EVALUATING THE WATER QUALITY WITHIN THE RETICULATION SYSTEM OF KWEKWE MUNICIPALITY DURING THE DRY AND WET SEASONS.

BY

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Abstract

The research sought to evaluate the water quality within the reticulation system of Kwekwe municipality during the dry and wet seasons and to measure the water quality parameters such as pH, turbidity, total coliforms, free and combined chlorine from the source, final stage of treatment and throughout the distribution system. It also had to consider how distance from one sampling point to another affect the quality of water. It had to consider measurement, the water treatment process, causes for poor water quality as well as desired international standards of World and Health Organisation, (WHO). Data was collected from nine different sampling points including schools, clinics, residential areas of Mbizo and Amaveni, Dutchman Pool Waterworks formerly known as Sebakwe Treatment Works as well as dam water. The data was collected in January and February 2016 representing wet season as well as in May and June 2016 representing dry season. Laboratory tests were conducted in order to analyse the quality of water at the different sampling sites. For statistical analysis both one way and two way ANOVA were used. Regression analysis was done to establish a relationship between water quality parameters and distance.

Declaration

The undersigned certify that they have read and recommended for submission to the department of Land and Water Resources Management, in partial fulfilment of the Bachelor of Science Degree in Land and Water Resources Management, a research by Silence Chinomona entitled:

EVALUATING THE WATER QUALITY WITHIN THE RETICULATION SYSTEM OF KWEKWE MUNICIPALITY DURING THE DRY AND WET SEASONS.

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Dedication

I dedicate this piece of work to my father Philip, my mother Memory and my siblings Sincere, Kundai, Onai and Terrence.

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I would like to thank my industrial supervisor, Mr Tafirenyika for assisting me in coming up with the study. His contribution is greatly appreciated. I would also like to thank my academic supervisor Professor Munodawafa for helping me with my research.

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CHAPTER 1

1.0 Introduction

The key ingredient for human survival is water. It is needed for industrial, agricultural and domestic purposes such as drinking, sanitation, oil refining, cooling, scrubbing of metals such as iron, zinc, copper and lead, irrigation, food processing inter-alia (Karamouz et al., 2013). Water is also an important solvent in chemical industries.

Water scarcity has become a major global concern, with one third of the world facing water shortages due to rapid population growth, poor management of water resources, effects of climate change and variability as well as economic growth in many cities especially those in arid and semi-arid regions (Mays, 2009). The global population of people who live in urban areas increased by 49 percent in 2005 from 13 percent recorded in 1900 and is expected to rise up to sixty percent by 2030 (Herrera, 2011). It has been also estimated that by 2030, 75 million to 250 million people in Africa will be living in areas of high water stress (Craun et al. 2002). Water problems in the water supply cycle emanate from the resource, the treatment stage, during distribution to the consumer’s house and within the household plumbing system (Chatterjee, 2001).

Poor water quality incurs many economic costs such as decrease in crop production, industrial production, increased water treatment costs, and water-related diseases such as cholera, typhoid and schistosomiasis. There is no data to suggest that there has been an overall improvement in water quality on a global scale and about 3.5 million deaths related to inadequate water in supply networks and poor hygiene occur each year, especially in developing countries (The World Water Development, 2012). For instance, case study one of the Mexico City, reports 40 percent losses in the distribution system and poor water quality due to contamination caused by erratic low pressures within the system (Miloradov and Marjanovic, 1998).

Safe drinking water is water with microbial, chemical and physical characteristics that meet the WHO guidelines on the drinking water quality (WHO/UNICEF, 2000). Where adequate water treatment is not readily available, the impact on public health can be devastating. A striking example occurred in May 2000 in the Canadian town of Walkerton, Ontario. Seven people died and more than 2 300 became ill after E. coli and other bacteria infected the town′s water supply (AWWA, 2000). Even after the well was contaminated, the Walkerton disaster could have been prevented if the required chlorine residuals had been maintained (Dennis, 2002). Lack of improved water supply led to the cholera outbreak in 2008-2009 in Zimbabwe, over 4 000 people died and 100 000 people were infected (WHO, 2014). Monitoring the quality of water ensures that environmental standards are being met, assists researchers in predicting and learning from natural processes in the environment and determining human impacts on an ecosystem (Craun et al., 2002).

Harare is the local authority and is still failing to produce water that has no harmful poisonous chemical substances, micro-organisms, has lowest possible levels of colour, temperature, suspended solids, odour and taste, minimum corrosivity to metals as well as lowest possible content of staining materials such as iron (Christian et al., 2001). The majority of Harare residents collect their drinking water from the contaminated Lake Chivero and this indeed denotes a point of difficulty as only 40 percent of Harare residents have access to sustainable water supply networks whereas 60 percent of consumers make use of bottled water (Nhapi, 2009).

1.1 Justification

The Dutchman Pool Treatment Plant was not efficient in supplying good water to Kwekwe residents. The study was done to ensure that the water quality from the treatment plant to consumers is maintained during the dry wand wet seasons because of the problems associated with the reticulation system which include the following; corrosion of metal pipes, microbiologic contamination responsible for the outbreak of acute diseases, and chemical contaminants which pose cumulative and chronic health risks to human beings, hence water quality is the key to human right.

1.3 General Objective

To evaluate the water quality within the reticulation system during the dry and wet seasons.

1.4 Specific Objectives

To measure the quality of water (pH, turbidity, free chlorine, combined chlorine and total coliforms) during dry and wet seasons from the source (dam), final stage of treatment, and at seven selected distribution points in Kwekwe municipality.

To establish the relationship between water quality parameters and distance.

To evaluate the quality of water in terms of WHO standards and identify the causes for poor water quality.

1.5 Hypotheses

There are significant differences in the (pH, turbidity, free chlorine, combined chlorine, and coliforms) of water in dry and wet seasons within different sampling points.

Distance significantly affects the concentration of free chlorine, turbidity, pH and coliforms.

Water of Kwekwe municipality significantly varies from WHO standards.

CHAPTER 2

2.0 Literature Review

Declining water quality has become a global issue of concern as human populations grow, industrial and agricultural activities expand, and climate change as well as variability threatens to cause major alterations to the hydrological cycle (World Water Development Report, 2009). Some studies tend to focus on the direct and indirect impacts of agriculture to the quality of water which include: upland drainage, soil nutrients and pesticides being transferred from fields to water course during rainfall events (White and Hammond, 2009), others have focused on waste water pollution leading to lack of drinking water and farming (Min, 1997). And yet others have looked at chlorination as an important water quality treatment process in that it eliminates slime bacteria, moulds algae that grow in water supply reservoirs on the walls of water mains and in storage tanks (Haas, 2011).

The goal of water treatment from surface sources such as lakes, reservoirs, or rivers is to remove contaminants and organisms through biological, chemical, and physical processes to make it safe for drinking. The United States of America began to use chlorine in water treatment after the outbreak of cholera in London, 1854 due to sewage-contaminated drinking water well (Symons, 1992). The Americans drinking water comes from lakes, rivers and groundwater then flows from intake points to a treatment plant, a storage tank, and finally to their houses through various pipe systems (Kirmeyer et al., 1994). This suggests a conventional water treatment system. Unlike the Americans, the cities in China make use of the modified conventional water treatment plant for drinking water production which include ozonation, catalytic ozonation and adsorption with granular activated carbon or the combined processes of peroxidation and biological filtration (Hand et al., 2011). Ozone is used for disinfection, taste, colour and odour control, oxidation of organic pollutants such as iron and manganese, oxidation of micro- and macro-pollutants and the improvement of coagulation (Baker, 2002) thus it is of importance to maintain the quality of water (Langlais et al., 1991; Mays, 2009).

In Africa, water supply systems are damaged and the water sources are contaminated. For instance, South Africa’s surface sources are increasing in toxicity due to bacterial growth such as salmonella and Escherichia leading to water pollution (Stoddard, 2013). In 2010, the quantity of bacteria found in the surface waters was five times more than the recommended WHO standards (Mellor, 2013). Moreso, rural municipalities in South Africa lack efficient and effective water cleaning facilities, causing rural areas to not have enough potable water (McCarthy and Humphries, 2013). Furthermore, Zimbabwe’s conventional water supply system in Harare is malfunctioning and needs rehabilitation (Nhapi, 2009).

2.1 The Conventional Water Treatment Process

Water treatment process include the following processes: pre-treatment which is screening and preliming; coagulation, flocculation, sedimentation, filtration, disinfection and supply. The reasons for water quality treatment are: to protect the health of the community, to supply a product which is aesthetically desirable and to protect the property of the consumers (Post et al., 2011).

Coagulation is the first process of water treatment and is said to be the physical and chemical changes which take place between the soluble coagulant and the alkalinity in the water to form precipitated or incipient floc (Agriculture and Agricultural Food Canada, 2006). The first step of this process is the feeding of the chemical to the water and then mixing is the second step (WHO, 1996). Mixing refers to the rapid and uniform distribution of a coagulant before chemical reactions have occurred to any marked degree. Raw water mixes with a chemical known as a coagulant such as aluminium sulphate.

Flocculation follows soon after the coagulation process and is the agglomeration of destabilised colloid and metal hydroxides precipitates into larger particles, known as flocs of suitable of suitable size and density to be removed by settling tanks and filters (Douglas et al., 2004). It is difficult to tell when coagulation stage ends and when flocculation begins as the process follow each other or happen in sequence. If the chemical conditions are incorrect, some or all of the colloidal particles will remain dispersed (Beverly, 2014) Particles must collide in order to flocculate. Motion and particle concentration facilitate collision (Beverly, 2014). The collision rate is a function of the rate of motion and the size and number of particles. In order to achieve collision of the destabilised particles, the water must be kept in a state of controlled agitation. Contact with material previously precipitated accelerates the rates of growth into large particles (Hubbard, 2004). Generally, the higher velocities are required where the suspended matter is relatively heavy as for instance, in a softening plant or where turbid river water is treated.

Another process is sedimentation which is the removal of particulate matter, chemical flocs and precipitates from suspension by gravity settling. Settling tanks or clarifiers are there to reduce the load on the filters (WHO, 1996). Sedimentation or settlement becomes more desirable as the quantity of suspended matter present after coagulation increases. Therefore clarification reduces the work done by the filtration process.

Filtration is the final polishing of water from the sedimentation tanks. This occurs soon after the sedimentation process. Filtration is aimed at producing a sparkling water, removing fine organic and inorganic material and reducing the bacterial contents and the contaminants that cause taste and odour (AWWA, 2004). Some coagulant for floc formation is necessary to obtain effective filtration. During the process, water is passed through a sand bed and all suspended matter that is large enough is removed. Rapid or mechanical sand filters are used for this filtration process. The filter plant consists of a clean bed of fairly course sand which removes previously coagulated solids (Christian et al., 2001). The efficiency of the filters depend upon the effectiveness of preliminary coagulation and sedimentation and the sand condition as well. An underdrainage system is provided and it is capable of uniformly collecting the filtered water and distributing the relatively large flow of water when the filter is being backwashed or cleaned (Dennis, 2002). Water gravitates through the sand and collects in the underdrainage system and passes on to the contact tanks for chlorination and pH correction.

Disinfection is the killing of disease-causing micro-organisms. Chlorine gas is the main disinfectant used at the Dutchman Pool Waterworks and in its absence, Calcium Hypochlorite (HTH) is used. At the treatment works the chlorination practiced is called post chlorination in which the addition of chlorine is subsequent to filtration. The chlorine is added in the filter effluent pipe so that the water is exposed to the chlorine for some time in the clear well before it is pumped into the distribution system.

Activated carbon is added to the water for odour removal if the water is not odour free. Residual disinfectants are removed by catalytic reduction and organics are removed by adsorption (Saha et al., 2001). Activated carbon adsorb organic material because the carbon surface and contaminants are stronger than forces keeping the contaminants dissolved in water (Lim and Okada, 2005)

Water from the filtration process usually has a low pH because of the acidic coagulants and dissolved carbon dioxide. These might cause corrosion within the pipes and diseases such as ulcer, thus there is need to add lime in order to correct pH (Zhang et al., 2008). Water is then tested within a laboratory so as to meet the standards of the World Health Organisation.

For the final purification process, water flows into the reservoir also known as contact tanks. The chemicals added have a tendency of reacting with suspended and dissolved salts in the water creating salts. These salts settle at the bottom of the contact tanks and this enables chlorine to mix with the water (Otterstetter and Craun, 1997). Clean water is then pumped to the distribution reservoirs by the high lift pumps.

2.2 Water Quality Parameters

2.1.1 pH

pH measures how acidic or alkaline the water is and is measured on a scale from 0 to 14 where 1 is the most acidic, 14 is the most alkaline and 7 is the neutrality point (Chatterjee, 2001). The quantity of hydrogen and hydroxyl ions in a solution which determines whether the solution is acidic or basic is known as pH (Zhang et al., 2008).

The higher pH of any substance or solution, the more electrical resistance that substance or solution holds and electricity travels slower with higher pH. Human blood is basic with a pH between 7.3 and 7.5 (Williams, 2003). If the pH of blood drops below 7.3, acidosis occurs and if the blood pH rises above 7.5, alkalosis occurs (Gordon et al., 2008). Death occurs if blood pH goes below 7.0 or above 7.8 thus our human existence depends upon a balanced and buffered blood pH (Williams et al., 2003).

The logarithmic scale is used to express the concentration of hydrogen ions (H^+) and hydroxide ions (OH^-) and this scale has become known as the pH scale (Schincariol, 2005). The scholar is said to have known that water had a nearly balanced concentration of positive hydrogen ions and negative hydroxide ions. Scientists measured the concentrations of hydrogen ions in pure water, acidic water and alkaline water (U.S. EPA, 2011). The pure water contained a hydrogen ion concentration of 1 x 10^{-7} moles per litre. The acidic water (hydrochloric acid) contained a hydrogen ion concentration of 1 x 10^{0} moles per litre. The alkaline water (sodium hydroxide) contained a hydrogen ion concentration of 1 x 10^{-14} moles per litre. (Schincariol, 2005).

Municipalities such as Kwekwe practice post liming especially when using aluminium sulphate as a coagulant. Post liming is the application of lime after all the treatment processes have been done in order to raise pH (Navalon et al., 2008). When using ferric chloride especially during the rainy season, pre-liming is done in order to raise the pH of water as the chemical is highly acidic (Kohlmann, 2003).

For pH measurement a lovibond comparator with suitable disc is used with two cuvettes and an iron indicator called phenol red (Chatterjee, 2001). In the absence of the iron indicator some phenol red pills are used with the lovibond comparator and cuvettes. The lovibond comparator of pH is almost the same with that of chlorine. The Kwekwe municipality has the desired pH is 6.5- 8.5 and it bases on the WHO standards (WHO, 2011). The phenol red is prepared by dissolving the phenol red powder weighing 0.1 grams in 500ml of methanol. The easiest way to measure pH is the use of the litmus paper. Some measure pH using the pH meter and it is more reliable that an indicator solution (William, 2003).

2.1.2 Turbidity

Turbidity is fine suspended materials in a solution and can be removed by physical means (Mann et al., 2007). It can be also argued that turbidity is the cloudiness or haziness of a fluid caused by large number of individual particles that are generally invisible to the naked eye, similar to smoke in air. Very small particles will settle only very slowly or not at all if the sample is regularly shaken or disturbed or if the particles are colloidal while some suspended material will be large enough and heavy enough to settle rapidly to the bottom of a container if a liquid sample is left to settle (Herz et al., 2002). It is these small particles that cause the liquid to appear turbid.

Total Suspended Solids are detrimental to pumps and also give the water bad colour and taste. It is important that these Total Suspended Solids (TSS) be kept within the standards. Higher turbidity level in drinking water would imply higher risk that people develop gastrointestinal diseases (U.S. EPA, 2002). The suspended solids are said to interfere with water disinfection with chlorine because particles act as shields for the virus and bacteria. In an open water body, turbidity may be caused by the growth of algae. The clarifiers and other intake structures usually develop algae during the rainy season (Letterman and Yiacoumi, 2011). Human activities such as construction of roads, mining and agriculture lead to high levels of sediments entering water bodies during rain storms due to storm water runoff (Hubbard et al., 2004).

Industries such as quarrying, and coal recovery can generate high levels of turbidity from colloidal particles (Wijnen et al., 2014). Areas that are prone to high erosion rates as well as urbanised areas also contribute large amounts of turbidity to nearby waters through stormwater pollution from paved surfaces such as roads and bridges (Mann et al., 2007).

In lakes, reservoirs and rivers, high turbidity can reduce the amount of light reaching lower depths which can inhibit growth of submerged aquatic plants and consequently affect species which are dependent on them such as fish and shellfish (US E.P.A., 2001). Higher turbidity affects the ability of fish gills to absorb dissolved oxygen for instance, the Chesapeake Bay in the eastern United States, but for many mangrove areas, higher turbidity is needed to support certain species such as to protect juvenile fish from predators, thus turbidity has both positive and negative impacts upon the environment (Diersing, 2009). Turbidity values as high as 600 Nephelometric Turbidity Units (NTU) are needed for proper ecosystem health for most mangroves along the east coast of Australia- Moreton Bay (Mann et al., 2007).

The Formazin Turbidity Unit (FTU) is the most commonly used unit of measurement in determining the concentration of suspended particles in a sample of water by measuring the incident particles in a sample of water by measuring the incident light scattered at right angles from the sample (Vasudevan, 2010). This method measure scattered light at 90 degrees from the incident light beam. The scattered light is captured by a photodiode which produces an electronic signal that is converted to a turbidity (Linden and Rosenfeldt, 2011). Water containing one milligram of finely divided silica per litre has a turbidity of 1 NTU which is equivalent to 1 FTU (WHO, 2007). The turbidity of treated water and raw water acceptable limit is 5 NTU and not more than 10 NTU in adverse cases (WHO, 2013).

Some make use of the spectrophotometers in measuring turbidity. A spectrophotometer is commonly used for the reflectance or transmittance of solutions, transparent or opaque solids such as polished glass or gases (Langmuir et al., 2005). In a spectrophotometer light source shines on the sample and a fraction of light is reflected or transmitted from the sample (Allen et al., 2010). The light from the sample is directed to the entrance slit of the monochromator.

The monochromator separates the wavelengths of light and focuses each of them onto the photo detector sequencially. The detector then converts how much light the sample transmitted or reflected into a number and then one can take a reading from there. Most common spectrophotometers are used in the ultraviolet and visible regions of the spectrum and some of these instruments operate into the near -infrared region as well (Robert et al., 2016).

2.1.3 Free or residual chlorine

Free chlorine refers to the hypochlorous acid (HOCl) and the hypochlorite (OCl^-) ion or bleach commonly added in drinking water for disinfection and is measured using chlorine gas or sodium hypochlorite (Foster, 2015). It is the chlorine that is available for disinfection after the process of chlorination has been done (Hammer and Hammer, 2001). Chlorine is used effectively in taste and odour control as well as the removal of iron and manganese (Hammer and Hammer, 2001). When ammonia or organic nitrogen is also present, chloramines known as monochloramine, dichloramine, and trichloramine will quickly form.

Determination of free chlorine is done using chlorine test kit which include; a colour disc comparator, DPD number one and two test tubes (WHO, 2013). The colour disc comparator has windows through which one sees whether the colour in both the first and second test tube match. A pink colour indicates the presence of chlorine and if the difference between free and total chlorine is high it means that there is still room for chlorine to react with impurities, hence a small difference is preferred. Free available residual chlorine is necessary to obtain equivalent bacterial kills under the same pH conditions, temperature and contact time (Kleijnen, 2011). The typical levels of free chlorine in drinking water are 0.2 to 0.5 milligram per litre (WHO, 2013). The desired standards for free chlorine ranges from 0.2 to 2.0 milligram per litre, although regulatory limits allow levels as high as 4.0 milligram per litre (White, 1972).

2.1.4 Combined chlorine

Combined chlorine is the chlorine that has combined already with other molecules in the water and thus cannot be used for further disinfection of the water (Baker et al., 2002). The level of combined chlorine will always be higher than or equal to the level of free chlorine (Laubusch, 1960). The practices of combined chlorination involve the application of chlorine to water to produce with natural ammonia present or purposely added and to maintain that residual through part or all of the treatment plant or distribution system (Kleijnen, 2011). The combined chlorine forms have lower oxidation potentials than free available chlorine forms (Mann et al., 2007). When combined chlorine is desired, the characteristics of water will determine how it can be accomplished. If the water contains too little or no ammonia, the addition of both chlorine and ammonia is required and if the water has existing free available chlorine residual, the addition of ammonia will convert the combined available residual chlorine (Navalon et al., 2008).

2.1.5 Total coliforms

Coliforms are a broad class of bacteria found in the environment, including the faeces of man and other warm-blooded animals (September et al., 2007). Waterborne pathogens cause diseases such as hepatitis, giardiasis, and dysentery (Meller et al., 2013). Drinking water must be free of disease-causing organisms called pathogens which can be viruses, protozoa or bacteria. To test water for specific harmful viruses, protozoa and bacteria is very time consuming and expensive (Kleijnen (2011). Coliform bacteria are used as water quality indicator for the coliforms may be associated with the sources of pathogens contaminating water. For total coliforms some microbial tests for bacteria are done (Meller et al., 2013). When collecting samples the sample container should not be contaminated. Aerators, screens, or other devices are removed from the tap before collecting samples and the water is turned on to a moderate flow for a minimum of three minutes (Feng et al., 2013). One collects the sample leaving an air space of about 2.54 cm at the top of the bottle and a cap is put on it (Post et al, 2011).

The Membrane Filter Technique makes possible a more rapid and more reproducible determination of coliform densities using much larger volume of sample and provides a direct enumeration of the bacterial density rather than a statistical estimate (September, 2007). The sterilization procedure is done. One wraps the funnel and base of the filtration unit separately in Kraft paper and autoclaving at a temperature of 121 degrees Celsius for ten minutes (Geissler et al., 2000). There is need to autoclave grid marked membrane filters and absorbent pads for ten minutes at 121 degrees Celsius. Glassware is sterilized before use by dipping it in 95 percent ethyl alcohol. A single sterile absorbent pad is placed in each sterile petri dish, 1.8 ml of prepared Endo medium is added and the filter holder base is inserted into the neck of a one litre side arm vacuum flask (Warburton, 2000). Using alcohol-flamed sterile forceps, one places a sterile filter disc, grid side up, on the filter holder base, carefully places the filter holder funnel in place and lock it (Warburton, 2000).Water sample of an appropriate size of 100-500ml for finished waters is poured into a funnel and drawn through the membrane filter into the filter flask by vacuum. The funnel is rinsed three times with 20-30ml volumes of sterile buffered dilution water (Logan and Regan, 2006). The funnel is removed carefully and transferred to the prepared dish with sterile forceps, rolled onto the absorbent pad to avoid entrapping air bubbles. The dishes are incubated in an inverted position for 18-22 hours at 35 degrees Celsius or more in an incubator with 100 percent humidity (Feng et al., 2013). Then one starts to count with the aid of a lower power microscope all dark colonies having a sheen or metallic-appearing surface lustre using for illumination a light source located directly above the filter. The estimated coliform density is recorded as the number of coliform per 100 ml sample and calculated by dividing the number of coliforms counted per 100 ml sample with the ml of sample filtered and multiplying by 100 percent (Geissler et al., 2000).

2.2 Causes of poor water quality

Quality of the chemical at inception that is coagulant is one of the causes for poor quality of water. When a chemical coagulant is added, it undergoes hydrolysis that is metal hydroxyl ions are formed (McCarthy and Humphries, 2013). Aluminium salts such as aluminium sulphate, sodium salts such as sodium aluminate and ferric salts such as ferric chloride are examples of coagulants (Carlson et al., 2000). Ten percent solution is the chemical dosage for aluminium sulphate. For treated water of Kwekwe municipality, 1000kg of aluminium sulphate is diluted into 10000 litres and gives a ten percent solution when multiplied by 100. For pH correction a 5 percent solution is used for treated water and 500kg is put in 10 000 litres of water for plant water giving a 5 percent solution when multiplied by 100 percent. When mixing, there has to be a balance for both positive and negative ions and if this is not so the quality of water deteriorates (Chinhanga, 2010).

Another cause of poor quality water is the intake structure such as screens. In a conventional water system, these are there just before the low lift pumps and are important in removing dead fish, logs, and leaves (Kohl, 2006). The structures should be kept free of sludge, growth, mineral ions such as manganese and debris and this helps in improving the quality of water, screens also help to protect mechanical machinery such as pumps thereby reducing downtime due to unplanned breakdowns (Herrera, 2011). A metallic and salty taste may indicate pollution in the water supply.

Precipitation is also among factors affecting water quality. Precipitation in form of mist, snow and rain is said to be the main source of freshwater (World Bank, 2009). It has contaminants that are undesirable to the quality of water such that the turbidity levels of water rise Wanielista et al. (Undated). In industrialised areas rain is acid because of dissolved oxides and nitrogen formed from burning fossil fuels in factories and cars (Gordon, 2003).

The major factor that might have caused an increase in the turbidity levels for raw water is construction, logging, mining sites and some tilled land for agriculture have an increased level of exposed soil and decreased vegetation (Shock, 2005). These loosen the soil leaving it exposed to erosion and runoff whereby the soil is carried by erosion agents such as wind and rain to a nearby stream, hence it is a non-point source of turbidity. This scenario might have happened to the Sebakwe River, the main water source which pours water into the Dutchman pool dam. It has also been argued that the Sebakwe River is covered by the water hyacinth weed which blooms leaving no space for sunlight penetration hence higher turbid water levels (Kreger, 2004).

Agriculture contribute to the pollution of water sources. Pesticides, algicides and fertilizer application affect the quality of both groundwater and surface waters (White and Hammond, 2009) When deforestation has taken place so as to create a farming area, the land becomes susceptible to wind and rain which are erosion agents and the sediments are transported and deposited into rivers and dams.

Corrosion of metal pipes within the reticulation system is another cause for poor quality of water (Marchand and Rabideau, 2011). As water passes through the distribution system, the water quality can degrade by chemical reactions and biological processes. Corrosion of metal pipe materials in the distribution system can cause the release of metals into the water with undesirable aesthetic and health effects (McNeill and Edwards, 2004). Release of iron from unlined iron pipes can result in consumers' reports of red water at the tap and release of copper from copper pipes can result in reports of blue water and or a metallic taste (MOE, 2009). Copper and lead levels at the consumer's tap are regulated to protect consumer health.

Recreation affect the quality of water. Recreation is an activity of leisure which is discretionary as well as an essential element of human biology and physcology (Mclean et al., 2005). The activities bring about enjoyment, amusement and pleasure. Many people make use of marine environments for sea sports among the coastal populations such as boat cruising especially in Europe and other developing countries including Zimbabwe and pollute water by urinating inside the water and dumping litre (Mclean et al., 2005).

Mining activities such as gold panning acid mine drainage also have negative effects upon the quality of water. Mining uses large amounts of water especially gold panning. The amount of water used in the mining companies of South Africa have been limited by reducing output from 2011 to 2012 and the country remains the fourth largest mining nation in the world (Greve, 2013). Furthermore, they are illegal miners in the city of Kwekwe who engage into gold panning activities and end up breaking distribution pipes inorder to access water for the panning process. This makes water a scarce resource and causes pollution. The tailings from surface mining often carry heavy metals within them and these metals become toxic at low dissolved concentration within surface water resources such as lakes killing aquatic life and polluting water resources (Bernstein, 1996).

Furthermore, acid mine drainage is among the sources of water pollution and this is the outflow of water consisting of iron, manganese and aluminium ions from old and abandoned mines. These give an orange colour to water within the rivers and lakes, altering the dissolved oxygen level thereby increasing the turbidity of both surface and groundwater water. (Stoddard, 2013).

CHAPTER 3

3.0 Materials and Methods

3.1 Study Area

The study was carried out within the city of Kwekwe at the Dutchman Pool Waterworks formerly known as Sebakwe Treatment Works, within residential areas and town which include the following: Mbizo Poly Clinic, National Foods Limited, Kwekwe Polytechnic, Amaveni, Civic centre, Zaoga Masasa and Chana Primary School. Some samples for treated water as well as raw water were considered giving a total of nine sampling points.

Kwekwe is a city situated on the Highveld of Zimbabwe at an altitude of 1.220 metres. The geographical location of Kwekwe is 18^0 55^1 $00^{''}$S and 29^0 49^1 $00^{''}$ E (Buchholz and Oberthur, 2007). The average annual temperature is 19 °C and drought years are hotter than wet years (Musapindira, 2014). Kwekwe receives mean annual rainfall of between 600 to 900 mm Chenje (2000). The climate is hot and wet during the summer rainy season from mid-November to mid-March, with cool, dry weather from May to mid-August in the winter season, and warm dry weather from August to mid-November (Chinhanga, 2010).Winters are characterised mainly by their cold nights, with an average minimum temperature of 7 °C and are the sunniest time of the year (Chinhanga, 2010). Limestone, basaltic and periodititic, metavolcanics and metasediments characterise the soils of Kwekwe (Cheshire et al. 1980). Fig.1 shows the location of Kwekwe city and the sampling points used in the study:

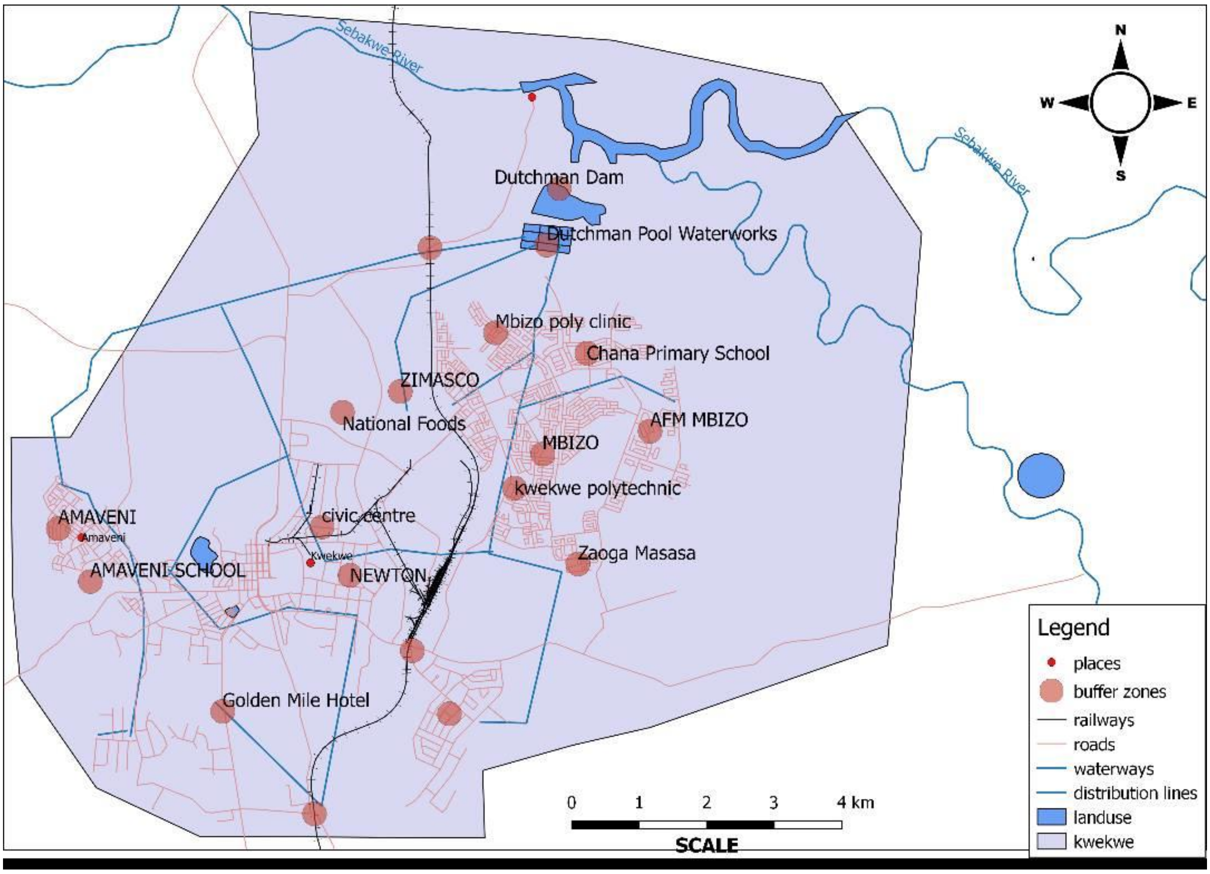

Fig 3.1 is showing the map of Kwekwe city showing sampling points within the reticulation system.

The red dots signify the sampling points. Mbizo and Chana were the nearest points whereas Zaoga Masasa and Amaveni were the furthest. Distance was measured from the Dutchman Pool Waterworks to the individual sites.

Table 3.1: Distance between sampling points

Sampling point	Distance (km)
Dutchman Pool	0
Dutchman Pool Waterworks	2.0
Chana Primary School	4.5
Mbizo Poly Clinic	4.5
National Foods	6
Civic Centre	8.5
Kwekwe Poly	9
Amaveni	9.5

Zaoga	10

3.2 Sampling Method

Random sampling was done and nine different sampling points were selected and sampled for pH, turbidity, free chlorine, total chlorine and faecal coliforms every month within the Kwekwe municipality. At the laboratory, some quality control tests were also conducted every morning. The tests were both for final or treated and raw water. When collecting the samples, some squeeze bottles were used and the water from the tap was allowed to run for five to ten minutes before collecting the sample. Chlorine was tested first because it tends to vapourize. Samples were collected between January and February 2016 representing the wet season as well as May and June 2016 standing for the dry season. Nine samples were collected each month giving a total number of thirty-six samples.

3.3 Analytical methods

3.3.1 pH

For pH measurement a lovibond comparator with suitable disc, two cuvettes and an iron indicator, phenol red were used. For the nine samples, one millilitre of the indicator solution was added into 10 millilitres of water in the right chamber of the lovibond comparator and shaked gently. The colour developed was matched against permanent glass colour standards supplied by the manufacturer of pH to the desired value (Chatterjee, 2001).

3.3.2 Turbidity

Turbidity was measured using both direct reading turbidimeter and portable turbidimeter in NTU (Nephelometric Turbidity Unit) which is equivalent to FTU (Formazin Turbidity Unit). The instrument was first calibrated using Formazin standard method, (Sabnis, 2010). A sample cell with approximately 30 millilitres of water was put into a turbidimeter and light shone upon it. A photodiode captured the scattered light which produced an electronic signal that is converted to turbidity and a reading was taken in NTUs.

Fig 3.2: The Direct Reading Turbidimeter.

3.3.3. Free chlorine

For free chlorine DPD (diethyl- p-pheneylene di amine) number one was used. The pill was dissolved in ten milligrams of water of each of the samples. This is also confirmed by Kennith, (2008) who argues that only ten milligrams of water is required for the method to be effective. Using the chlorine test kit, a blank sample and a sample under investigation were put upon the chlorine lovibond, a reading was taken and results were recorded on a record sheet. This was done for eight treated water samples.

3.3.4 Combined chlorine

Combined chlorine has to be determined in order to interpret the amount of chlorine used within the distribution system. (Rose, 2002). DPD number four was used for a short time and since the pills were not always available due to their costs, DPD three was added to DPD one. Each sample of water was dissolved into ten millilitres of water. A chlorine lovibond was used to take the reading by exposing the instrument to light and then read through its transparent windows. Two samples were put upon the lovibond, one with a DPD pill and the other one blank. Readings were taken when the blank sample matched with the other sample in terms of the colour of water.

3.1.5 Coliforms

For total coliforms some microbial tests for bacteria were done using the Membrane Filter Technique (Feng et al., 2013; Weagant, 2001). Samples were collected using sterilized or disinfected glass bottles. The samples were left in an incubator for eighteen hours under a temperature of forty-four degrees Celsius.

3.4 Statistical Analysis

For statistical analysis, both one way and two way ANOVA were used using GenStat version seventeen and Microsoft Excel 2013. The hypothesis test was done at 5% significant level. The months and standard plots and sampling points were the treatments. pH, turbidity, free chlorine, combined chlorine and total coliforms were the variates. Regression Analysis was done using Microsoft Excel.

CHAPTER 4

4.0 Results and Discussion

4.1. pH

For Kwekwe municipal water the pH of water within the reticulation system ranged from 7 to 7.4. The pH of water in the wet season was neutral at 7 and near alkaline at 7.4. pH was significantly higher during the dry season than during the wet season ($p<0.05$).

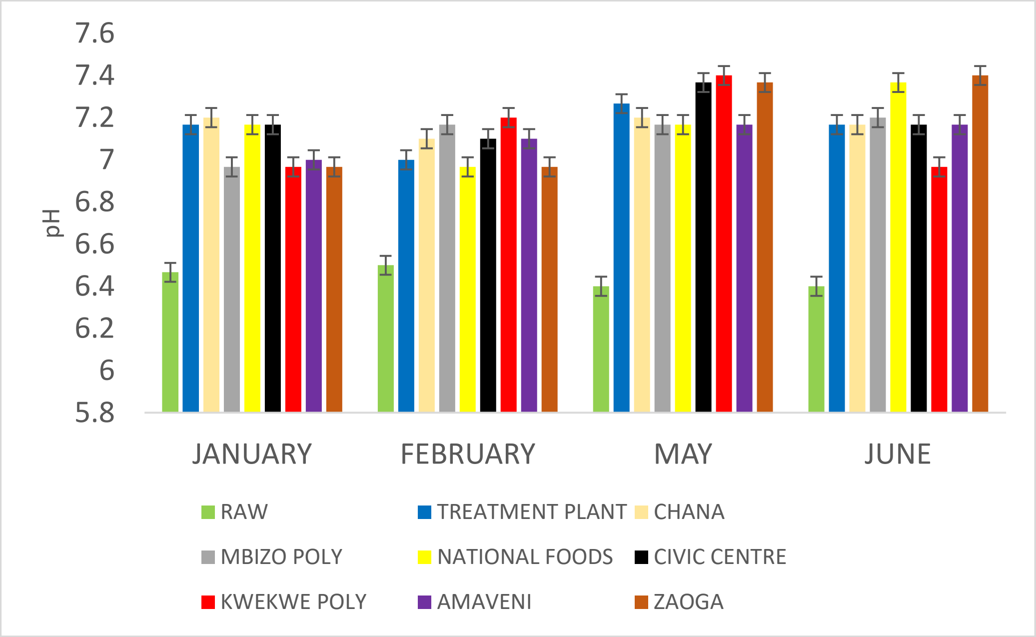

Fig 4.1: pH values of different sampling sites for both dry and wet season.

The neutral to near alkaline pH is as a result of the quality of calcium hydroxide (hydrated lime) used in pH correction which is a strong alkaline. It tends to raise the pH of water because of the balance between hydroxyl ions, calcium and magnesium ions (McDevitt, 2013). The pH of water should range from 6.5 to 8.5 hence, the potential hydrogen was within the WHO permissible ranges for all the sites (WHO, 2013).

4.1.2 Free chlorine

The winter season had the least levels of free chlorine which were 0.3 milligrams per litre whilst the summer season had 1.0 milligrams per litre. Residual chlorine was higher within individual sites closer to the Dutchman Pool WaterWorks than the points that are far away from the treatment plant.

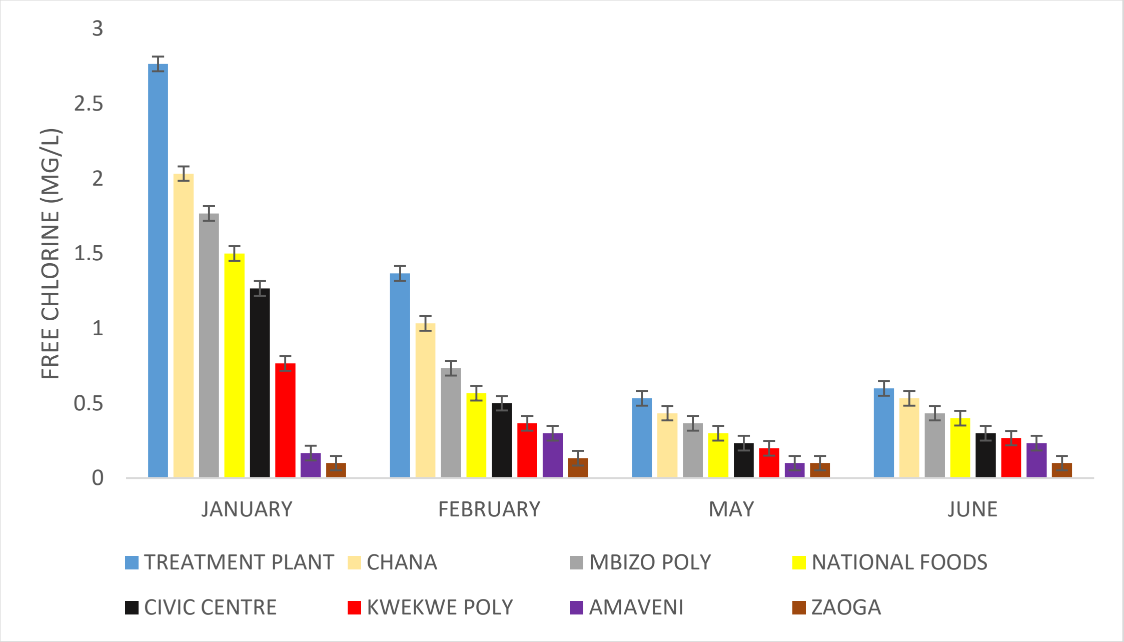

Fig 4.2 Free chlorine levels of different sampling sites for the dry and wet season.

The high concentrations of free chlorine are as a result of increased chlorine dosage also known as chlorine burn inorder to meet greater demand thereby killing viruses, cysts or worms. (Baker et al., 2002). Chlorine burn would result in killing of biofilms thereby maintaining constant residual chlorine level (Foster, 2015). The contact time which is the time when the chemical is introduced into water to the time when the water is used is also the contribution factor varying free chlorine levels at different locations. From Fig. 4.2, Chana exhibited relatively high chlorine level of 1.5 milligrams per litre during the wet season because there was less contact time so chlorine residual is bound to be high. Mbizo Poly, National Foods, Civic Centre, Kwekwe Poly and the treatment plant had chlorine residual values of 1.3, 1, 0.9, 0.6 and 2.1 milligrams per litre. Low chlorine residuals of 0.2 and 0.1 milligrams per litre at Amaveni and Zaoga respectively during the wet season were due to the accumulation of biofilms within the distribution supply network and these use up available chlorine (Foster, 2015). Free chlorine levels should range from 0.3 to 0.5 milligrams per litre (WHO, 2014). All sites were still showing higher levels of chlorine during summer except for Zaoga and Amaveni. However, the chlorine values during the winter for Kwekwe Poly, Zaoga and Amaveni did not meet the WHO standards and the values were 0.2; 0.2 and 0.1 milligrams per litre respectively. Higher chlorine levels impart chlorine odours and taste to water supplied to consumers (Foster, 2015).

4.1.3 Combined chlorine

The wet season had higher chlorine values of 1.5 milligrams per litre compared to 0.7 milligrams per litre during the dry season. The chlorine concentration tends to decrease with distance from the treatment plant to an individual site.

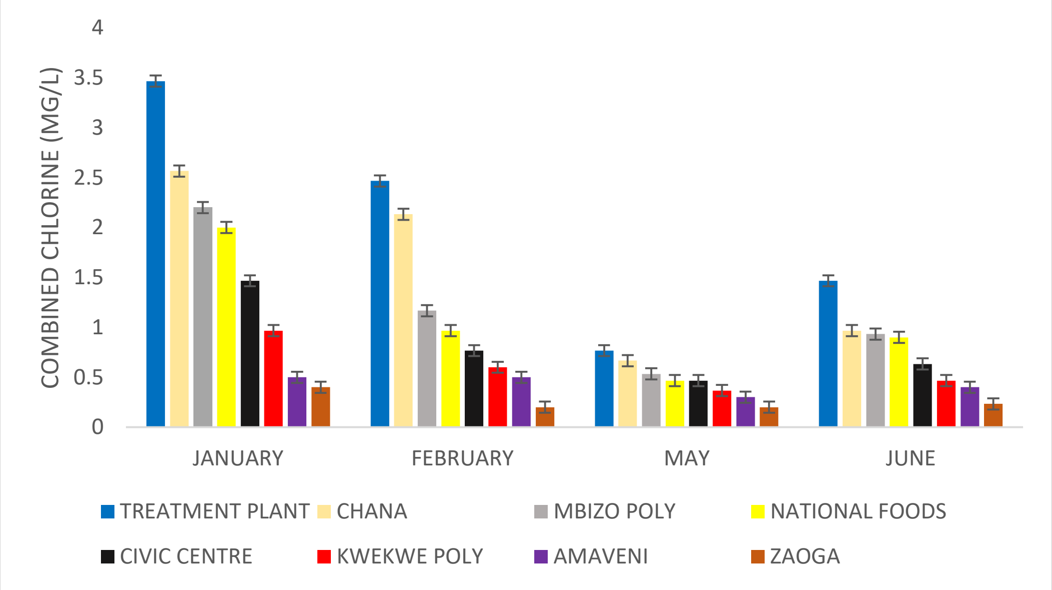

Fig 4.3 Combined chlorine levels of different sampling sites for the dry and wet seasons

The combined chlorine concentrations for the Treatment Plant, Chana, Mbizo Poly and National Foods were high during the wet season with the following values; 2.4, 1.7, 1.5 and 1.1 milligrams per litre. Higher values of combined chlorine was due to contact time. The distribution points are 4.5, 4.5 and 6 kilometres from the treatment plant (Fig. 3.1). A great difference between free and combined chlorine would imply that there is still room for chlorine to react with impurities, hence a small difference is preferred (Gates et al, 2009). There is a difference of 1 milligram per litre for National Foods in June which is part of the dry season. Chana had a difference of 0.9 milligrams per litre. Mbizo Poly had a difference of 0.4 milligrams per litre.

The desirable standards for combined chlorine in drinking water range from 0.5 milligrams per litre of water to 1 milligram per litre, combined chlorine levels for Chana and Mbizo poly did not meet the WHO guidelines most probably due to the reasons outlined above (WHO, 2014). Moreso, Kwekwe Poly, Amaveni and Zaoga were 0.4, 0.4 and 0.2 milligrams per litre during the dry season and these were below the WHO standards.

4.1.4 Total Coliforms

Total coliforms were present in raw water during the wet and dry seasons and amounted to 15 and 4.7 coliforms per 100 millilitres of water respectively. Total coliforms in water were significantly higher during the wet season as compared the dry seasons for ($p< 0.001$), Fig. 4.4

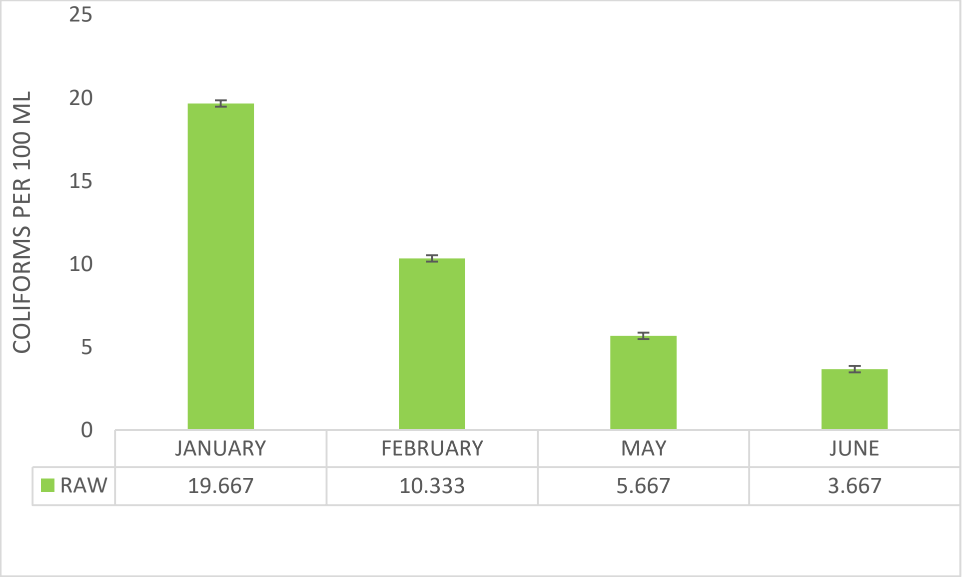

Fig 4.4 Total coliforms in raw water in both summer and winter seasons.

More coliform bacteria were observed during the summer season because of time and weather conditions. The wet season tends to provide warmer environment favoured by coliform bacteria (Abera1 et al., 2011). Winter had the least amount of coliforms most probably due to the dry and cold conditions not conducive for microbial life. Coliforms are found in larger quantities during the rainy season compared to the dry season (Aberal et al., 2011). No coliforms were observed within the eight treated water samples of National Foods Limited, Amaveni, Mbizo Poly Clinic, Zaoga Masasa, Kwekwe Polytechnic, Chana Primary School, Civic centre as well as the Treatment Plant. This implies that the plant was efficient in removing all the coliforms and free chlorine was effective. Treated water becomes unsatisfactory for drinking when it contains coliforms. The WHO guidelines entails that there should be zero coliforms per one hundred millilitres of water sample in drinking water (WHO, 2010). Both Faecal coliform and Escherichia coli should be absent in drinking water as they cause severe death and illness to humans.

4.1.5 Turbidity

The turbidity of water during the wet season was higher with a value of 5.3 NTUs as compared to 1.7 NTUs during the dry season. The water within the reticulation system was below the WHO standards particularly for Amaveni, Kwekwe Poly and Civic Centre with turbidity values of 7, 7.3, 5.3 NTUs during the wet season. Raw water turbidity was 13 NTUs during the wet season. Therefore, the turbidity of water was significantly higher during summer than winter seasons for different sampling sites ($p < 0.001$) for both treated and raw water.

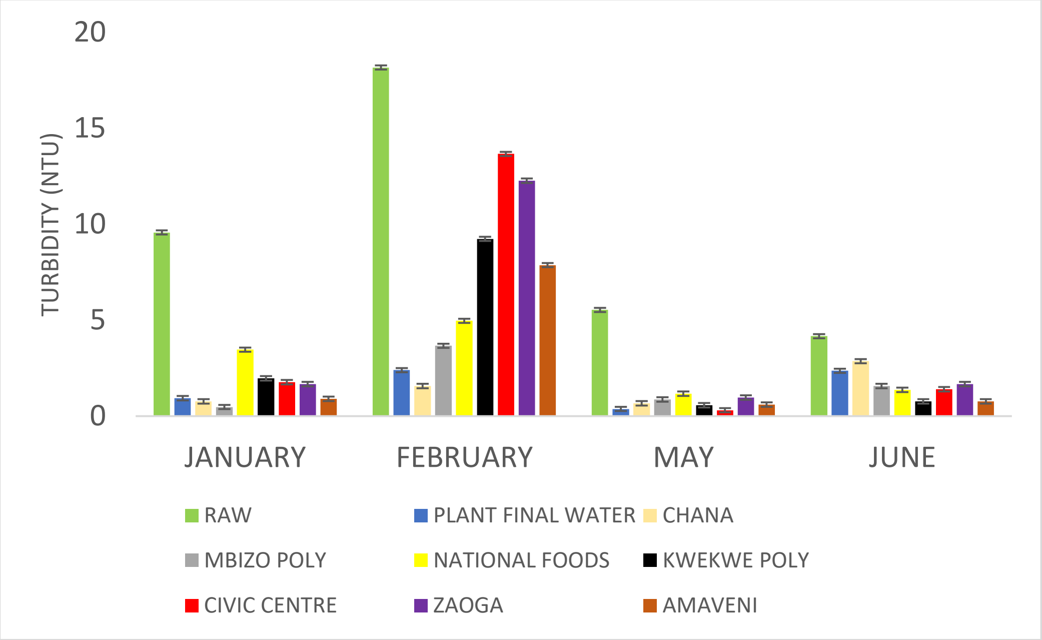

Fig 4.5 Turbidity of different sampling sites for both dry and wet seasons.

Higher turbidity values within the reticulation system were as a result of the bursting of pipes allowing foreign substances such as soil particles to enter into drinking water leading to its deterioration. Raw water turbidity had to be taken into consideration as it determines the efficiency of the plant. If the pollution is very high then the treatment plant efficiency is also high. Within the distribution system, the turbidity increased due to the accumulation of biofilms within the pipes. The guidelines for the turbidity of both treated and raw water is 5 NTUs (WHO, 2010). During the dry season, all sites met the standard of WHO as the values ranged from 0.7 to 4.9 NTUs.

4.2 Relationships between the different parameters and distance

4.2.1 Free chlorine concentration

There is an inverse proportionality between distance and free chlorine concentration as shown in Fig 4.6. In other words, free chlorine decreases with increasing distance from the treatment plant to an individual site during the wet season. This relationship is strong at R^2= 0.93.

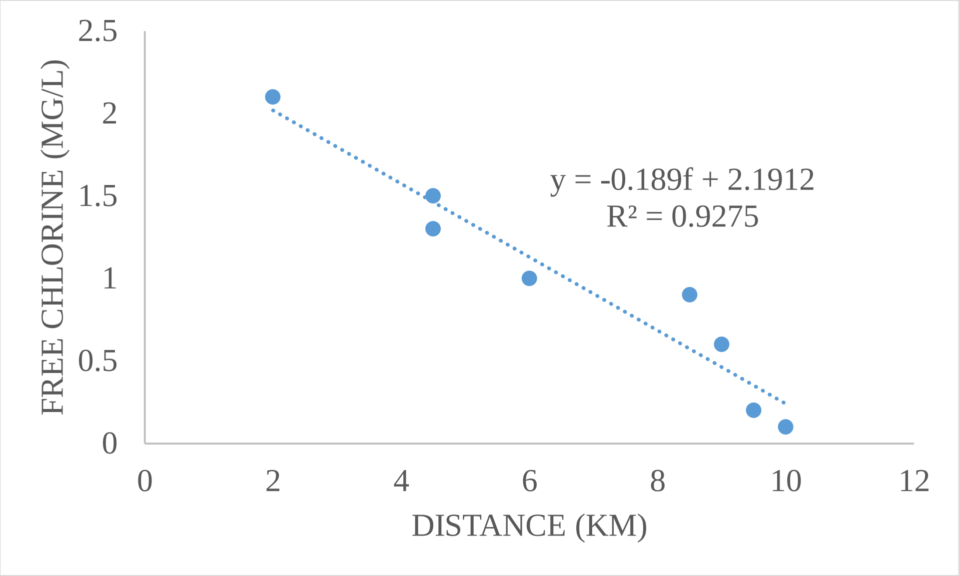

Fig 4.6 The change in free chorine concentration in response to distance during the wet season.

There is an inverse proportionality between distance and free chlorine concentration during the dry season hence an R^2 value of 0.91.

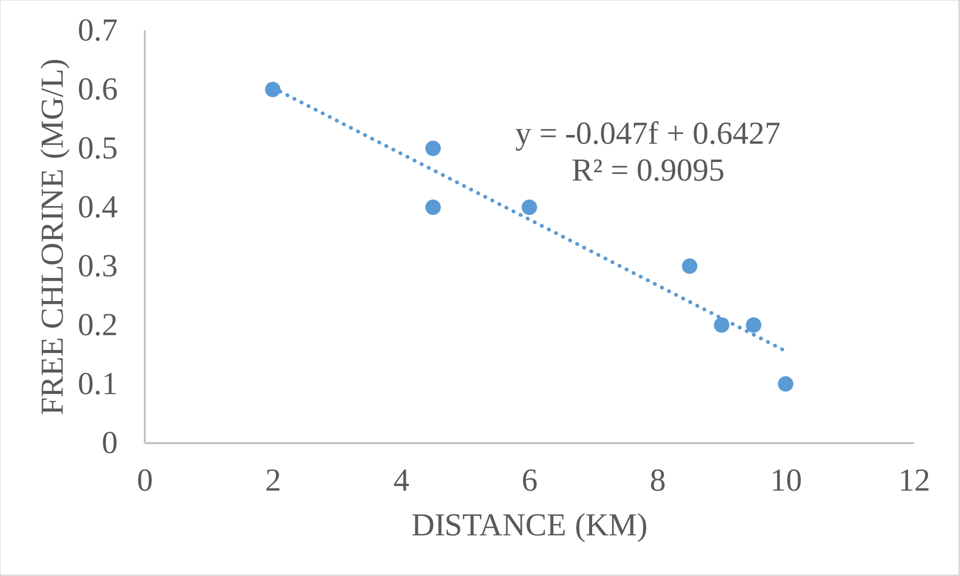

Fig 4.7 The change in free chorine concentration in response to distance during the dry season.

4.3 Combined chlorine

Combined chlorine is inversely proportional to distance where chlorine concentration decreases with increasing distance. There is an inverse proportionality between distance and combined chlorine concentration (R^2= 0.91).

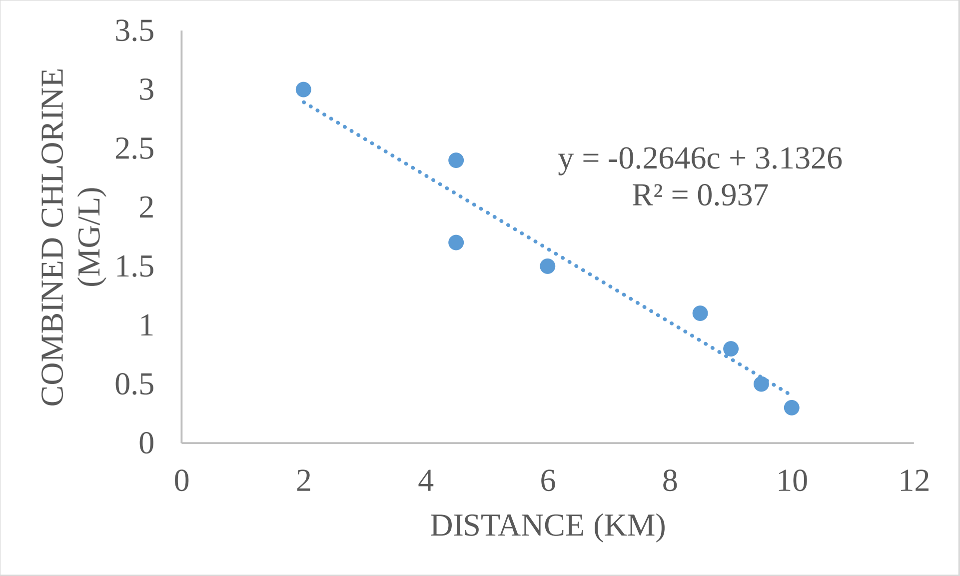

Fig 4.8 The change of combined chlorine concentration in response to distance during the wet season.

There is an inverse proportionality between distance and combined chlorine concentration during the dry season as shown in Fig. 4.9. The changes in distance are influencing combined chlorine concentration as $R^2 = 0.90$.

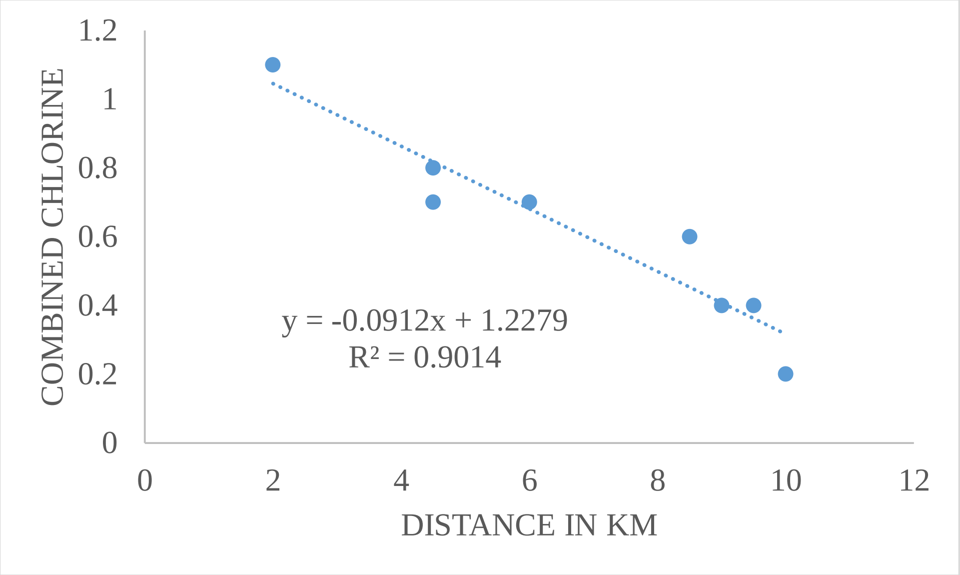

Fig 4.9 The change of combined chlorine concentration in response to distance during the dry season.

There are changes in the combined chlorine concentration in response to distance. The greater the distance, the smaller the amount of chlorine and the smaller the distance, the greater the amount of chlorine.

4.4 pH

The change in distance does not influence the pH values hence $R^2 = 0.1$ hence there is a direct proportionality between distance and pH value.

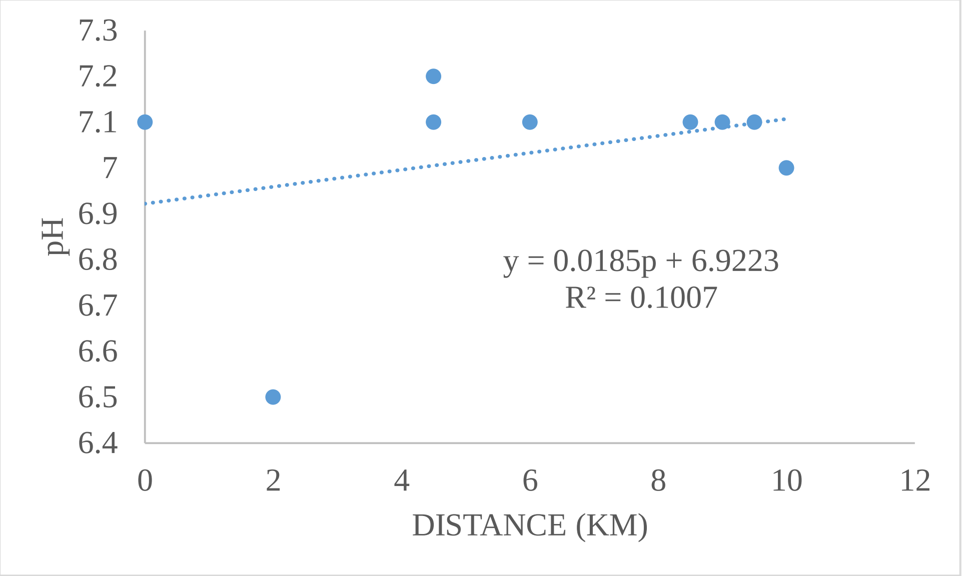

Fig 5.0 The change in free chorine concentration in response to distance during the dry season.

The change in distance does influence the pH values hence R^2= 0.2. There is a poor but positive relationship between pH and distance for both the dry and wet seasons.

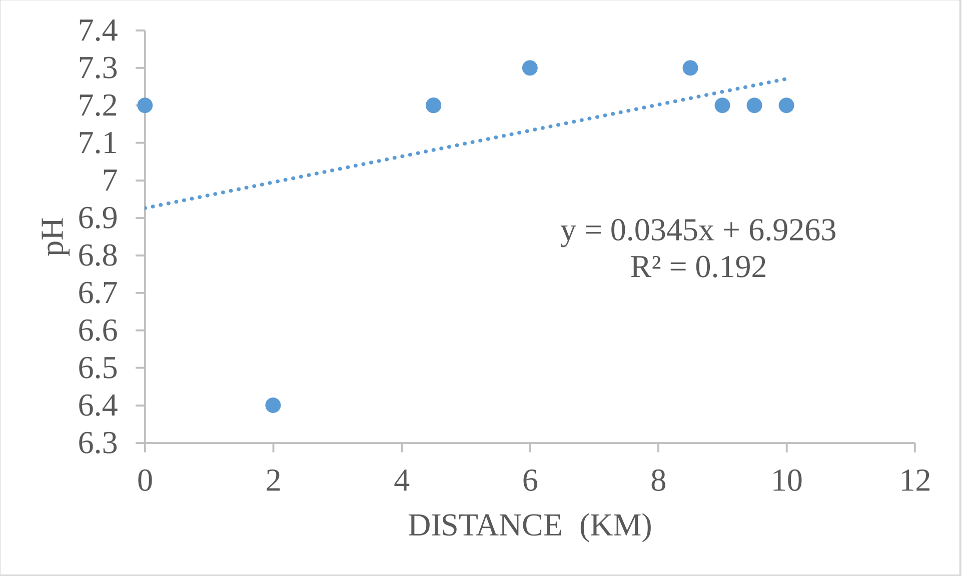

Fig 5.1 The change in free chorine concentration in response to distance during the dry season.

4.5 Turbidity

There is no relationship between distance and turbidity (R^2=0).

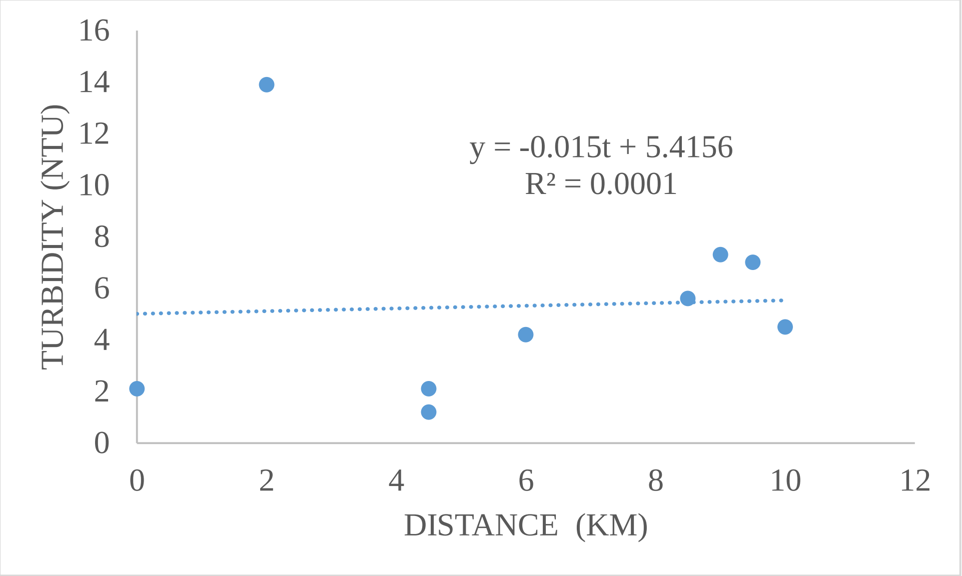

Fig 5.2 The change in turbidity in response to distance during the wet season.

There is a direct proportionality beween distance and turbidity. In other words, change in distance is not correlated to turbidity. In simpler terms, changes in distance are not influencing turbidity values as R^2= 0.3 (Fig 5.4).

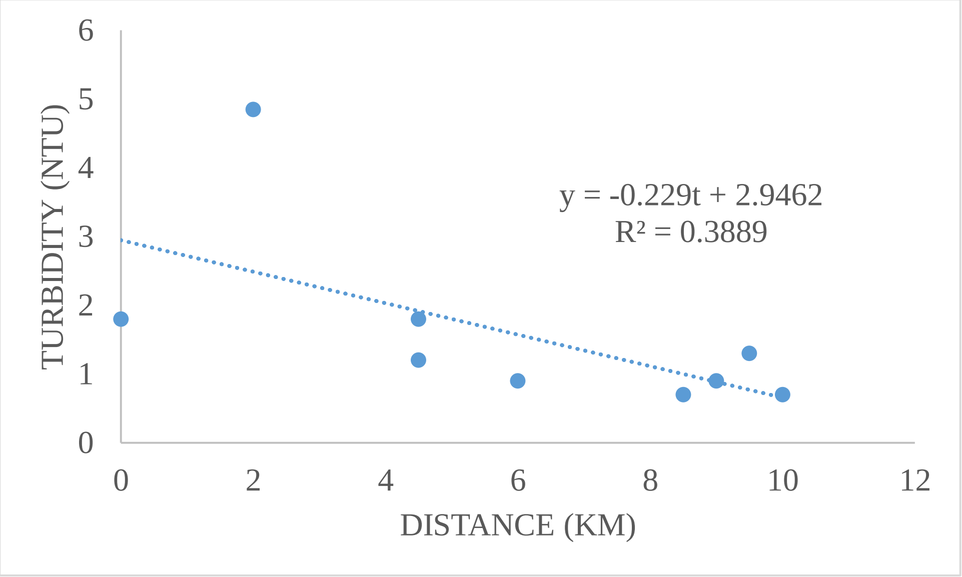

Fig 5.4 The change in turbidity in response to distance during the dry season.

CHAPTER 5

5.0 Conclusion and Recommendations

5.1Conclusion

Water quality standards for Kwekwe Municipality were at most within the recommended standards of WHO especially pH and coliforms. Zero coliforms were recorded for treated water and the pH ranged from 7 to 7.4. However, it is very difficult to achieve all water quality standards at once. Turbidity and chlorine concentrations were problematic as they were quite high within the reticulation system as well as from the source.

5.2Recommendations

Water quality within the reticulation system should be tested on a regular basis such that the source of the water related problems can be detected. The chemicals required for water treatment and quality control tests should be available at Dutchman Pool WaterWorks. Kwekwe municipality should rehabilitate some engineering structures such as screens as these lower the quality of drinking water. Chlorine dosage need to be reduced as it has detrimental effects to human health. Kwekwe municipality should also protect its water sources such as Dutchman Pool and Sebakwe River so that the treatment is less expensive as the water will be clean.

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Appendices

Appendix I

Analysis of Variance

Variate: pH

Source of variation	d.f	s.s	m.s	v.r	Fpr
Month	3	0.495556	0.165185	81.09	<.001
Standard plot	8	5.474074	0.684259	335.91	<.001
Month standard plot	24	1.091111	0.045463	22.32	<.001
Residual	72	0.146667	0.002037		
Total	107	7.207407			

Appendix II

Analysis of variance

Variate: Free_chlorine

Source of variation	d.f	s.s.	m.s	v.r.	F pr.
Month	3	15.285313	5.095104	2126.65	<.001
Standard_plot	7	14.022396	2.003199	836.12	<.001
Month.Standard_plot	21	8.410521	0.400501	167.17	<.001
Residual	64	0.153333	0.002396		
Total	95	37.871562			

Appendix III

Analysis of variance

Variate: Total_chlorine

Source of variation	d.f.	s.s	m.s.	v.r	F pr.
Month	3	20.079167	6.690356	2141.78	<.001
Standard_plot	7	30.528333	4.361190	1395.58	<.001
Month.Standard_plot	21	10.770833	0.512897	164.13	<.001
Residual	64	0.2000000	0.003125		
Total	95	61.578333			

Appendix IV

Analysis of variance

Variate: Turbidity

Source of variation	d.f	d.f	m.s.	v.r.	F pr.

Month	3	839.49815	279.83272	23247.64	<.001
Standard_plot	8	564.79574	70.59947	5865.19	<.001
Month.Standard_plot	24	488.37685	20.34904	1690.54	<.001
Residual	72	0.86667	0.01204		
Total	107	1893.53741			

Appendix V

Analysis of variance

Variate: Coliforms

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Month	3	50.77778	16.92593	457.00	<.001
Standard_plot	8	1031.40741	128.92593	3481.00	<.001
Month.Standard_plot	24	406.22222	16.92593	457.00	<.001
Residual	72	2.66667	0.03704		
Total	107	1491.07407			

Appendix VI

SUMMMARY
OUPUT: pH

Regression Statistics	
Multiple R	0.523071
R Square	0.273603
Adjusted R Square	0.169832
Standard Error	0.187835
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.093025	0.093025	2.636603	0.148455
Residual	7	0.246975	0.035282		
Total	8	0.34			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Uppe 95.0*
Intercept	6.850333	0.128926	53.13401	2.19E-10	6.545473	7.155194	6.545473	7.1551
X Variable 1	0.0305	0.018784	1.623762	0.148455	-0.01392	0.074916	-0.01392	0.0749

Appendix VII

SUMMARY OUTPUT: Free chlorine

Regression Statistics	
Multiple R	0.964672
R Square	0.930592
Adjusted R Square	0.919024
Standard Error	0.191156
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.939506	2.939506	80.4449	0.000107
Residual	6	0.219244	0.036541		
Total	7	3.15875			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.462815	0.180413	13.651	9.6E-06	2.021361	2.904269	2.021361	2.9042
X Variable 1	-0.22227	0.024782	-8.96911	0.000107	-0.28291	-0.16163	-0.28291	-0.161