UNIVERSITY OF NAIROBI

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING

IRON REMOVAL FROM BOREHOLE WATER: A CASE STUDY OF KIAMBU TOWN

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Abstract

Water is crucial not only for sustaining life but also for socio-economic development of a country. However, its availability in the right quality remains a great challenge. Groundwater is presently one of the major sources of water supply in Kiambu town and its environs. The town is surrounded by hilly Kikuyu farmland although it is under urbanization as Nairobi is growing fast and more people are settling in neighbouring towns. Kiambu Water and Sewerage Company is a Water Service Provider operating within Kiambu Town, under a Service Provision Agreement with Athi Water Services. In its mandate to ensure efficient and economical provision of water services in Kiambu Town it has drilled 11 boreholes within the Town. The water from some of the boreholes contains iron concentrations in excess of the WHO recommendations, which gives the water a sour metal taste, stains laundry and food cooked in the water receives an unappetizing colour. As a result, people use unprotected surface water instead hence the need for removal of the iron. Also in an attempt to remove the iron from water, various methods are used which may not be effective hence the need for evaluation of the treatment methods. The purpose of this study is to therefore evaluate the use of chlorine as a treatment method for removal of iron in the borehole water.

Thuku BH was identified for sampling since it contains iron in excess of the WHO recommendations of 0.3 mg/l. Two samples were collected and tested at the University of Nairobi Public Health Engineering Laboratory in order to establish the concentration of iron. The efficiency of chlorine in removal of iron was determined by comparing the difference in the iron concentration before and after treatment. A bench test was carried out to determine chlorine dosage. Different retention times were tested to assess the effect on iron concentration.

The iron concentration in Thuku BH was found to be 0.6 mg/l. Therefore, the water required treatment. The result from the performance evaluation of the chlorination method showed 66.7 percent efficiency in iron removal. From the laboratory test, it was determined that the chlorine dosage for Thuku BH was 2 mg/l. The amount of chlorine required to treat Thuku BH water was calculated to be $2.42\ \mathrm{kg\ Cl_2/day}$. The results showed remarkable iron removal with increased retention time with 83.3% percent iron removal with a retention time of one hour. Therefore, it was concluded that chlorination method is an effective method in removal of iron but it requires a higher retention time than the 20 minutes for full oxidation of iron to take place.

Dedication

I dedicate this project to my beloved family for their unending support, sacrifice and commitment to my education and well-being. May the Almighty God bless you and reward you abundantly.

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List of Abbreviations

mg/l: milligram per litre

ppm: parts per million

pH: power of Hydrogen

KEBS: Kenya Bureau of Statistics

WHO: World Health Organization

DO: Dissolved Oxygen

$\mu S/cm$: Micro siemens per centimetre

L, l: Litre

Cl_2: Chlorine

BH: Borehole

CHAPTER ONE

1. INTRODUCTION

1.1 Background information

Drinking water is a basic necessity of life. While relatively small quantities will sustain human life, much more is needed for cooking, personal hygiene, and cleaning and sanitation systems. Most of the water used in Kenya for domestic, commercial or industrial uses comes from either surface water or groundwater. Typical surface water supplies are void of iron. Groundwater is a major source of safe water for drinking and other domestic purposes for the rural/urban population of Kenya which may have iron content in excess of 0.3 mg/L. The most common source of water in the rural areas where springs or streams of sufficient capacity are not available is groundwater abstracted from shallow wells. For community water supply systems, groundwater at great depth should always be the preferred source because the water is generally free from pathogenic contamination, although there may be other forms of undesirable pollutants.

Iron (Fe) accounts for about 5% of the earth's crust, making it the second most abundant metal after aluminium which accounts for about 8.2% of the earth's crust. It often exists in insoluble form in groundwater supplies. The presence of iron in drinking water supplies maybe a result of geological formations and the use of metallic pumping equipment for groundwater withdrawal.

Iron can occur in water in a number of different forms. The type of iron present is important when considering water treatment. As water percolates through the ground strata it dissolves the iron from the iron ore deposits as ferrous bicarbonate $[Fe\ (HCO_3)^2]$, sometimes referred to as clear water iron. Iron normally wants to revert back to its natural state as iron ore. Iron very easily comes out of solution and precipitates to a solid particle of ferric hydroxide $[Fe(OH)^3]$ often referred to as red water iron. Simple changes to the water supply such as temperature, pressure or even a change of pH can promote the change from clear water iron to red water iron. The addition of oxygen to a water supply may easily cause this conversion. The higher the pH, the faster this reaction can take place. Iron will precipitate to a solid particle much faster at a pH of 8 than at a pH of 6. Thus, the pH of the water supply has a major impact on iron precipitation. Iron can form compounds with naturally occurring acids, and exist as organic iron. Organic iron is usually yellow or brown, but may be colourless.

The presence of iron in drinking water does not present a big health hazard. On the contrary iron is an essential nutrition element. The problems with iron are mainly aesthetic. Concentration of iron in excess of 0.3 mg/l may cause nuisance, even though its presence does not affect the hygienic quality of water. In domestic applications iron will stain fixtures, laundry, porcelain, dishes, utensils, glassware, sinks and other water-using appliance or surfaces that the iron-laden water contacts. These stains may vary from a light yellow to a red or light brown colour. Iron can give water a metallic taste that may be considered unpalatable and odours that are undesirable for domestic use. In industrial applications iron deposits build up in pipelines, pressure tanks, water heaters and water softening equipment. These deposits restrict the flow of water and reduce water pressure. More energy is required to pump water through clogged pipes and to heat water if heating rods are coated with mineral deposits. This raises energy and water costs. Also it limits the effectiveness of any appliance that uses water, like water heater, and shortens major appliance lifespan and costs one money in the form of higher utilities. While none of these effects are hazardous to humans, water processing or the environment, they cause consumers to spend more money to clean and maintain appliances every year.

Water contaminated with iron often contains iron bacteria. Iron bacteria is a term applied to a group of small organisms which appear to convert ferrous iron to the ferric state as part of their metabolism. These microorganisms combine dissolved iron with oxygen and use it to form rust-colored deposits. In the process, the bacteria produce a reddish-brown slime that builds up on well screens, pipes, inner walls of toilet tank and plumbing fixtures hence leading to clogging of the water systems. Iron bacteria in wells do not cause health problems, but they can have the following unpleasant and possibly expensive effects; cause odors, corrode plumbing equipment, reduce well yields (clog screens and pipes) and increase chances of sulfur bacteria infestation. These bacteria feed on the minerals in the water. Iron bacteria are most commonly problematic in wells, where water has not been chlorinated.

1.2 Problem statement

The problem of iron in water affects a large population in Kenya. This is because many people are tending to use borehole water, which is considered to be relatively easily available and free from pathogenic contamination for both domestic and industrial purposes. The high concentration of iron in well water leads to clogging of wells, shortened lifespan of major appliances and more energy requirement for pumping water through clogged pipes and for heating water in industries. Consumers are therefore forced to spend more money to clean and maintain appliances every year. In the process of cleaning and maintaining homes or factories, people quite often use cleaning solutions that may be toxic or hazardous to them and the environment at a substantial expense. It is hence more practical and economical to remove the iron from the water supply before it is distributed rather than to deal with the effects of clear and red water iron. Therefore, there is need to carry out a study which endeavours to alleviate the problem of high iron concentration in water supply system hence reducing the cost consumers spend to clean and maintain appliances.

1.3 Project objective

The overall aim of this project is to investigate the concentration of iron in boreholes in Kiambu town and evaluate chlorination method of iron removal.

The specific objectives are to;

a) Establish iron concentration in the borehole water.
b) Evaluate the use of chlorine as a treatment method for removal of iron in the borehole water.
c) Investigate the effect of detention time on iron concentration.

1.4 Project Scope

The study involved identifying a borehole which contains high amounts of iron within the study area. The sampling area is as shown in figure 1.1 below. To ascertain the levels of iron concentration in the water, two samples were taken from the borehole for laboratory analysis.

Testing and analysis of the borehole water was carried out to determine the concentration of iron present in the water. The water was also tested for pH, temperature, conductivity and dissolved oxygen. The removal of iron was then carried out using chlorination method after establishing the water quality. A bench test was carried out to determine the chlorine dosage for that particular borehole. A laboratory test was then carried out to investigate the effect of detention time on iron concentration.

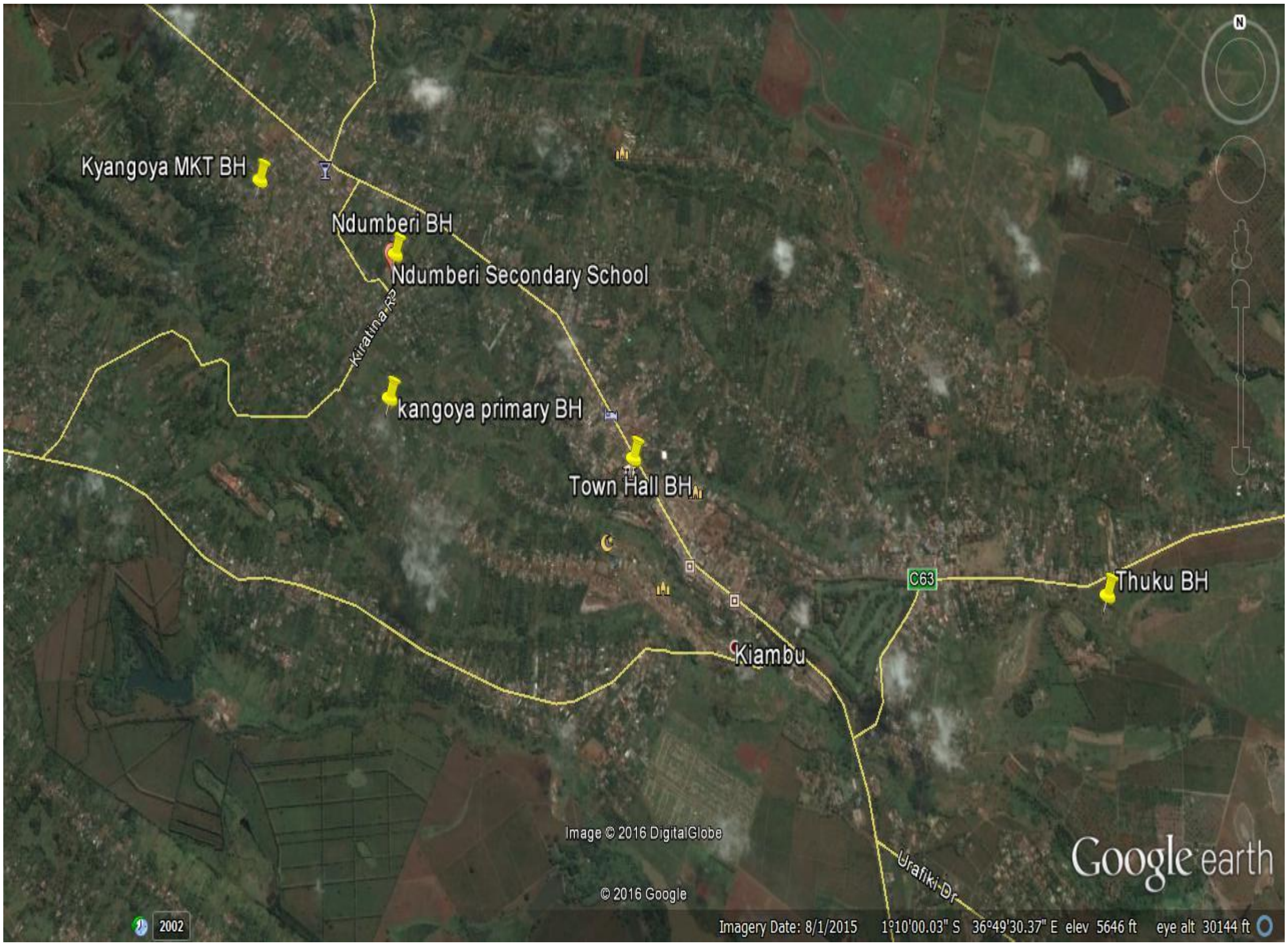

Figure 1.1: Google earth image showing the sampling area

CHAPTER TWO

2 LITERATURE REVIEW

This chapter gives a perspective of iron in water supply systems. The chapter presents an overview of iron in water, treatment methods for iron removal, theory and literature specific to the study topic, and contribution to literature.

2.1 IRON IN DRINKING WATER

The element iron (Fe) is one of the most abundant constituent of the rocks and soils (Hem, 1985). Iron is present in practically all soils, gravels, sand and rocks, sometimes in considerable amount, but often only in small traces. It is usually found in the form of oxides, common varieties of which include red haematite, ferric oxide,Fe_2O_3, brown haematite, hydrated iron oxide, $Fe_2O_3.nH_2O$, and magnetic oxide of iron, Fe_3O_2. Other forms are ferrous carbonate, $FeCO_3$and the sulphide,FeS_3, known as iron pyrites (Thresh et al., 1958).It often exists in insoluble form in groundwater supplies and may be carried along in surface water. Most areas derive their water from groundwater, surface water and rainfall. The type of source will depend on the topography of the area, the reliability and abundance (Huda, 1995). Groundwater serves the great majority of people who live in rural areas since among the various sources of supply, groundwater is considered to be unpolluted. Nevertheless, high concentrations of iron in groundwater can be inconvenient and make the water unsuitable for drinking. The importance of determining the amount of iron when evaluating the usability of a water for domestic and industrial purposes has led to the inclusion of an iron determination in all complete water analysis, even though the amount present maybe a very small part of the total dissolved solids.

Iron is typically present in well water in three common forms. While there are other forms of iron in well water, they are typically much less common than the three listed below. They are as follows;

a) Bacterial iron in well water

Iron bacteria is usually identified by slime in places such as toilet reservoirs or by the presence of a slimy mass fouling softeners or filters.

b) Ferric iron in well water

Ferric iron is also known as red water iron. Ferric iron in well water is essentially clear water iron that has been exposed to oxygen usually from the air, thereby oxidizing. Carbon dioxide leaves the water and the oxygen combines with the iron to form ferric ions (Fe^{3+}). This gives the water a red rust coloring.

c) Ferrous iron in well water

Ferrous iron is often called clear water iron because it is clear when poured. Ferrous iron is found in water that contains no oxygen. Typically, it comes from deeper wells and groundwater sources. Carbon dioxide acts on iron in the ground to form soluble ferrous bicarbonate. In water this forms ferrous ions (Fe^{2+}).

The WHO recommends concentration of 0.3 mg/L for ferrous iron and 1.0 mg/L for total iron. Iron concentrations higher than the WHO recommendation are responsible for causing the reddish brownish colour to the water, staining laundry and giving the water some sour taste but do not present any health hazard.

2.1.1 Disadvantages of iron in water

Water containing high concentrations of iron is objectionable owing to the production of discolorations, turbidity, deposit and taste. Ferruginous waters have an unpleasant metallic flavor or bitter taste. The water may react with tannins in coffee, tea and other beverages to produce a black sludge. Water in wells may similarly acquire an inky colour owing to the combination of iron and tannin derived from trees, particularly oaks (Thresh et al., 1958)

Even small traces of iron in water lead to accumulation of appreciable deposits in distribution mains and reservoirs, and these often prove troublesome to water authority and consumers hence the need for periodical main-flushing (Thresh et al., 1958). The presence of much loosely adherent rust in mains leads to the supply of ferruginous water to the consumers, with the usual complaints of discolorations, turbidity, deposit and impaired palatability .These complaints may be intermitted and arise when changes occur in the velocity, pressure or direction of flow of the water in the mains. Under such conditions, growths of iron bacteria often develop in the distribution system, when difficulties such as blocking of mains, meters and pipes are accentuated, and complaints of discolored, turbid and unpalatable water become more serious. Hydrogen sulphide and iron sulphide may also be produced, when the water drawn from taps emits an offensive odour, which consumers often associate with sewage. Water containing iron is also not suitable for many industrial purposes such as paper-making, dyeing, photographic film manufacture and ice-making.

2.1.2 Advantages of iron in water

Iron is used as construction material, inter alia for drinking-water pipes. Iron oxides are used as pigments in paints and plastics. Other compounds are used as food colors and for the treatment of iron deficiency in humans. Various iron salts are used as coagulants in water treatment.

In the right concentration in water, it is essential for the nutrition and healthy development of most plants and animals. It is possible that drinking water that is high in iron may be beneficial, as it adds small amounts of iron to diet. However, while drinking water that contains iron may help mediate iron deficiency symptoms, it should not be depended on solely as the only source of iron in diet.

2.2 SOURCES OF IRON IN WELL WATER

The presence of iron in drinking water supplies maybe as a result of geological formations and the use of metallic pumping equipment for groundwater withdrawal

2.2.1 Influence of soil and bedrock on groundwater

The concentration of iron is mainly influenced by the chemical composition of the surrounding soil and bedrock. The presence of iron in groundwater is often attributed to the solution of rocks and minerals, chiefly oxides, sulphides, carbonates and silicates. Iron occurs in the silicate minerals of igneous rocks such as the pyroxenes, the amphiboles and the dark ferromagnesian micas. Iron also occurs in oxides such as magnetite (Fe_3O_4), hematite (Fe_2O_4) and limonite ($2Fe_2O_3.3H_2O$). The sulphide and carbonate minerals, pyrite (FeS_2) and siderite ($FeCO_3$) are also important sources of iron in water (Hem, 1985).

The water that soaks into the earth percolates through the upper layers of the geological strata and eventually recollects in porous ground strata known as zones of saturation. Wells are drilled into the earth until they reach these zones. As water percolates through the earth, it dissolves minerals that are in the soil such as iron, manganese, calcium and magnesium just to name a few. The kind and concentration of constituents depend upon various geological, geo-hydrological and physical factors of the aquifers (Huda, 1995). The quality and composition of the dissolved mineral in groundwater depend upon the type of rock or soil with which it has been in contact or through which it has percolated and the duration it has been in contact with these rocks. The quality of groundwater also varies from season to season (Huda, 1995). When the rainwater percolates deeper through the soil and bedrock a great improvement in the water quality occurs. Suspended particles are removed by filtration, organic substances are degraded and micro-organisms die due to lack of nutrients (Kapulu, 2013). Therefore, groundwater is likely to be a very clean alternative compared to other water sources such as surface water. However, dissolved mineral compounds are not removed, and actually the content of minerals can increase due to leaching of salts from the underground layers. Groundwater supplies may have a little iron or extremely high amounts of iron. Iron is considered to be one of the most unstable minerals in groundwater supply.

Rainwater absorbs organic matter when the water percolates through the layers of the soil. At a deeper level the organic matter is oxidized, which gives reducing characteristics to the water. When the water reaches sediments containing ferric iron (Fe3+), the ferric iron is reduced to ferrous iron (Fe2+) (Andersson & Johansson, 2002).

2.2.2 Corrosion of hand pump and casing

Corrosion is a natural process, which converts refined metal to their more stable oxide. It is the gradual destruction of materials by chemical reaction with their environment. Most metals occur in nature in the form of oxides that must be reduced to obtain the useful metals. Corrosion (the oxidation of metals) is simply the process by which the metals return to their natural state. Iron maybe added to the groundwater from contact with well casing, pump parts, piping, storage tanks, and other iron objects which maybe in contact with the water (Hem, 1985).

One can be able to determine if the iron in groundwater boreholes is from corrosion or something else by performing the pump test and measuring the iron content over time. The concentration of iron will decrease rapidly after a few minutes of continuous pumping if corrosion of pipes is the reason for high iron content in the water. The iron source can also be determined by replacing the casing with a corrosion resistant device and then measuring the iron content in the water.

Samples from wells should be taken as near as possible to the pump discharge, and should be taken from clear water delivered after the pumping equipment has been in operation long enough to remove water that might have been standing in the well in contact with the casing or pump, or the period since the well was previously pumped. For purposes of evaluation of a water source or various uses, the iron added to water through the rusting of well casing and other similar influences may be significant, but it is not of interest for geochemical interpretation and may lead to erroneous conclusions (Hem, 1985)

2.3 CHEMISTRY OF IRON IN NATURAL WATER

Iron occurs in water at two levels of oxidation, either as a bivalent ferrous iron (Fe2+) or as trivalent ferric ion (Fe3+). The chemical behaviour of the two forms is somewhat different, although both maybe present in the same solution under certain circumstances (Hem, 1985). Iron in water will tend to be in the ferrous state under reducing conditions. The exposure of water to air results to the oxidation of the unstable ferrous salts (ferrous bicarbonate) to ferric state (colloidal ferric hydroxide). The water thus becomes opalescent and discoloured, and a deposit finally forms which undergoes further oxidation. In the oxidation of ferrous bicarbonate, carbon dioxide is released and again becomes available for further iron dissolving action (Thresh et al., 1958). The reaction can be represented as follow;

$$4Fe(HCO_3)_2 + O_2 + 2H_2O = 4Fe(OH)_3 + 8CO_2$$

The oxidation reaction requires only one molecule of oxygen for each four molecule of ferric hydroxide produced. Some contact of natural water with oxygen before or during sampling is almost unavoidable. The precipitation of ferric hydroxide is commonly observed in stored sample bottles which contain water that has ferrous iron in solution. Some air space is usually left when the bottles are filled, and this reaction could result, from the small amount of air thus made available in the bottles.

An important principle about chemical reactions is that, if allowed enough time, they will reach equilibrium with the surrounding environment. When the conditions of that environment are changed, such as pumping water from an underground aquifer, the chemical equilibrium is upset. The change in chemical equilibrium will lead to either solution or precipitation of certain elements such as iron. A general rule of thumb is that oxygenated water will have only low levels of iron. The reason is that iron reacts with oxygen to form compounds that do not stay dissolved in water.

Conversion of iron to ferric state may have a marked effect on the pH. In the pH range of 6 to 8, the amount of ferric iron in solution is theoretically limited by the solubility of ferric hydroxide, about 4×10^{-10} to 5×10^{-6} mg of iron per liter (Hem, 1985). At a pH of 3, the solubility of ferric hydroxide is appreciable and increases rapidly as the pH decreases below 3. In natural waters the influence of other dissolved constituents or the formation of complex ions may cause considerable deviation from theoretical solubility's. In the presence of carbon dioxide, the solubility of ferrous ions is controlled by the solubility of ferrous carbonate and is greatly reduced but is still between 1 ppm and 10 ppm between pH 7 and 8, when 25 ppm of bicarbonate is present. Between pH 6 and 7 the solubility of ferrous iron may be much greater than 10 ppm even in the presence of more than 100pp of hydrogen carbonate. Hence, it can be stated that the reactions involved in waters containing ferrous and bicarbonate ions tend to lower the pH. Ferric ions in solution tend to enter into hydrolysis reactions that in effect remove $OH^-$and lower the pH. A solution containing large amounts of Fe^{3+} and SO_4^{2-} would have a pH well below 3. Ferrous ions may also enter into hydrolysis reaction to lower the pH. Probably the amount of ferrous iron that may dissolve from rocks also is determined by the reducing power of the environment of the water. Waters that are strongly acidic are usually more stable with respect to iron than those containing bicarbonate (Hem, 1985)

The chemistry of iron in natural water is further complicated by a tendency for the formation of complex ions, and is influenced by certain kinds of microorganisms. The activity of microorganisms in dissolving and precipitating iron from water may lead to the processes of oxidation and reduction of iron. Certain types of bacteria for example exist without oxygen and promote a highly reducing environment favorable for taking iron into solution in the ferrous state. Other bacteria may actually derive the energy for the life processes from oxidation of ferrous state to ferric state hence, aiding in production of ore deposits and removal ferrous iron in water (Nordell, 1961).

Waters which have been exposed to the atmosphere are frequently found to contain iron, part of which, is in solution and part in suspension hence being referred to as dissolved iron and total iron (Hem, 1985). Dissolved iron is the iron that appears to be in solution at the time the aliquot for the iron determination is withdrawn from the water sample in the laboratory. Total iron includes all the irons in the solutions, and that which has precipitated in the sample bottle. The dissolved iron determination often is not representative of the conditions existing in the sample at the time of collection, because by the time the iron determination is started there has being opportunity for oxidation of ferrous iron and precipitation of ferric hydroxide. In some instances, the oxidation and precipitation will be complete and in other instances there will partial, depending on the length of time the sample has been in storage, the opportunity which has been afforded for dissolved carbon dioxide to escape, and various other factors which are not usually controlled. Total iron values, on the other hand should represent more closely the actual concentration in the sample at the time of collection, but they will also include iron that was in suspension as well as what was in solution, unless the sample is filtered or otherwise, clarified When it is collected(Hem, 1985).when drawn from an underground source, the water may initially be clear and bright, but after a short period of time opalescence or deposit, due to oxidation of soluble salts to the insoluble form occurs thus by the time a sample is received in the laboratory for analysis, the iron which was originally in solution may entirely be precipitated.

Because of the possibilities of iron being in colloidal form and also being contaminated, it is not a good constituent on to which to base conclusion in the geochemical interpretation of water analyses. Presence of large amounts of iron in groundwater which can be definitely attributed to solution underground of ferrous iron, may have some significance in showing the minerals present in the aquifer and suggesting the chemical conditions under which the water existed in the aquifer (Hem, 1985).

2.4 TREATMENT METHODS FOR IRON REMOVAL

Problems attributed to iron can therefore be avoided by (Thresh et al., 1958):

a) Treatment of the water before distribution if it contains more traces of iron, or if it is unduly corrosive to metals
b) Protection of mains by bituminous linings, or the use of specially selected mains, such as asbestos-cement tubes
c) Avoidance of dead end mains
d) Avoidance of disturbances in mains
e) Periodical flushing of mains

A decision as to the methods of treatment to be employed is influenced by the state of combination in which the metals are contained in the water, and the character of the water in respect of its gaseous, mineral, organic and biological constituents (Hem, 1985). Each case must be individually considered, adequate analyses made, and experimental treatment carried out before the most suitable method can be decided. The possible presence of manganese in association with iron must be ascertained because it demands special measures for its removal. Manganese is not oxidized and precipitated as readily as iron therefore, if suitable precautions are not observed the treatment may remove the iron, but allow the manganese to remain in the water and produce discoloration in the water and deposit in mains and reservoirs

Iron can be removed from source water by several technologies; for example, aeration, water softener, oxidizing filter, chlorination and filtration. The traditional removal method for iron from groundwater involves aeration or precipitation by oxidation and removal of free carbon dioxide, followed by separation of the suspension by sedimentation and/or filtration. This method is based on accelerating the rate of oxidation. When the Fe^{2+}ion gets in contact with oxygen, Fe^{3+}ion is formed and iron oxide or iron hydroxide precipitates. The oxidation step is usually followed by detention (contact time) and filtration (Hoffman *et al*., 2006). Detention and/or filtration are applied for the solid/liquid separation. Detention provides the time for the precipitation of iron, and in addition, effects some iron removal by settling. If the total iron concentration is high, sedimentation tanks with sludge collection and removal facilities are used instead of a simple detention tank. Filtration is relied upon to remove the rest of the iron. Filtration options consist of sand (only), anthracite and sand (dual media), manganese greensand, and various synthetic filtration media (Hoffman *et al*., 2006). This method works very well for amounts of iron < 5 mg/L and where there is no organic matter in the water

2.4.1 Polyphosphate treatment

Preventive measures may sometimes be used with reasonable success. Polyphosphates do not remove iron from water. Rather they stabilize and disperse the iron so that the water remains clear and does not produce iron stains. Addition of sodium hexametaphosphate on well waters before the oxygen of the air has had an opportunity of converting ferrous iron to the ferric state helps keep the metal ions in suspension hence moving through the system without creating accumulations that periodically cause badly discolored water (Sittig, 1973). Polyphosphates react with dissolved iron by trapping them in a complex molecule that is soluble in water. Polyphosphates can be fed into the water system with controlled injection equipment. Polyphosphate treatment is a relatively cheap way to treat water for low levels of iron. However, the preventive treatment has the following disadvantages;

1) Relatively large concentrations of the agent may be required up to four times the iron content of the water,
2) Its use should be limited to waters having an iron content of less than 1 milligram per litre (Thresh et al., 1958).
3) Such treatment must be applied with caution because over-dosing will detach pre-existing deposits and cause more serious blocking of mains and meter boxes than were experienced with the rusty water itself prior to the introduction of this form of treatment.
4) Polyphosphates are not stable at high temperatures. If water is treated prior to heating in a water heater, the polyphosphates will release iron in the heater as they break down. The released iron will then react with oxygen and precipitate. The boiling causes reversion of polyphosphate to the orthophosphate which has no equivalent sequestering action.

Polyphosphate treatment is not suited for treatment of iron in municipal supplies at the point of use. This is because such iron may be partially or completely precipitated and insoluble before it enters the home. Polyphosphates are not effective in the control of precipitated iron, organic iron, or iron bacteria. Therefore, the only permanent solution to iron problems is removal by treatment of water.

2.4.2 Aeration, Sedimentation and Filtration

The simplest form of iron oxidation in treatment of well water is plain aeration (Sittig, 1973). A typical tray-type aerator has a vertical riser pipe that distributes water on top of a series of trays from which it then drips and platters down through the stack. The trays frequently contain coke or stone contact beds that develop and support oxide coatings that speed up the oxidation reaction by reducing the free carbon dioxide by 90 percent (Sittig, 1973). The type of aeration equipment mostly used in iron removal is the coke-tray type aerator. To a lesser extent, wood-slat aerators have been employed. Rectangular, wood forced-draught aerator, with one removable side for cleaning out growths is sometimes used for this purpose. Pressure aerators are also employed, but since they do not reduce the free carbon dioxide content of the water, they are used only in special cases. The open aerators have the advantage of reducing the free carbon dioxide content of the water, which simultaneously raises its pH (Nordell, 1961).

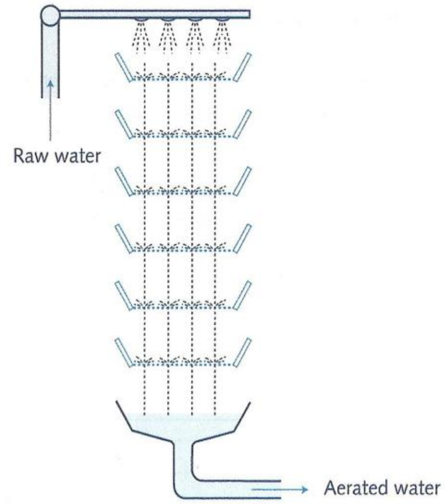

Figure 2.1: Multiple-tray aerator (Source: Ken Ives)

Open aeration in which water is projected, splashed or sprayed in the atmosphere, is a simple and economical process in which free carbon dioxide is dissipated, and iron is oxidized and precipitated from solution. Free carbon dioxide should be reduced to less than 10 mg/L to remove any corrosive tendencies by the constituent. Aeration also dissipates hydrogen sulphide which is not infrequently present in ferruginous waters (Sittig, 1973). Aeration may not suffice to obtain adequate removal of free carbon dioxide and precipitation of iron, and its seldom effective when manganese is also present in the water.

High iron concentrations could require a sedimentation step before filtration due to the high content of precipitates that will rapidly clog the filter. Sedimentation is frequently used in water treatment for elimination of suspended particles with a higher density than water. The particles accumulate at the bottom of this sedimentation tank and the clear water in the upper part of the tank is decanted to a filter.

Sedimentation is then followed immediately by filtration which provides sufficient treatment. Rapid or mechanical filters are usually employed in such cases and the filters often contain special iron removing media such as polarite, birm, or selected zeolite sands, in addition to ordinary filter sand (Nordell, 1961). In certain instances, the use of slow sand filters is justified and yield satisfactory results, but they cannot be effectively used for removal of large amounts of iron from waters, owing to rapid clogging (Sittig, 1973). Sedimentation in tanks followed by rapid filtration is required in such cases.

Removal of iron from groundwater by oxidation, precipitation and filtration through a slow sand filter generally does not need other chemical pre-treatment (Pontius,1990). The removal mechanisms in slow sand filters are both physical and biological. Reduction in organic constituents and chemical transformations, such as oxidation of ammonia and nitrate, are caused by micro-organisms in the filter (Pontius, 1990). For removal of iron there are some bacteria that are able to derive energy from the oxidation of ferrous iron into ferric iron, whilst others seem to oxidize and store the iron for no clear purpose (Tyrrel *et al.*, 1998). When treating water from boreholes, the bacteria responsible for the process appear to be natural in the well environment. Therefore, the micro-organisms necessary to initiate the process are carried with the groundwater onto the filters. The bacteria start to grow when the concentration of ferrous iron approaches 0.3 mg/l. The population of iron-reducing bacteria requires oxygen for its growth and tends to grow on the surface of the filter-bed and form a slimy orange mat (Tyrrel *et al.*, 1998). After running a filter for about 7-10 days this film is developed and the bacteria starts to oxidise the reduced iron compounds. This oxidation process carries on as long as the bacteria film is intact and no cleaning of the filter has been done

When it is required to remove only small traces of iron, and when experiments have shown that these are readily precipitated from the water, rapid sand filters can be inserted in a pressure system. It is possible in such cases to inject air to assist in the precipitation of the iron prior to filtration of the water (Hem, 1985).

2.4.3 Chemical treatment

2.4.3.1 Chemical oxidation, sedimentation and filtration

Chemical oxidation is the common method for removing iron from well water without softening treatment. High levels of dissolved or oxidized iron and manganese (combined concentrations of up to 25 mg/L) can be treated by chemical oxidation. This method is particularly helpful when iron is combined with organic matter or when iron/manganese bacteria are present (Hem, 1985).

The system consists of a small pump that puts an oxidizing chemical into the water while it is still in the well or just before it enters a storage tank. This pump operates whenever the well pump operates. The oxidizing chemical may be chlorine, potassium permanganate or hydrogen peroxide. The specific dosage requirement depends on the concentration of metal ions, pH and mixing conditions. The chemical must be in the water for at least 20 minutes for oxidation to take place, longer if the water contains colloidal iron. After solid particles have formed they are filtered, often with a sand filter. Adding aluminum sulfate (alum) improves filtration by causing larger particles to form.

A chlorine solution is injected with a chemical feed pump ahead of a sand filter. Soluble iron begins to precipitate almost immediately after contact with the chlorine solution. However, approximately 20 minutes of contact time is needed for the precipitate to form particles that can be filtered. When chlorine is used as the oxidizing agent, excess chlorine remains in the treated water. If the particle filter is made of calcite, sand, anthracite or aluminum silicate, a minimum amount of chlorine should be used to avoid the unpleasant taste that results from excess chlorine. An activated carbon filter will remove excess chlorine, as well as small quantities of iron particles. Chlorine oxidizes iron best at a pH of 6.5 to 7.5. An additional advantage of using the chlorination system is its bactericidal effect. Iron and manganese bacteria along with other bacteria, are destroyed. Potential clogging problems in the sand filter are eliminated. Chlorine should not be used for high levels of manganese because manganese requires a pH higher than 9.5 for complete oxidation. The chemical reaction for the oxidation of iron with chlorine is as follows;

$$2Fe(HCO_3)_2 + Cl_2 + Ca(HCO_3)_2 = 2Fe(OH)_2 + CaCl_2 + 6CO_2$$

Potassium permanganate is more effective than chlorine for oxidizing manganese at pH levels higher than 7.5. Potassium permanganate is poisonous and a skin irritant. There must be no excess potassium permanganate in treated water and the concentrated chemical must be stored in its original container away from children and animals. Using this chemical requires careful calibration, maintenance and monitoring. Theoretically, 1mg/l of potassium permanganate oxidizes 1.06mg/l of iron (Sittig, 1973). In practice the amount needed is often less than this theoretical requirement.

$$Fe^{2+} + Mn^{2+} + Oxygen = FeO_2 + MnO_2$$

$$Fe(HCO_3)_2 + KMnO_4 = Fe(OH)_3 + MnO_2$$

$$Mn(HCO_3)_2 + KMnO_4 = MnO_2$$

Effective filtration following chemical oxidation is essential, since a significant amount of the flocculent metal oxides are not heavy enough to settle by gravity. Iron carried over to the filter, coat the medium with oxides that enhance filtration removal (Sittig, 1973).

2.4.3.2 Lime-soda Water softening process

Lime is the most efficient and economical chemical for use in the removal of free carbon dioxide, iron and manganese particularly when preceded by aeration. It should be applied in such dose that the final pH of the water, after settlement and filtration, is in the 7.5 to 8.5 range, and thorough mixing of the lime and water should take place (Hem, 1985). Ferrous bicarbonate maybe removed by any of the cold-lime or lime soda water softening processes or by the hot lime water softening process by oxidizing the iron, usually by aeration, so that it will precipitate in the sludge as ferric hydroxide. Since the hot lime-soda water-softening process is used exclusively for boiler feed purposes, a small amount of ferrous bicarbonate in the water is of value as it ensures absence of dissolved oxygen in the treated water. In the cold lime-soda processes, the aeration is usually performed in an open type aerator mounted above the softener (Nordell, 1961).

Chlorination can be employed to control growths of iron bacteria in the treatment plant, if these prove troublesome but such difficulties are usually avoided if the lime dosage is maintained at a sufficiently high level. The supernatant water runoff from the sedimentation tanks to the filters should be almost clear, since good chemical treatment and sedimentation yield the best filtration results in respect for the quality of the final water and operation economy.

Shock treatment is the most common method of killing bacteria and chlorine is the chemical most often used in this process. It is almost impossible to kill all the iron and manganese bacteria in a system, hence the need to repeat the shock chlorination treatment when the bacteria grow back. If repeated treatments become too time consuming, it can be more efficient to install a continuous application system that injects low levels of liquid chlorine or drops chlorine pellets into the well automatically. Chlorine rapidly changes dissolved iron to solid iron that will precipitate. Therefore, a filter may be needed to remove particles if a continuous chlorination system is used

Because it is difficult to get rid of iron bacteria once they exist in well systems, prevention is the best safeguard against accompanying problems. For well drillers, prevention means disinfecting everything that goes into the ground with a strong (250 ppm) chlorine solution. Iron bacteria are nourished by carbon and other organics, and it is essential that these are not introduced into any part of the well system during the drilling process. Tools, pumps, pipe, gravel pack material, and even the water used in drilling should be disinfected. Use of a tank that circulates chlorinated water instead of digging a mud pit will help avoid contamination from soil. When the well is completed, it should be purged, shock chlorinated (using 1000 ppm solution), and then pumped.

The removal of an existing growth from tanks and mains can be effected mechanically by scraping and vigorous washing, followed by heavy chlorination. The affected tanks or mains, after flushing should be filled with chlorination water having a residual chlorine content of 10 mg/l, allowed to stand for twenty-four hours and then flushed to waste. In raw water tanks and pipelines, the development of growths can be restrained by regular chlorination in such a dose that the water flowing through the parts retains approximately 0.5mg/l of chlorine

The best line of defense against growths of iron bacteria is the proper purification of the water before distribution to the consumers (Sittig, 1973). If free carbon dioxide, iron or organic matter are present, and oxygen deficient appropriate treatment should be applied as follows

1. Aeration to remove free carbon dioxide, introduce oxygen and precipitate iron. Chlorine may be of use here.
2. The addition of lime to remove carbon dioxide, to precipitate iron and to increase alkalinity and pH.
3. Sedimentation in tanks, and filtration to remove the precipitated iron together with the organic matter

2.4.3.3 Zeolite water-softening process

With clear deep well water containing ferrous bicarbonate, the iron may be removed simultaneously with the hardness, by the zeolite water softening process (Nordell, 1961). The zeolite recommended for simultaneous softening of the water and removal of the iron are either of the greensand, carbonaceous or synthetic resin types (Nordell, 1961). Manganese zeolite is a natural greensand coated with manganese dioxide that removes soluble iron from solution. After the zeolite becomes saturated with metal ions, it is regenerated using potassium permanganate.

Permanganate solution is applied to the water ahead of a pressure filter that contains a dual-media anthracite and manganese zeolite bed. The iron oxidized by the permanganate feed is removed by the upper filter layer. Any irons not oxidized are captured by the underlying manganese zeolite layer. If surplus permanganate is inadvertently applied to the water it passes through the coal medium and regenerates the greensand. When the bed becomes saturated with metal oxides, it is backwashed to remove particulate matter from the surface layer and to regenerate the zeolite with potassium permanganate (Sittig, 1973).

In the removal of iron by the zeolite process, the raw water should not come in contact with air, for this would precipitate ferric hydroxide on and in the zeolite bed. Therefore, if the iron bearing water is not clear and free from suspended ferric hydroxide, it should be filtered before reaching the zeolite units. In this respect, the carbonaceous type of cation exchange has one advantage over the green sand zeolite: namely, If some aeration of water as inadvertently taken place and the bed gets fouled with ferric hydroxide, inhibited hydrochloric acid can be used to clean the carbonaceous cation exchanger without harming it, whereas the greensand zeolite cannot be cleaned, without injuring, with mineral acid of sufficient strength to dissolve ferric hydroxide (Nordell, 1961)

Carbonaceous zeolite can be successfully used for the simultaneous softening of water and removal of traces of dissolved iron. Small carbon or silico-carbon, tap or domestic filters can be obtained for household use to remove iron from water. They should be thoroughly cleaned at intervals in order to maintain their efficiency (Hem, 1985)

2.4.4 Iron Removal with Water Softeners

Water softeners can remove dissolved ferrous iron by ion exchange, just as they remove calcium and magnesium. Ion exchange relies on the ability of softening resin to attract iron ions as well as hardness ions like calcium and magnesium. Iron is removed during normal operation of the water softener. The iron is later removed from the exchange medium along with calcium and magnesium during regeneration and backwashing. Removing ferrous iron in a softener can be an effective and economical way of treating iron problems. However, there are limitations on the amount of iron that can be removed. Some water softeners are capable of adequately treating water having iron up to 10 ppm. However, others are limited to treating water with iron no greater than 1 ppm. The unit needs to be specially designed if more than a couple parts per million of iron are in the water.

Because the resin so strongly selects for the iron, it is harder for the sodium regenerant to knock the iron off the resin. It is important to have an effective backwash to clean the resin and prevent channeling. An under-bed and perhaps even a turbulator will assist in this. Any ferric iron in the water will foul the resin. Unlike iron oxidized by air that forms the familiar dry rust, ferrous iron oxidized in water first forms ferric ions. These in turn combine with free hydroxyl ions in the well water to produce ferric hydroxide, which will pass straight through the softener and into service and cause staining. Even worse, ferric hydroxide is a sticky gelatinous substance that will clog the resin and coat it when coagulated. Over time, the softener ceases to function effectively on either iron or hardness. At higher pH levels the softener will be ineffective. At low pH levels it is hard to precipitate iron from water. When the pH is above neutral it is much harder to keep the iron in the water dissolved. When the water's pH rises above 7.2 to 7.3, the softener's ability to grab iron from the water becomes increasingly limited. Despite these limitations, softeners perform well in removing small quantities of clear water iron.

One of the disadvantages of depending on ion exchange for iron removal is precipitation by oxygen. Some of the precipitate becomes tightly bound to the exchange resin and over time reduces the exchange capacity by plugging pores and blocking exchange sites. If iron bacteria are present, the problem is even worse. Also, if suspended particles of insoluble forms of iron are present in the water prior to softening, they will be filtered out on the resin and cause plugging. Suspended iron should be filtered out before water enters the softener.

A clogged water softener can be cleaned by acid regeneration if the unit is made to withstand acid corrosion. The manufacturer should be consulted before this is attempted. Problem iron bacteria can be eliminated by chlorinating and filtering the water at some point before it reaches the softener. As long as levels of iron in the water do not exceed the manufacturer's recommendations, iron clogging should not be a significant problem. When iron levels are higher than recommended by the manufacturer, iron removal will be necessary prior to softening.

Many factors affect the ability of softeners to remove iron successfully; the form of iron and its concentration, softener design, the presence or absence of organic matter and dissolved oxygen, cleaning procedures, regeneration frequency, pH, and temperature and usage characteristics

Summary of treatment methods for iron;

1. Polyphosphate Effective for 0-3 ppm.
2. Ion Exchange softener ………………Effective for 0-10 ppm
3. Lime-soda or zeolite water softening process using Greensand Filter ……. Effective for 0-10 ppm
4. Chemical oxidation using chlorine, sedimentation and filtration Effective for 0->25ppm.

CHAPTER THREE

3 METHODOLOGY

This chapter describes the methods used to achieve the objectives. It also gives an overview of the study area. The study was conducted for boreholes in Kiambu Town.

3.1 Description of the study Area

Kiambu Town is the headquarters and the capital of Kiambu County located North East of Nairobi City at 1° 10' 0" S, 36° 50' 0" E, and about 1,720 m above sea level. Kiambu Town is 13 km from Nairobi city. The town has an urban population of 88869.Apart from central Kiambu; there are villages such as Ndumberi, Riabai, Kihingo, Ngegu, Kanunga and Kangoya among others which are part of the Kiambu Town. The town is surrounded by hilly Kikuyu farmland although is under urbanization as Nairobi is growing fast and more people settle in neighboring towns. Kiambu is seen as a future anchor to the capital city Nairobi which is undergoing rapid development with limited space for growth. Kiambu town is now a favoured location for real estate development as a lot of structures are coming up for residential and commercial purposes.

Kiambu Water and Sewerage Company is a Water Service Provider operating within Kiambu Town, under a Service Provision Agreement with Athi Water Services. Its mandate is to ensure efficient and economical provision of water and sewerage services within Kiambu Town. In order to achieve its objectives of provision of quality water it has drilled some boreholes within the municipality which act as the source of their water as shown in Table 3.1.

Table 3.1: Boreholes in Kiambu Town

No.	Water sources	Year drilled	Total depth h (m)	Yield (m^3/hr.)
1	BH 1&2C 263 & C460	1940	140	-
2	BH3 C2057	1953	147	20
3	BH4 C2819	1971	236	8
4	BH5 C3875	1971	165.5	9
5	BH6 C3892	1973	170	17
6	Thuku BH C6708	1986	-	72
7	Town Hall BH C11597	1997	207	18
8	Waithaka BH	2006	-	14
9	Kangoya Pry BH C11271	1996	175	3
10	Ndumberi BH C11270	1996	202	2.5
11	Kangoya MKT BH C12816	2000	223	9
Total				172.5

Permission for taking the samples from boreholes was first obtained from the Kiambu Water and Sewerage Company. The Company personnel assisted in identifying the one which had high concentrations of iron from their borehole data. From the 11 boreholes Thuku borehole was identified for sampling. The sampling station is as shown in figure 3.1. below.

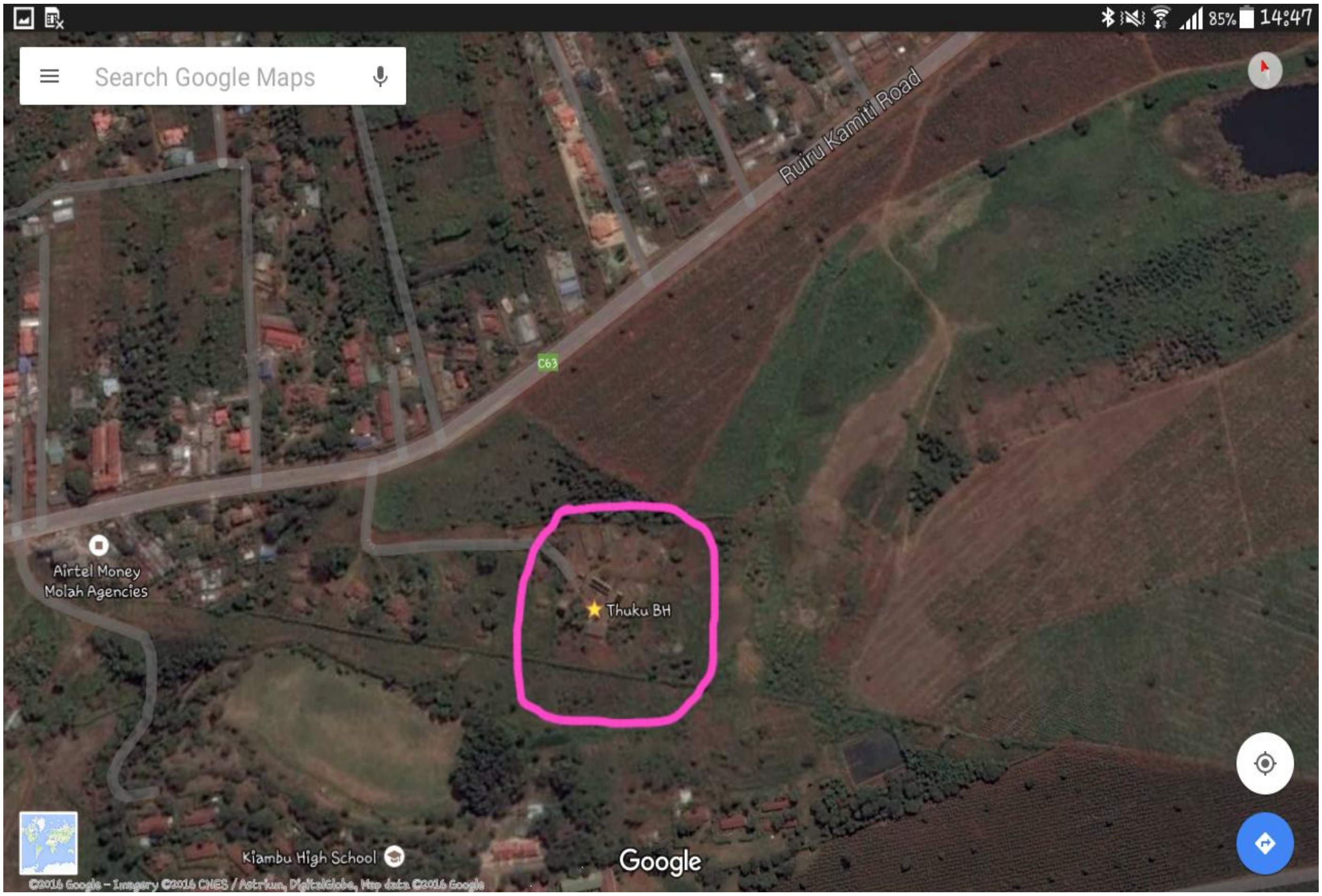

Figure 3.1: A Google earth image showing the sampling station

3.2 Sampling

The water was being pumped continuously from the borehole hence the assumption that the pipe materials had not affected the sampled water. Two samples were taken and put in clean labeled 10litre bottles for easy identification. To stabilize the pH and thereby to prevent iron from precipitation before analyses in the laboratory, 1-2 ml of nitric acid was added to the sample. The sample bottles were then sealed with clean corks.

The pH, temperature, conductivity and dissolved oxygen of the water sample was not taken immediately in the field as it is supposed to because there was no Public Health Laboratory within the locality. The working principle assumed that none of the ferrous ion in the water sample was oxidized to ferric ion and other insoluble compounds before analysis in the laboratory. The samples were observed for any colour visible to the naked eye and recorded.

The water samples were transported to the University of Nairobi, Public Health Engineering Laboratory where the temperature, conductivity, dissolved oxygen and iron tests were carried out on the same day to avoid oxidation of the water samples.

3.3 Laboratory analysis

Laboratory tests were carried out at Public Health Engineering laboratory at the University of Nairobi for each of the sample obtained in accordance to the Standard Methods for the Examination of Water and Wastewater (APHA, 2005). The tests were restricted to those which had effect on the solubility of iron in the borehole water. The tests conducted included;

a) pH
b) conductivity
c) Temperature
d) Colour
e) Dissolved oxygen
f) Iron(Fe)

The testing procedure for dissolved oxygen, colour and pH was conducted using the standard methods as described in Appendix 2

The testing procedure for iron was conducted using the standard method as given in the Standard Methods of the Examination of water and wastewater (APHA) as described in Appendix 2. The test results were then compared to the WHO standard value of 0.3 mg/l and the Kenya Water Quality Regulations Standards (KEBS). The iron was found to be in excess of 0.3mg/l in the samples. Therefore, chlorination method of iron removal was evaluated for the removal of the iron to the required standard.

3.4 Chlorination (oxidation) and filtration/settling treatment for the iron

For removal of iron from the water sample, chlorine solution was added so as to oxidise the iron. The amount of chlorine used and contact time was determined by simple bench or jar tests. Five, 1,000 mL graduated jar test beakers were filled with equal amounts of the sample water. Using a prepared chlorine solution each beaker was dozed with increasing amounts of solution. The stock solution was prepared by dissolving 1 grams of chlorine into 1,000 mL of distilled water. Each 1.0 mL of this stock solution was equal to 1 mg/L when added to 1,000 mL of the sample water. The pH of the samples was first checked before adding chlorine since chlorine oxidizes iron best at a pH of 6.5 to 7.5 to ensure the sample pH was in that range. After dosing each beaker, the samples were then mixed at 150 r.p.m for one minute then followed by 40 r.p.m for 15 minutes and left to stand. Soluble iron began to precipitate almost immediately after contact with the chlorine solution. It was observed that the higher the amount of chlorine fed, the more rapid the reaction was. Approximately 20 minutes of contact time was needed for the oxidation process to occur and full sedimentation of iron particles to take place. A residual chlorine test was then carried out to determine the amount of chlorine which had oxidized the iron in each beaker.

When chlorine is used as the oxidizing agent, excess chlorine remains in the treated water resulting in unpleasant taste. Therefore, to determine the appropriate dosage of chlorine for optimum oxidation of iron, a residual chlorine test was carried out. The beaker in which the amount of residual chlorine in the water sample was within the WHO limit of 5 mg/l was selected to be the most appropriate dosage of chlorine for removal of iron. The treated water sample was then tested for iron using the method described in Appendix 2. The test results before and after treatment were then compared to know the percentage of iron removed using the chlorination method.

3.5 Effect of detention time on iron concentration

After determining the chlorine dosage for the borehole water, 6 different jars were filled with the water sample and given a chlorine dosage of 2 mg/l at the same time. They were then mixed thoroughly and allowed for different contact times. After the first 10minutes the Jar No 1 was taken and the water sample tested for iron concentration. After 20 minutes the Jar No 2 was taken and the water sample tested for iron concentration. The trend continued for jar No 3,4,5,6 which were tested for iron after 30, 40, 50 and 60 minutes respectively. The results were then recorded.

CHAPTER FOUR

4 RESULTS AND DISCUSSION

4.1 Results from water analysis

The summary of the results obtained from the iron, pH, temperature, D.O, Conductivity and colour laboratory tests are shown in Table 4.1.and Table 4.2.

Table 4.1: Results of Thuku BH water tests and WHO guidelines

PARAMETER	UNITS	THUKU BH SAMPLE	WHO STANDARDS
Iron.	mg/l	0.6	MAX 0.3
pH	pH scale	6.7	6.5-8.5
Temperature	℃	23.8	–
D.O	Mg/l	3.45	>4
Conductivity	$\mu S/cm$	155	MAX 2500
Colour	Degrees Hazel	5	MAX 15

Table 4.2: Results of tests of treated water samples

PARAMETER	UNITS	TREATED WATER SAMPLE	WHO STANDARDS
Iron.	mg/l	0.2	MAX 0.3
pH	pH scale	7.4	6.5-8.5
Temperature	℃	24	–
D.O	Mg/l	4.74	>4
Conductivity	$\mu S/cm$	90	MAX 2500
Colour	Degrees Hazel	5	MAX 15

The water sample from Thuku BH was observed to be clear in appearance but on arrival in the laboratory it had turned to light brown in colour. The colour change may have been as a result of oxidation of some of the iron in the samples since it was impossible to fill the 10litre bottle without leaving some air space. Additionally, contact of the sample water with oxygen before or during sampling is almost unavoidable. Therefore, the oxygen may have oxidized the iron in the water sample causing the change of colour.

The concentration of iron in the raw water sample was found to be 0.6 mg/l. These concentration was much less than the amount of iron Kiambu Water and Sewerage Company found in their tests. The difference in concentration may have been because of oxidation of some iron in the raw water by oxygen in the process of transportation and handling of the water sample.

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4.1.1 Iron.

The iron concentration in the raw water of 0.6 mg/l exceeded the recommended or acceptable limit for iron in drinking water set by WHO of 0.3 mg/l. Therefore, the water required treatment before supply to the public to avoid staining of laundry, utensils and plumbing fixtures.

After treatment of the water with chlorine, the iron concentration reduced to 0.2 mg/l, which was within the acceptable limit. The water was therefore safe for use for both domestic and commercial purposes. Figure 4.1 below illustrates the variation of the iron levels in the raw and treated water samples against the recommended WHO standard.

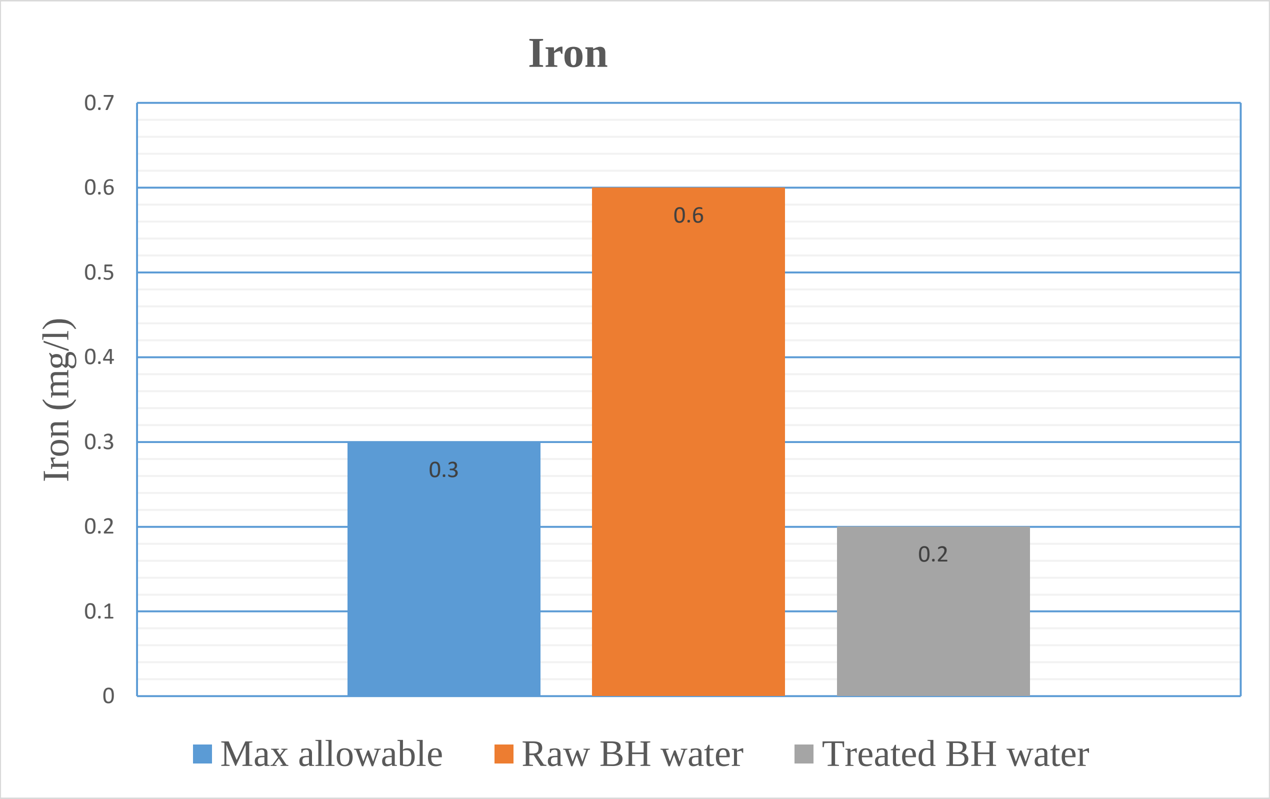

Figure 4.1: A chart showing variation of iron in the water sample

4.1.2 Conductivity

The maximum acceptable conductivity of water is 2500µS/cm as recommended by WHO. The conductivity of the raw borehole water sample was 155µS/cm while that of treated borehole water sample was 90µS/cm and hence both raw and treated water samples were within the acceptable range.

Conductivity is the ability of water to transmit electric or heat which is mainly the ionic activity within the water. Electrical Conductivity in the treated borehole water was slightly lower than the raw borehole water. The reduction in electrical conductivity was attributed to the removal of iron which constitutes part of the total dissolved solids hence the reduction in conductivity of the water therefore making the water safer for drinking.

Conductivity can be directly associated with the number of ions in a solution and hence it is higher in water with more total dissolved solids. Soil and rocks release dissolved solids into the waters that flow through or over them. Therefore, the geology of a certain area will determine the conductivity. Pure water is a poor conductor of electricity. Conductivity is also affected by temperature. The warmer the water, the higher the conductivity.

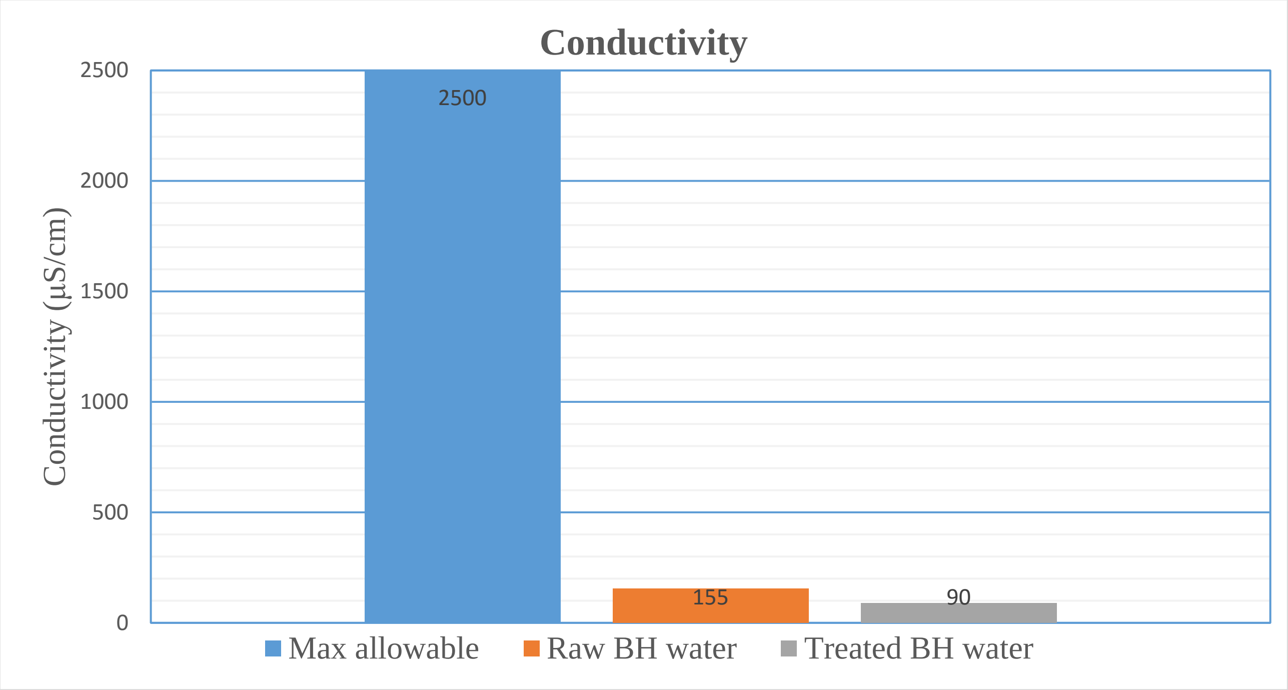

Figure 4.2:A chart showing variation of conductivity in the water samples

4.1.3 Dissolved oxygen

The dissolved oxygen of the raw borehole water was 3.45 mg/l while that of the treated borehole water was 4.74 mg/l. WHO recommends a dissolved oxygen concentration of greater than 4 mg/l for drinking water therefore the treated water was within the required limit. Dissolved Oxygen concentration greater than 4 mg/l makes drinking water taste better, however water with very high dissolved oxygen may cause corrosion of water pipes.

Oxygenated water will have only low levels of iron. The reason is that iron reacts with oxygen to form compounds that do not stay dissolved in water. The high concentration of iron in the raw water indicated that the amount of dissolved oxygen was low since oxygen oxidizes iron leading to its precipitation.

The amount of dissolved oxygen in the water sample increased on exposure to the air in the laboratory while carrying out the treatment works for the iron resulting to oxidation of some of the dissolved iron. Upon exposure to the atmosphere and removal of iron from the water samples, the amount of dissolved oxygen increased in the water sample.

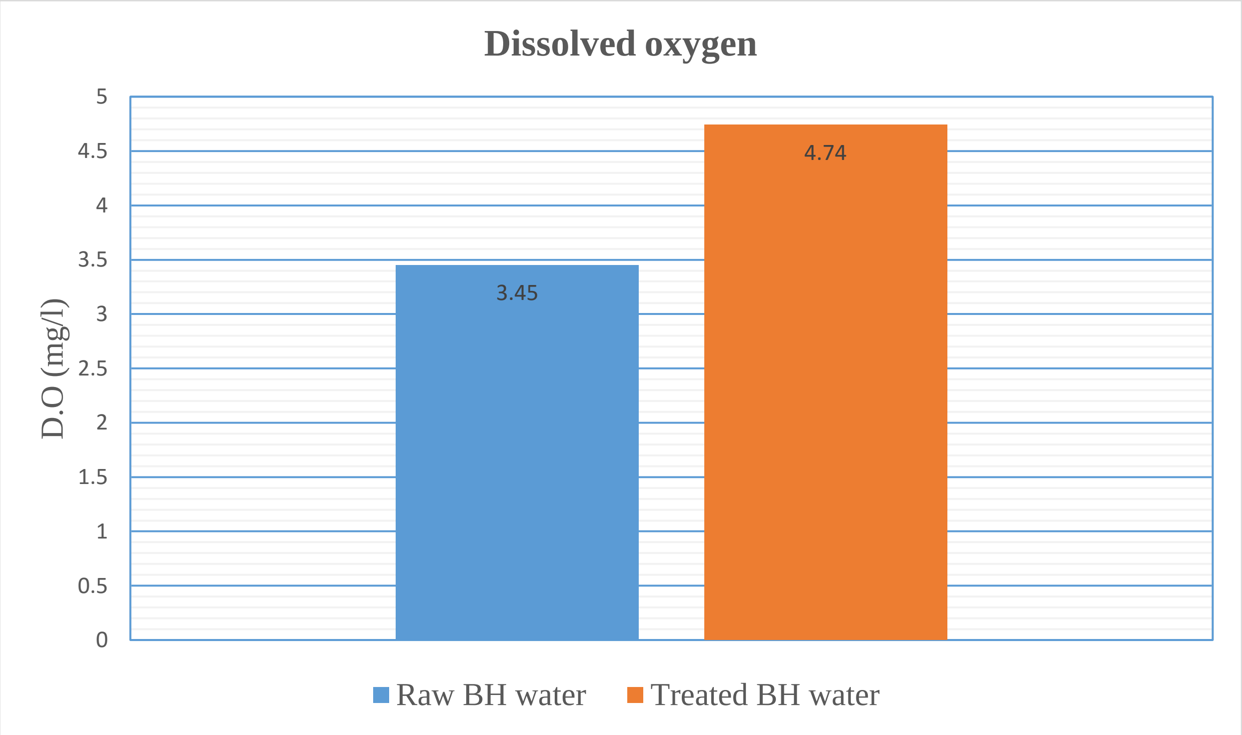

Figure 4.3:A chart showing variation of dissolved oxygen in the water samples

4.1.4 pH

The pH value obtained for raw borehole water was 6.7 while that of treated borehole water was 7.4. Both the raw and treated samples fell within the recommended WHO standards of 6.5 to 8.5. The hydrogen ion (pH) concentration shows how basic or acidic a water sample is. This is mainly attributed to the type of rock and its mineral content, which dissolves in water to form hydroxides which leads to increase in pH. Excessive acidity and alkalinity is harmful to human health, changes the taste of the water and may cause damage or blockage of the conduits.

The variation in pH between the raw and treated water samples was due to the addition of chlorine when treating the iron therefore raising the pH of the water sample. The chemical reaction for the oxidation of iron with chlorine is as follows;

$$2Fe(HCO_3)_2 + Cl_2 + Ca(HCO_3)_2 = 2Fe(OH)_2 + CaCl_2 + 6CO_2$$

The pH of the raw water was within the required limits of 6.5 to 7.5 for optimum oxidation of iron using chlorine. After precipitation and removal of the iron, some residual chlorine remained in the water thus raising the pH of the water sample.

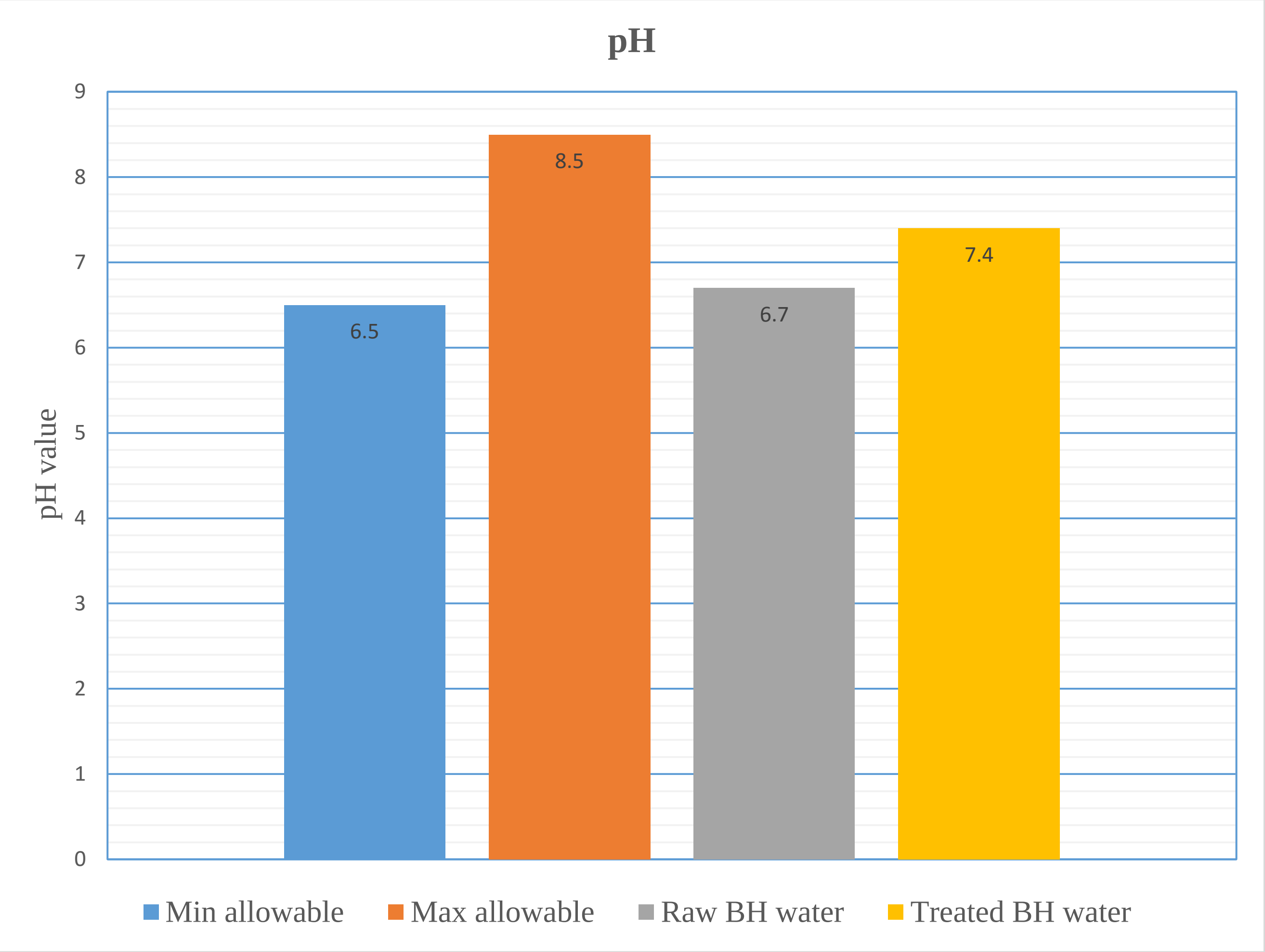

Figure 4.4: A chart showing variation of pH in the water samples

4.2 Performance evaluation of chlorine in iron removal

After the standard 20 minutes settling or detention time required for oxidation of iron by chlorine, the amount of iron that remained is as shown in Table 4.3

Table 4.3: Iron removal by chlorine

WATER SOURCE	**IRON CONCENTRATION**		**IRON REMOVAL (%)**
	Before (mg/l)	**After (mg/l)**	
Thuku BH	0.6	0.2	66.7

The efficiency of using chlorine as a treatment method for removal of iron in the borehole water was found to be 66.7%. Also the efficiency of iron removal increased with higher detention time, as shown in Table 4.5. Therefore, the 66.7% efficiency could be attributed to the short retention time for chlorine which was 20 minutes. For higher performance of chlorine in oxidation of iron much longer retention time is needed after addition of chlorine to water since all chlorine may not have reacted with iron by the end of 20 minutes

4.3 Determination of chlorine dosage

The summary of the results obtained from the jar test is shown in Table 4.4 below.

Table 4.4: Required chlorine dosage and residual chlorine after a contact time of 20minutes

JAR NO.	chlorine added (ml)	Chlorine dosage (mg/l)	Residual chlorine (mg/l)
1	1	1	0
2	2	2	1.0
3	3	3	2.0
4	4	4	3.0
5	5	5	4.0

From the results obtained it was determined that the amount of chlorine that was utilized to completion was 1 mg/l. To ensure that the iron which was not oxidised during the detention time would be oxidised, residual chlorine of 1 mg/l would be left in the water system. The minimum amount of chlorine would be left in order to avoid the unpleasant taste that results from excess chlorine. Therefore, a chlorine dosage of 2 mg/l was used. The amount of chlorine to be used per day in treating Thuku BH which yields water at rate of $72m^3/hr$ was found to be $2.42\ kg\ Cl_2/day$ as shown in appendix 1. The bench or Jar test was used to determine the chlorine dosage. The amount of chlorine to be used per day in treating the water depends on many factors such as iron concentration, yield rate of the borehole; purity of the chemical and dosage rate.

4.4 Effect of changing the detention time on iron concentration after adding chlorine

The summary of the results obtained from the change of detention time test is shown in Table 4.5 below.

Table 4.5:Effect of contact time on iron concentration

TIME (min)	Iron concentration (mg/l)	Iron Removal (%)
0	0.6	0
10	0.3	50
20	0.2	66.7
30	0.15	75
40	0.1	83.3
50	0.1	83.3
60	0.1	83.3

A graph of iron concentration against detention time is shown in Figure 4.5. After a contact time of 60 minutes the iron removal was 83.3% percent (Table 4.5). Removal of iron was most effective during the first 20 minutes of retention in the jar. The results show remarkable iron removal with increased detention time with the most effective removal occurring during the first 20 minutes of retention in the jar. The amount of iron removed in the last three jars, which had a retention time of 40, 50 and 60 remained the same. This may have been as a result of all the iron having reacted with the chlorine

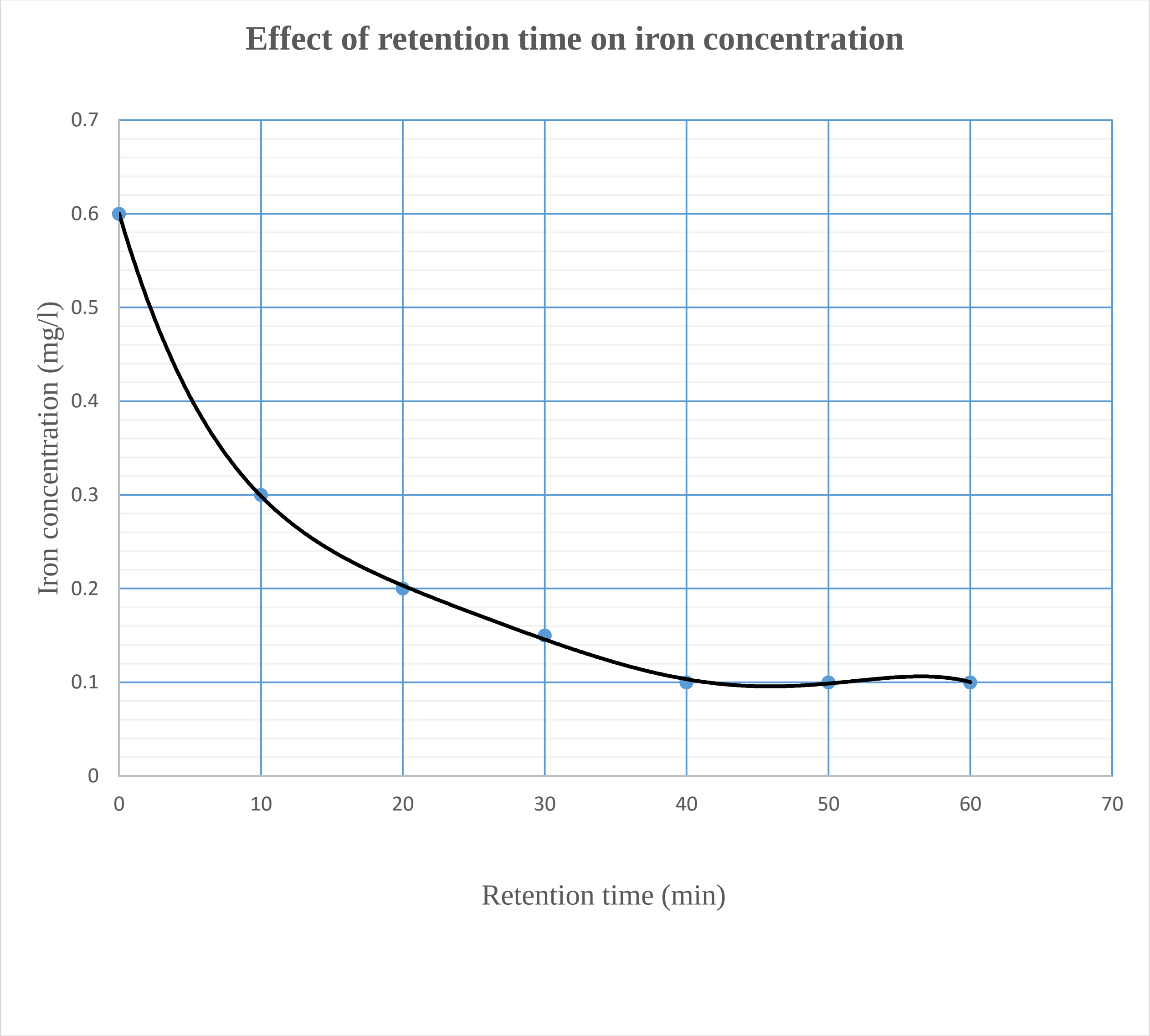

Figure 4.5:The graph of iron concentration against detention time

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The following conclusions were drawn from the study

1. The iron concentration in Thuku BH was 0.6 mg/l. This concentration was above the WHO recommendation of 0.3 mg/l. For that reason, the water requires treatment before supply to the public.
2. The performance evaluation of chlorine in removal of iron showed efficiency of 66.7% with a retention time of 20 minutes. Thus, it can be concluded that chlorination is an effective method in removal of iron from borehole water. From the results and analysis done, it can be also concluded that the efficiency of chlorine in iron removal can be increased by increasing the retention time.
3. Results and analysis show that the amount of chlorine required to treat Thuku BH water was $2.42 \text{ kg } Cl_2/\text{day}$. Therefore, treating the water before supply to the public will be more economical than having to clean and maintain appliances after distribution of the water without treatment.
4. The results showed 83.3% iron removal with a retention time of one hour, with the most effective removal occurring during the first 20 minutes of retention. Consequently, it can be concluded that a standard retention time of 20 minutes can be used in the chlorination method.
5. The conductivity of the well water reduced significantly from 155µS/cm to 90µS/cm after removal of the iron while the dissolved oxygen increased from 3.45 mg/l to 4.74 mg/l, which shows improvement in the overall quality of the well water with removal of iron.

5.2 Recommendation

The recommendations from the study are as follows:

1. Kiambu Water and Sewerage Company should consider incorporating treatment works for the iron in the Thuku BH. This can be done using the aeration method or chlorination method since the main idea of the iron removal is to achieve sufficient aeration of the water leading to the maximum formation of iron precipitates which are removed in the sedimentation process.
2. The retention time when using chlorination method for removal of iron should be increased beyond the standard 20 minutes to ensure higher efficiency of iron removal.
3. The borehole water should be tested for manganese which occurs naturally in surface and groundwater. The possible presence of manganese in association with iron in borehole water must be ascertained because it demands special measures for its removal.
4. Further studies should be undertaken to establish more economical, user friendly and sustainable method for removing iron from boreholes.

REFERENCES

Andersson, H. and Johansson, J., (2002). *Iron Removal from Groundwater in Rakai District,* Uganda – A Minor Field Study, M.Sc. Thesis, Lulea University of Technology

Hem, J. (1985). *Study and interpretation of the chemical characteristics of natural water*. [Reston, Va.?]: Dept. of the Interior, U.S. Geological Survey.

Hoffman, Lytle, D., Sorg, T. J., Chen, A. S. C., & Wang, L. (2006). *Design Manual: Removal of Arsenic from Drinking Water Supplies by Iron Removal Process*. National Risk Management Research Laboratory, Office of Research and Development, US Environmental Protection Agency.

Huda M.K, (1995), *Ground water quality in deep aquifers of Bangladesh,* Unpublished M.Sc. Engineering Thesis, Department of Civil Engineering, Buet, Dhaka.

Kapulu, M. (2013). *Iron removal in borehole: A case study of Luapula Province Zambia*. Saarbrücken: Lap Lambert Academic Publishing.

Pontius, F. (1990). *Water quality and treatment*. New York, N.Y.: McGraw-Hill.

Nordell, E. (1961). *Water treatment for industrial and other uses*. New York: Reinhold Pub. Corp.

Singh, S. (1999). *The code book*. New York: Doubleday.

Sittig, M. (1973). *Pollutant removal handbook*. Park Ridge, N.J.: Noyes Data Corp.

Thresh, J., Beale, J., Suckling, E. and Taylor, E. (1958). *The Examination of Waters and Water Supplies. Thresh, Beale & Suckling. Seventh edition by Edwin Windle Taylor, etc*. Pp. viii. 841. J. & A. Churchill: London.

Tyrrel, S., Gardner, S., Howsam, P., & Carter, R. (1998). *Biological removal of iron from well-handpump water supplies*. Waterlines, Vol.16, No.4, Pg.29-31 IT Publications, London

APPENDICES

APPENDIX 1: Determination of chlorine dosage

Calculation of amount of chlorine (kg) to be used per day

Data

Thuku BH yields water at rate of $72m^3/hr$.

The calcium hypochlorite used contained 70%chlorine

The rate at which chlorine is fed into the system = 2mg/l.

Calculation

The yield from the borehole per day $=\frac{72m^3}{hr} \times \frac{24hr}{day} = 1728m^3/day$

The chlorine contained in the Chlorine dosage of 2mg/l is as calculated below

$$=\frac{70}{100} \times \frac{2mg}{l} = 1.4mg/l$$

For every 1 000 m^3 of water of flow, we will need to use 1.4kg of chlorine.

Therefore, the amount of chlorine required per day;

$= 1.4\ kg\ Cl_2/1000m^3 \times 1728m^3/day$

$= \mathbf{2.42\ kg\ Cl_2/day}$

APPENDIX 2: Laboratory test procedures

A: Iron Laboratory Analysis Procedure (adapted from APHA)

REAGENTS

a) Dilute hydrochloric acid
b) Potassium permanganate solution
c) Ammonium thiocyanate solution
d) Amyl acetate alcoholic solution

APPARATUS

a) Separating funnels
b) Lovibond comparator
c) Disc no 3/11

PROCEDURE

1) 5ml of the sample was added to 1ml of hydrochloric acid and two drops of potassium permanganate in a separating funnel and mixed.
2) 5ml of ammonium thiocyanate solution and 10ml of amyl acetate alcoholic solution were then added and the mixture shaken vigorously.
3) The mix was then allowed to settle and the lower aqueous layer discarded.
4) The upper layer was transferred to a comparator cell.
5) Steps (a)-(d) were repeated using distilled water instead of the sample.
6) The cells were placed in the comparator and the color produced matched against the standard disc.
7) The iron content of the sample was then calculated as follows;
   Mg Fe/l (disk reading × 200)

B: Colour Laboratory Analysis Procedure (adapted from APHA

APPARATUS

a. Nessler cylinder
b. Lovibond nessleriser
c. White light cabinet
d. Hazen disk No. NSA

REAGENT

- Water sample

PROCEDURE

1. A Nessler cylinder was filled with the water sample up to the mark.
2. The cylinder was then transferred to the right hand compartment of a Lovibond nessleriser used in conjunction with a white light cabinet.

3. The color was matched against the standard Hazen disc number NSA.
4. The color was read, in degrees hazen directly from the disc

C: Dissolved oxygen Laboratory Analysis Procedure (adapted from APHA

APPARATUS

a. DO bottles with stoppers
b. Pipette
c. Arlenmeyer flask

REAGENTS

a. Manganous Sulphate Solution
b. Alkali-azide-iodide reagent
c. Sulphuric acid, concentrated
d. Starch indicator solution
e. Standard Sodium Thiosulphate Solution (0.025N)

PROCEDURE

1. The sample in the DO bottles was collected by displacing the volume of bottles at least for a minute. The stopper was carefully replaced so as not to trap any air bubble in the bottle.
2. The stopper was removed and 2ml each of reagents ‘a’ and ‘b’ above were added in quick succession with the tip of the pipette well below the water level in the bottle and the stopper carefully replaced.
3. The contents were mixed several times and the precipitate allowed to settle halfway down the bottle.
4. 2ml of conc. Sulphuric acid using a bulb was added to the contents of the bottle with the tip of the pipette below the level of the water. The stopper was replaced and the contents mixed and allowed to settle till all the precipitate dissolved.
5. 203ml from the bottle was measured and transferred to an arlenmeyer flask and titrated against standard sodium thiosulphate solution till the color changed to pale yellow. About 1ml of starch indicator solution was added and the titration continued till the blue color disappeared.

D: pH Laboratory Analysis Procedure (adapted from APHA

APPARATUS

- **a.** pH meter
- **b.** 2 Beakers

REAGENTS

- Water sample

PROCEDURE (pH meter)

a) Approximately 75ml of sample was placed in a 100ml beaker.
b) The electrodes were then raised carefully out of the beaker and rinsed in distilled waterand drops of water wiped from the electrodes.
c) The electrodes were then immersed in the beaker containing the sample and the sector switch to the ‘pH’.
d) The PH was then read directly from the meter.

The sector switch was then turned to ‘CHECK’ and the electrodes were then carefully raised from the beaker and rinsed in distilled water and replaced in a beaker of distilled water

E: Residue chlorine Laboratory Analysis Procedure (adapted from APHA

. APPARATUS

- Lovibond comparator
- Disc No. 3/2A

REAGENTS

- Orthotolidine solution.
- Sample

PROCEDURE

1. Two cells were filled with 10ml of the sample
2. 0.1ml of the Orthotolidine reagent was added to one cell and the contents mixed. It was then placed in the right hand compartment of the comparator
3. A ‘blank cell’ was then placed in the left compartment.
4. The residual chlorine concentration was read by matching the color standards of the disc with color in the cell.

APPENDIX 3: Water quality guidelines

PARAMETER	UNITS	WHO STANDARDS	KEBS STARDARDS
Iron.	mg/l	MAX 0.3	MAX 0.3
pH	pH scale	6.5-8.5	6.5-8.5
Residual chlorine	mg/l	MAX 5	MAX 5
D.O	mg/l	>4	–
Conductivity	$\mu S/cm$	MAX 2500	MAX 2500
Colour	DegreesHazel	MAX 15	MAX 15

APPENDIX 4: Water samples and lab templates

Plate 1: Thuku BH

Plate 2: Sampling

Plate 3:Stirring of the water samples in jar test after adding chlorine

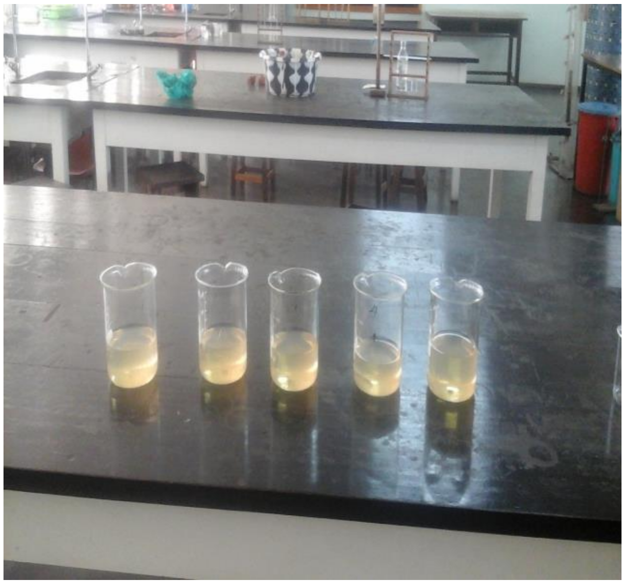

Plate 4: Settling of the water samples after mixing in jar test

Plate 5: Conducting the iron experiment test