SAFETY AND QUALITY OF BOREHOLE WATER: A CASE OF DAR ES SALAAM REGION

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EXTENDED ABSTRACT

This study was conducted to assess the safety and quality of the borehole water consumed in Dar es Salaam based on depth and distance from the septic tank. It covered the three districts of Dar es Salaam namely Ilala, Kinondoni (including Ubungo) and Temeke (including Kigamboni). A Randomized Complete Block Design with two factors, depth (treatments) and distance to the septic tank (block) was used. Depth was studied at 4 levels, shallow (0-30 m), medium (31-50 m), deep (51-80 m), and very deep (>80 m) while the distance from the septic tank to the borehole was examined at two levels: less than 15 m and more than 15 m. This was replicated two times. A total of 48 samples of borehole water were collected and analyzed for physico-chemical (pH, B.O.D, total hardness and metal contaminants {copper (Cu) and lead (Pb)}) and microbiological qualities (for coliforma *E.coli* and *C. perfringens*) and analyzed according to standard procedures in the Water Development and Management Institute (WDMI) and Tanzania Bureau of Standards (TBS) laboratories. Results were compared to WHO (2011) and TBS (2008) standards. Data was analyzed using R- statistics for ANOVA and means were separated by Tukey‘s Honest at $p < 0.05$. The results of pH, B.O.D and *C. perfringens* were significantly decreased as the depth increase while levels of total hardness, coliforms and *E. coli* were significantly higher in deep and very deep boreholes water. Also, the levels of B.O.D were significantly lower in boreholes which were located near the septic tank than those which were far. Microorganisms however, were significantly higher the boreholes located far from the septic tank compared to near. This was unexpected, however other factors were also considered. The distance between the septic tank and borehole did not affect significantly neither the pH nor the total hardness of water.

DECLARATION

I, Chenge, Lawrence, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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The above declaration is confirmed;

Dr. L. Chove Date
(Supervisor)

Dr. R. Mongi Date
(Supervisor)

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DEDICATION

This work is dedicated to my parents who trained me to be honest and resilient even in situations that are challenging and to my wife Irene for allowing me to be away from them for a long period of time.

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LIST OF ABBREVIATIONS AND SYMBOLS

B.O.D	Biochemical Oxygen Demand
C.O.D	Chemical Oxygen Demand
$CaCO_3$	Calcium carbonate
CFU	Colony Forming Unit
Cu	Copper
DDCA	Drilling and Dam Construction Agency
ICP – MS	Inductively Coupled Plasma – Mass Spectrometry
ISO	International Organization for Standardization
L	Litre
Log	Logarithm
mg	milligram
mL	millilitre
NBS	National Bureau of Statistics
Pb	Lead
SUA	Sokoine University of Agriculture
TBS	Tanzania Bureau of Standards
UNEP	United Nations Environment Programme
WDMI	Water Development and Management Institute
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Water is essential for the survival of any forms of life and it accounts for about 70% of the weight of a human body (Khadsan and Mangesh, 2003). It is important to sustain life, and its satisfactory adequate, safe and accessible supply must be available to all (WHO, 2011). Water supply is an essential in domestic, industrial, commercial and agricultural areas (Liu, 2013).

There are three main types of water sources, which are ground, surface and water obtained from desalination (Liu, 2013). Groundwater refers to all the water occupying the voids, pores and fissures within geological formations, which originated from atmospheric precipitation either directly by rainfall infiltration or indirectly from rivers, lakes or canals (Ojo *et al*., 2012). It is an important part of the water resource constituting 97% of global fresh water (Bharti *et al*., 2011) and its occurrence is influenced by geological conditions (Kashaigili, 2012). In many developing countries over the years, groundwater remains one of the dependable sources of usable water in fast growing towns and villages where the supply of potable water is not consistent (Ishaya and Abaje, 2009). In Tanzania, groundwater is an important water source supplying more than 25 % of the domestic water consumption (Kashaigili, 2012). Domestic supply in both urban and rural areas is a largest user of groundwater and consumes 755,000 m^3/day accounting for 60% of total use against demand of 0.8 to 3.4 million m^3/day (Kashaigili, 2012).

Safe drinking water is defined as water that does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (WHO, 2011). Tanzania Bureau of Standards (2008) defined drinking water as potable water intended for human consumption and specified the general requirement for water shall be free from microorganisms and chemical substances which may be hazardous to health. These include absence of colour, turbidity, having palatable and acceptable taste and odour. Therefore, drinking water quality has been classified into microbiological (*Coliforms* and *E.coli*), chemical and physical limits such as metal contaminants, organoleptic, salinity and hardness, natural and artificial organic pollution as well as radioactive materials (TBS, 2008). The microbial, chemical and physical constituents may affect the appearance, odour or taste of the water. Consumers evaluate the quality and acceptability of the water on the basis of these criteria (WHO, 2011). Access to safe water is related to all seventeen Sustainable Development Goals (FAO, 2015). Therefore, determination of chemical, physical and bacterial characteristics of groundwater is important in judging its usefulness (Ojo *et al*., 2012).

1.2 Problem Statement and Study Justification

Dar es Salaam is the third fastest growing city in Africa (ninth fastest in the world), after Bamako of Mali and Lagos of Nigeria with a population of 4.4 million people (NBS, 2014). It has an annual average population growth rate of 5.6% and a population density of 3133 people/km^2 which is the highest in Tanzania (NBS, 2013). The city is expected to reach a population of 5.12 million by 2020 (NBS, 2014).

In view of the above and due to the increasing industrialization, there is a tremendous increase in water demand (Khadsan and Mangesh, 2003). The demand is estimated to be double of what is supplied which is 286 million liters per day while 545 million liters per day were being demanded (NBS, 2014). Furthermore, lack of an efficient distribution network in the city leads to widespread of private deep and shallow wells which leads to an increased risk of groundwater contamination from pit latrines, sewage, septic tank effluents and other waste (Khadsan and Mangesh, 2003).

The risk of contamination of groundwater is higher because approximately 80 % of the people are living in unplanned areas (UNEP, 2014). It has been shown that high population densities are found in unplanned settlements of the city (Mtoni *et al*., 2012). Moreover due to vast anthropogenic activities, groundwater quality is being lost causing extremely health problems to consumers (Ishaya and Abaje, 2009). Liu (2013) reported that increasing of urbanization and industrialization is associated with increasing level of pollution, which will ultimately pollute water resources. The use of contaminated drinking water can result to long or short term serious health risk or outbreaks of water borne diseases like dysentery, cholera and typhoid (Saria and Thomas, 2012).

Additional recharge of groundwater resulted from the rainfall which raises water table is a common situation in informal settlements located in flooding areas. This condition causes overflow of pit latrines and thus groundwater especially shallow wells are polluted (Kasala *et al*., 2016). Furthermore, Kasala *et al.* (2016) reported that 4% population in Dar es Salaam is served by central sewerage system. This indicates that a large number of people especially those in the informal settlements use other sanitation alternatives that discharge raw waste directly into water streams during rainfall. In this regards it necessitates to assess the quality and safety of bore/well water consumed in Dar es Salaam.

1.3 Objectives of the Study

1.3.1 Overall objective

The main objective of this study was to assess the quality and safety of borehole water consumed in Dar es Salaam.

1.3.2 Specific objectives

i. To assess the effect of depth and distance of borehole from septic tank on physico-chemical characteristics of the water
ii. To examine the effect of depth and distance of borehole from septic tank on microbiological quality of the water

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CHAPTER TWO

PAPER ONE

EFFECT OF DEPTH AND DISTANCE OF BOREHOLE FROM THE SEPTIC TANK ON PHYSICO-CHEMICAL CHARACTERISTICS OF WATER

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Abstract

The aim of this study was to examine the effect of depth and distance of the boreholes from the septic tank on physico-chemical parameters of the borehole water consumed in Dar es Salaam. Samples were collected from 48 boreholes in Ilala, Kinondoni (including Ubungo) and Temeke (including Kigamboni) districts and subjected to pH, B.O.D, total hardness, copper and lead analyses in relation to safety and quality levels set by WHO and TBS. The data obtained was statistically analyzed using R-Software for ANOVA and means were separated using Tukey‘s honest at $p<0.05$. The effect of depth on physico-chemical characteristics of water indicated that pH and B.O.D significantly ($p<0.05$) decreased as the depth borehole increased while total hardness was significantly ($p<0.05$) higher in very deep boreholes. The effect of distance between septic tank and borehole on physico-chemical quality of water showed that pH and total hardness were not significantly affected by distance between septic tank and borehole despite the fact that levels of B.O.D were significantly ($p<0.05$) lower in the borehole water situated far from the septic tank compared to those situated near to the septic tank. Based on the physico-chemical characteristics of water, 25% of the samples did not comply with WHO and TBS limits while 75% complied, most of which had shallow depth and situated near the septic tank. It may thus be concluded that depth and distance between septic tank and borehole had effect on physico-chemical characteristics of water.

2.1 Introduction

Water is important for the existence of any forms of life (Khadsan and Mangesh, 2003). There are a lot of guidelines, standards and regulations on drinking water quality that can offer public health protection (WHO, 2011). Drinking water is defined as potable water intended for human consumption (TBS, 2008). Safe water is important for human health and sustainable development (Sungsitthisawad and Pitaksanurat, 2013). In many developing countries, citizens' access to reliable and safe water is a challenge (Kapongola *et al*., 2014). Groundwater is commonly an alternative water resource in areas where surface water is not accessible (Sungsitthisawad and Pitaksanurat, 2013). Groundwater constitutes 97% of global fresh water (Bharti *et al*., 2011). Groundwater quantity, quality, accessibility and recharge depend mostly on geology, geomorphology, land use and levels of precipitation (Elisante and Muzuka, 2015).

There are many factors that have to be considered when accessing the quality and safety of the groundwater as the drinking water. The water quality and safety indicator include the testing for total coliforms, faecal coliforms (*E. Coli*), inorganic contaminants, organoleptic (appearance, taste and odor), salinity and hardness, natural and artificial organic pollution and pH (TBS, 2008). The quality of groundwater is the result of the processes and reactions that act on the water and varies from one place to another basing on the depth of the water table (Mohan *et al*., 2014). Groundwater can be contaminated by chemicals as well as microorganisms (Bharti *et al*., 2011). Furthermore, groundwater resources in coastal areas like Dar es Salaam are always in danger of contamination by sea water intrusion (Mtoni *et al.*, 2012).

Generally groundwater becomes purer with increase in depth (Ojo *et al*., 2012). Boreholes in Tanzania are classified as shallow (0-30 m), medium (31-50 m), deep (51-80m), and very deep (>80 m) (Baumann *et al*., 2005, Kashaigili, 2012). It has been reported by Likambo (2014) that the further the distance the borehole is from the potential source of pollution, the more difficult it will become to become contaminated. In Tanzania there is limited information on the physico-chemical qualities of groundwater based on their depth and distance to septic tanks. Hence this work carried out to study the effect of depth and distance of boreholes from septic tanks on physico-chemical quality of water in Dar es salaam

2.2 Material and Methods

2.2.1 Study area

This study was carried out in three districts of Dar es Salaam region namely Kinondoni (including Ubungo), Ilala and Temeke (including Kigamboni).

2.2.2 Materials

Materials used for this study were samples of borehole water from the three districts of Dar es Salaam. Other materials such as analytical grade reagents and chemicals, apparatus and laboratory equipment were obtained from TBS and WDMI Laboratories. Tape measure was purchased from a supplier in Dar es Salaam.

2.2.3 Study design

Randomized Complete Block Design was used in the study, where depth of the borehole (at 4 levels) and distance from the septic tank (at two levels) were the principal factors. The effects of these factors on physico-chemical quality of water were assessed. The mathematical model is as depicted in equation 1.

$$Yij = \mu + \alpha i + \beta j + \varepsilon ij \qquad (1)$$

Where μ is overall mean, αi is the effect of treatment *i* (depth of the borehole), βj is effect of block *j* (distance to septic tank) and εij random error.

2.2.3.1 Sampling plan and data collection

Purposive sampling plan was used to collect samples from selected boreholes in the three districts of Dar Es Salaam, Kinondoni (including ubungo), Ilala and Temeke (including Kigamboni). A total of 48 samples of borehole water were collected, 16 samples from each district. Samples of two litres of water were collected after sterilization of the water tap/nozzle using cotton wool soaked in 70% (v/v) ethanol and water allowed to run for 1 minute. Sampling was carried out from November 2016 – January 2017. Samples were collected in transparent clean and sterile 500 mls glass bottles (Duran, made in Germany) whereas samples for B.O.D analysis were collected in amber glass bottles. Samples were stored in an insulated ice box maintained at 0^0 to 4^0 C and transported to the TBS laboratory for metal contaminants analysis and WDMI laboratory for pH, B.O.D and total hardness analysis.

2.2.4 Physico-chemical laboratory analyses

2.2.4.1 pH

The pH of the boreholes water samples were determined according to ISO 10523:2008. Results were recorded in two decimal points.

2.2.4.2 Total hardness

Total hardness was analyzed according to ISO 6059:1984 procedures. Results were expressed in milligram per litre of $CaCO_3$.

2.2.4.3 Biochemical Oxygen Demand (B.O.D)

The Biochemical Oxygen Demand of the water samples for 5 days at 20^oC were determined according to ISO 5815-2:2003. The samples were equilibrated at 20^oC followed by determination of the dissolved oxygen concentration at day 0 and day 5. The results were expressed in milligram per litre.

2.2.4.4 Metal contaminants {Copper (Cu) and Lead (Pb)}

Analysis of Copper (Cu) and Lead (Pb) were carried out according to ISO 11885:2007. Results were expressed in mg/L.

2.2.4.5 Statistical data analysis

Data were analysed using R- statistical package software version 3.3.0. Analysis of Variance (ANOVA) was carried out to determine the significant difference between the main factors. Means were separated using Tukey's Honest at $p<0.05$.

2.3 Results and Discussion

2.3.1 The effect of depth of the borehole on physico-chemical characteristics of the water

2.3.1.1 Effect of depth on pH of water

The pH of the water samples collected as shown in Fig. 1. There were significant differences ($p<0.05$) in pH between the various levels of depths in all the districts. The shallow and medium boreholes had higher pH than the deep and very deep boreholes which were significantly different ($p<0.05$) at all depth levels for all the districts.

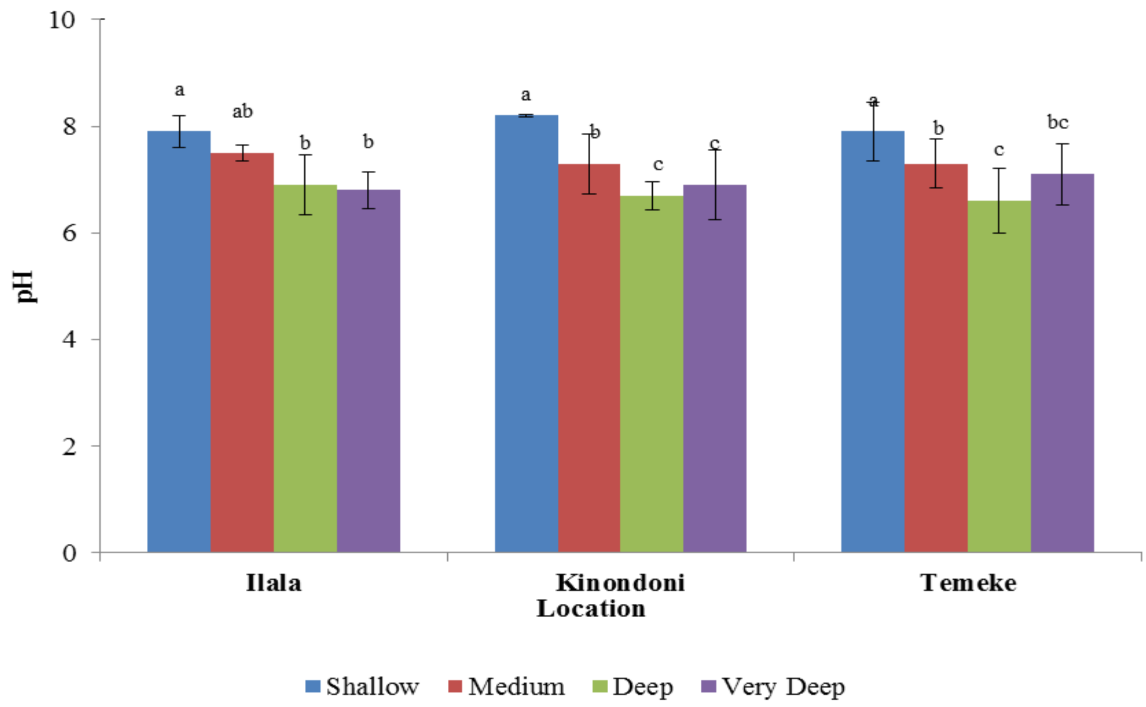

Figure 1: Effect of depth on pH. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

These findings reveal that the pH of water from shallow and medium borehole was significantly ($p<0.05$) higher (ranging from 7.3 to 8.2) compared to deep and very deep wells (ranging from 6.6 to 7.1). Furthermore all the shallow and medium boreholes water pH was within the recommended pH for drinking water which is 6.5 – 9.2 for Tanzania (TBS, 2008) and 6.5 – 8.5 (WHO, 2011). It was further revealed that 25% and 16.7% of the deep and very deep boreholes water respectively, did not comply with the WHO (2011) and Tanzania standards (2008) as they showed a slightly acidic pH, ranging from 5.72 to 6.45. The lower the pH of water the more likely to be corrosive (WHO, 2011). The slightly higher pH of the shallow and medium boreholes water most of which were around or near the coastal area of Dar es Salaam was attributed by their origin, being limestone aquifer (Mtoni *et al.*, 2012).

The limestone was found along a narrow coastal belt (Mato, 2002). In additional (Witte, 2012) found that higher pH value for boreholes water that were closer to the coast and indicated that they were possibly caused by the presence of the coral reefs. When calcite in the reef dissolves, calcium and carbonate were set free, carbonate reacts with the hydrogen ions in the water to form bicarbonate and hence these alkaline ions are released into the groundwater. Furthermore, Mtoni *et al*. (2012) reported that bicarbonate was the dominant anion in the upper aquifer while in the lower aquifer chloride was the dominant anion. Aina and Oshunrinade (2016) confirmed that alkalinity of water was due to the presence of carbonates, bicarbonates, and hydroxides.

2.3.1.2 Effect of depth on Biochemical Oxygen Demand (B. O. D)

There were significant differences ($p<0.05$) in Biochemical Oxygen Demand (B. O. D) between the depth categories within the districts (Fig. 2). Shallow boreholes had significantly ($p<0.05$) higher B.O.D compared to the rest of the depth categories (Fig. 2). Significantly ($p<0.05$) similar lowest values in deep and very deep boreholes were observed in Ilala, Kinondoni and Temeke. Therefore, the amount of B.O.D significantly ($p<0.05$) decreased as depth of the borehole increased. Also the results showed that the Temeke boreholes water contained highest amount of B.O.D followed by Ilala and Kinondoni had least amount of B.O.D as shown in Fig 2.

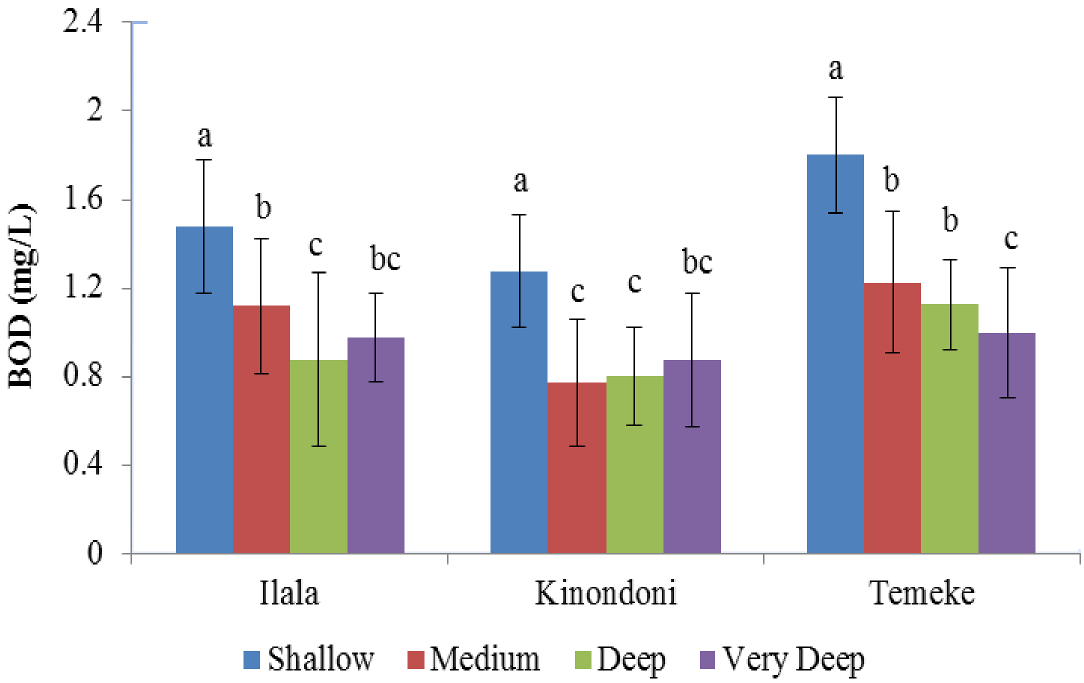

Figure 2: Effect of depth on B.O.D. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

The B.O.D of the borehole water decreases as the depth of the well increases. Ojo *et al*. (2012) revealed that groundwater is become purer with increase in depth. All samples were within the maximum B.O.D (6.0 mg/L) established by TBS (TBS, 2008). The higher level of B.O.D indicates groundwater pollution (Ojo *et al*., 2012). In shallow boreholes the B.O.D was higher than deep boreholes indicating that shallow boreholes water contained more organic matter compared to deep boreholes. Sindelar (2015) reported that water that moved into and through soil was cleaned. Therefore, as water moved to the deeper aquifers it was further cleaned compared to that which moved on the upper aquifers.

2.3.1.3 Effect of depth on total hardness of water

Figure 3 showed that there were significant differences (p<0.05) in total hardness within and between the districts at each level of depth. Very deep boreholes had the significantly

($p<0.05$) highest levels of water hardness compared to shallow boreholes. The highest levels were found in very deep borehole of Kinondoni and Temeke as shown in Figure 3. The lowest levels were found in the shallow boreholes in Ilala, Kinondoni and Temeke respectively. On average the Kinondoni boreholes had the highest levels of total hardness followed by Temeke and lastly Ilala.

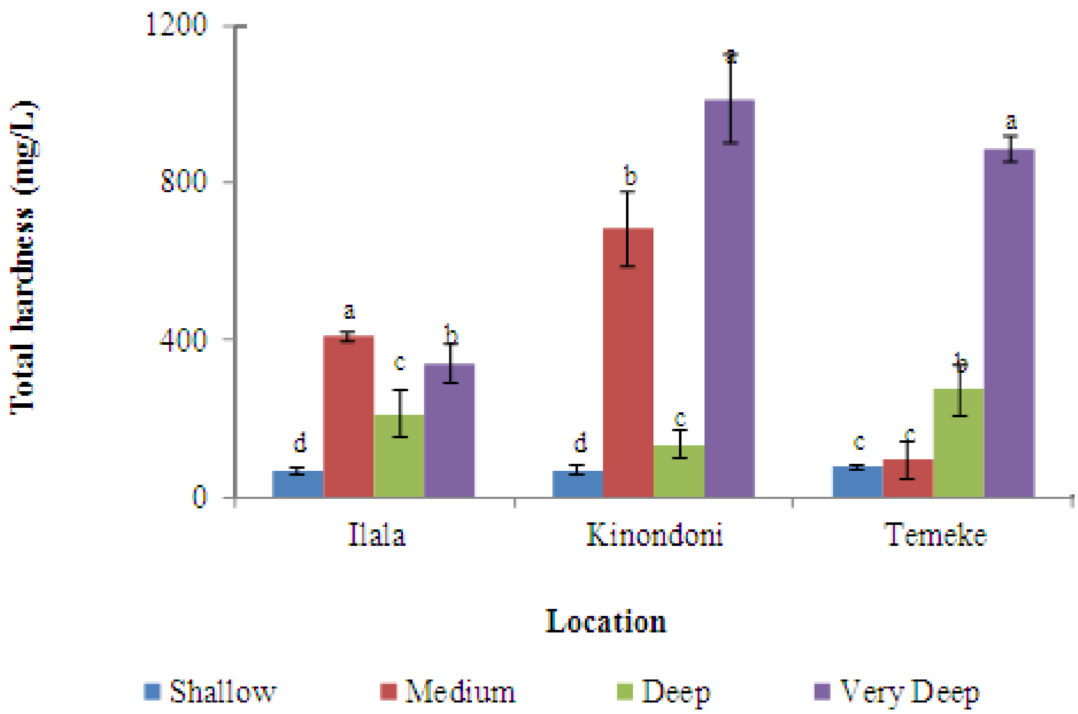

Figure 3: Effect of depth on total hardness. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

Groundwater is normally harder than surface water because of its high solubilizing potentials from rocks containing gypsum, calcite and dolomite (Ojo *et al.*, 2012). Despite of other negative effect, minerals dissolved in water have benefits of contributing to the taste of drinking water (WHO, 2011). According to the TBS specification the maximum hardness of drinking water is 600 mg/l (TBS, 2008). About 16.7% of all samples did not comply whereby 62.5% were from very deep boreholes. Aina and Oshunrinade (2016) reported that water hardness was caused by natural accumulation of salts from contact with soil and geological formation. Therefore the longer groundwater takes to move through the sediments, the more mineralized it becomes. Thus, groundwater increased in mineral content as it moved along through the pores and fracture openings in rocks. This caused deeper waters to be highly mineralized.

2.3.1.4 Effect of depth on metal contaminants (Lead and Copper)

The levels of the copper and lead were detected in all districts (Fig. 4 and 5). There were significant differences ($p<0.05$) in copper within and between the districts with shallow, medium, deep and very deep. All the samples met the maximum limits established by WHO (2011) and TBS (2008). The highest copper values were found in medium depth of Ilala and very deep depth of Temeke while the least levels were identified in very deep of Ilala followed by very deep of Kinondoni (Fig. 4). Lead was detected only in deep and very deep boreholes whereby in Ilala and Temeke were found only in deep boreholes while in Kinondoni were found only in very deep boreholes (Fig. 5).

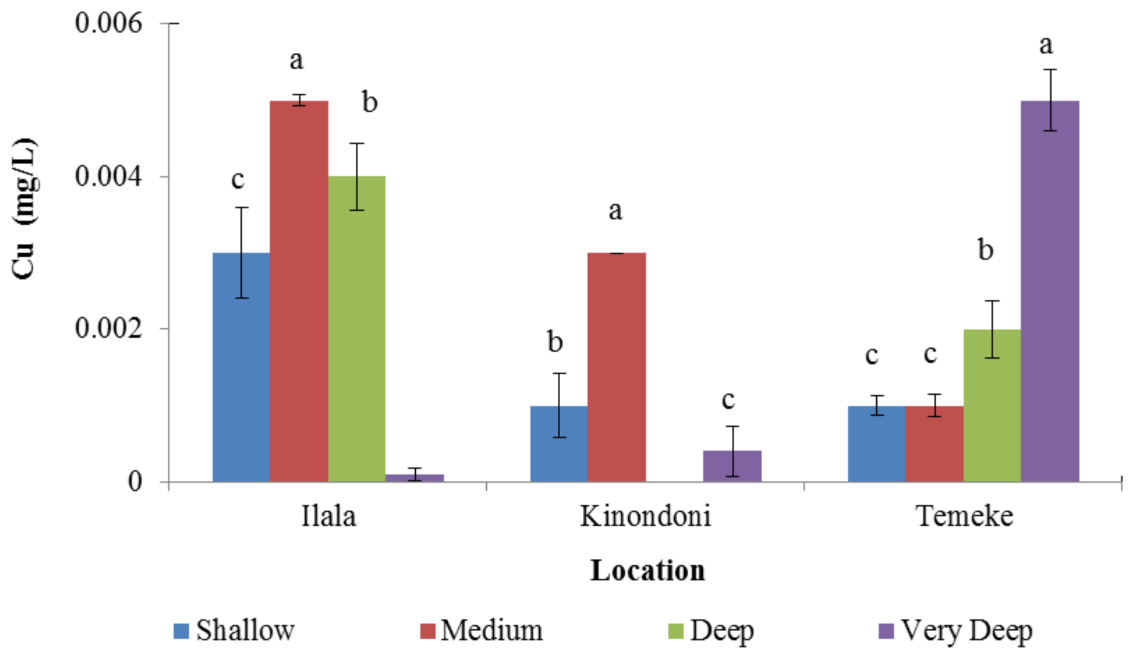

Figure 4: Effect of depth on copper. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

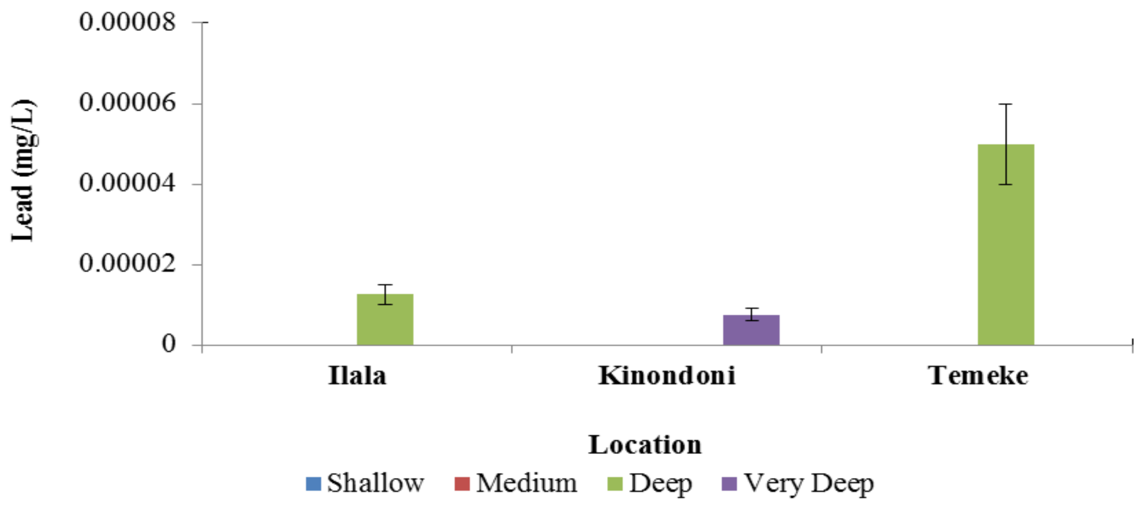

Figure 5: Effect of depth on lead. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

Contamination of metals from pipe fitting was rare regardless of the water acidic pH because of changes in technology from using metal pipes to PEX pipes (Crosslinked Polyethylene). PEX pipes are being commonly used nowadays as domestic water pipes. WHO (2011) realized that plumbing materials, pipes, fittings and coatings can result in elevated heavy metal. Shallow and medium boreholes showed less amount of lead compared to deep and very deep boreholes as it was identified by WHO (2011) that waters with high pH, calcium and alkalinity are less corrosive to the metal parts of water distribution systems. Furthermore WHO (2011) acknowledged that high levels of dissolved oxygen have been shown to accelerate copper corrosion from copper pipes. Moreover groundwater depth and quality varies from place to place as it affected the quality of water as it moved in various kinds of rocks, soils and pick up natural contaminants (Peter-Ikechukwu *et al*., 2015).

2.3.1.5 Compliance of physico-chemical characteristic of water to TBS and WHO limits in relation to depth

Table 1 shows distribution of boreholes’ depth according to their compliance on WHO and Tanzania physico-chemical specifications. Despite of the observed variations, entirely water samples from different depths levels were within the maximum allowable limits for BOD and Metal contaminants (Copper and Lead) set by WHO and TBS.

Table 1: Distribution of boreholes' depth according to their compliance with WHO and Tanzania physico-chemical specifications

Depth	Pass (%)	Parameter Fail					Total (%)
		pH	B.O.D	Hardness	Combination	Sub Total	
Shallow	12 (100)	-	-	-	-	0 (0)	12 (100)
Medium	9 (75)	-	-	3	-	3 (25)	12 (100)
Deep	9 (75)	3	-	-	-	3 (25)	12 (100)
V. Deep	6 (50)	1	-	4	1	6 (50)	12 (100)

This indicates that 16.7% of the samples total hardness were above 600 mg/L established by TBS (2008) and 10.4% of all samples did not complied with pH 6.5 – 8.5 (WHO, 2008) and or pH of 6.5 – 9.2 (TBS, 2008).

2.3.2 The effect of distance from the septic tank to the borehole on physico-chemical characteristics of the water

2.3.2.1 The effect of distance between the septic and borehole on pH

Figure 6 shows that there were no significant differences ($p<0.05$) in pH resulted from the effect of the distance between septic tank and borehole.

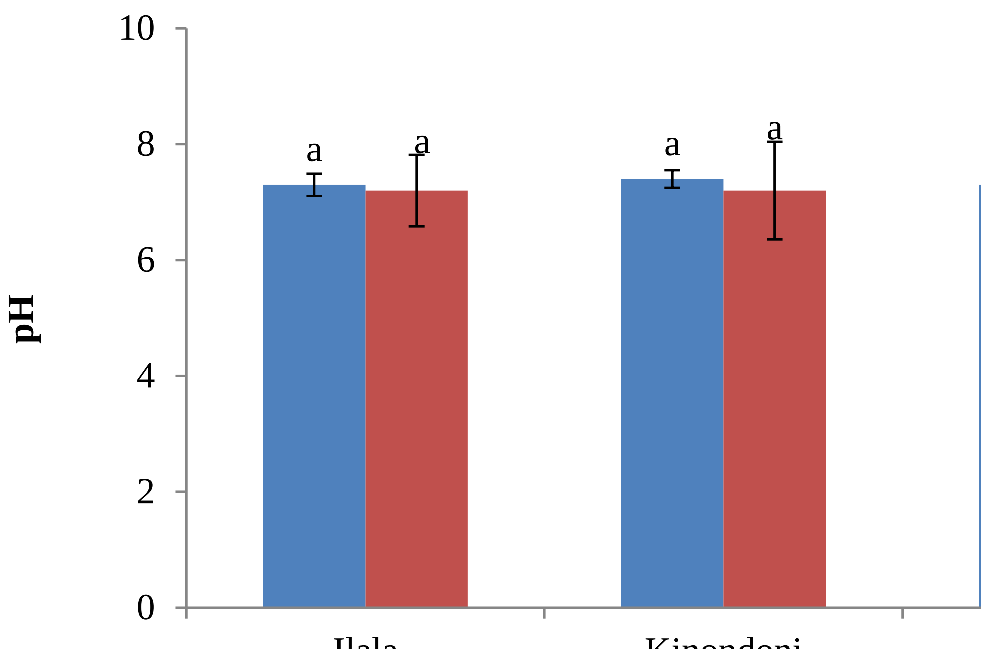

Figure 6: Effect of distance between borehole and septic tank in relation to pH. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

Fubara-Manuel and Jumbo (2014) reported that the effect of distance from the septic tanks to boreholes is noticeable especially where the adjoining geological formation was fissured. Furthermore, Fubara-Manuel and Jumbo (2014) indicated that there was no significant difference in pH resulted from distance of septic tank to borehole. In addition Eze and Eze (2015) confirmed that there was slight variation in pH but these variations did not show any correlations with the distance of the borehole from septic tank.

2.3.2.2 The effect of distance between the septic tank and borehole on B.O.D

There were significant differences ($p<0.05$) in Biochemical Oxygen Demand (B.O.D) of the near (<15m) and far (> 15m) distance between borehole and septic tank (Fig. 7). The amount of B.O.D were significantly ($p<0.05$) decreased as the distance between the borehole and septic tank increased. The B.O.D of the boreholes water was significantly ($p<0.05$) higher to the near distance between borehole and septic tank and significantly ($p<0.05$) lower to the far distance between borehole and septic tank. The highest values of B.O.D were found in the borehole water which was located near distance to the septic tank of Ilala and Temeke district while lowest value were detected in borehole water which was located far away from septic tank of the Ilala district (Fig. 7).

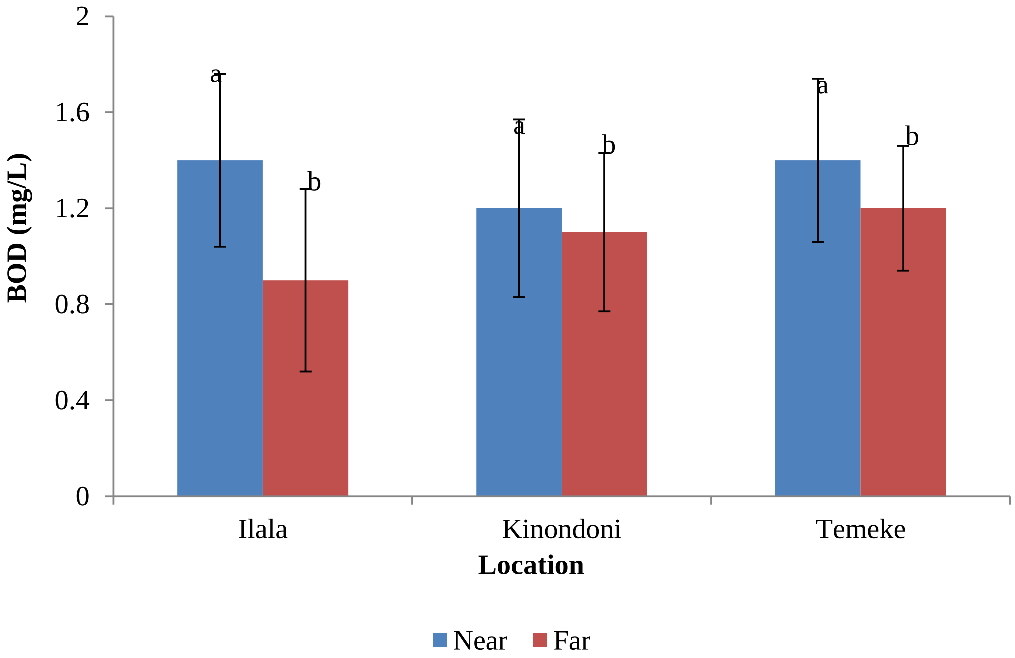

Figure 7: Effect of distance between borehole and septic tank in relation to B.O.D. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

The B.O.D results of all samples ranged from 0.9 to 1.4 mg/L, which complied with the limit set by TBS of 6 mg/L maximum (TBS, 2008). Abong'o *et al.*, in 2017 carried Chemical Oxygen Demand (C.O.D) on boreholes water in relation to distance between boreholes and septic tanks and revealed that the C.O.D levels were higher as distance from septic tanks decreased.

Therefore, there was higher organic matter in boreholes water which were close to the septic tank. The higher organic matter in the water was contributed by effluent from the septic tank. In view of the above McQuillan (2004) confirmed that domestic water utilization adds organic matter (typically measured as Biochemical Oxygen Demand, (BOD) to sewage. Therefore the higher organic matter in water measured in form of B.O.D to boreholes which were located near the septic tank was contributed by sewage within the septic tank.

2.3.2.3 The effect of distance between the septic and borehole on Total hardness

There were significant differences ($p<0.05$) in total water hardness of boreholes located at distances near (< 15m) and far (>15m) from the septic tank in Ilala and Kinondoni districts (Fig. 8). In Ilala district, the far the distance between borehole and the septic tank, the higher the levels of total water hardness. The situation of the Ilala district was different from the Kinondoni district in which boreholes near the septic tank had significantly higher the levels of total hardness water compared to borehole located far from the septic tank (Fig. 8). However, in Temeke district, there were no significant differences ($p<0.05$) in total hardness of the boreholes water which were located far and near distance from the septic tank (Fig. 8).

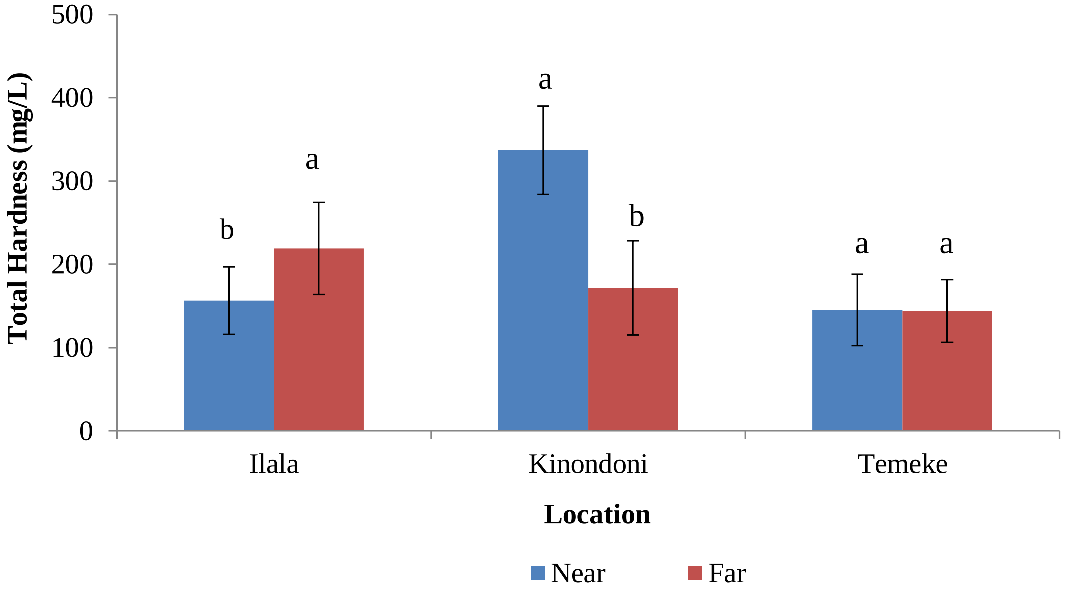

Figure 8: Effect of distance between borehole and septic tank in relation to water hardness. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at $p<0.05$

Fig. 8 shows that water hardness was less affected by the distance between the borehole and septic tanks, hence there could be other factors which might have contributed to water hardness more than distance between septic tank and boreholes. Palamuleni and

Akoth (2015) reported other factors which may contributed to groundwater minerals composition were seasonal changes, the types of soils, rocks and surfaces through which it moved, this could be due to the fact that as groundwater passed through the sediments, metals were dissolved and may later be found in high concentrations in the water. Hardness was caused by calcium and magnesium and it had no health effect but it affects acceptability of the water (WHO, 2011). According to Waskom and Bauder (2009) in order to protect the boreholes from septic tank regardless of the distance between them, boreholes should be uphill from septic systems in relation to the soil type, the hydrologeology and age of the boreholes.

This meant that even if the distance between the septic tank and boreholes was far, it might be contaminated if it was located downhill from the septic tank. Groundwater moved to the direction of the lowest hydraulic head (where groundwater was released into streams, lakes) from a high hydraulic head which was a recharge area (Witte, 2012). In addition Waskom and Bauder (2009) reported that total dissolved solids (TDS) in groundwater may vary depending on well recharge characteristics and TDS measures the total amount of dissolved minerals, metals, salts and may contain undesirable amounts of calcium, magnesium, sulfate, chloride, or other salts. Peter-Ikechukwu *et al*. (2015) concluded that distance between septic tank and borehole had little or no correlation with TDS and total hardness.

2.3.2.4 The effect of distance between the septic and borehole on metal contaminants (Lead and Copper)

There were significant differences ($p<0.05$) in copper for boreholes which were located near and far from the septic tank in all districts (Fig. 9). The levels of copper increased significantly ($p<0.05$) as the distance between the borehole and septic tank increased.

The significantly ($p<0.05$) high values of copper were found in the borehole water which located far away from the septic in the Ilala and Temeke districts. The significantly ($p<0.05$) low levels were found in the boreholes water located near to the septic tank in Kinondoni followed by Temeke and lastly Ilala districts (Fig. 9). The amount of lead detected was very much lower compared to copper. The lead was detected only in the borehole which were located near distance to the septic tank in Temeke and Kinondoni districts (Fig. 10) while in Ilala district lead was only detected in borehole water located far away from the septic tank (Fig. 10).

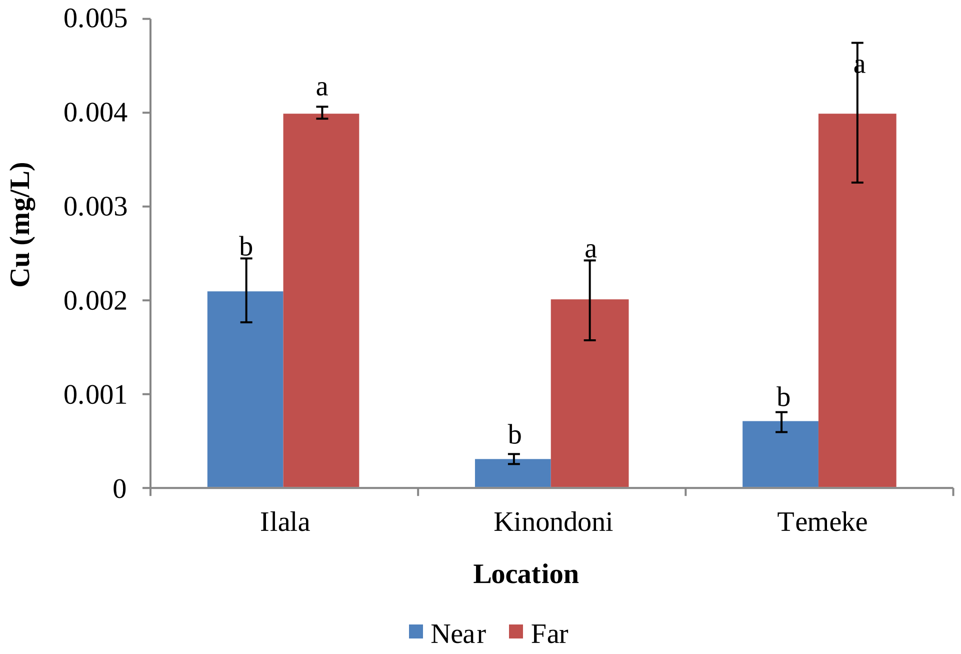

Figure 9: Effect of distance between borehole and septic tank on copper. Bars are expressed as mean ± SD (n=48). Bars with different letters are significantly different at p<0.05

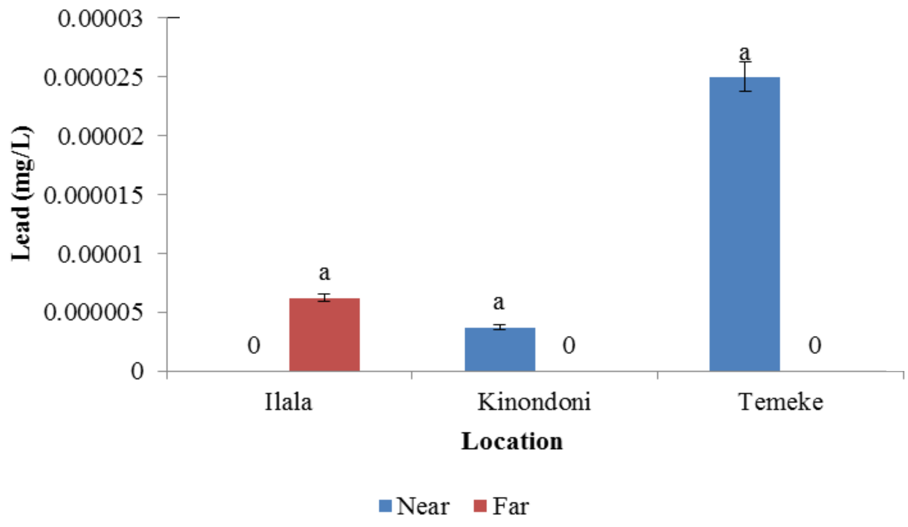

Figure 10: Effect of distance between borehole and septic tank on copper and lead. Bars are expressed as mean±SD (n=48). Bars with different letters are significantly different at p<0.05

Copper and lead levels indicated that the levels of these metals contaminants were low and complied with the maximum limits established by TBS and WHO (Fig. 9 and 10). Mkude (2015) explained that the levels of copper in boreholes of Dar es Salaam were very minimal and its source might be due to the intrusion of industrial and domestic wastes. Palamuleni and Akoth (2015) stipulated that groundwater chemical composition varied from place to place, seasonal changes, the types of soils, rocks and surfaces through which it moved and naturally occurring metals present in the rocks and sediments dissolved and might later be found in water. Furthermore, lead contamination to groundwater may be the result of entry from industrial effluents, old plumbing, household sewages, agricultural run-off containing phosphate fertilizers, human and animal excreta (Mkude, 2015). The earlier statements concur with the results which showed that lead were commonly found in the water from the boreholes which were near the septic tank.

The pH values of neutral and slightly alkaline decreases the availability of the metal ions in water as the metal would remain attached to substrate and complexes, therefore, significantly low levels of metal contaminants could resulted from the neutral pH of the samples of both near and far distance between septic tank and borehole (Kihampa, 2013).

2.3.2.5 Compliance of borehole water to WHO and Tanzania standards on physic-chemical parameters based on distance between borehole and septic tank

The effect of distance between borehole and septic tank on physico-chemical limits compliance set by WHO and TBS (Table 2). About 79.2% of the near distance between the septic tank and borehole comply with the WHO and TBS specification while 70.8% of the far distance (>15m) complied. Therefore 20.8% and 29.2 % of borehole waters sampled from near and far from the septic tank did not comply with the WHO and Tanzania specification. However, there were no significant differences at $p<0.05$ between these sample. In view of Table 2, all the samples which did not comply with WHO and TBS were contributed by levels of pH, total hardness or combination of pH and total hardness. Compliance to TBS and WHO physico-chemical limits were highly affected by pH followed by total hardness and finally combination of total hardness and pH (Table 2).

Table 2: Distribution of boreholes' distance to septic tank according to their compliance with WHO and Tanzania physico-chemical specifications

Distance	Pass (%)	Parameter Failed					Total (%)
		pH	B.O.D	Hardness	Combination	Sub Total	
Near	19 (79.2)	5	-	-	-	5 (20.8)	24 (100)
Far	17 (70.8)	4	-	2	1	7 (29.2)	24 (100)

The samples of the borehole water which did not comply with WHO and TBS standards were observed mostly in samples which were obtained far from the septic tank. However, there were no significant differences between samples which did not complied with specifications located far and near distance to the septic tank. All of the borehole water samples which did not comply with WHO and TBS specifications on physico-chemical characteristics of the borehole water resulted from the effect of distance to the septic tank were attributed by pH and total hardness (Table 2). The boreholes water pH and total hardness (Fig. 6 and 8) were not affected by the distance between septic tank and boreholes. Palamuleni and Akoth (2015) mentioned factors which contributing to groundwater minerals composition were seasonal changes, the types of soils, rocks and surfaces through which it moved. Fubara-Manuel and Jumbo (2014) reported that there was no significant difference ($p<0.05$) in pH resulting from distance from the borehole to the septic tank. In addition Eze and Eze (2015) confirmed that there was slight variation in pH but variations did not show any correlation with the distance of the borehole from septic tank. Since all the samples which did not comply with WHO and Tanzania physico-chemical parameters were contributed by the levels of pH and total hardness but from Fig. 6 and 8, borehole water pH and total hardness were not affected by distance between septic tank and borehole. Hence, this concluded that all samples that did not comply on pH and total hardness parameters were not contributed by the effect of distance between borehole and septic tank being near or far.

2.4 Conclusion

The study showed that both the depth of the borehole and the distance from the borehole to the septic tank have effect on the physico-chemical quality of the water. The levels of pH and B.O.D decreased significantly as the depth of the boreholes increased, while for very deep boreholes water had significantly higher levels of total hardness compared to shallow boreholes. The distance between the septic tank and boreholes had no effect on pH and total hardness while the B.O.D decreased significantly as distance between the septic tanks and boreholes increased. Generally, regardless of the depth of the boreholes and distance to the septic tank, the levels of copper and lead detected were very low. Thus, except for pH and total hardness of some samples, all physico-chemical parameters were within the limits stipulated by TBS (2008) and WHO (2011) standards.

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CHAPTER THREE

PAPER TWO

EFFECT OF DEPTH AND DISTANCE OF BOREHOLE FROM SEPTIC TANK ON MICROBIOLOGICAL QUALITY OF WATER

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Abstract

A study was conducted to assess the effect of depth and distance of the borehole from the septic tank on the microbiological quality of the of the borehole water consumed in three districts of Dar es Salaam Region. A total of 48 samples were collected and subjected to the total coliforms, *E.coli* and *C. perfringens* analyses using membrane filtration techniques. The data obtained were analyzed using R-software for ANOVA and means were separated using Tukey's Honest at $p<0.05$. There were significant ($p<0.05$) differences in microbiological properties of water samples obtained from the various depths within and between the districts. Deep and very deep boreholes water contained significantly ($p<0.005$) higher levels of coliforms bacteria and *E. coli* than shallow boreholes water while levels of *C. perfringens* significantly ($p<0.05$) decreased as the depth increased. It was also found that boreholes water located far away from the septic tanks contained significantly ($p<0.05$) higher levels of coliforms bacteria, *E.coli* and *C. perfringens* than boreholes located near the septic tank. This could be contributed by other factors such as groundwater flow direction and age of the borehole. Furthermore 75% of the borehole water samples which were located far distance to the septic tank did not comply with the limits set by TBS and WHO while only 54.2 % of the borehole which were located near to septic tank did not comply. It may thus be concluded that both depth and distance affected microbiological quality of borehole water.

3.1 Introduction

Water is one of the God's given precious and obligatory substance for man's life and it has no substitute for our daily life (Mato, 2002). It is one of the most abundant and essential resources for man, and occupies about 70% of earth's surface of which 97% is contained in the oceans (Ukpong and Okon, 2013). Having safe drinking water is a human right and need for everyone (Peter-Ikechukwu *et al*., 2015). As its accessibility and availability does not only play a crucial role in economic development and social welfare, but also it is an essential element in health (Eze and Eze, 2015). Groundwater is particularly important as it accounts for about 88% of man's safe drinking water (Eze and Eze, 2015). Safe drinking water is defined as water that does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (WHO, 2011). TBS (2008) defined drinking water as potable water intended for human consumption and specified the general requirement for water shall be free from microorganisms and chemical substances which may be hazardous to health.

Groundwater makes up over 95 % of the world's available freshwater resources (Elisante and Muzuka, 2015) and its quality variations are controlled largely by geology (Kashaigili, 2012). It is increasingly being used globally as the surface waters are getting polluted due to human activities (Moyosore *et al*., 2014). Arwenyo *et al*. (2016) reported that worldwide, 1.1 billion people do not have access to clean water and 2 million children die yearly due to avoidable water borne diseases. Over 50 percent of residents in Dar es Salaam City rely on groundwater supply. Unfortunately, uncontrolled development of both shallow and deep aquifers, along with climatic circumstances increases the risk of contamination (Mtoni and Walraevens, 2010). The unwholesomeness of drinking water resulting from contaminants released from different anthropogenic sources has become a global concern (Adeniyi *et al*., 2016). In many developing countries access to reliable and safe water remains a challenge (Kapongola *et al*., 2014).

Lu *et al*. (2007) noted that the quality of wastewater can have a major impact on groundwater especially in municipalities with no access to public sewage systems. In Dar es Salaam large part of the population is living in unplanned areas and they are not connected to the public sewage system (Witte, 2012). Moreover, Witte (2012) found that the sewage system was outdated, with cracks causing sewage water leaks. Fubara-Manuel and Jumbo (2014) identified that the most common cause of pollution of groundwater is attributable to close proximity of septic tanks to boreholes especially where the adjoining geological formation is fissured and can serve as a vehicle for spreading illness caused by such microorganisms as *Vibrio cholera*, *Yersinia enterocolitica*, *Escherichia coli* and vector borne diseases.

Another factor which contributes to the groundwater contamination and pollution is depth. Ojo *et al*. (2012) reported that groundwater is becoming more pure with increase in depth. Theoretically, depth-to-water is important because there is a greater chance for contaminant attenuation as the depth-to-water increases, due to longer travel times and more contact with potential sorbents (Kanyerere *et al*., 2012). Boreholes depth in Tanzania are classified as shallow (0-30 m), medium (31-50 m), deep (51-80 m), and very deep (>80 m) (Baumann *et al*., 2005, Kashaigili, 2012). However, in Tanzania there is limited information on the microbiological quality of groundwater based on their depth and distance to the septic tank. This work was therefore, carried out to study the effect of depth and distance of boreholes from septic tanks on microbial quality of water: in Dar es salaam

3.2 Material and Methods

3.2.1 Study area

This study was carried out in three districts of Dar es Salaam region namely Kinondoni (including Ubungo), Ilala and Temeke (including Kigamboni).

3.2.2 Materials

Materials used for this study were boreholes water from Dar es Salaam. Other materials such as analytical grade reagents and chemicals, apparatus and laboratory equipment were obtained from WDMI Laboratories. Tape measure was purchased from supplier in Dar es Salaam.

3.2.3 Study design

Randomized Complete Block Design was used in the study where depth of the borehole with four levels and distance from the septic tank with two levels were the principal factors. The effects of these factors on microbiological parameters were assessed. The mathematical model is as depicted in equation 2

$$Yij = \mu + \alpha i + \beta j + \varepsilon ij \qquad (2)$$

Where μ is overall mean, αi is the effect of treatment i (depth), βj is effect of block j (distance to septic tank) and εij random error

3.2.3.1 Sampling plan and data collection

Purposive sampling plan was used in this study to collect samples from selected boreholes in the three districts of Dar Es Salaam, Kinondoni (including ubungo), Ilala and Temeke (including Kigamboni). A total numbers of 48 samples was collected, 16 samples from each district. Samples were collected after sterilization of water tap/nozzle using cotton wool soaked in 70% (v/v) ethanol and allowing water running for 1 minute. One liter of borehole water was collected in each sample. Sampling was carried out from November 2016 – January 2017. The samples were collected in 500 mls transparent clean and sterile autoclavable glass bottles (Duran, made in Germany) having the capacity of 500 mls. Samples were stored and transported in insulated box maintained at 0^0 to 4^0 C to the WDMI laboratory for analysis.

3.2.4 Microbiological analyses

3.2.4.1 Enumeration of *Escherichia coli* and coliforms

The enumerations of *Escherichia coli* and *coliforms* of borehole water samples were determined according to ISO 9308-1:2014 procedures. Results were expressed in CFU/100ml.

3.2.4.2 Enumeration of *Clostridium perfringens*

The enumerations of *Clostridium perfringens* of borehole water samples were determined according to ISO 14189:2013 procedures. Results were expressed in CFU/100ml.

3.2.4.3 Statistical data analysis

Data were analyzed using R- statistical package software for Analysis of Variance (ANOVA) to determine the significant difference between the main factors. Means were separated using Tukey's Honest at $p<0.05$.

3.3 Results and Discussion

3.3.1 The effect of depth of the borehole on bacteriological characteristics of the water

3.3.1.1 The effect of depth on coliforms bacteria contamination in water

There were significant differences ($p<0.05$) in coliform counts between the depth categories within the districts (Fig. 11). Water from all three districts in all depth categories contained coliforms bacteria except in medium depth of the Temeke district (Fig. 11). Deep and very deep boreholes water contained significantly ($p<0.05$) higher levels of coliforms bacteria compared to shallow boreholes water. In Kinondoni and Temeke the highest levels of coliforms bacteria were detected in the deep and very deep boreholes water while in Ilala highest levels of coliforms bacteria were detected in very deep and medium depth boreholes water (Fig. 11).

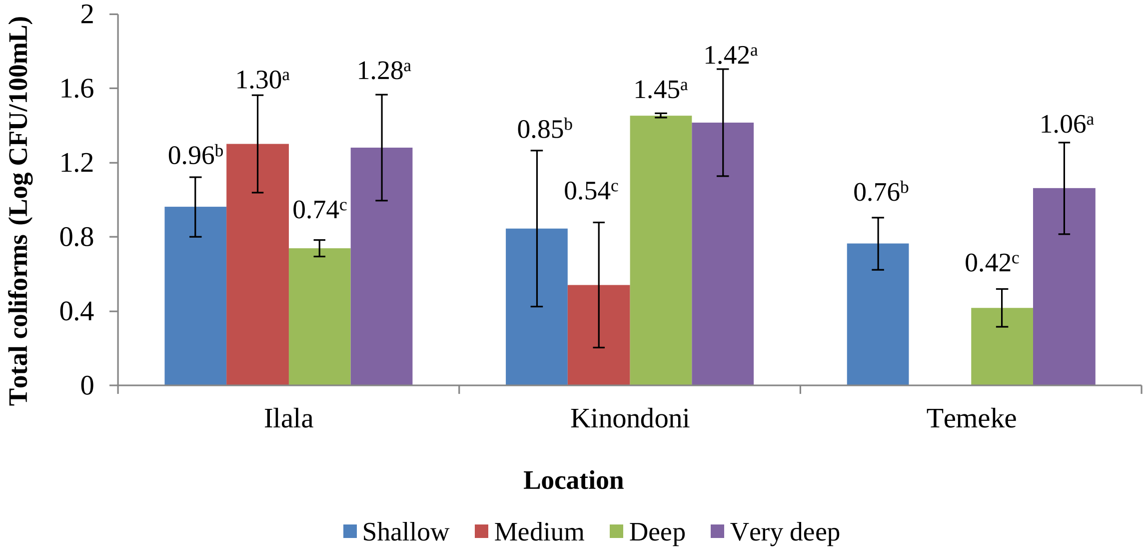

Figure 11: Effect of depth on total coliforms count (Log CFU/100ml) within each location (district). Values are expressed as mean ± SD (n=48). Bars values with mean values with different superscript letters are significantly different at $p<0.05$

Coliforms were detected in the shallow, medium, deep and very deep boreholes water, this was attributed by the fact that coliforms bacteria are ubiquitous. Therefore coliforms can be found in soil, vegetation, in surface water and intestines of warm-blooded animals while *C. perfringens* and *E. coli* reside only in the intestines of warm-blooded animals (WHO, 2011).

As a consequence of the above statements the number of coliforms bacteria detected in all boreholes water were significantly higher than the *C. perfringens* (Fig. 11 and 13). Additionally, to coliforms bacteria being ubiquitous, can survive and grow in water distribution systems unlike *C. perfringens* and *E. coli* (WHO, 2011). Furthermore, the levels of Coliforms were above the limits established by TBS and WHO in the all depth levels within all districts except for medium depth in Temeke (Fig. 11). Therefore, boreholes water from all depth categories within all districts except for medium depth in Temeke were not suitable for direct human consumptions. Olatunji and Oladepo (2013) reported that coliforms bacteria were used as indicators to determine if treated water was acceptable for human consumption. This indicates that the borehole water regardless of the depth, should be treated in such a way that it is free from coliform bacteria before consumption. Coliforms bacteria can be used to assess the cleanliness and integrity of distribution systems and the potential presence of biofilms (WHO, 2011).

Fig. 11 revealed that deep and very deep boreholes water contained higher levels of Coliforms bacteria compared to shallow boreholes water. This situation explained by Treyens (2009) that the reduced pressure or suction in long water lines such as in deep and very deep boreholes can draw in bacteria-laden water or soil into pipes through joints. Eni *et al*. (2013) explained that existences of coliforms in deep aquifer were associated with large pore sizes of soils and soil layers often do not adequately protect aquifers from contamination since they allow some microbes to penetrate groundwater even at great depths which opposing most of people believe. NBS (2014) confirmed that one of the major components of soil type found in Dar es salaam was sandy loam soils in which water drained well.

3.3.1.2 The effect of depth on *E. coli* contamination in water

There were significant differences ($p<0.05$) in *E. coli* contaminations within and between the districts in shallow, medium, deep and very deep boreholes water (Fig. 12). *E. coli* were detected in all the shallow, medium, deep and very deep boreholes water in Ilala and Kinondoni districts. In Temeke district *E.coli* were detected only in the shallow boreholes. In Kinondoni and Ilala districts however, deep and very deep boreholes water had significantly ($p<0.05$) higher levels of *E. coli* than in shallow boreholes water.

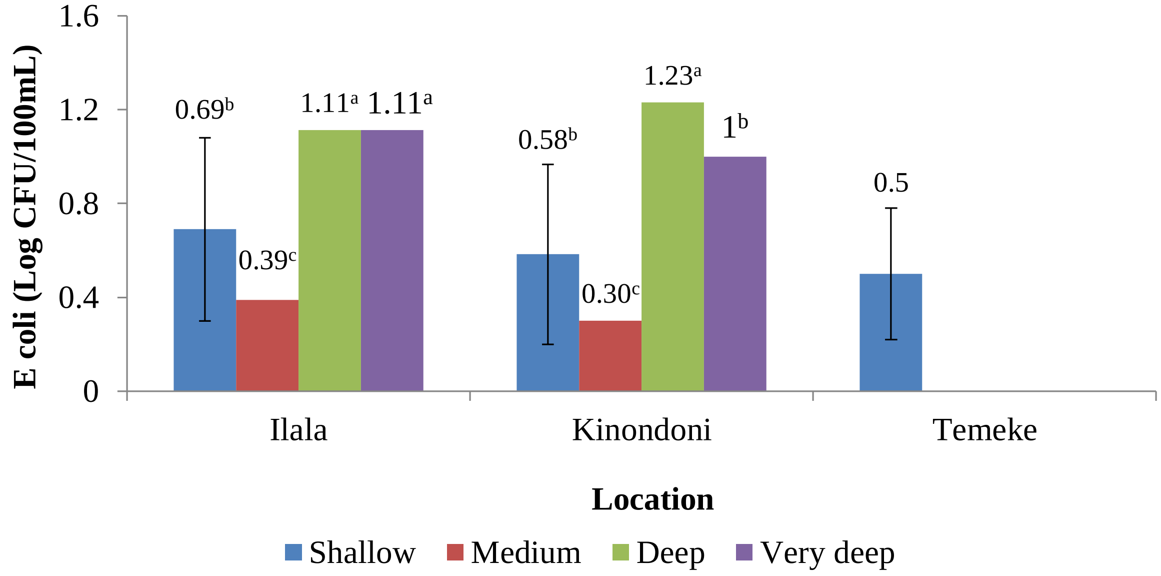

Figure 12: Effect of depth on *E. coli* count (Log CFU/100ml) within each location (district). Values are expressed as mean ±SD (n=48). Bars values with mean values with different superscript letters are significantly different at p<0.05

The results above are similar to the study of Eni *et al*. (2013) where they found that the degree of microbial contamination was significantly ($p<0.05$) higher in the deeper boreholes water than in shallow. Furthermore according to Eni *et al*. (2013) there was theoretical consideration that the deeper you sink a borehole the better the water quality, but this was not the case for microbial parameters analyzed in their study. This could be associated with large pore sizes of soils and soil layers in Dar es salaam region, one of major components of soil is sandy loam and is associated with high capacity of water draining (NBS, 2014).

Escherichia coli is considered the most suitable indicator of faecal contamination (WHO, 2011). The presence of *E.coli* in the shallow, medium, deep and very deep boreholes water in Ilala and Kinondoni districts suggest that it was not suitable for human consumption and it exceeded the limits set by WHO (2011) and TBS (2008). Therefore, treatment that will ensure water is free from *Escherichia coli* is important before consumption. *Escherichia coli* occurs in high numbers in human, animal faeces and sewage. *Escherichia coli* was the indicator of recent faecal pollution since water temperatures and nutrient conditions present in drinking-water distribution systems are highly unlikely to support their growth similar to other coliforms bacteria (WHO, 2011).

3.3.1.3 The effect of depth on *C. perfringens* contamination in water

There were significant differences ($p<0.05$) in *C. perfringens* within the Ilala district in shallow, medium, deep and very deep borehole water (Fig. 13). The *C. perfringens* was detected only in Ilala district and the levels decreased significantly ($p<0.05$) as the depth of the boreholes water increased. No *C. perfringens* were detected at any depth in Kinondoni and Temeke districts as well as in very deep boreholes of Ilala district (Fig. 13).

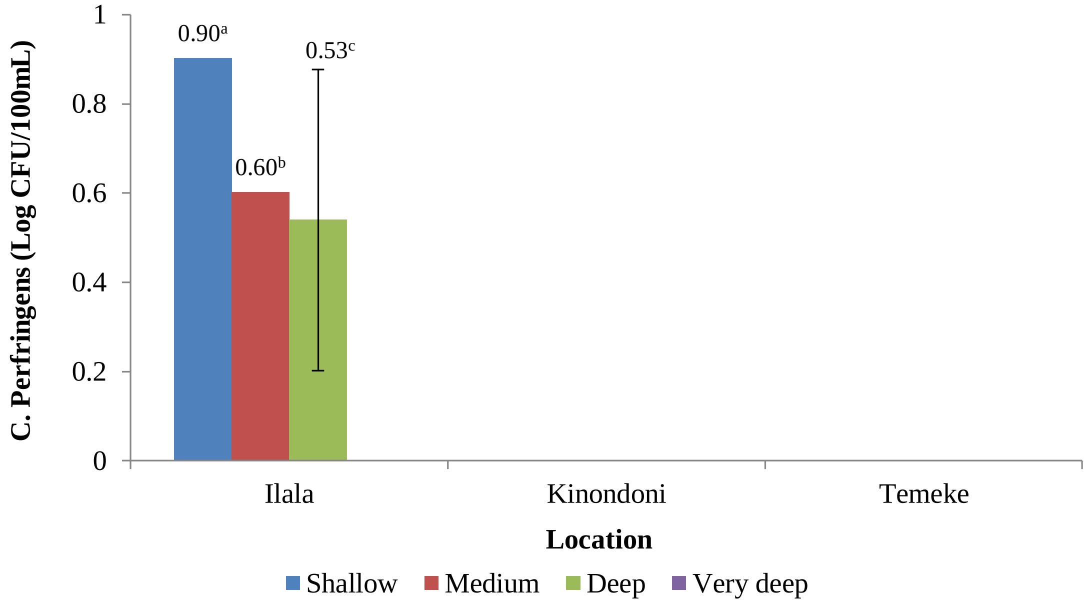

Figure 13: Effect of depth on *C. perfringens* count (Log CFU/100ml) within each location (district). Values are expressed as mean ±SD (n=48). Bars values with mean values with different superscript letters are significantly different at $p<0.05$

The levels of *C. perfringens* detected were above the limit established by WHO (2011). Therefore, water from those boreholes were not suitable for human consumption. *C. perfringens* is a member of the normal intestinal flora of 13–35% of humans and other warm- blooded animals (WHO, 2011). Hence, this revealed that water intended for human consumptions was contaminated by warm blooded faecal matters. *C. perfringens* was detected only in one district and the levels detected were lower than levels of *E.coli*. These situations explained by the WHO (2011) that the numbers of *C. perfringens* excreted in faeces are normally substantially lower than those of *E. coli*. Moreover, because of the *C. perfringens* excreted in faeces were significantly lower than *E. coli*, this could causes *C. perfringens* not be detected even if there was faecal contamination reflected by *E. coli* detection.

The *C. perfringens* levels were decreasing as the depth of the boreholes increases which opposing to the levels of *E.coli* detected although both measure feacal pollution (Fig. 12 and 13). WHO (2011) reported that there was some evidence for growth of *E.coli* in tropical soils. *C. perfringens* had been shown to be a better indicator of human fecal contamination in tropical waters (John *et al*., 1995). Therefore, *E.coli* was regarded as a less reliable but acceptable indicator of faecal pollution and *C. perfringens* was highly specific indicator of faecal pollution. In addition, *C. perfringens* can serve as an indicator of faecal pollution that took place previously and hence, can indicate sources liable to intermittent contamination (WHO, 2011).

3.3.1.4 Compliance of microbiological characteristic of water to WHO limits in relation to depth

Table 3 demonstrated that 64.6% of the samples did not comply with the limits set by the WHO (2011) and only 35.4% of the samples were within the limits (Table 3). Therefore, most of the borehole water samples contained higher microbial load, which they are not suitable for human consumption. For that reason 64.6% of the samples were not suitable for human uses they require treatments before consumption. The same table also revealed that 75% of the shallow, deep and very deep borehole water did not comply with WHO (2011) specification for drinking water while in medium depth only 33.3% of samples did not comply.

Table 3: Distribution of boreholes' depth according to their compliance with WHO and Tanzania microbiological level specifications

Depth	Pass	Fail					Total
	N (%)	Total coliforms	*E.coli*	*C. Perfringens*	Combination	Sub Total	
Shallow	3 (25)	1	-	-	8	9 (75)	12 (100)
Medium	8 (66.7)	1	-	-	3	4 (33.3)	12 (100)
Deep	3 (25)	5	-	2	2	9 (75)	12 (100)
Very deep	3 (25)	7	-	-	2	9 (75)	12 (100)

3.3.2 The effect of distance from the septic tank to the borehole on microbiological characteristics of the water

3.3.2.1 The effect of distance between the septic tank and borehole on coliforms bacteria

There were significant difference ($p<0.05$) in coliforms bacteria of near and far distance between borehole and septic tank in all districts (Fig. 14). In all three districts the levels of coliforms detected in the borehole water located far from the septic tank were significantly higher than those which were located near the septic tank.

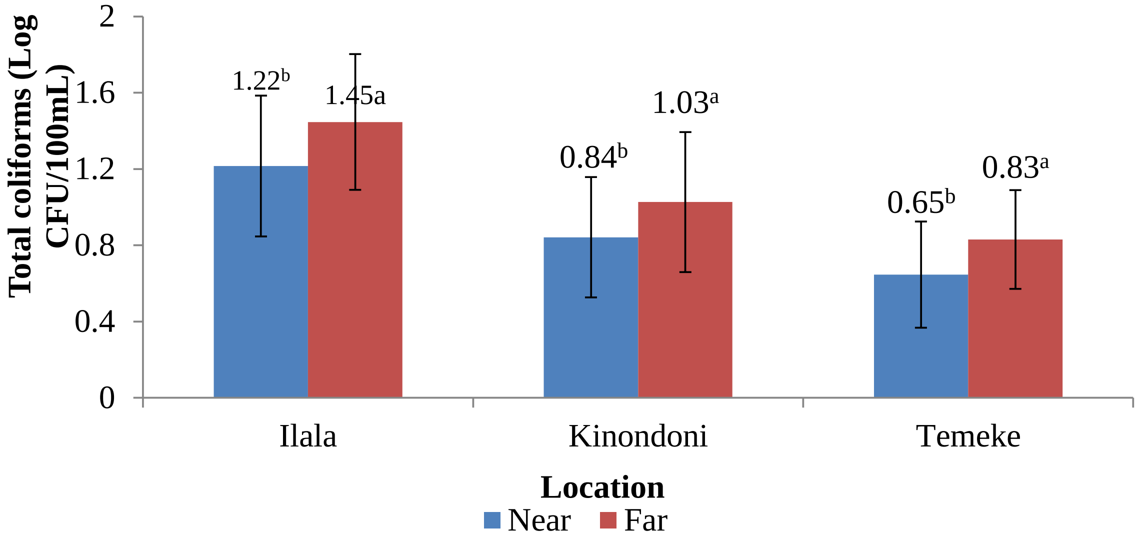

Figure 14: Effect of distance between septic tank and borehole on total coliform counts (Log CFU/100 ml) within each location (district).Values are expressed as mean ±SD (n=48). Bars values with mean values with different superscript letters are significantly different at $p<0.05$

Both the near and far distance between the septic tanks and borehole contains coliforms bacteria to the level that water is not suitable for human consumption based on the limit set by TBS (2008) and WHO (2011). In the study of Olatunji and Oladepo (2013), the well water samples from near pit latrines and far from pit latrines were unacceptable for human consumption because of their high bacterial loads. Also the levels of the Coliforms bacteria in water of the far distance from the septic tank were higher compared to the near distance. Francy *et al*. (2000) identified that total coliforms are ubiquitous in the environment. Kanyerere *et al*. (2012) found that some of the total coliforms could be representative of naturally-occurring bacteria that do not necessarily reflect sewage contamination of the groundwater. These observations suggest coliforms contamination to the borehole water not only came from the septic tank. In additional to distance between septic tank and borehole, location of the borehole also had effect on the microbial load. Kanyerere *et al*. (2012) reported that boreholes located downhill from latrines makes them vulnerable to microbial contamination and concluded that there was no significant general relationship between the distance from latrines and/or animal corrals and the degree of contamination. This could be due to the fact that groundwater flows from uphill (upstream) to downhill (downstream), therefore, if the borehole was located downhill from the septic tank will be easily contaminated regardless of the distance between them as groundwater flow between them. Bourne (2001) confirmed that regardless of the distance, a potential pollution source should not be located uphill from a well.

3.3.2.2 The effect of distance between the septic tank and borehole on *E.coli*

There was significant difference ($p<0.05$) in *E.coli* in borehole located near and far from the septic tank in all districts (Fig. 15). In the Ilala district the boreholes water which were near to the septic tank contained significantly ($p<0.05$) higher levels of *E.coli* than those located far from the septic tank but in Kinondoni and Temeke districts, the levels of *E.coli* detected in the borehole water located near the septic tank were significantly ($p<0.05$) lower than those located far from septic tank (Fig. 15). In general the levels of *E.coli* found in the samples of the borehole water which were located far from the septic were significantly ($p<0.05$) higher than samples which were located near from the septic tank.

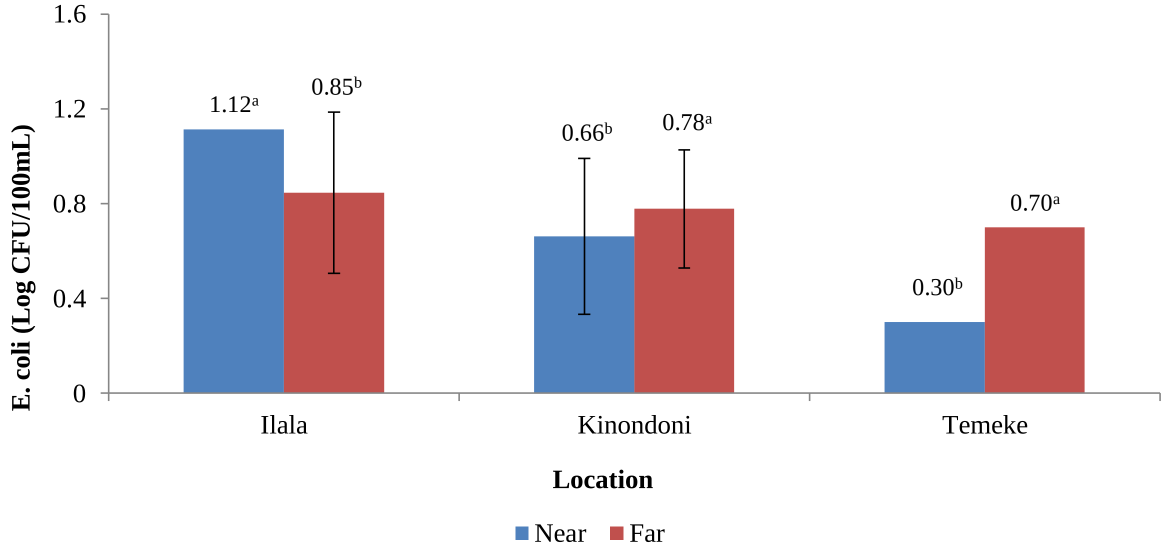

Figure 15: Effect of distance between septic tank and borehole on *E. coli* count (Log CFU/100ml) within each location (district).Values are expressed as mean ±SD (n=48). Bars values with mean values with different superscript letters are significantly different at $p<0.05$

E. coli were detected in boreholes water located both far and near distance to the septic tank. Suggesting that, there was recent faecal contamination in the boreholes water located far and near distance to the septic tank. Consequently boreholes water should be treated before consumption regardless of the distance between the septic tank and boreholes.

The presence of *E.coli* count suggested that both boreholes water samples near and far from the septic tank were not suitable for human consumption. Similarly to Fig. 14 which showed that coliforms bacteria were significantly ($p<0.05$) higher to the boreholes water located far from the septic tank than those located near the septic tank also *E.coli* enumerated in the boreholes water located far from the septic tank were significantly ($p<0.05$) higher than those located near the septic tank (Fig. 15). These results contrasting the known theory that the closer the borehole is to the pollutants (such as septic tank) the easier it is for the water to become contaminated. Banda *et al*. (2014) highlighted that positioning of boreholes and septic tanks is determined mainly by two factors which include the distance from groundwater source to septic tank and direction of groundwater flow in the area (Fig. 16). In the previous statements, even if borehole was located at a far from the septic tank, if the groundwater flow direction was from the septic toward borehole, that borehole could easily be contaminated by feacal matter. According to Bourne (2001) in order to avoid borehole water feacal contamination caused by groundwater flow, septic systems must be properly sited at least 100 feet downhill from boreholes.

Although the location of the borehole has effect on water quality but other factors need to be considered such as age of the boreholes. The long term usage of boreholes may lead to deterioration of the water quality, because the pipeline might become corroded with random cracks and in most cases clogged with sediment which later may allow the passage of inorganic metals and bacteria (Peter-Ikechukwu *et al*., 2015). Wells in regions with fractured rocks or karst were highly vulnerable to faecal pollution (Krauss and Griebler, 2011). Hence, regardless of the distance between the septic tank and boreholes fissured rocks or soil can contribute to *E.coli* contamination in the groundwater. Also Banda *et al*. (2014) commented that the release of pollutants into the environment may result if a septic tank system was improperly sited and constructed.

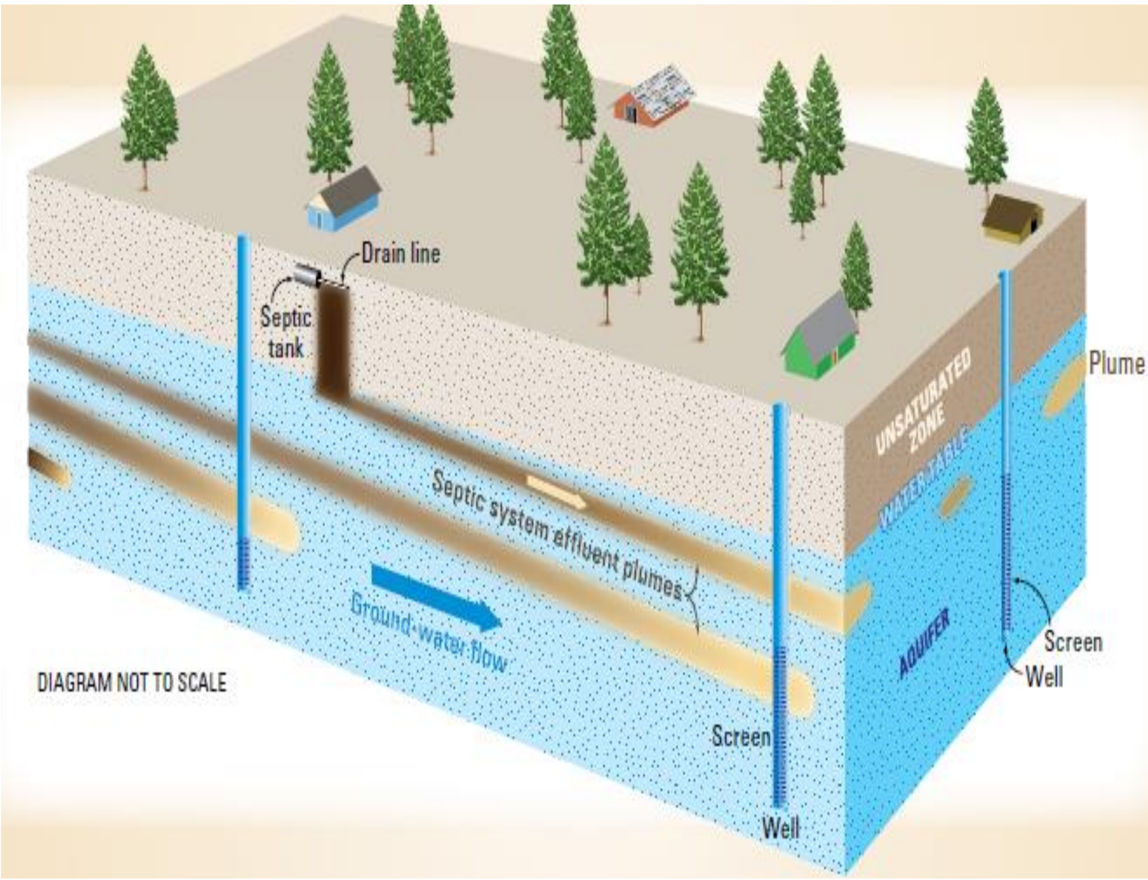

Figure 16: The effect of groundwater flow direction to the borehole water quality regardless of the distance between septic tank and borehole.

Source: Williams *et al*. (2007)

3.3.2.3 The effect of distance between the septic and borehole on *C. perfringens*

According to Fig. 17 *C. perfringens* were detected only in the Ilala district to the boreholes that were located far from the septic tanks and there was significant difference ($p<0.05$) to those enumerated in boreholes located near to the septic tank of the same district. The *C. perfringens* were not detected in boreholes water from Kinondoni and Temeke districts.

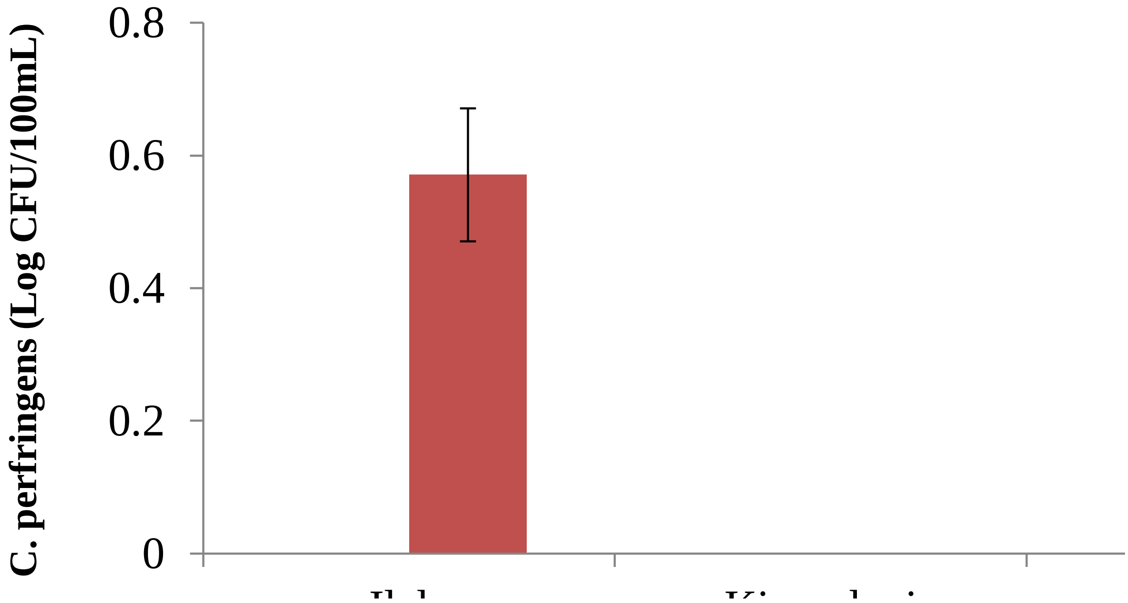

Figure 17: Effect of distance between septic tank and borehole on *C. perfringens* count (Log CFU/100ml) within each location (district). Values are expressed as mean ±SD (n=48). Bars values with mean values with different superscript letters are significantly different at p<0.05

C. perfringens count was significantly lower compared to *E.coli* although both indicate feacal contamination. The *C. perfringens* was detected only in one district and the levels detected were significantly ($p<0.05$) lower than those of *E.coli*. The numbers of *C. perfringens* excreted in faeces were normally substantially lower than those of *E. coli* (WHO, 2011).

C. perfringens was found only in the borehole water which were located far away from the septic tanks which contradict with known facts that boreholes that were near to the septic tanks were vulnerable to feacal contamination. Banda *et al*. (2014) confirmed that only direction of groundwater flow had a relationship with groundwater quality at 5 percent significance level.

3.3.2.4 Compliance of microbiological characteristic of water to WHO limits in relation to distance between septic tank and borehole

The results on Table 4 below pointed out that 75% of the boreholes water which were located far from the septic tank did not comply with the limits set by TBS (2008) and WHO (2011) while only 25% boreholes water which were located far complied with the limits. Also for the boreholes water which were located near distance to the septic tank 54.2 % of the samples did not comply with TBS (2008) and WHO (2011) limits while 45.8% complied. Suggesting that boreholes water should be treated regardless of the distance to the septic tank.

Table 4: Distribution of boreholes' distance to septic tank according to their compliance on WHO and Tanzania microbiological level specifications

Distance	Pass (%)	Fail					Total
		Total coliforms	*E.coli*	*C. Perfringens*	Combination	Sub Total	
Near	11 (45.8)	6		-	7	13 (54.2)	24 (100)
Far	6 (25)	8	-	2	8	18 (75)	24 (100)

In view of the above table, although the distance between the septic tank and borehole contributed to borehole microbiological contaminations but are there other factors which contributed much to the borehole microbiological contaminations such as groundwater flow direction, age of the borehole and age of septic tank.

3.4 Conclusion

The study revealed that depth of the borehole and distance between septic tank and borehole affected the microbiological quality of water. The total coliforms bacteria counts were significantly higher in the water of the deep and very deep boreholes compared to shallow boreholes. In addition all the boreholes depth categories in Ilala and Kinondoni contained coliforms bacteria and *E.coli* counts that were beyond TBS (2008) and WHO

(2011) limits. It was observed that 64.6% of all water samples did not comply with specifications for coliforms, *E.coli* and *C. perfringens*. Bacterial counts were significantly higher in boreholes water that were located far from the septic tanks. Hence, 75% of the boreholes water which were located far from the septic tanks were not suitable for human consumption.

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CHAPTER FOUR

4.0 OVERALL CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The study on the safety and quality of borehole water, on selected area of Dar es salaam revealed that the borehole depths and the distance of the borehole to the septic tank had effects on the physico-chemical and microbiological qualities of borehole water. The depth of the borehole affected the pH, B.O.D and total hardness. In general, the pH and B.O.D of the borehole water significantly decreased as the depth of the borehole increased while total hardness were significantly ($p<0.05$) highest in the very deep boreholes. Regarding the effect of distance between septic tank and borehole on the physico-chemical characteristics of the borehole water, B.O.D was significantly ($p<0.05$) higher to the borehole located near the septic tank compared to those located far to the septic tank. The borehole water pH and total hardness were not affected by the distance between the septic tank and borehole. In addition there were no significantly ($p<0.05$) differences in samples which did not comply with WHO (2011) and TBS (2008) on physico-chemical parameters as a result of effect of distance of borehole to the septic tank.

The effect of depth and distance between septic tank and borehole on the microbiological quality of boreholes water detailed that total coliforms bacteria, *E.coli* and *C. perfringens* were affected by the depth and distance between septic tank and borehole. The total coliforms bacteria and *E.coli* were significantly ($p<0.05$) higher in deep and very deep borehole while *C. perfringens* were significantly ($p<0.05$) decreased as the depth increased. In relation to effect of distance between the borehole and septic tank on the microbiological quality of water, coliforms bacteria, *E.coli* and *C. perfringens* were significantly ($p<0.05$) higher to the borehole water situated far from the septic tank compared to borehole located near to the septic tank. Hence the samples of boreholes water which did not comply with WHO and TBS microbiological specification were significantly ($p<0.05$) higher for borehole located far from the septic tank compared to near the septic tank.

4.2 Recommendations

Based on the findings of this study the followings are recommended to the people:

i. All boreholes water should be treated to improve its quality and safety for human consumption regardless of the distance from potential pollutants.

ii. Before drilling the borehole, the drillers should take into consideration of all the factors that will affect the water quality such as depth, distance to the potential pollutants, groundwater flow direction and soil structure.

iii. More studies should be carried out on the combination effects of depth, distance to the septic tank, groundwater flow direction, age of the borehole, weather conditions (dry or wet) and soil structure on the borehole water quality.