and 7).

3.3 Water Turbidity

There were no significant differences among the test and control samples collected in the dry season (ANOVA: $F_{3, 39}$=2.06; p=0.1224) or wet season (ANOVA: $F_{3, 39}$=1.46; p=0.2430) (Table 3). The levels of turbidity demonstrated an upward trend from the dry to wet seasons in all the three study areas, but there was no significant variation over the two seasons (Figs. 8, 9).

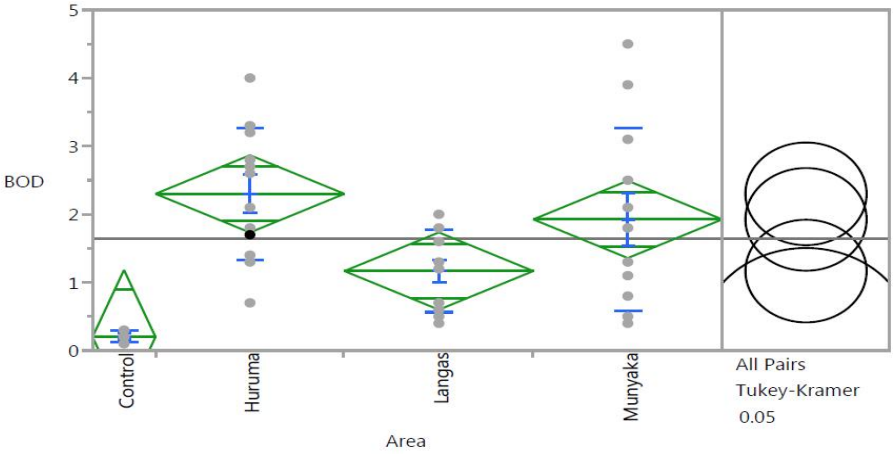

Fig. 4. Tukey-Kramer one way analysis of BOD by area over the dry season; 0.05 level of significance

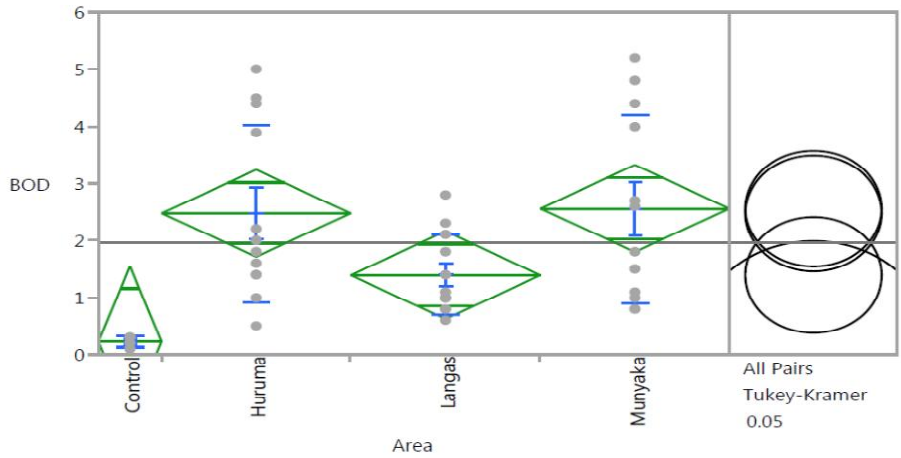

Fig. 5. Tukey-Kramer one way analysis of BOD by area over the wet season; 0.05 level of significance

Table 2. Levels of pH –log [H^+] in samples from different water wells in three centers during dry and wet seasons

Water well	Dry season		Wet season	
	pH January 2015	pH March 2015	pH April 2015	pH May 2015
MA1	6.70	6.80	7.58	6.38
MA2	6.22	6.30	8.33	7.28
MB1	7.42	7.20	7.59	6.46
MB2	6.28	6.50	7.46	7.16
MC1	6.41	6.30	7.17	6.54
MC2	6.68	6.90	7.19	6.39
LA1	5.94	6.10	7.65	7.16
LA2	5.72	5.98	7.29	7.28
LB1	6.20	6.32	7.70	6.98
LB2	5.98	6.10	7.51	7.16
LC1	6.15	6.22	7.06	6.99
LC2	5.62	5.89	7.22	7.19
HA1	6.92	7.22	6.89	6.76
HA2	6.44	6.52	6.77	7.28
HB1	5.89	6.18	7.01	6.99
HB2	6.00	6.12	7.36	7.02
HC1	6.72	6.42	7.07	6.48
HC2	6.61	6.78	7.23	7.32
CA	7.11	7.31	7.51	6.81
CB	7.28	7.16	7.32	7.01

3.4 Levels of Phosphorus

In both seasons, there were no significant differences in levels among the control and test samples from the three centers (ANOVA: dry season $F_{3, 39}$=0.71; p=0.5503; wet season $F_{3, 39}$=1.35; p=0.2748). There were parallel increases in the phosphorus levels from the dry to wet seasons for Huruma and Langas areas, Munyaka and Huruma having similar mean values of phosphorous (Table 4). There was no significant difference in values of phosphorus among the test and control samples over the dry and wet seasons (Figs. 10, 11).

Table 3. Mean (±SEM) turbidity (NTU) of samples from different water wells in three centers during dry and wet seasons

	Dry season		Wet season	
	n	Turbidity (NTU)	n	Turbidity (NTU)
Control	4	2.42±0.59 a	4	5.72±0.28 a
Munyaka	12	6.31±0.65 a	12	6.94±0.83 a
Huruma	12	5.51±0.51 a	12	6.01±0.47 a
Langas	12	8.20±2.04 a	12	9.07±1.84 a

Means (±SEM) within the same column followed by different letter (s) are significantly different at p=0.05, One way ANOVA: Tukey test

Table 4. Mean (±SEM) level of phosphorus (mg/L) in samples from different water wells in three centers during dry and wet seasons

	Dry season		Wet season	
	n	Phosphorus (mg/L)	n	Phosphorus (mg/L)
Control	4	0.01±0.00 a	4	0.01±0.00 a
Munyaka	12	0.01±0.00 a	12	0.01±0.00 a
Huruma	12	0.01±0.00 a	12	0.01±0.00 a
Langas	12	0.01±0.00 a	12	0.01±0.00 a

Means (±SEM) within the same column followed by different letter (s) are significantly different at p=0.05, One way ANOVA: Tukey test

3.5 Levels of Nitrogen

In both seasons, there were no significant differences in nitrogen levels among the control and test samples from the three centers (ANOVA: dry season $F_{3, 39}$=1.63; p=0.2003; wet season $F_{3, 39}$=1.59; p=0.2079). There was a steep shift in levels of nitrogen from the dry to wet season in Munyaka while changes in Huruma and Langas were moderate (Table 5). There was no significant difference in values of nitrogen among the test and control samples over the dry and wet seasons (Figs. 12, 13).

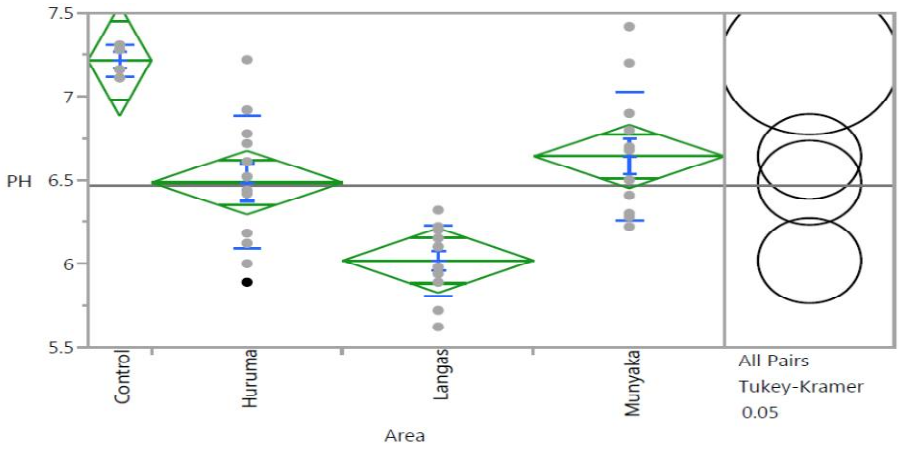

Fig. 6. Tukey-Kramer one way analysis of pH by area over the dry season; 0.05 level of significance

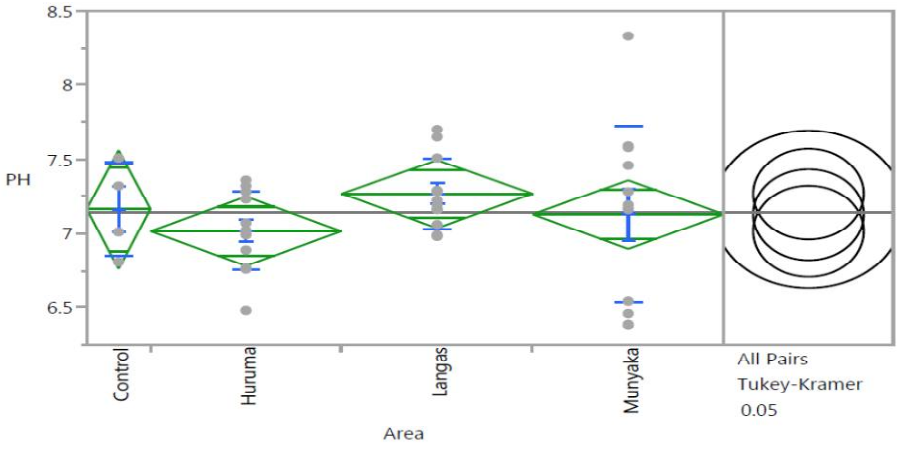

Fig. 7. Tukey-Kramer one way analysis of pH by area over the wet season; 0.05 level of significance

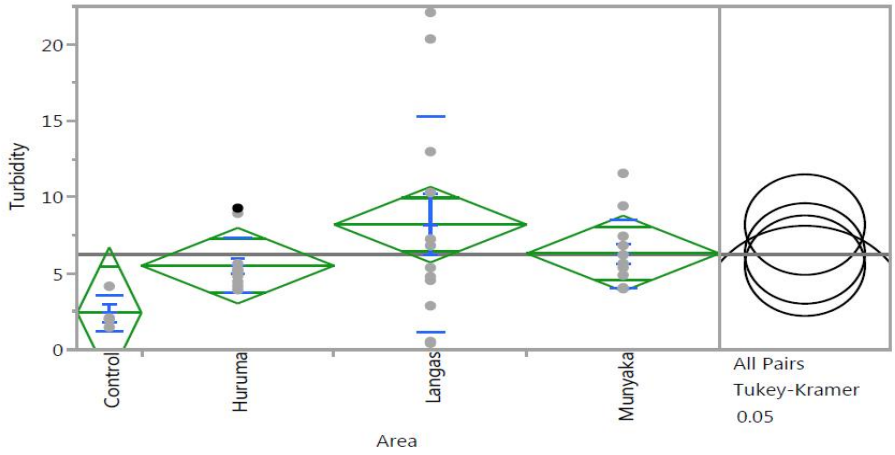

Fig. 8. Tukey-Kramer one way analysis of turbidity by area over the dry season; 0.05 level of significance

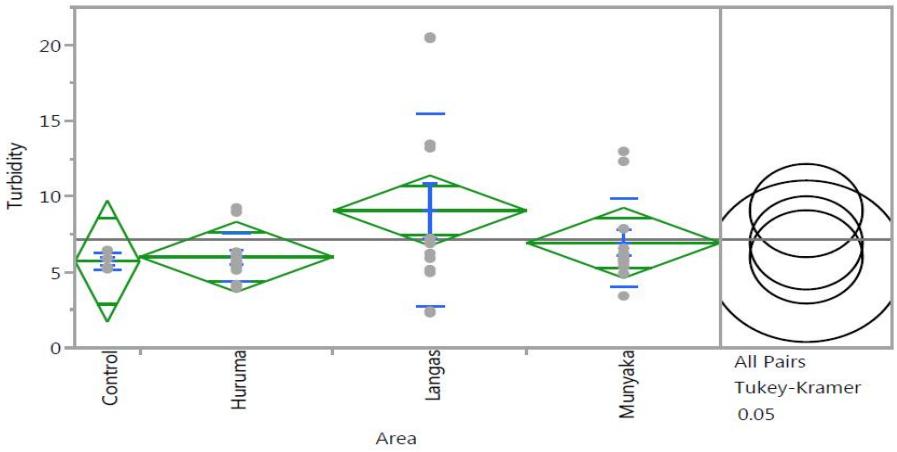

Fig. 9. Tukey-Kramer one way analysis of turbidity by area over the wet season; 0.05 level of significance

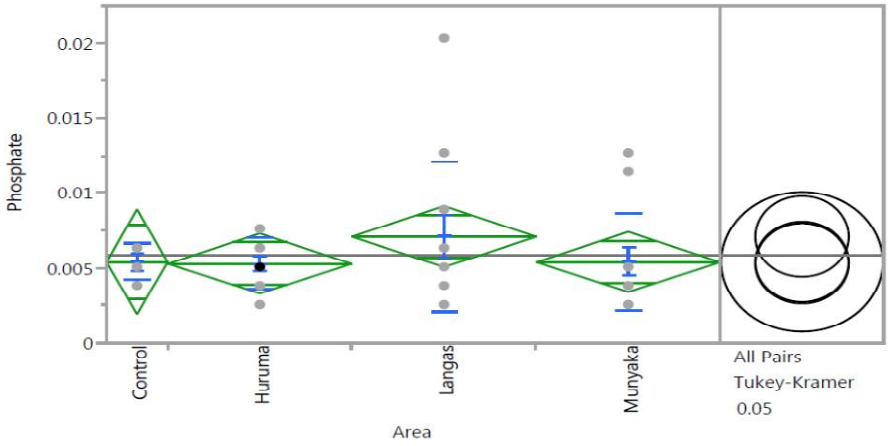

Fig. 10. Tukey-Kramer one way analysis of phosphorus by area over the dry season; 0.05 level of significance

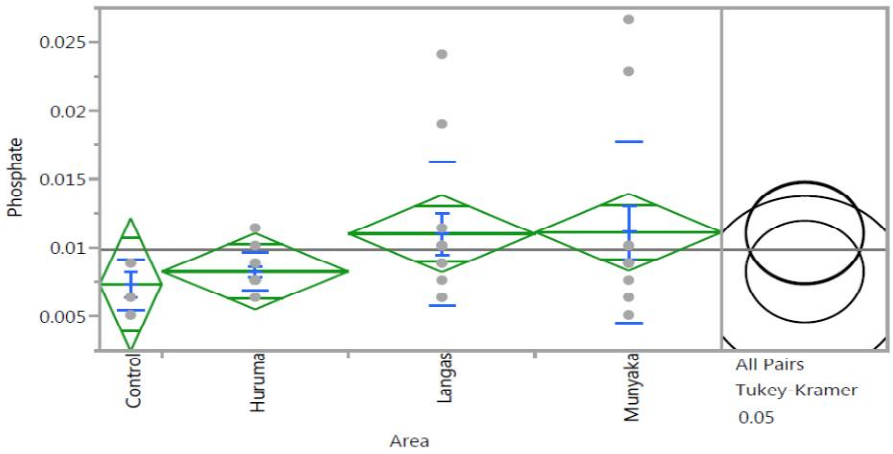

Fig. 11. Tukey-Kramer one way analysis of phosphorus by area over the wet season; 0.05 level of significance

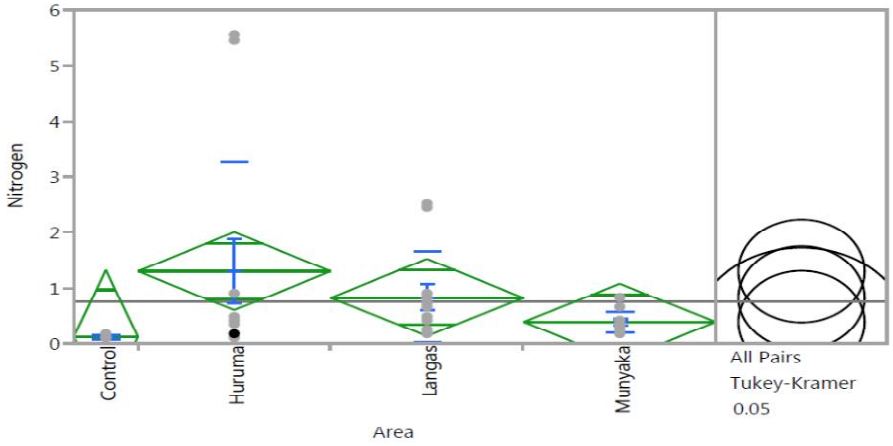

Fig. 12. Tukey-Kramer one way analysis of nitrogen by area over the dry season; 0.05 level of significance

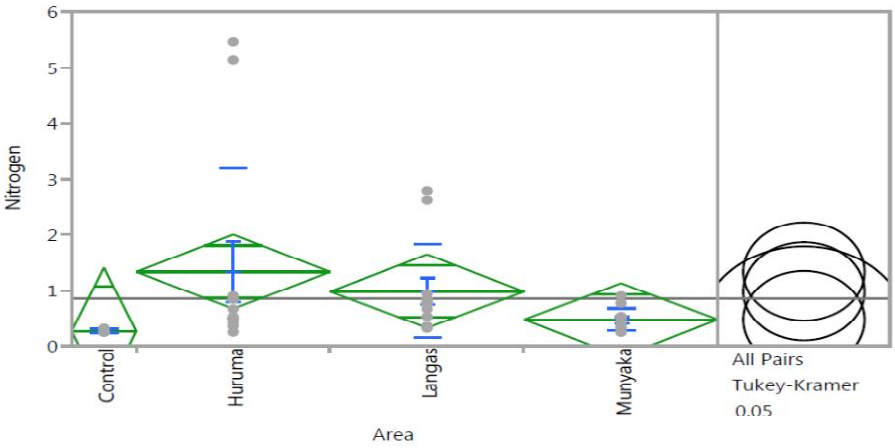

Fig. 13. Tukey-Kramer one way analysis of nitrogen by area over the wet season; 0.05 level of significance

Table 5. Mean (±SEM) level of nitrogen (ppm) in samples from different water wells in three centers during dry and wet seasons

	Dry season		Wet season	
	n	**Nitrogen (ppm)**	**n**	**Nitrogen (ppm)**
Control	4	0.12±0.02 a	4	0.26±0.02 a
Munyaka	12	0.39±0.06 a	12	0.47±0.06 a
Huruma	12	1.30±0.57 a	12	1.34±0.54 a
Langas	12	0.83±0.23 a	12	0.98±0.24 a

Means (±SEM) within the same column followed by different letter (s) are significantly different at p=0.05, One way ANOVA: Tukey test

Table 6. Correlation probability between variables over the dry and wet seasons

pH	**pH**	**Temp**	**TS**	**TSS**	**TDS**	**BOD**	**Turbidity**	**Phosphorous**	**Nitrogen**
	<0.0001	**0.4014**	**0.5340**	**0.7988**	**0.5752**	**0.9066**	**0.6403**	**0.4547**	**0.1297**
Temp	0.4014	**<0.0001**	0.8989	0.8135	0.0707	0.6774	0.1417	0.7645	0.4579
TS	0.5340	0.8989	**<0.0001**	**<0.0001***	0.1126	0.9733	0.4150	0.6788	0.0694
TSS	0.7988	0.8135	**<0.0001***	**<0.0001**	0.0514	**0.0216***	0.1508	0.4925	**0.0183***
TDS	0.5752	0.0707	0.1126	0.0514	**<0.0001**	**0.0353***	0.6652	0.4677	0.7040
BOD	0.9066	0.6774	0.9733	**0.0216***	**0.0353***	**<0.0001**	0.4178	0.1251	0.6518
Turbidity	0.6403	0.1417	0.4150	0.1508	0.6652	0.4178	**<0.0001**	**0.0138***	0.1123
Phosphorous	0.4547	0.7645	0.6788	0.4925	0.4677	0.1251	**0.0138***	**<0.0001**	0.2205
Nitrogen	0.1297	0.4579	0.0694	**0.0183***	0.7040	0.6518	0.1123	0.2205	**<0.0001**

**. Correlation is at 0.05 level of significance*

3.6 Pairwise Correlation between Variables

Pearson's correlation method revealed that there was a significant correlation between TSS and TS (r=0.894, p=<0.0001), TDS and TS (r=0.471, p=0.002), BOD and TS (r=0.695, p=<0.0001), BOD and TSS (r=0.6227, p=<0.0001) and phosphorous and turbidity (r=0.5903, p=<0.0001) during the dry season (Table 6). During the wet season there was a significant relationship between TSS and TS (r=0.717, p=<0.0001), BOD and TSS (r=0.3622, p=0.0216), BOD and TDS (r=0.3338, p=0.0353), phosphate and turbidity (r=0.3862, p=0.0138) and nitrogen and TSS (r=0.3714, p=0.0183) (Tables 7 and 8).

4. DISCUSSION

4.1 Proximity of Water Wells to Pit Latrines and Garbage Dumpsites

This study demonstrated that majority of the water wells were situated less than 15 m from the pit latrines and garbage dumpsites. Seventy five percent of wells were located 1 to 15 meters from a pit latrine and 45 percent of the wells were located 1 to 15 m from a garbage dumpsite. Results show that this proximity has adverse implications for the quality of well waters. Given the varying transport distances observed for microbiological and chemical contaminants originating from pit latrines and garbage dumpsites, researchers have recommended latrine siting guidelines. Banks [13] suggested that pit latrines should be located not less than 15–30 m from groundwater abstraction points. Banerjee [14] concluded that, with the exception of fissured rock, the safe distance between a pit latrine and water source should be 10 m. South Africa's groundwater guidelines recommend that pit latrines are located at least 75 m from water sources [15]. Water Aid [16] suggests that latrines and water sources should be at least 50 m apart. Vinger [17] suggested that wells are likely to be contaminated if pit latrines are < 12 m away. Both the water wells used as controls in this study (CA and CB) revealed that, despite being >30m from pit latrines and garbage dumpsites there was contamination of the waters with *E. coli* in the dry and wet seasons.

4.2 Physico-chemical Characteristics

BOD is defined as the amount of oxygen required by bacteria while stabilizing decomposable organic matter under aerobic conditions [18]. The study revealed that BOD values in the water samples were well within the KNWQS of between 0.8 – 5 mg/l during both dry and wet seasons. The Biochemical Oxygen Demand in the water wells during the dry season and the wet season varied between 0.1 mg/l - 5.2 mg/l. These BOD findings suggest that there are insignificant seepages from the pit latrines into the water well. The findings are in agreement with those by Kimani [9] who found normal BOD levels in well waters. High BOD value in wells may result from the pit latrines, garbage dumpsites and rain water wash off that discharge off organic wastes into the well water, resulting in the uptake of oxygen in the oxidative breakdown of these wastes. The permissible limit for BOD as per KNWQS is between 0.8 -5 mg/l.

The pH value of well waters in the study area varied from a minimum of 5.76 during the dry season to a maximum of 8.33 during the wet season. Some of the pH values were outside the permissible limit of 6.5 to 8.5 given by KNWQS during the dry period, which were more of acidic. This may be attributed to high evaporation rates and a low water table. The higher values of pH in wet season may be attributed to dilution by rain waters [19] and to addition of agricultural and domestic waste [20]. These findings are also in agreement with those by Smet [21] who reported that changes in water pH was attributed to high evaporation rates and a low water table. The higher values of pH in wet season in this study can also be attributed to dilution by rain waters. In a similar study in Ghana, Kwasi [22] reported pH values of between 5.03 and 6.54 for borehole water samples over the dry period. These pH values were very low compared to the WHO standard for drinking water (6.5-8.5) which he also attributed to high evaporation rates. No health-based guideline value has been proposed for pH.

There was a significant variation in turbidity of the water samples. This ranged from a minimum low turbidity of 0.49 NTU to a maximum turbidity of 20.49 NTU. The results show that the turbidity of water wells was above the KNWQS of <5 NTU during the dry and wet season. The turbidity of the water during the two seasons averaged 6.25±0.99 NTU and 7.15±0.91NTU in the dry and wet season respectively. This can be attributed to washing of particles from the surroundings into the wells and human activities such as agriculture that was common on the small study residential plots on which the water wells were located. Kwame [23] reported similar results, where turbidity was higher in surface water samples, followed by shallow well samples and was lowest in borehole samples confirming a relationship between turbidity and TSS. The high turbidity values seen in this study is an indication of poor filtration process of water supplies through the soil. Turbidity monitoring is therefore critical because it is an indication of poor filtration process of water supplies through the soil.

Table 7. Pairwise correlation between test variables over the dry season

Variable	By variable	correlation	count	Lower 95%	Upper 95%	Signif prob
Temp	pH	-0.1474	40	-0.4388	0.1720	0.3641
TDS	pH	-0.2056	40	-0.4860	0.1132	0.2032
TDS	Temp	0.2024	40	-0.1164	0.4834	0.2103
SS	pH	-0.1942	40	-0.4768	0.1249	0.2299
SS	Temp	0.2303	40	-0.0875	0.5056	0.1528
SS	TDS	0.8943	40	0.8078	0.9431	<0.0001*
S	pH	-0.0796	40	-0.3817	0.2378	0.6252
S	Temp	0.0301	40	-0.2841	0.3384	0.8540
S	TDS	0.4708	40	0.1867	0.6823	0.0022*
S	SS	0.0451	40	-0.2702	0.3517	0.7821
BOD	pH	0.0772	40	-0.2400	0.3796	0.6357
BOD	Temp	0.1829	40	-0.1364	0.4677	0.2587
BOD	TDS	0.6949	40	0.4894	0.8273	<0.0001*
BOD	SS	0.6227	40	0.3861	0.7825	<0.0001*
BOD	S	0.2772	40	-0.0376	0.5419	0.0833
Turbidity	pH	-0.2948	40	-0.5553	0.0184	0.0648
Turbidity	Temp	0.0144	40	-0.2984	0.3245	0.9296
Turbidity	TDS	0.1175	40	-0.2013	0.4139	0.4701
Turbidity	SS	0.1927	40	-0.1264	0.4756	0.2336
Turbidity	S	-0.1093	40	-0.4069	0.2094	0.5021
Turbidity	BOD	-0.1395	40	-0.4322	0.1798	0.3906
Phosphate	pH	-0.1704	40	-0.4576	0.1490	0.2931
Phosphate	Temp	-0.0435	40	-0.3503	0.2717	0.7897
Phosphate	TDS	-0.0995	40	-0.3987	0.2188	0.5412
Phosphate	SS	-0.1208	40	-0.4167	0.1981	0.4576
Phosphate	S	-0.0164	40	-0.3263	0.2966	0.9199
Phosphate	BOD	-0.1589	40	-0.4482	0.1605	0.3273
Phosphate	Turbidity	0.5903	40	0.3417	0.7618	<0.0001*
Nitrogen	pH	-0.0554	40	-0.3607	0.2606	0.7341
Nitrogen	Temp	0.0695	40	0.2474	0.3729	0.6700
Nitrogen	TDS	0.2498	40	0.0669	0.5208	0.1200
Nitrogen	SS	0.1663	40	0.1532	0.4542	0.3052
Nitrogen	S	0.2058	40	-0.1129	0.4862	0.2026
Nitrogen	BOD	0.2567	40	0.0596	0.5261	0.1098
Nitrogen	Turbidity	0.2860	40	-0.0280	0.5487	0.0736
Nitrogen	Phosphate	0.3415	40	0.0335	0.5902	0.0310*

**. Correlation is at 0.05 level of significance. (TDS stands for total solids, SS stands for total suspended solids and S stands for total dissolved solids)*

The values of total solids varied from a minimum of 0.061 g/l during the wet season to a maximum of 0.075 g/l during the dry season. This may be attributed to less runoff water levels in dry season and diluted waters during the wet season. All water samples were within permissible limits of KNWQS of total dissolved solids in Kenya (1.2 g/L). Total dissolved solids in the study area groundwater samples reveal a fairly larger range of variation from 0.03 - 0.095 g/L. These results are in agreement with those of Edeonovo [24] who found that the total solids (TS) values were within the range of 0.060 – 0.260 g/L. Suspended solids consist of fine particles of organic and inorganic matter, which is regarded as a type of pollution because water high in concentration of suspended solid may adversely affect taste in drinking water. The major dissolved components of ground waters include the anions of bicarbonate, chloride and sulphates, and the cations of sodium, calcium, magnesium and potassium. The permitted limits are 0.030 g/L or below.

The levels of phosphorus in the waters of the wells from the three study areas were within the acceptable KNWQS of less than 0.05mg/l during the dry and wet seasons. There was a wide variation in phosphate concentrations during the study period which ranged from a minimum of 0.005mg/l to a maximum of 0.008 mg/l. There was tendency for phosphates to increase in the concentrations during the wet season. This may be attributed to contamination by surface run off from farms, waste waters and underground rock material. The finding of this study is in agreement with that of Le Chevallier [25] that surface water sources have a relatively high concentration of phosphorus. This may be attributed to storm water runoff, agricultural runoff, erosion and sedimentation and direct input by

animals. However, concentrations in the groundwater may be due to natural decomposition of rocks and minerals that contain phosphates. The introduction of phosphorus from surface water runoffs in form of phosphates in aquatic environment is a major cause of eutrophication. Phosphorus occurs naturally, almost solely as phosphate. Most phosphates are dissolved but some are in combination with suspended particles in the water and may contribute to turbidity. The concentration of phosphate encountered in the natural water environment is normally not enough to causes any detrimental health effect on humans or animals. Phosphate like any other nutrient is harmless in lower concentrations but becomes harmful only in higher doses. The human lethal oral dose of phosphorous (white) is 1mg/kg of body weight and as little as 0.2 mg/kg may produce adverse effects. Death from cardiovascular collapse can occur within 12 hrs if ingested [26]. Other forms of phosphorous are also known to interfere with digestion in all other animals including humans and can lower capacity of the human body to store calcium at doses of 15mg/kg of body weight or above [26].

Presence of nitrates in water indicates the final stage of mineralization. The mean levels of nitrogen over the two seasons were 0.816±0.3 and 0.907±0.00ppm (n=36) for the dry and wet period respectively, an indicator of increased pollution during the wet season. Study findings revealed that there was significant seasonal variation in nitrogen and all the parameters were within the range. Sundaray [27] showed that high nitrogen contents in water are unsafe and unhealthy for human use. Consumption of nitrogen above the permissible limit creates severe problem of blue baby disease in children and gastric carcinomas [28], [29]. Ninety percent of the water wells in this study were located less than 30 m from either a pit latrine or garbage dumpsite or both, a clear indication of contamination of well waters with nitrates.

Table 8. Pairwise correlation between test variables over the wet season

Variable	By variable	correlation	count	Lower 95%	Upper 95%	Signif prob
Temp	pH	0.1364	40	-0.1829	0.4296	0.4014
TDS	pH	-0.1013	40	-0.4002	0.2171	0.5340
TDS	Temp	-0.0207	40	-0.3301	0.2927	0.8989
SS	pH	-0.0416	40	-0.3486	0.2735	0.7988
SS	Temp	-0.0385	40	-0.3459	0.2763	0.8135
SS	TDS	0.7165	40	0.5213	0.8404	<0.0001*
S	pH	0.0913	40	-0.2266	0.3917	0.5752
S	Temp	0.2888	40	-0.0250	0.5507	0.0707
S	TDS	0.2548	40	-0.0616	0.5247	0.1126
S	SS	0.3102	40	-0.0014	0.5669	0.0514
BOD	pH	0.0191	40	-0.2941	0.3287	0.9066
BOD	Temp	0.0079	40	-0.2489	0.3715	0.6774
BOD	TDS	0.0055	40	-0.3066	0.3164	0.09733
BOD	SS	0.3622	40	0.0571	0.6054	0.0216*
BOD	S	0.3338	40	0.0249	0.5846	0.0353*
Turbidity	pH	-0.0762	40	-0.3787	0.2410	0.6403
Turbidity	Temp	0.2365	40	-0.0809	0.5104	0.1417
Turbidity	TDS	0.1325	40	-0.1867	0.4264	0.4150
Turbidity	SS	0.2314	40	-0.0863	0.5064	0.1508
Turbidity	S	-0.0706	40	-0.3739	0.2464	0.6652
Turbidity	BOD	0.1317	40	-0.1875	0.4258	0.4178
Phosphate	pH	0.1216	40	-0.1974	0.4173	0.4547
Phosphate	Temp	0.0489	40	-.02667	0.3550	0.7645
Phosphate	TDS	-0.0676	40	-0.3712	0.2429	0.6788
Phosphate	SS	0.1117	40	-0.2070	0.4090	0.4925
Phosphate	S	-0.1182	40	-0.4144	0.2007	0.4677
Phosphate	BOD	0.2465	40	-0.0704	0.5183	0.1251
Phosphate	Turbidity	0.3862	40	0.0850	0.6228	0.0138*
Nitrogen	pH	-0.2437	40	-0.5160	0.0734	0.1297
Nitrogen	Temp	-0.1208	40	-0.4166	0.1982	0.4597
Nitrogen	TDS	0.2901	40	-0.0235	0.5517	0.0694
Nitrogen	SS	0.3714	40	0.0678	0.6121	0.0183*
Nitrogen	S	-0.0620	40	-0.3664	0.2544	0.7040
Nitrogen	BOD	0.0736	40	-0.2435	0.3765	0.6518
Nitrogen	Turbidity	0.2550	40	-0.0614	0.5248	0.1123
Nitrogen	Phosphate	0.1981	40	-0.1209	0.1800	0.2205

**. Correlation is at 0.05 level of significance. (TDS stands for total solids, SS stands for total suspended solids and S standsfor total dissolved solids)*

Concentrations of nitrates in well water near latrines are highly variable. A number of studies have reported nitrate concentrations being above 100 mg/l [13,30,31]. Other studies have reported increased groundwater nitrate concentrations in water wells near latrines, [32,33]. High nitrate concentrations have been attributed to latrines through assumptions based on general proximity, but pinpointing the actual sources of nitrate in groundwater has proved challenging [34]. The actual sources of nitrate may be from numerous potential sources in the environments including; pit latrines, plant material, animal manure, garbage dumpsites, livestock pens, soil, and fertilizers [35,17]. The findings of this research are in agreement with findings of Girard [36], who used nitrogen isotopes to determine the source of nitrate pollution in a fractured rock aquifer of Niger. Due to fermentation of faeces and ammonia volatilization in latrines, isotopic enrichment of residual matter creates a nitrate source that is isotopically distinguishable from nitrate of other sources. Nitrate concentrations in wells reached 11.6milliequivalents/l, which may have been a consequence of contamination by latrines and deforestation. Girard [36] cautioned that, given annual population growth rates and increased latrine densities, wells that had safe nitrate concentrations at the time of the study might become polluted in the future. The findings of this study are also in agreement with findings of Zingoni [33]. They demonstrated that the high nitrate concentrations in groundwater were associated with the areas with highest human population densities and areas with highest number of pit latrine in the settlement. Vinger [17] also associated groundwater nitrate concentrations to have been correlated with proximity to pollution sources, including pit latrines, in South Africa.

5. CONCLUSION

This study concluded that proximity to pit latrines and garbage dumpsites influenced pH and turbidity in underground water in the study areas. This study further concluded that proximity to pit latrines and garbage dumpsites to water wells did not affect BOD and nutrient levels in the study areas. This may be attributed to topography of the area and land tenure system in the area which was the key influence on location proximity of water wells to pit latrines and garbage dumpsites, as most homes are on 1/8 or less of an acre. The number of people who use pit latrines and develop garbage dumpsites is expected to increase as populations grow and countries strive to meet the Sustainable Development Goals (SDGs). The use of groundwater as a source of drinking water is also increasing, thus a growing need to understand how garbage dumpsites and pit latrines impact groundwater quality and human health. This study concludes that the location of garbage dumpsites and pit latrines are an important factor to consider when planning residential areas because pit latrines and garbage dumpsites pose a health risk to residents through contamination of ground water. The recommended safe distance by the KNWQS, for safe abstraction of ground water is that; it should be located 31m or above from a source of pollution. But given the small sizes of plots in the study areas, this safe distance is not easy to implement. This study further concludes that there are poor sanitation facilities in the three areas of study as seen on location of pit latrines and garbage dumpsites; 90% of the wells were located between 5 m to 25 m from either a pit latrine or a garbage dumpsite. The results indicate that most of the physico-chemical parameters of the water samples were not within the WHO and KNWQS limits for drinking water and the ground water is therefore unsuitable for drinking. Nutrient levels were generally lower in the study areas over the study period and were higher during the wet season. Nutrient level indicated little influence from the proximity to the pit latrines and garbage dumpsites thus can be related to farming practices in the study areas.

6. RECOMMENDATIONS

In view of the findings, this study makes the following recommendations:

Groundwater flow channels are among the most important factors affecting contamination of water wells by pit latrines and garbage dumpsites. In many areas, including Munyaka, Langas and Huruma, the groundwater flow direction is unknown. Groundwater flow models are needed to better define the limits of chemical transport and pathogen dispersion from sources of pollution to water abstraction sites. An improved understanding of contaminants leaching from pit latrines and the transport pathways involved is needed particularly for managing sanitation in Munyaka, Langas and Huruma, which are densely populated areas.

Preventive methods such as proper well site selection and construction should be followed to ensure ground water supplies are safeguarded against contamination by any material that could be dangerous to human health. There are available guidelines for site-specific assessment, and general procedures for siting pit latrines with respect to water abstraction points, but this information needs to get to slum residents.

This study recommends review of the 30 m location distance of water wells and other water abstraction points from pollution sources and regular monitoring of water quality from the wells. Further, this study recommends construction of standard communal water wells and availing of garbage collection tanks with frequent garbage collection by County Governments. These would ensure that standards are followed on construction of the communal water wells and on waste disposal.

This study recommends that farmers should be cautious in the application of organic and inorganic fertilizers in order to avoid wash-off or leaching of pollutants into ground water abstraction points. This could be done by construction of standard drainage tunnels which would direct the excess surface rain run-offs to the main waste water drainage systems hence avoid contamination of ground waters.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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