SUITABILITY OF ATHI RIVER WATER FOR IRRIGATION WITHIN ATHI RIVER TOWN AND ITS ENVIRONS

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DECLARATION

I understand that plagiarism is an offence and I therefore declare that this thesis is my original work and has not been presented for an academic award in any universityor any institution of higher learning.

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LIST OF ABBREVIATIONS AND ACRONYMS

Adj.RNa……………………..New Adjusted Sodium Adsorption Ratio

Adj.SAR…………………….Adjusted Sodium Adsorption Ratio

APHA……………………...American Public Health Association

Cd…………………………Cadmium

dS/m………………………deci-Siemens per meter

DSTP……………………...Dandora Sewage Treatment Plant

EC…….…………………….…Electrical Conductivity of water

IEBC………………………Independent Electoral and Boundaries Commission

Meq/L……………………..Milli-equivalents per Liter

Mn…………………………Manganese

MOWD……………………Ministry of Water and Development

Ni………………………….Nickel

Pb………………………….Lead

SAR……………………….Sodium Adsorption Ratio

SoE………………………..State of Environment

US…………………………United States

USDA……….…………….United States Department of Agriculture

UN…………….…………..United Nations

UNEP……………………..United Nations Environment Programme

WHO………………………World Health Organization

WRMA……………………Water Resources Management Authority

ABSTRACT

The main aim of this study was to assess the suitability of the Athi River water for irrigation in Athi River area and its environs. The study area was within Athi River and Muthwani ward within Mavoko Constituency and in Machakos County, Kenya. Seven sampling points were selected along the study transect (about 8 km) and sampling was done once every week from 21st January to 6th March 2015 (dry season). The water samples collected were analyzed for selected physico-chemical and bacteriological parameters. Field observations and administration of questionnaires was used to identify major sources of pollution into the river. The data collected was analyzed using SPSS version 16 and Microsoft Office Excel 2007. The level of *E.coli* was above the NEMA and FAO standards at all sampling points (1,073 ± 355-2,203 ± 433 MPN/100ml). The range of concentration and values of physico-chemical parameters were pH 7.74 - 8.71;, TDS, 497.57-1731 mg/L;, Electrical conductivity (EC), 0.72-2.47 dS/m; Ca, 0.03-0.54 me/L; Mg, 0.20-0.64 me/L; Na, 0.28-0.85 me/L;, Magnesium Hazard, 47.6-86.8; Cr, 0.02-0.11 mg/L; Pb, 0.08 - 0.25 mg/L; and Sodium Adsorption Ratio (SAR), 0.44-1.31. Municipal effluent was identified as the major source of water pollution. Most of the parameters in the water samples were within the recommended limits though there was an increasing trend in their concentration from sampling point 1 to sampling point 7. Moderate sodicity hazard was reported at three sampling points. Based on the results of physico-chemical parameters Athi River water within the study area can be classified as suitable for irrigation. However it imperative that periodic monitoring of river water quality and effluent discharges into the river is done and the public is made aware of the dangers paused by the high concentration of *E.coli*. Future studies/ research need to consider the analysis of pollutants in the plant and animal tissues to ascertain the potential impact of biomagnification and bioaccumulation the pollutants.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Water is a commodity that is consumed and acts as a carrier of other substances or properties such as organic and inorganic chemicals, heavy metals, disease vectors and energy. Whereas the quantity of water on earth remains constant, its quality changes both temporally and spatially and is highly influenced by human activities. As such, a negative impact that may arise from the consumption of water may cause great strain on the supply systems (Kiithia, 2012).

The world experiences a number of water related problems including water scarcity and waterborne diseases. Water pollution has been identified by Waruguru *et al*. (2011) as one of the major problems facing many countries of the world. It is caused by a variety of anthropogenic and natural factors. For example, it may result from the discharge of various substances directly into the water bodies, or indirectly through the catchment areas. Muiruri *et al*. (2013), identified weathering of soils and rocks and a variety of anthropogenic activities as the two independent factors that result into the presence of heavy metals in water hence creating a societal health risk in rivers that are otherwise useful for domestic purposes. According to Deepali (2010), heavy metals are important for proper functioning of biological systems but their deficiency or excess could lead to a number of disorders. These problems are exacerbated by poor waste management from unplanned settlements and higher population growth rates without a corresponding improvement in the appropriate infrastructure.

Water pollution has been a perpetual problem in the world since the onset of civilization. Howarth *et al.* (2002) reported that some 60% of coastal rivers and bays in the U.S. have been moderately to severely degraded by nutrient pollution and attributed the pollution cause to increased human activity. In the first case study of the Ganga River in India, Sharma (1997) reported that human activities largely contributed to the pollution of the four major river basins of which the Ganga sustained the largest pollution. The study reported that 75% of the pollution load was from municipal sewage and that the majority of the surrounding cities lacked sewage treatment facilities.

Kenya too has not been an exception regarding water pollution particularly in rivers. Water resources in Kenya are increasingly becoming polluted from both point and nonpoint sources due to agriculture, urbanization, and industry which contribute to organic, inorganic and aesthetic pollution of water (Kiithia, 2012). Just like other developing countries, the quest to get industrialized within the shortest possible period of time has worsened the pollution of water bodies. Kiithia (2012) observed that the problem of water pollution and quality degradation in the developing countries is increasingly becoming a threat to the natural water resources and that this phenomenon is attributed to the increasing quest of these countries to attain industrialization status and diversification of the national development goals and Kenya is no exception to this phenomenon. Pollution of several rivers in Kenya has been documented by various studies and reports. Musyoki *et al*. (2013) in an assessment of the quality of Nairobi River and Athi River waters found out that the waters were highly contaminated with pathogenic bacteria while Musyoki (2012) reported pollution of Nairobi River and Athi River were polluted by effluents from the Dandora Sewage Treatment Plant (DSTP). While Waruguru *et al*. (2011) observed that the city of Nairobi has experienced rapid industrialization and growth in population in the last 100 years but the population growth and increased industrialization have not been matched by development of infrastructure to deal with waste disposal. Consequently, the unplanned disposal of garbage, human and industrial waste has resulted in increased pollution of water bodies.

Water quality degradation problem is not a new phenomenon in Kenya. Initial research reports on the problem in the country dates back to the 1950's. In Kenya, the problem of water quality degradation was first exposed by MOWD (1976 a & b) in a case study of three rivers; Nzoia, the Nyando and Kerio. These reports contain the chemical characteristics of water shortly before and after establishment of factories along their courses. Nzoia River which drains into Lake Victoria carries the effluents discharged from Pan Africa Paper Mill in Webuye upstream and from Mumias Sugar Factory downstream; Nyando which also discharges its waters into Lake Victoria receives waste from Chemilil and Muhoroni sugar factories. Kerio River which drains the Kerio Valley with intermittent flow into Lake Turkana is periodically polluted by effluents from fluorspar factory established three decades ago. All these three reports are a clear indication of the effects of industrial growth on the quality of water courses as their effluents are a major contributing factor to water quality degradation (Kiithia, 2012).

Athi River town and its environs is a host to several industrial establishments and is characterized by poor waste management. Two unplanned settlements, Kwa Mang'eli and Chalenzi are situated close to the banks of Athi River and therefore potentially polluted runoff from poorly managed waste from these slums drains into the river. UN-HABITAT (2006) observed that Mavoko, popularly known as Athi River, is a growing industrial town. Figure 1.1 shows that there has been an exponential increase in the number of industries established in Athi river area from 1950 to 2004. This industrial growth has not been matched with the development or expansion of infrastructure to deal with the increased waste volumes from the industries. GOK (2004) also points out that the manufacturing industry in Kenya is associated with exploitation of natural resources, destruction of habitats, and generation of wastes and discharge of pollutants into the environment. A number of industries in Athi River area are manufacturing industries.

In a microbial survey of Athi River and its upstream distributaries, Muiya (2011) established that both microbial and chemical pollution particularly lead, arsenic and chromium pose a pollution risk to Athi River thus endangering the health status of the people downstream. Muiruri *et al*. (2013) also reported the presence of heavy metals in the water and fish tissues from the Athi-Galana-Sabaki tributaries and that level of heavy metals such as lead (Pb), nickel (Ni), manganese (Mn) and cadmium (Cd) were higher than the World Health Organization's (WHO's) limits. Athi River mainly receives domestic and industrial pollution from Mavoko town-Athi River town and its environs (UN-HABITAT, 2006) before confluence with Nairobi River to the east side of the city. As such Athi River is not free from pollution conditions that characterize other rivers in the world and in Kenya.

1.2 Justification of the Research

Water is a universal solvent. As such, it not only has multiple uses, but also, it can be rendered useless or harmful if its quality is altered, creating a myriad of problems. The Athi River town or Mavoko area is characterized by industrial establishments and poor waste management (UN-HABITAT, 2006). The Mavoko/ Athi River area offer a good opportunity for the expansion of the Nairobi Metropolitan Region and therefore the area is of strategic importance. As such, the area has experienced rapid industrial growth as shown in Figure 1.1. This rapid industrial growth has been characterized by growth of slums. A large percentage of waste from the slums and the increased industrial activity end up in the river.

Two unplanned settlements; Kwa Mang'eli and Chalenzi are situated close to the banks of the river. UN-HABITAT (2006) observes that a high population of Mavoko's inhabitants lives in appalling slum conditions with poor hygienic conditions. Both Industrial and domestic waste are poorly managed and there is a high possibility that they end up in the Athi river, negatively impacting on its quality.

Athi River waters serve both the upstream communities and downstream communities in various ways. Muiruri *et al*. (2013) observes that the waters of Athi River are useful for irrigation, drinking, and fisheries, while Musyoki *et al*. (2013) emphasize the use of the Athi River waters for domestic and agricultural farming by downstream communities. UN-HABITAT (2006) further notes that the Athi River is a major source of fresh water for domestic use in slums, but it is polluted by the runoff from the waste which is prominent in the water and the surrounding areas. It is therefore imperative that the quality of the water in Athi River be ascertained to verify if it meets the recommended standards for various uses under which the water is subjected to. It is of essence that the farmers on the banks of the river and the public in general be informed of the quality of the water regarding agricultural use and inform the relevant government agencies for remedial measures if the quality is below the recommended standards.

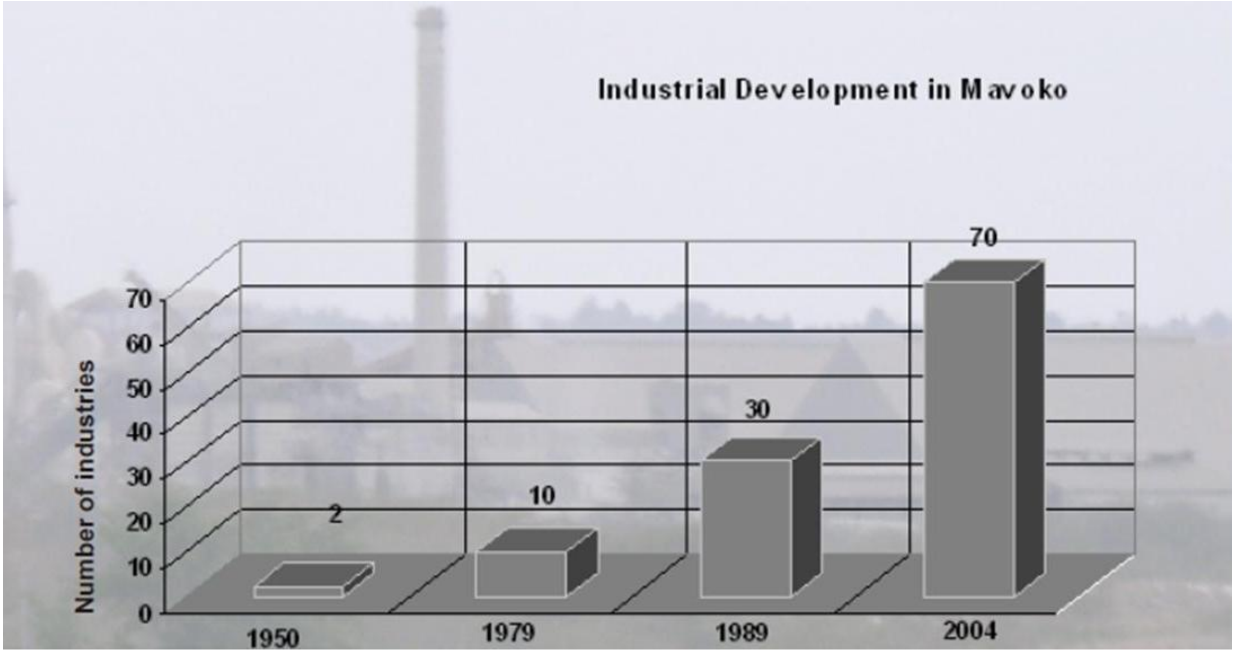

Figure 1.1: An exponential increase in the number of industries in Athi River/ Mavoko from 1950-2004 (Source: UN-HABITAT, 2006)

1.3 Problem Statement

Water pollution is one of the main environmental concerns especially in developing countries. The Athi River town is characterized by heavy industrial activity, poor waste management and mushrooming slums which may have negative impacts to the quality of water in the Athi River (UN-HABITAT, 2006). GOK (2015b) reported that the effluent discharge from the Export Processing zone sewage treatment works was polluting Athi River and that Athi River town is also characterized by poorly maintained sewage systems leading to the pollution of Mbagathi and subsequently pollution of Athi River

WRMA (2015) also observed that water pollution in the Athi Catchment arises from major cities of Nairobi, Mombasa, Machakos, Athi River and Kitui due to sewage disposal, industrial discharges and solid waste disposal. Although the government of Kenya came up with Water Quality Regulations (GOK, 2006) to curb pollution of water bodies, there have been reports of non-compliance by discharging bodies. The domestic/agricultural use of Athi River water may therefore put at risk the health of the locals and impact negatively on the economy.

The purpose of this study was to determine the suitability of the Athi River waters for irrigation use in Athi River town and its environs.

1.4 Objectives of the Study

The main objective of this study was to assess the suitability of the Athi River water for irrigation. The specific objectives were;

i) To identify the major pollution sources into the Athi River.

ii) To determine the physical, chemical and bacteriological characteristics of the water within the study transect.

iii) To evaluate the suitability of Athi River water for irrigation

1.5 Research Questions

i) Which are the major pollution sources into the River?

ii) Which are the physical, chemical and bacteriological characteristics of the water within the study transect?

iii) Is the Athi River water suitable for irrigation?

1.6 Limitations of the Research

When analyzing water quality of any water body, it is always a good practice to determine the quality of the water during low and high tide i.e. dry season and wet season. This research was aimed at assessing the water quality during the irrigation period which in most cases is the dry season as no farmer will practice irrigation along the riparian section when it has rained. As such, collection and analysis of water samples was only done in one season; the dry season.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

This chapter examines various studies and publications related to the proposed topic of research. The chapter seeks to bring to light findings of various literature sources, published and unpublished, related to major pollution sources of rivers, the ideal water qualities for irrigation purposes and the impact of water pollution on irrigated agriculture. An overview of the literature reviewed is also given.

2.2 Sources of Water Pollution in Rivers

Broadly, sources of water pollution have been classified into point and non-point sources. A point source is a single identifiable localized source of water pollution while non-point sources are diffuse sources which cannot be traced back to a particular location because pollution result from a wide variety of human activities on the land as well as natural processes. Water resources in Kenya are increasingly becoming polluted from both point and non-point sources due to agriculture, urbanization, and industrial developments which contribute to organic, inorganic and aesthetic pollution of water (Kithiia, 2012). The pollutants enter waterways through untreated sewage, storm drains, septic tanks and run-off from farms among others (GOK, 2009). In addition, according to GOK (2008), development of water supplies has not been matched by a corresponding increase in facilities of sanitary disposal of wastewater. As a result, wastewater is discharged into rivers, valley depressions and dams leading to high pollution levels. In addition, main sewer systems suffer from constant breakages and/or leakage due to increased discharge to fixed systems.

Budambula and Mwachiro (2005) observed that the main sources of water pollution are industrial discharge, sewage, agricultural waste, fertilizers, seepage from waste sites, decaying plant life, road, railway and sea accidents involving large oil carriers. Muiya (2011) observes that river water is open to many polluting agents especially those which gain direct entry of discharges from urban centers and that both microbial and chemical pollution poses a pollution risk to Athi River thus endangering the health status of the people downstream. The main cause of water pollution in Mavoko (Athi River) is industrial pollution, poor waste management and municipal waste water (UN-HABITAT, 2006).

Ogedengbe and Oke (2011) reported alkaline soil at areas in close proximity to a cement factory and attributed the pollution to the operations of the cement factory. There is potential pollution of the Athi River from the cement factories in the area. GOK (2015a) points out that most of cement factories within the County are located in Athi River area. Besides, Sharma (1997) also reported that seventy five percent (75%) of the pollution load in the Ganga River in India was from untreated municipal sewage from nearby towns. Indeed, WRMA, (2015) reported that Athi River town is characterized by poorly maintained sewage systems leading to pollution of Athi River.

2.3 Water Quality for Irrigation Water

Hamza (2012) lists the following as characteristics of water for irrigation which are essential in determining its quality; Salinity hazard, Sodium hazard (sodicity), Soluble Sodium percentage, Acidity and Alkalinity, Residual sodium carbonate and specific ions like chloride, magnesium, sulfate and nitrate. Tak *et al.* (2012) observed that microbial pathogens are one of the potential irrigation water quality parameters but it is often neglected and *E.coli* is the most preferred indicator of microbial contamination.

Salinity is the amount of dissolved salts in water (total soluble salt content) while salinity hazard is the potential of the dissolved hazards inhibiting plant growth (Bauder *et al*., 2008). Hamza (2012) notes that salinity hazard is the most influential water quality guideline on crop productivity and is measured by electrical conductivity (EC) of the water and the total dissolved solids (TDS) in water. The author further notes that irrigation water with a high EC reduces yield potential and can result in a physiological drought condition. Table 2.1 shows FAO’s general guidelines for the assessment of salinity hazard of irrigation water using electrical conductivity of the water and the total dissolved salts (TDS) in the water.

Table 2.1: FAO General guidelines for assessment of salinity hazard of irrigation water

Parameter	Limitation/Problem		
	None	**Moderate**	**Severe**
Electrical Conductivity of water (EC) in deciSiemens per meter ((dS/m)	<0.75	0.75-3.0	>3.0
Total Dissolved Solids (TDS) (mg/L)	<450	450-2000	>2000

Source: Bauder *et al*. (2008).

Hamza (2012) notes that toxicity of sodium (sodium hazard or sodicity) occurs with the accumulation of sodium in the plant tissues and exceeds the tolerance limit of crop and Tak *et al.* (2012) points out that reductions in water infiltration can occur when irrigation water contains high sodium relative to the calcium and magnesium contents. The most common measure to assess sodicity (sodium hazard) in water is the Sodium Adsorption Ratio (SAR) which defines sodicity in terms of relative concentration of sodium (Na) to the sum of calcium (Ca) and magnesium (Mg) ions in the sample. Table 2.2 shows FAO guidelines for assessment of sodium hazard of irrigation water of irrigation water based on Sodium Adsorption Ratio and Electrical conductivity of the water.

Table 2.2: FAO General Guidelines for assessment of sodicity of irrigation water

	Limitation		
	None	**Moderate** **EC (dS/m)**	**Severe**
When SAR =0-3 and EC	>0.7	0.2-0.7	<0.2
When SAR =3-6 and EC	>1.2	0.3-1.2	<0.3
When SAR =6-12 and EC	>1.9	0.5-1.9	<0.5
When SAR =12-20 and EC	>2.9	1.3-2.9	<1.3
When SAR =20-40 and EC	>5.0	2.9-5.0	<2.9

Source: Bauder *et al*. (2008).

According to Hamza (2012), the sodium in irrigation water can also be as percent sodium or Soluble Sodium Percent (SSP) using the following equation:

$$SSP = \frac{Na}{Ca + Mg + Na + K} \times 100$$

Where all ionic concentrations are expressed in meq/l

The author observed that irrigation water with SSP greater that 60% may result in Na accumulation and possibly a deterioration of soil structure, infiltration, aeration and reducing soil permeability.

The alkalinity or acidity of irrigation water is determined by the pH of the water. The water is defined as acidic if it has a pH of less than 7.0 and basic if it has a pH of more than 7.0. The normal pH range for irrigation water is 6.5 to 8.4 and irrigation water with a value outside the normal range may cause a nutritional imbalance or may contain a toxic ion (Tak *et al.*, 2012).

Residual Sodium Carbonate (RSC) represents the amount of sodium carbonate and sodium bicarbonate in water when total carbonate and bicarbonate levels exceed total amount of calcium and magnesium. Waters with RSC of 1.25-2.50 meq/L are within the marginal range, while RSC values of 2.50 meq/L or greater are considered too high making the water unsuitable for irrigation use. RSC is determined by the formula below (Hamza, 2012)

$RSC= (CO_3^{2-}+HCO_3^{-})-(Ca^{2+}+Mg^{2+})$

Ayers and Westcot (1994), states that in determining water availability for irrigation, information is required on both the quantity and quality of the water. The authors observe that in most cases, the quality need has often been neglected.

Tak *et al.* (2012) observed that Soil scientists use various physico-chemical parameters to describe irrigation water effects on crop production and soil quality; these include, Salinity hazard - total soluble salt content, Sodium hazard - relative proportion of sodium to calcium and magnesium ions, pH - acidic or basic, alkalinity - carbonate and bicarbonate and specific ions such as chloride, sulfate, boron, and nitrate. However, another potential irrigation water quality parameter that may affect its suitability for agricultural system is microbial pathogens, which has often been neglected by many researchers. Zorka *et al*. (2008) points out that coliform bacterium have been used to evaluate the general quality of water in the past. The authors found out that various sources of water had moderate pollution from coliform bacteria and did not recommend the water to be used for irrigation unless it was subjected to a treatment process.

Competition for use of limited water resources and the subsequent increased pollution of water resources has led to growing attention to the quality of water available for irrigation. Typically, qualities of irrigation water which deserve consideration include the salt content, the sodium concentration, the presence and abundance of macro- and micro-nutrients and trace elements, the alkalinity, acidity, and hardness of the water. Under some circumstances, the suspended sediment concentration, bacterial content, and temperature of irrigation water may also deserve attention (Bauder *et al*., 2008). Numerous water quality guidelines have been developed by many researchers for using water in irrigation under different condition. The classification of US Salinity Laboratory (USSL) (see Figure 2.1) is also widely used to assess salinity and sodicity hazards of irrigation water. In this diagram, the salinity hazard of the water is determined and classified from low (C1) to very high (C4). The sodium hazard of the water is also determined and categorized from low (S1) to very high (S4). Irrigation waters can be plotted on this chart to determine its potential viable agricultural use.

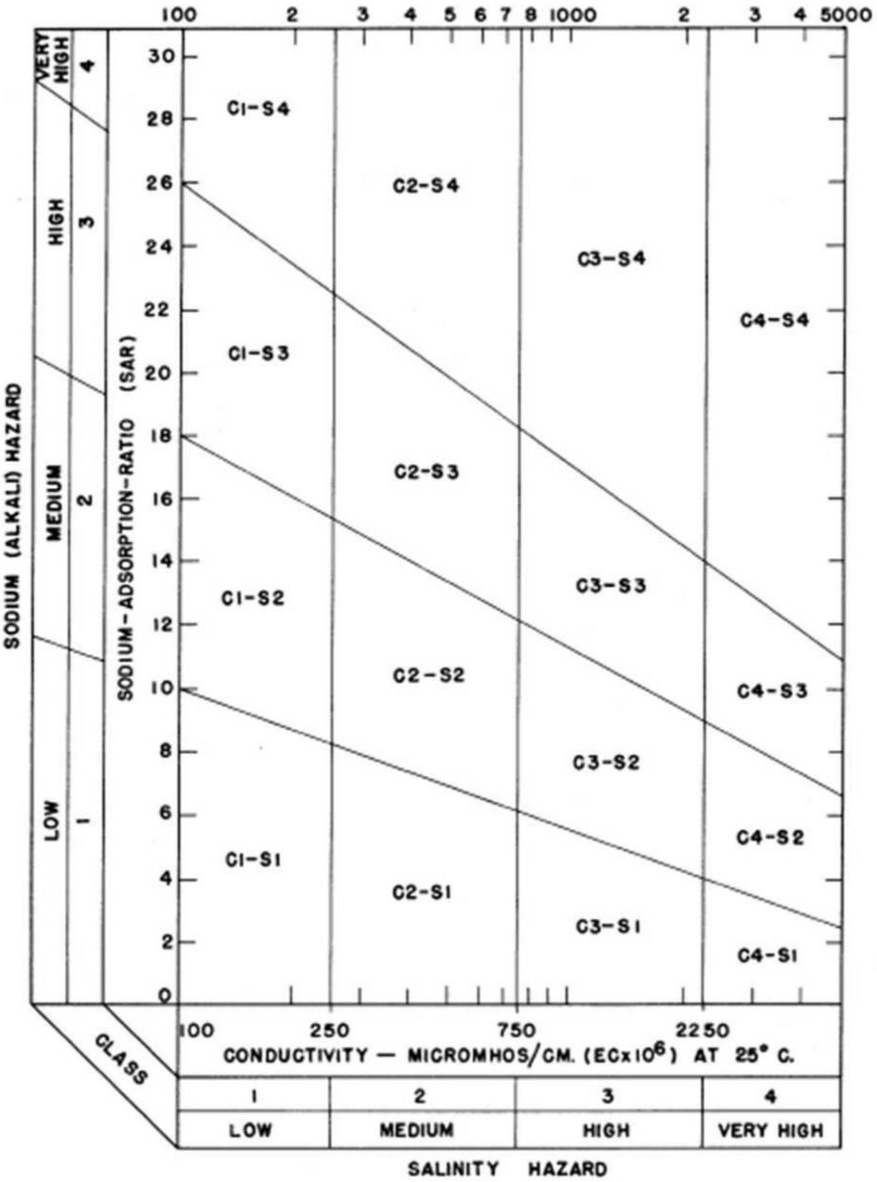

Figure 2.1: US Salinity Diagram (Allison et. al. 1954)

2.4 Impacts of Water Pollution on Irrigated agriculture

Various parameters/ qualities of irrigation water have an impact on the yield and health of crops and soil fertility. Bauder *et al.* (2008) observed that salinity (the amount of salt dissolved in water) directly affects plant growth and generally has an adverse effect on agricultural crop performance and can adversely affect soil properties thus leading to a long term decrease in irrigated crop productivity. The authors further note that saline conditions restrict or inhibit the ability of plants to take up water and nutrients, regardless of whether the salinity is caused by irrigation water or soil water which has become saline because of additions of salty water, poor drainage, or a shallow water table. Ayers and Ayers and Westcot (1994) observed that plants uptake water through a process of osmo-regulation, wherein elevated salt concentration within plants causes water to move from the soil surrounding root tissue into the plant root. When the soil solution salinity is greater than the internal salinity of the plant, water uptake is restricted. The result is often a smaller plant than one not affected by salinity.

Yield reduction may occur even where plant symptoms appear minimal. In situations of elevated salinity plant tissue may die, thereby exhibiting necrosis at the leaf edges. Additionally, saline water may lead to concentrations of some elements which can be toxic to plants (Ayers and Westcot, 1994). The authors also observed that the reduced water uptake by the plant due to salinity can result in slow or reduced growth and may also be shown by symptoms similar in appearance to those of drought such as early wilting. Some plants exhibit a bluish-green colour and heavier deposits of wax on the leaves. These effects of salinity may vary with the growth stage and in some cases may go entirely unnoticed due to a uniform reduction in yield or growth across an entire field. Various crops have varying salinity tolerance levels and varying effects on the yield with an increase in soil salinity (see Figure 2.2). As the salinity is increased, the yield reduces. Irrigation water with high salinity will consequently lead to an increase in soil salinity leading to a reduction in the yield.

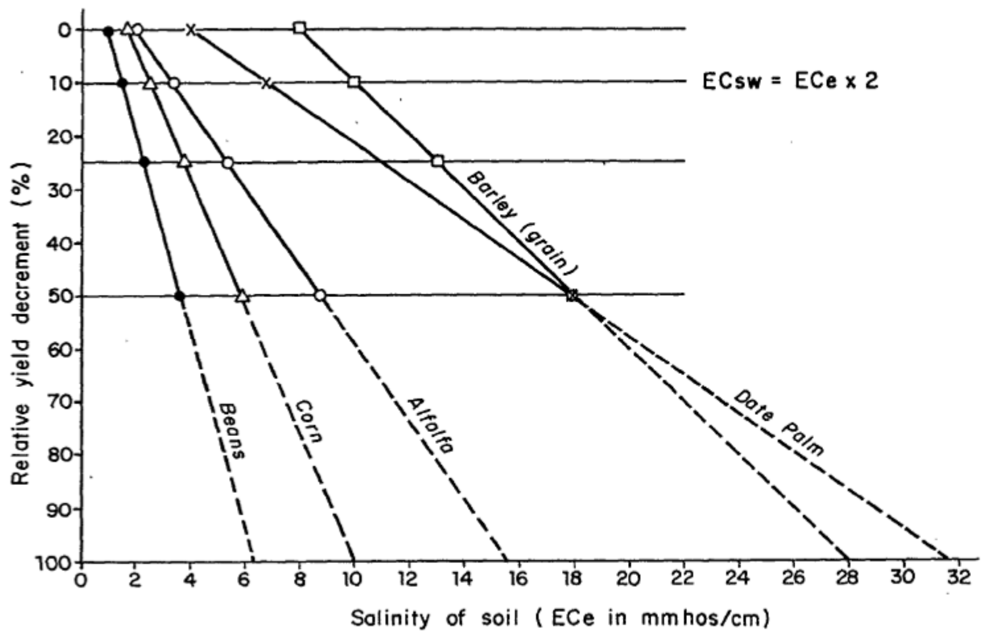

Figure 2.2: Effects of soil salinity on various crop yields (From: Ayers & Westcot (1994)

From the literature reviewed, it is evident that water pollution is a problem that cuts across all countries irrespective of their geographical location and economic status and that deteriorating water quality is a world-wide problem.

There are a number of gaps that were identified in the literature reviewed. Zorka *et al*. (2008) sampled biological indicators; coliform bacteria, zooplankton and zoobenthos in the assessment of irrigation water quality leaving out important physical and chemical parameters e.g. salinity, permeability and sodicity while Hamza (2012) assessed physical and chemical parameters to determine irrigation water quality and failed to consider biological indicators. In an attempt to determine the pollution status of Athi River and its tributaries, Muiya (2011) sampled several physico-chemical and biological parameters. However, the study did not give any preference to the effects of pollution on a specific use of water and thus pertinent parameters regarding irrigation water quality e.g. calcium, magnesium, sodium, carbonate and bicarbonate ions were not sampled.

Broadly, the literature reviewed tended to be biased either towards physico-chemical parameters of water or bacteriological indicators. Literature on the general pollution on water failed to highlight physico-chemical parameters pertinent to irrigation water quality while literature on irrigation water quality failed to sample bacteriological indicators of water quality yet it is an important aspect of irrigation water quality since it can affect the health of the farmers, consumers and that of the crops.

This study will endeavor to find out the physico-chemical parameters and the bacteriological indicators i.e. *E.coli* of the Athi River water in Athi River ward. These parameters will be used to establish the suitability of the water for irrigation.

CHAPTER THREE

3.0 METHODOLOGY

3.1 Introduction

In this section, the procedures that were used to acquire and analyze data and information in order to realize the study objectives are described. Tools and instruments that were used have also been highlighted.

3.2 Description of the study area

3.2.1 Location

The study transect is within Athi River town and its environs which is within the jurisdiction of Mavoko constituency in Machakos County (Figure 3.1). Athi River area popularly known as Mavoko is about 25km Southeast of Nairobi Central Business District (CBD) and is characterized by rapid industrial development and growing residential premises due to its proximity to Nairobi. The town is situated on latitude 1^{o} 27'S and longitude 36^{o} 58'E. The section of the river under study transverses three administrative wards namely Athi River, Kinanie and Muthwani within Mavoko Constituency.

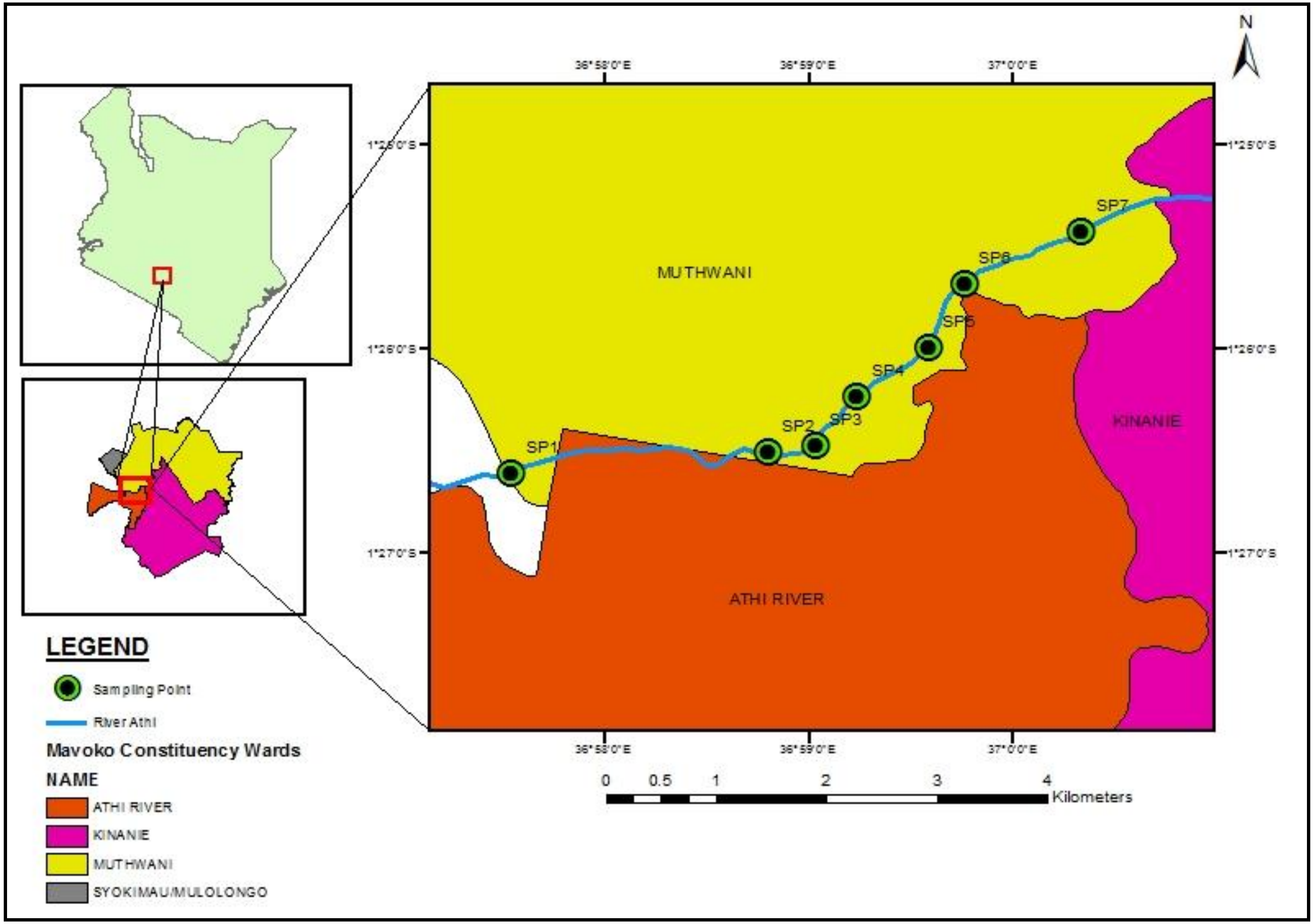

Figure 3.1: Map of the study area showing the sampling stations along the Athi River and its location in Kenya and Mavoko Constituency (insets)

3.2.2 Physical and Climatic Conditions

The study area falls within Machakos County. The county has two distinct rainy seasons; the long rains fall between March and May and the short rains fall between October and December. The annual average rainfall varies from 500 -1300 mm with high altitude areas receiving more rain than low lying areas. The temperatures also vary with altitude, the mean monthly temperature ranges from 12^{o}C in the coldest months (July-to August) to 25^{o}C in the hottest months (March to October) (GOK, 2015b).

Irrigation is done on the banks of the River and the predominant crop under irrigation is kales. The predominant land use activities in the study area is industrial, residential and agricultural (UN-HABITAT, 2006). The study area is within Athi River County Assembly Ward which has a population of approximately 51, 293 (GOK, 2012).

3.3 Research Design

The study design was purposive. Sampling points were deliberately chosen to assess the water quality of the Athi River within the study area. The first sampling point was located within the Nairobi National Park, North West of the Athi River town. The first point served as a control point since it is upstream of pollution sources in Athi River town. The last sampling point was located in Muthwani County Ward North East of Athi River town and before the Mto Mawe tributary. At this point, the water is leaving the Athi River area. Other five sampling points were then established between these two sampling points at varying intervals based on the surrounding activities as indicated in Table 3.1. The sampling points are shown in Figure 3.2. Water samples were collected in each of the sampling points for analysis of physicochemical and bacteriological water quality. Physicochemical parameters analyzed included electrical conductivity of the water (EC), total dissolved solids (TDS), pH, total alkalinity, calcium (Ca), magnesium (Mg), sodium (Na), chromium (Cr) and lead (Pb). Analysis for *E-coli*, as an indicator of bacteriological water quality, was also conducted as most of the crops grown are eaten raw or half-cooked thus endangering the life of the public.

Table 3.1: Sampling points and surrounding conditions

Sampling point	Surrounding Activities
Sampling point 1	Inside Nairobi National Park. Control point
Sampling point 2	At Bridge 39. Main Sewer line and sewer manholes
Sampling point 3	Near Mombasa road and Athi River Steel Plant. Construction activities in close vicinity.
Sampling point 4	Susceptible from runoff from the Athi River Tannery
Sampling point 5	Near Sewerage treatment ponds from residential estates (apartments)
Sampling point 6	Near flower farms and residential houses.
Sampling point 7	Before Mto wa Mawe tributary.

NB: All points had vegetable plots under irrigation

The results obtained from the samples were compared with the standards given in Table 2.1 to assess the salinity of the water. The best measure of water's likely effect on soil permeability is SAR considered together with its electrical conductivity. In this respect, general guidelines for assessing salinity (Table 2.1) and general guidelines for assessment of sodicity (Table 2.2) (Ayers and Westcot, 1994), was used to assess the water suitability for irrigation. The results were also compared with NEMA standards (appendix 3) and FAO standards (appendix 4 and 5).

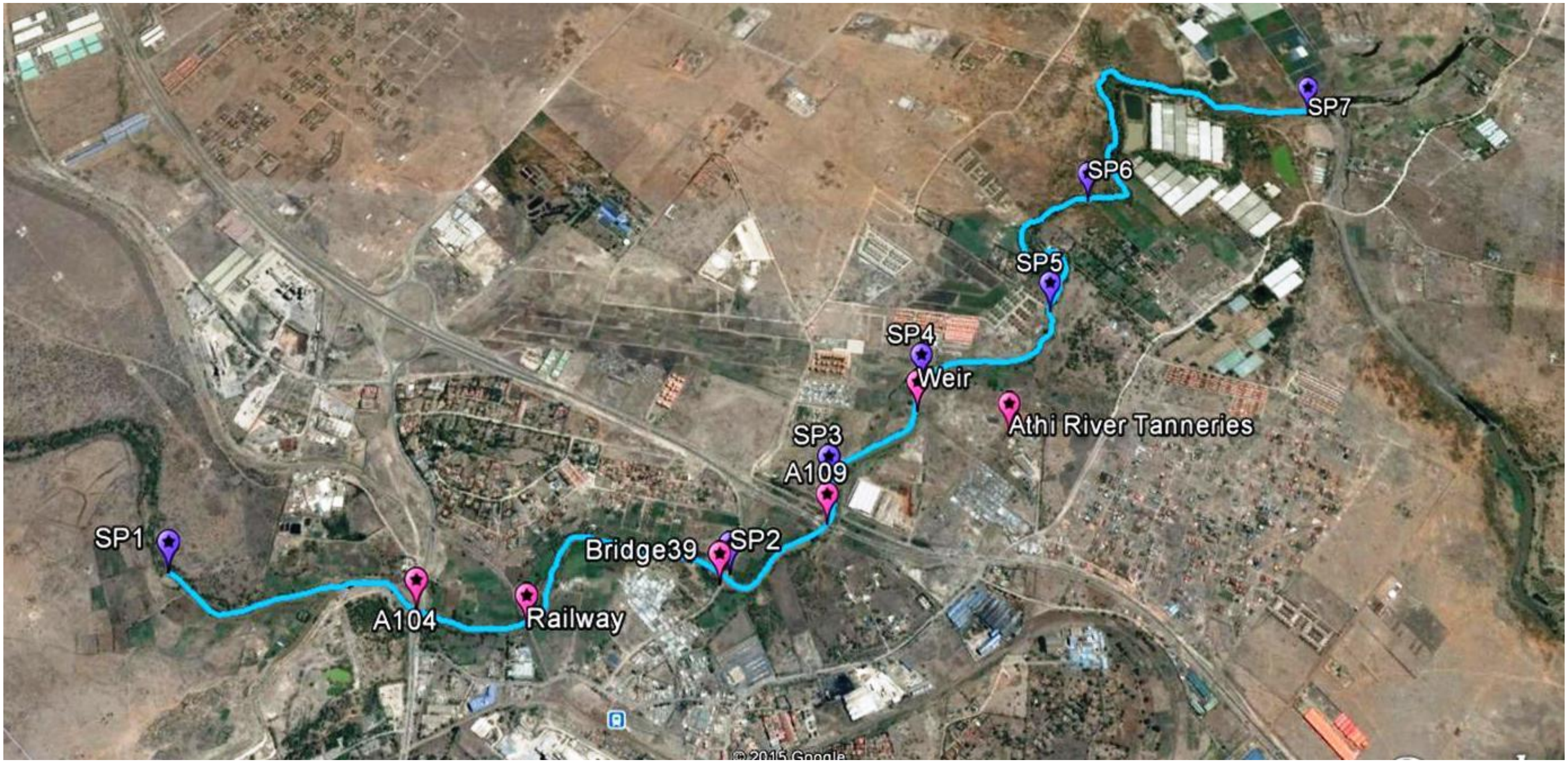

Figure 3.2: Satellite image of the study area with locations of sampling station (SP1 to SP7) indicated

Questionnaires were administered to ten (10) farmers owning different plots at every sampling point in order to assess their views on the impact of the irrigation water quality on crop yield.

The average area under irrigation at each sampling point covers a radius of 100 meters from the river and the average size of each plot under irrigation and owned by a farmer was estimated to be one acre. The following simplified formula for proportions by Yamane (1967) was applied to get the number of plots to be observed, the number of 25m by 25 m sub-plots to be observed under every plot and the number of farmers to be interviewed at every sampling point.

$$n = \frac{N}{1 + N(e)^2}$$

Where n= Sample size, N= Population size and e=level of precision.

3.3.1 Sample size for the number of plots at sampling point

The average width of the river is 10m.

Average area under irrigation at each sampling point=3.142 x $(100)^2$

= 31,420m^2

Where 3.14 is Π (pi)

Subtracting the area occupied by water from the above (31420-2000),

The area under irrigation becomes 29420m^2

N.B. The average size of each plot under irrigation and owned by a farmer was estimated to be one acre

Taking one acre to be equal to 4046.86 m^2, possible number of plots (N) = 29420/4046.86=7.2698

Therefore N=7.

Taking the level of precision to be 5%;

n=7/ $(1+7(0.05)^2)$ =6.8

Therefore n=7

3.3.2 Sampling size for interviews

Possible number of plots owned by individuals at every sampling point (N) is 7. Ten (10) farmers were interviewed at each sampling point.

Apart from getting farmers perceptions on the likely sources of pollution and impact of irrigation water quality on crop yield, a review of 2015 Environmental Audit reports of the ten (10) major companies listed in the Machakos County Integrated Development Plan was done. The industries listed in the Machakos County Integrated Plan included;

i. Mabati Rolling Mills
ii. Kenya Meat Commission
iii. Athi River Steel Plant
iv. East African Portland Cement Corporation
v. Bamburi Cement
vi. Mombasa Cement
vii. Savanah Cement
viii. Simba Cement
ix. Associated Battery Manufacturers
x. Athi River Mining

3.4 Sampling and Analysis of river water

Water samples were collected from each sampling point once every week from 21st January 2015 to 6th March 2015. The analysis of the physico-chemical parameters was conducted as per the Standard Methods of examination of water and waste water (APHA, 2005). At every sampling point, three water samples ten meters from each other were collected in 500ml bottles. The 500ml bottles were rinsed three times with the sample water before filling. The collected water samples were then mixed in a 1.5 Liter bottle. A 500ml sample was then taken from the mixture for laboratory analysis. The samples were kept under ice to maintain a temperature of 4^{o}C and then they were transported to the laboratory where they were refrigerated. The analysis of the water samples was done at Central Water Testing Laboratory, WRMA and at the Government Chemist Laboratories.

In the Laboratory pH, total dissolved Solids (TDS) and conductivity were measured on delivery of the samples using a conductivity meter with a pH and TDS probe. After measuring the samples for conductivity and pH, part of the sample was acidified with 10% HNO_3 to a pH of less than 2 for analysis of calcium (Ca), magnesium (Mg), sodium (Na), chromium (Cr) and lead (Pb). The analysis of the metals was done using CONTR AA 700 analytik-jena device by Flame Atomic Absorption Spectrometry (FAAS) in air acetylene flame. Total alkalinity was measured in un-acidified sample by titrating with sulphuric acid to pH 4.5 using phenolphthalein indicator.

To determine the sodium hazard of the water, the concentration values of sodium, calcium and magnesium analyzed were used to calculate the Sodium Adsorption Ratio (SAR) of the water using the following formula (Ayers and Westcot, 1985):

$$\text{S.A.R.} = \frac{Na^+}{\sqrt{\frac{1}{2}(Ca^{2+} + Mg^{2+})}}$$

Where: Na^+ is sodium concentration in me/L

Ca^{2+} is calcium concentration in me/L

and Mg^{2+} is magnesium concentration in me/L

The following formula by Paliwal (1972) was used to calculate the magnesium hazard at various sampling points.

$$MH = \frac{Mg}{Mg + Ca} * 100$$

Where concentration of calcium and magnesium ions are expressed in meq/L. MH is magnesium hazard.

Water samples for bacteriological (*E.coli*) analysis were collected, using 100 mL sterilized screw-capped glass bottles, once every week from the sampling stations between the month of January and February 2015. The samples were kept under ice to maintain a temperature of 4^oC before being delivered to Central Water Testing Laboratory, WRMA where they were refrigerated before being analyzed. The delivery to the laboratory was done within three hours after sampling.

E.Coli was analyzed using Multiple Tube Fermentation Technique (MTFT), a three- stage procedure in which the results were statistically expressed as Most Probable Number (MPN). The following are the three stages of MTFT that were applied:

(a) Presumptive Stage:

A series of lauryl tryptose broth primary fermentation tubes was inoculated with graduated quantities of the sample to be tested. The inoculated tubes were incubated at 35^oC for 24 hours, at which time the tubes were examined for gas formation. For the tubes in which there was no gas formation, incubation was to continue and examination for gas formation was done at the end of 48 hours. Any tube showing gas production during this test indicates the possible presence of coliform group bacteria and is recorded as a positive presumptive tube. Formation of gas in any amount within 48 hours was a positive presumptive test. This stage was done to confirm the presence of total coliforms

(b) Confirmed Stage

Fermentation tubes containing brilliant green lactose bile broth was inoculated with medium from the tubes showing a positive result in the presumptive test. Inoculation was performed as soon as possible after gas formation occurred. The inoculated tubes were incubated for 48 hours at 35^oC. Formation of gas at any time in the tube was an indicator of a positive confirmed test. This was a confirmatory test for *E.coli*.

(c) Completed test

The completed test was performed on all samples showing a positive result in the confirmed test. Two plates of eosin methylene blue were streaked with sample to be analyzed. The streaked plates were incubated for 24 hours at 35^oC. After incubation, two typical colonies (nucleated, with or without metallic sheen) was transferred to a lauryl tryptose broth fermentation tube and a nutrient agar slant. The fermentation tubes and agar slants were incubated at 35^{o}C for 24 hours or for 48 hours if gas had not produced. From the agar slants corresponding to the fermentation tubes in which gas formation occurs, gram-stained samples were examined. Formation of gas in the secondary tube of lauryl tryptose broth within the 48 hours and demonstration of gram-negative, nonspore-forming, rod-shaped bacteria from the agar culture constituted a positive result for the completed test, demonstrating the presence of a member of the coliform group. This was a secondary test for the presence of *E.coli*.

3.5 Research Instruments

3.5.1 Participant Observation

Field observations and documentation of the likely sources of pollution was done. Still photographs of the prevailing conditions were also taken and a visit made to eight of the ten (10) major companies listed in the Machakos County Integrated Development Plan (2015) for observations on their potential to pollute the Athi River.

3.5.2 Interviews

Interviews were mainly done on respondents who were particularly knowledgeable about water and sanitation in the Athi River area (key informants). WRMA officials from the regional office at Machakos and a representative from the Environmental Department from Mavoko Sub-County and Machakos County were interviewed. This was to seek the respondent's opinion on pollution of Athi River and on the likely sources of pollution and the mitigation measures being put in place as well as obtaining available monitoring records.

Ten (10) farmers from seven (7) different plots at every sampling point were also interviewed to document their experiences and perceptions in using the water for irrigation and effect on the crop yield.

3.5.3 Secondary Data Sources

Secondary data was obtained from review of relevant published and unpublished literature including books, journals, online materials, and reports. Relevant official and non-official documents within WRMA and Mavoko Sub-County environmental department were also examined to obtain data and information. Environmental audit reports of various industries in the area were also reviewed.

3.6 Data Analysis

Statistical Package for the Social Sciences (SPSS) version 16 for Windows and Microsoft Office Excel 2007 were used to calculate means and Standard Deviations, Descriptive graphs, tables and charts were also generated using SPSS and Microsoft Office Excel 2007.

CHAPTER FOUR

4.0 RESULTS

4.1 Sources of Water pollution at Athi-River

A review of the 2004 audit reports of ten factories (Mabati Rolling Mills, Kenya Meat Commission, Athi River Steel Plant, East African Portland Cement Corporation, Bamburi Cement, Mombasa Cement, Savanah Cement, Simba Cement, Associated Battery Manufacturers and Athi River Mining) in Mavoko revealed that four of them discharged their effluent waste into the municipal main sewer line while six had either sewerage treatment plants or septic tanks. However, only three out of the ten had complied with WRMA's effluent monitoring requirements of submitting quarterly effluent monitoring records to WRMA. Potential pollutants along the study transect were also identified (see Table 4.1)

Table 4.1: Potential pollutants along the study transect

Sampling Point	Potential Sources of Pollution
SP 1	• Pollution input from upstream areas (Ngong and Karen) • East African Portland Cement Company
SP 2	• Municipal sewer line • Athi River Mining Cement Company • Kwa Mangéli slums • Chalenzi Slums
SP 3	• Athi River Steel Plant • Construction site
SP 4	• Athi River Tannery • River Park Estate
SP 5	• Sewerage Treatment ponds • Manyatta residential area
SP 6	• Flower farms
SP 7	• Flower farms ; Evergreen crops Limited; Harvest flowers Limited

Table 4.2 shows the farmers perceptions on the sources of pollution into Athi River. Majority of farmers (44.29%) were of the view that the main source of pollution was municipal effluent while 15.72% and 11.44% were of the view that industrial effluent and street run-off respectively were the main pollution sources into the river. Twenty percent (20%) of those interviewed did not identify any source of pollution while 8.57% of those interviewed identified other sources that were not listed in the questionnaire e.g oil spillages from vehicles and construction sites near the river.

Table 4.2: Percentages of Farmers' response of perceptions on the sources of water pollution (N=70)

	Sources of water pollution				
	Industrial	**Municipal**	**Street Runoff**	**Others**	**None**
SP1	1.43	4.29	2.86	2.86	2.86
SP2	1.43	11.43	0	1.43	0
SP3	4.29	7.14	1.43	1.43	0
SP4	5.71	7.14	0	0	1.43
SP5	0	5.71	1.43	2.86	4.29
SP6	1.43	4.29	4.29	0	4.29
SP7	1.43	4.29	1.43	0	7.14
Total (%)	**15.72**	**44.29**	**11.44**	**8.58**	**20.01**

The views of the farmers on whether Athi River is polluted or not along the study transect varied from station to station (Table 4.3). Sampling point 7 had the highest percentage (19.15%) of farmers who perceived that the waters were polluted while sampling point 1 had the highest number of those who perceived the river not to be polluted (66.67%).

Table 4.3: Percentages of response by farmers on their perception on water quality (polluted or not) at each sampling point (N=70)

	SP1	SP2	SP3	SP4	SP5	SP6	SP7
Yes (%)	6.38	17.02	17.02	12.77	17.02	10.64	19.15
No (%)	66.67	11.11	-	11.11	-	11.11	-
Not Sure (%)	7.14	7.14	14.29	21.43	14.29	28.57	7.14

Note: Yes: The water is polluted, No: The water is not polluted, Not Sure: Do not know whether the water is polluted or not.

4.2 The Effect of water Pollution on the Crops

When asked if they had observed reduction in the size of the leaves of the kales during the dry season for the last 5-10 years, 74% of the respondents gave a negative reply (NO) while 19% confirmed (YES) and 7% were not sure.

When asked if they had experienced a reduction in yields over the time, 77.1% of the farmers gave a negative response while 22.9% of the farmers gave a positive response (Table 4.4).

Table 4.4: Farmers' responses on yield reduction (N=70)

	SP1	SP2	SP3	SP4	SP5	SP6	SP7	Average
Yes (%)	30	20	20	10	40	30	10	**22.9**
No (%)	70	80	80	90	60	70	90	**77.1**

Note: Yes: Those who had observed reduction in yield, No: Those who did not observe any reduction in yield

4.3 Physico-Chemical Parameters

The pH values for all the sampling points were within the NEMA (see

Appendix 3) range (6.5-8.5) with an exception of sampling point 7 which had a mean of 8.7 ± 0.51 (Figure 4.1). The lowest pH mean value (7.74 ± 0.1) was recorded at sampling point 3. There was an increasing trend in the pH from sampling point 1 to 7. The maximum value (9.3) was recorded at sampling point 7 while the minimum value (6.6) was recorded at sampling point 4. There was a significant statistical difference in the pH values between the sampling points at the $P<0.05$ level for the seven sampling points ($F(6, 35) = 5.88$, $P=0.0003$).

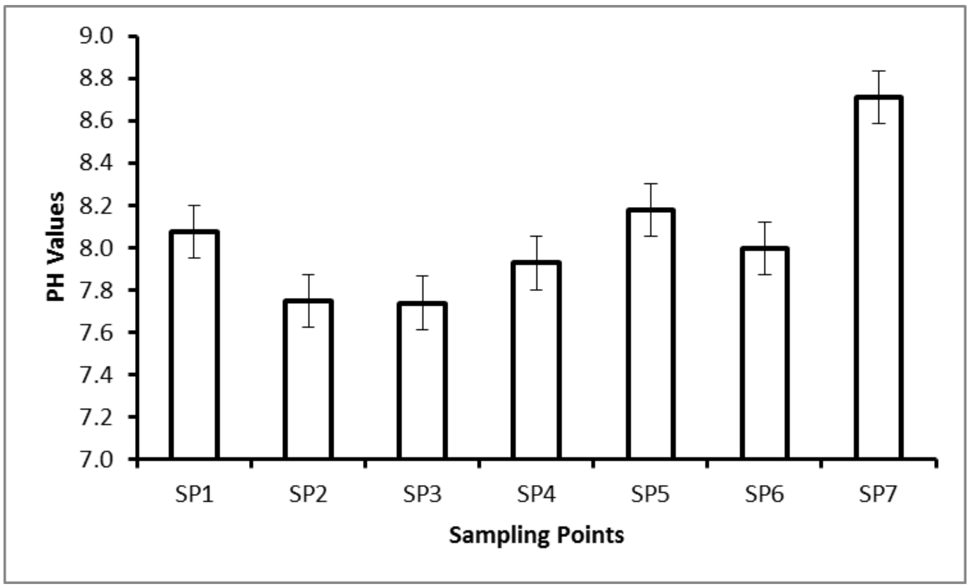

Figure 4.1: Mean and standard error of pH values for the sampling points along the study transect

The highest mean TDS (mg/L) concentration was recorded at sampling point 7 (1731 ± 326.7mg/L) while sampling point 3 had the lowest mean value (M=497.57 ± 71.5 mg/L) (Table 4.5). The mean TDS values for all sampling points were below the NEMA threshold (1200mg/L) with the exception of sampling point 4 (1321.7 mg/L) and sampling point 7 (1731 mg/L). The maximum value (2058mg/L) was recorded at sampling point 4 while the lowest value (403 mg/L) was recorded at sampling point 3. There was an increasing trend in the concentration of TDS from sampling point 1 to sampling point 7. There was significant statistical difference in TDS means between the sampling points at the $p<0.05$ level for the seven sampling points ($F(6, 35) = 10.04$, $p=1.89 \times 10^{-6}$).

Table 4.5: Mean Standard deviation, minimum and maximum of TDS concentrations (mg/L) along the study transect.

	SP1	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**
N	6	6	6	6	6	6	6
Mean	724.60	892.43	497.57	1321.67	580.25	847.67	1730.67
SD	388.409	141.015	71.493	696.941	62.326	160.464	326.719
Min.	525	640	403	451	507	714	1068
Max.	1516	1070	603	2058	640	1145	1932

The spatial variability of mean electrical conductivity (EC) is presented in Figure 4.2. EC varied with a general increasing trend from sampling point 1 to sampling point 7. Sampling point 7 had the highest mean EC (2.47 ± 0.47 dS/m) while sampling point 3 had the lowest mean conductivity (0.72 ± 0.11 dS/m). There was significant statistical difference in conductivity between the seven sampling points at the $p<0.05$ level ($F(6, 35) = 11.25$, $p=5.63 \times 10^{-7}$).

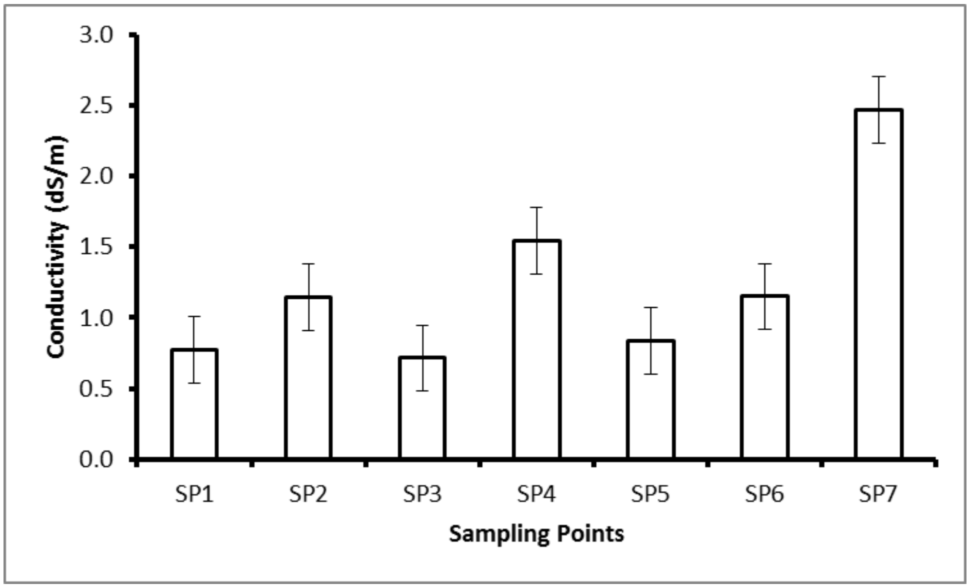

Figure 4.2: Mean and standard error of Conductivity values for the sampling points along the study transect.

The mean calcium concentration varied with a decreasing and increasing spatial trend from SP1 to SP7 (Figure 4.3). The highest concentration of calcium (0.54 ± 0.54 me/L) was recorded at sampling point 1, while the lowest concentration (0.03 ± 0.03 me/L) was recorded at sampling point 3. There was significant statistical difference in calcium concentration between the sampling points at the $p<0.05$ level ($F (6, 35) = 1.16$, $p=0.34$).

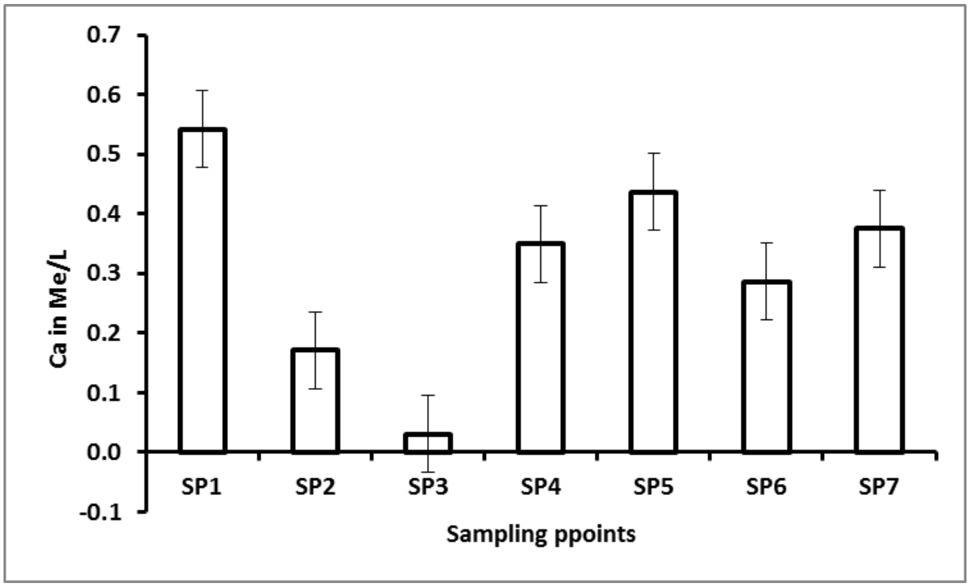

Figure 4.3: Mean and standard error of calcium concentration along the study transect

The magnesium concentration varied between 0.11 me/L (SP1) and 1.67 me/L (SP7) with the mean magnesium concentration showing a decreasing and increasing spatial trend (Table 4.6) but there was no significant statistical difference in the concentration between the sampling points at the $p<0.05$ level (F (6, 35) = 1.55, p=0.15). The highest mean in magnesium concentration (0.64 ± 0.37me/L) was recorded at sampling point 7 while the lowest mean (0.20 ± 0.04) was recorded at sampling point 3.

Table 4.6: Magnesium concentration (me/L) along the study transect.

	SP1	**SP2**	**SP3**	**SP4**	**SP5**	**SP6**	**SP7**
N	6	6	6	6	6	6	6
Mean	0.4915	0.3547	0.2004	0.4789	0.5224	0.5653	0.6355
SD	0.3246	0.1457	0.0434	0.1894	0.2961	0.4199	0.3721
Min.	0.110	0.166	0.150	0.295	0.215	0.168	0.209
Max.	0.856	0.504	0.246	0.821	0.822	1.362	1.067

The mean magnesium hazard for different sampling points along the study transect is shown in Figure 4.4. The mean values varied from between 47.6 (SP1) to 86.8 in SP3. The most downstream station (SP7) had a mean value of 62.9.

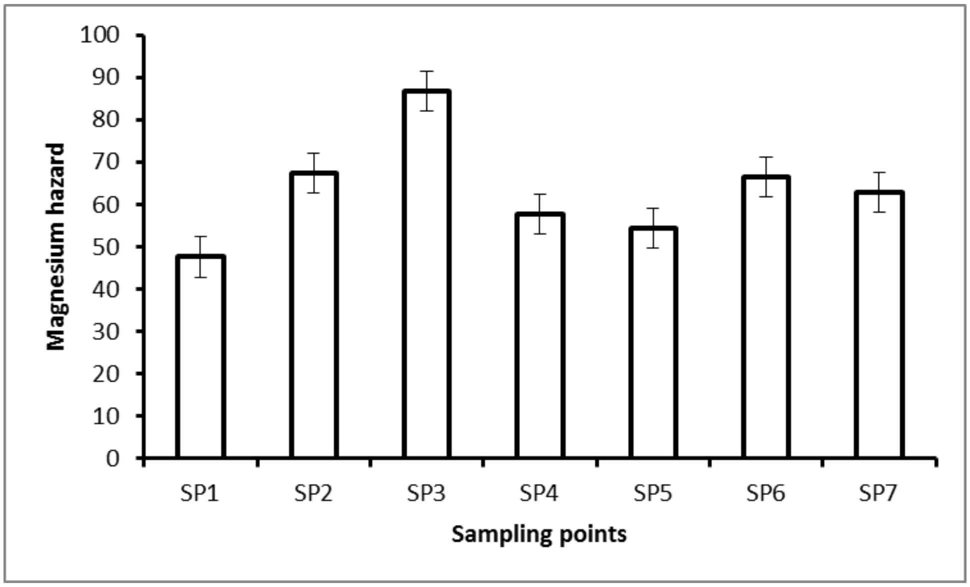

Figure 4.4: Mean and standard error of Magnesium Hazard (MH) along the study transect

Table 4.7 presents the mean, standard deviation and the maximum and minimum values of sodium concentration along the study transect. SP 4 had the highest mean concentration of sodium (0.8478 ± 0.4389me/L) while SP 3 had the lowest concentration (0.2826 ± 0.1044me/L). A general increasing trend of mean sodium concentration was observed along the study transect. There was significant statistical difference in the concentration of sodium between the sampling points at the $p<0.05$ level for the seven sampling points [F (6, 35) = 3.47, p=0.0086].

Table 4.7: Mean, Standard deviation, minimum and maximum of sodium concentrations (me/L) along the study transect.

	SP1	SP2	SP3	SP4	SP5	SP6	SP7
N	6	6	6	6	6	6	6
Mean	0.3188	0.3841	0.2826	0.8478	0.5217	0.5073	0.6961
SD	0.0594	0.1044	0.0659	0.4389	0.3739	0. 2124	0.3385
Min.	0. 217	0. 261	217	0. 304	0. 261	0. 261	0. 391
Max.	0. 391	0. 522	0. 391	1.391	1.261	0 .870	1.130

The mean chromium concentration along the study transect was between 0.02 ± 0.02 mg/L (SP2, and SP5) and 0.11 ± 0.24 mg/L (SP1) (Figure 4.5). There was no significant statistical difference in the concentration of chromium between the sampling points at the $p<0.05$ level ($F (6, 35) = 0.82$, $p=0.56$). The mean chromium concentration in the sampling points was below the NEMA recommended threshold value of 1.5 mg/L.

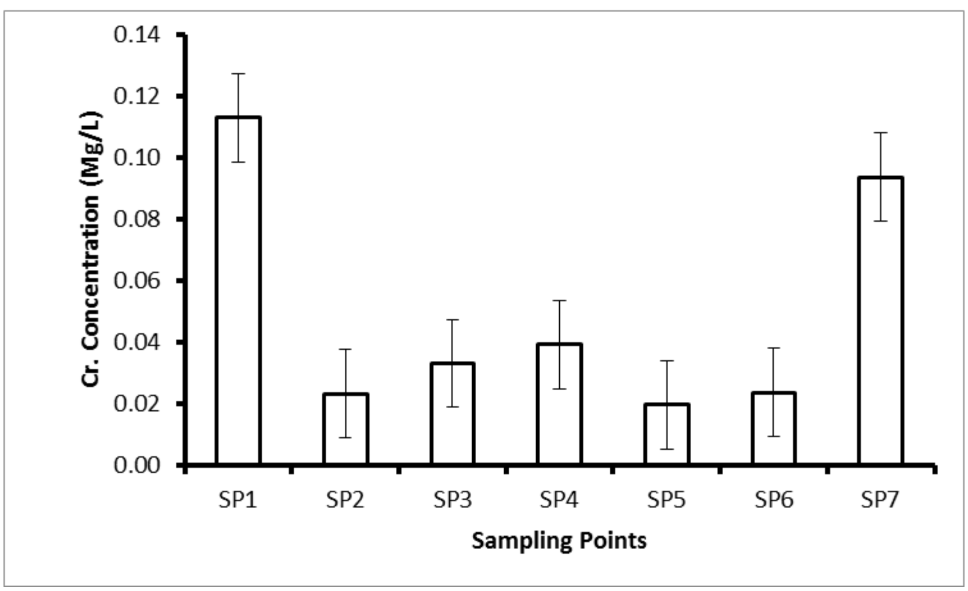

Figure 4.5: Mean and standard errors of chromium concentration along the study transect

Figure 4.6 presents the spatial variation of mean concentration of lead along the study transect. The concentration of lead varied between 0.08 ± 0.05 mg/L at SP 6 and 0.25 ± 0.35mg/L at SP4. The mean lead concentration was below the NEMA recommended threshold value for irrigation water (5mg/L) for all sampling points. There was no significant statistical difference between the sampling points at the $p<0.05$ level ($F (6, 35) = 0.85$, $p=0.54$).

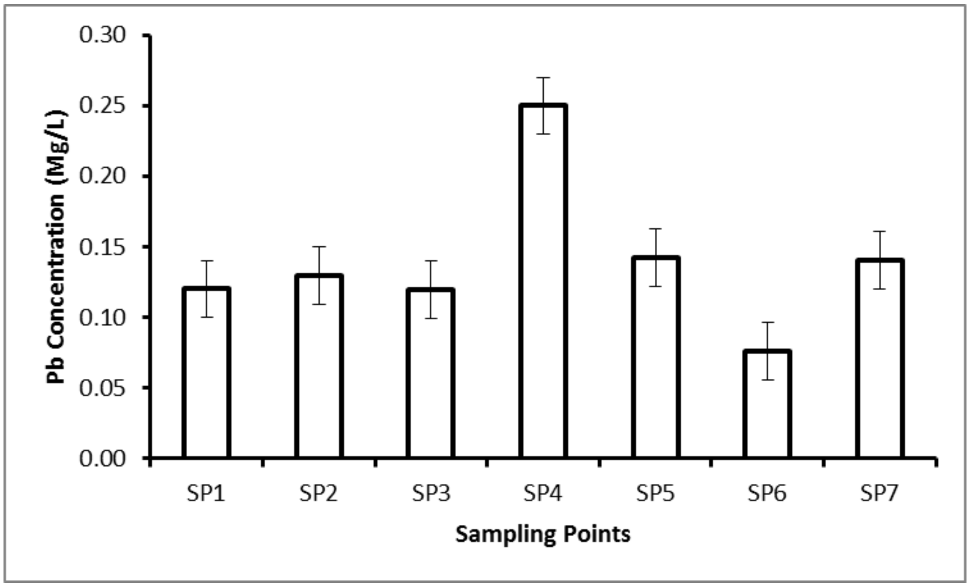

Figure 4.6: Mean and standard error of lead concentrations along the study transect

The mean SAR values along the study transect are presented in Figure 4.7. SAR mean values ranged from 0.44 in SP1 to 1.31 in SP4 and followed an increasing and decreasing tread along the study transect from SP1 to SP7. The SAR for all sampling points was below the NEMA threshold value of 6.

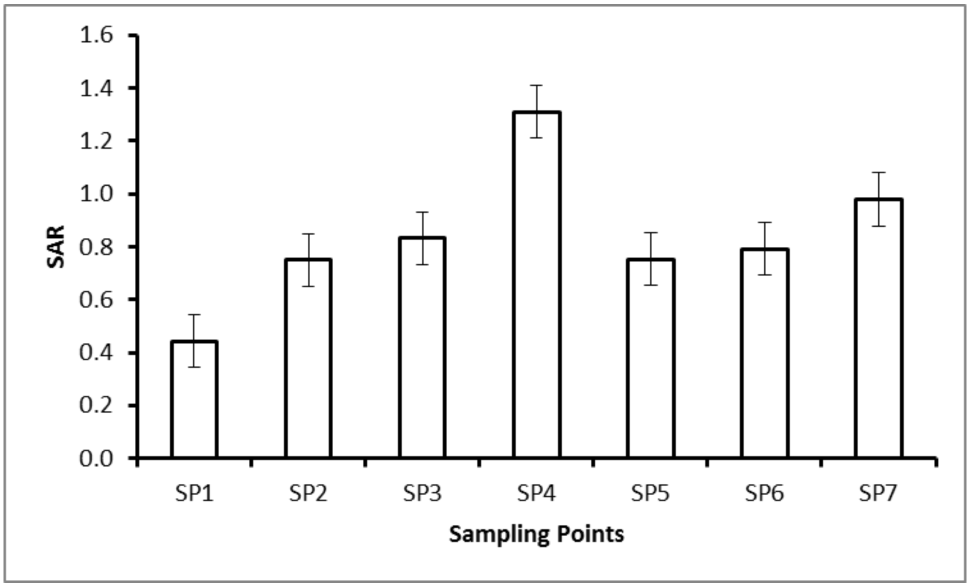

Figure 4.7: Mean and standard error of Sodium Adsorption Ratio (SAR) along the study transect

Comparison of the study results (SAR and EC) and the FAO general guidelines for assessment of sodicity of irrigation water (Bauder *et al*. 2008) show that the sodicity hazard for the water within the research area had a moderate sodicity hazard for the first three sampling sites and had no sodicity hazard for the last four sampling sites (Table 4.8).

Table 4.8: Sodicity hazards of river water at different sampling stations, based on EC and SAR

Sampling Point	SAR	EC (dS/m)	Sodicity Hazard
SP1	0.44	0.77	Moderate
SP2	0.75	1.14	Moderate
SP3	0.83	0.72	Moderate
SP4	1.31	1.54	None
SP5	0.75	0.84	None
SP6	0.79	1.15	None
SP7	0.98	2.47	None

4.4 Bacteriological Water Quality (*E. coli*)

The mean *E.coli* counts along the study transect are presented in Figure 4.8. The mean counts varied between sampling stations with the lowest count (1073 ± 355 MPN/100ml) recorded at SP4 while SP5 had the highest mean count (2203 ± 433 MPN/100ml). The mean *E.coli* counts showed an increasing trend and were above the NEMA recommended value (0 MPN/100ml) at all sampling points. There was significant statistical difference in the counts of *E.coli* between the sampling points at the $P<0.05$ level ($F(6, 28) = 2.5$, $P=0.46$).

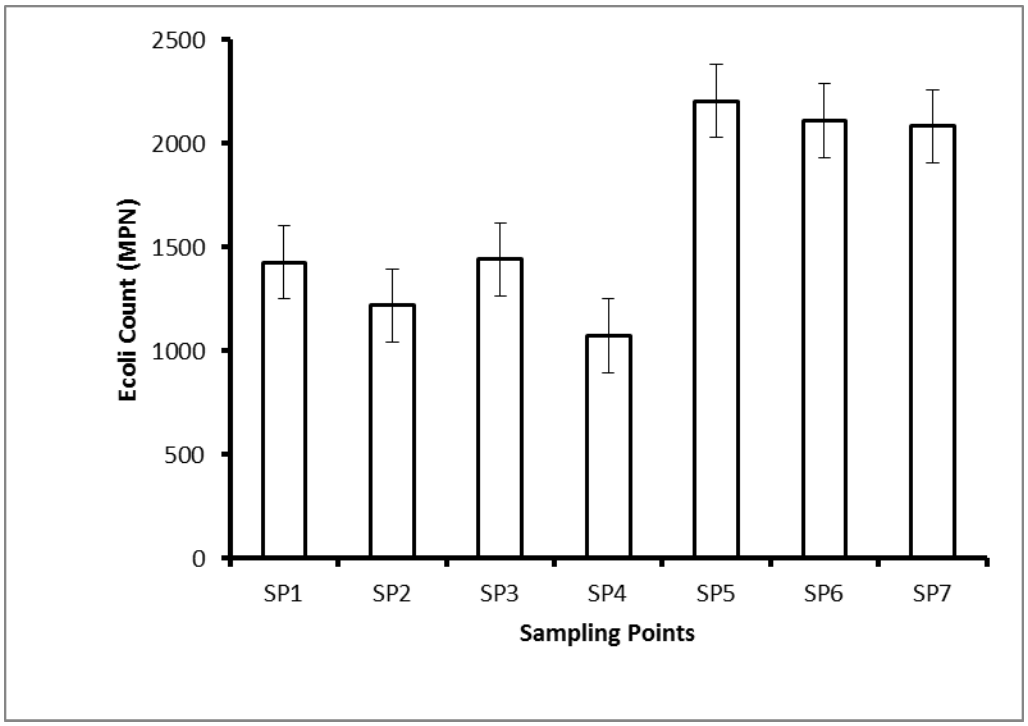

Figure 4.8: Mean and standard error *E.coli* Concentration (MPN/100ml) along the study transect

Potential sources for the high bacteriological content were observed and included septic tanks in close proximity to the river (e.g Plate 4.1), and blocked sewer systems (e.g Plate 4.2)

Plate 4.1: Open septic tanks (with leaking piping system) for a residential estate near the Athi River

Plate 4.2: Blocked sewer manhole in Athi River spewing raw sewage into the Athi River

CHAPTER FIVE

5.0 DISCUSSION

5.1 Sources of water pollution

During the dry season, pollution input into the river was mainly from the municipal waste and industrial effluents. Lack of treatment of municipal effluent and overflow of manholes and septic may be the main cause of pollution from these sources, based on observations made during the study.

The local residents who had the opinion that the waters of Athi River within the Athi River area were polluted referred to pollution from the municipal sources. As such, the majority of those interviewed were of the opinion that the river is majorly polluted by municipal sources. This is corroborated by the high levels of *E.coli* in the water (Figure 4.8). GOK (2004) attributes pollution of Kenyan rivers to be by effluent discharge from factories while Waruguru et al. (2012) attributed the pollution of Thome River in Nairobi to untreated sewage input. Santosh et al. (2007) observes that the deterioration of water quality is directly related to nonfunctioning and malfunctioning of wastewater treatment plants and lack of environmental planning and coordination. It is therefore important to establish the quality of the effluent from the factories and the municipal sewer system that is discharged into Athi River and assess the efficiency and adequacy of County and National government urban plans.

5.2 Physico-chemical parameters

5.2.1 pH Effect

The normal pH range for irrigation water is from 6.5 to 8.4 (Ayers and Westcot, 1985). Waruguru et al. (2012) reported a range of 7.6 – 8.1 for Thome River in Nairobi while this study measured pH of of 7.74- 8.71. Since Waruguru et al. (2012) carried out the study during both dry and wet seasons, the pH values may have been lowered by rain water and runoff. The findings of this study may have had relatively higher values since it was carried out during the dry season and therefore may have not been influenced by confounding factors associated with rain season. Bauder *et al*. (2008) also observed that high pH values above 8.5 are often caused by high carbonate (CO_3^{2-}) and bicarbonate (HCO^{3-}) concentrations. Irrigation water with a pH outside the normal range as observed at sampling point 7 (8.7 ± 0.51) may cause a nutritional imbalance or may contain a toxic ion.

The high pH value at sampling point seven may be due pollution input from the nearby flower farms or rock and soil formation at the areas near sampling point 7. There is need to carry out a full laboratory analysis of water and soil samples to establish the cause of high pH at sampling point 7. Remedial measures to be put in place include addition of sulphur, gypsum and other acid materials (Ayers and Westcot, 1994).

5.2.2 Magnesium Hazard

Although calcium and magnesium ions are essential for plant growth, they may be associated with soil aggregation and friability when in high concentration. In addition, high concentration of calcium and magnesium in irrigation water can increase soil pH, resulting in reduction of availability of phosphorus. According to Hamza (2012) water that contains calcium and magnesium concentrations higher than 10 meq/L or 200mg/L is not suitable for agriculture. All sampling points had magnesium and calcium concentration of less than 10 meq/L. These findings corroborates with findings of Kithiia (2010) in a study of a number of rivers in Kenya. However, 86% of the sampling points had a magnesium hazard (MH) values of more than 50, which has a potential to lead to salinity and alkali hazard to soils on long term use in irrigation (Haritash *et al*., 2008). The concentration of calcium was relatively high at the control point (sampling point 1) may be due to sources associated with nearby cement factories.

5.2.3 Sodium Hazard (SAR) and Salinity

As per the results of this study, the water from Athi River, at the study area, does not pause any salinity hazard to the soil. However, the increasing trend in SAR values from sampling point 1 to 7 indicates that there is potential for sodicity hazard in the future if monitoring and control measures are not put in place. Of great concern is that 42.9% of the sampling points had moderate sodicity (See Table 4.8). It has been observed that moderate sodicity has potential to cause sodium hazard in fine textured soils having high cation-exchange capacity, especially in the case of low soil leaching if gypsum is not present. However, such water can be used in coarse-grained soils or in organic soils with good permeability (Celkova, 2003). It is therefore important to profile the type of soil at the sampling points with moderate sodicity. The water is also not corrosive since its TDS exceeds 200mg/l. Low salinity water (TDS < 200 mg/l) is corrosive and tends to deplete the surface soils of their soluble salts and exchangeable cations (Ayers and Westcott, 1994).

5.2.4 Heavy metals

The results for the heavy metals (chromium and lead) corroborate with the findings of Kiithia (2012a) in which the concentration of lead downstream of Athi River was less than 0.01mg/L. Muiruri et al. (2013) also found out that the concentration of lead in the tributaries of Athi River ranged from 0.004 to 0.047 mg/L while that of chromium concentration ranged from ND (not detectable) to 0.068mg/L. However, due to bioaccumulation and biomagnification, the risk posed by heavy metals may be higher in the plant and animal tissues and thus there is need to carry out further research to establish heavy metal concentration in animal and plant tissues within the study area. The concentration levels of chromium were relatively higher at sampling point 1 compared to other sampling points (Figure 4.5), which may be due to tanning activities that were reported by the respondents to be taking place nearby. Human activities near this area (sampling point 1) need to be investigated further.

5.2.5 Microbial Water Quality

The level of *E.coli* within all the sampling points was higher than NEMA recommended values (0 MPN) with sampling point 5 having the highest count of 2203.25 MPN. This may be due to possible leakage from the nearby sewage treatment ponds or overflow untreated wastewater from manholes and septic tanks into the river or due wastewater from Kwa Mang'eli and Chalenzi informal settlements. Musyoki *et al.* (2013) also found out that microbial contamination of Nairobi River and Athi River was above the upper limits provided for by FAO and NEMA. KLDA (2014) also found the level of *E.coli* in Mbagathi Rive, an upper tributary of Athi River, (2500-5000 MPN counts) to be above the NEMA threshold. Thus both the farmers and those who consume salads prepared from the vegetables grown in the study area risk getting infected with gastrointestinal illness (GI). Channah *et al*. (2014) observed that in addition to gastrointestinal illness, illnesses such as eye infections, skin irritations, ear, nose, throat infections, and respiratory illness are also common in people who come into contact with water contaminated with *E.coli*.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Although the mean values of the physico-chemical parameters were within the FAO FAO/NEMA (2006) recommended limits, there was an increasing trend in concentration for most of the parameters (e.g. pH, TDS, conductivity, magnesium, sodium and chromium and lead from sampling point 1 to sampling point 7. This is an indication that there is pollution input from the Athi River area.

Of great concern is the level of microbial contamination (*E.coli*) which was higher than the FAO /NEMA recommended values and therefore poses a health risk to the users and the consumers of the vegetables which are grown in the area. In addition, all the points sampled had a moderate salinity hazard while 3 out of the seven sampled points had a moderate sodicity hazard. Should such a trend continue unabated, the quality of the river water and its potential for irrigation use will be compromised. Therefore there is need to take precautionary measures to arrest the pollution input before salinity and sodicity hazards become severe.

By and large, Athi River water within the study area can be classified with few exceptions (*E.coli*) as suitable for irrigation use. Special attention should therefore be given to the potential negative effects of *E.coli* when using the water.

6.2 RECOMMENDATIONS

There is need for public awareness regarding the Athi river water pollution problems and the consequences arising thereof within Mavoko Sub County. This can be done by the implementation of an integrated Environmental Education (EE) programme within the basins.

The programme should focus on the need for people living within Athi River and its environs to appreciate a cleaner environment. It should try to encourage people to properly manage their domestic raw wastes and avoid illegal dumping. The users of the kales should also be sensitized on hand washing and proper cooking of the kales.

Periodic monitoring of effluent from the residential estates and other entities that release their effluent into the river will aid in controlling microbial contamination and general pollution of the river. This can be done by ensuring that entities discharging effluent to the environment of municipal sewer lines adhere to requirements by regulatory bodies such as WARMA and NEMA.

Future studies/research need to carry out a water quality analysis of the river from upstream areas to where it joins the Nairobi River and profile the water quality status vis a vis a variety of uses and consider the analysis of pollutants in the plant and animal tissues to ascertain the potential impact of biomagnification and bioaccumulation of the pollutants.

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APPENDICES

Appendix 1: Sample Questionnaire given to the farmers

SOUTH EASTERN KENYA UNIVERSITY

Msc. (ENVIRONMENTAL MANAGEMENT)

QUESTIONNAIRE FOR POLLUTION OF ATHI RIVER AND ITS IMPACT ON IRRIGATION WATER QUALITY IN ATHI RIVER

This is questionnaire is for the purpose of academics only. Any information given will be treated with utmost confidentiality. Your participation is highly appreciated.

Part A: – Respondent General Background Information

1.1 Respondent's Name (Optional) Michael Mutuku

1.2 Age (Years) [ ]

- (i) 15-24 [ ]
- (ii) 25-44 [✓]
- (iii) 45-64 [ ]
- (iv) 60 and above [ ]

1.3 Gender of respondent: [✓] Male Female [ ]

1.4 Farming Zone (Sampling points): Tick one

1 [ ] 2 [✓] 3 [ ] 4 [ ] 5 [ ] 6 [ ] 7 [ ]

1.5 The number of years you have been farming in A. River

- (i)<1year [ ]
- (ii) 1-5 years [ ]
- (iii) 6-10 years [✓]
- (iv) 11-15 years [ ]
- (v) >15 Years [ ]

1

Part B: Sources of water pollution in Athi River

2.1 Do you think the A. River water is good for irrigation?

- [x] Yes
- [ ] No
- [ ] Not sure

2.2 If Yes, what are the likely sources of contamination?

- i) Industrial waste [ ]
- ii) Municipal waste water [x]
- iii) Agricultural activities [ ]
- i) Street runoff [ ]
- i) Others (Specify) Nearby Construction Sites

Part C: Effect of water pollution on the crops

3.1 Has the there been deterioration in the state of the crops (kales) over time?

- i)Yes [ ]
- ii) No [x]
- iii) Not sure [ ]

3.2 What is the size of your plot in acres? 1.2

3.3 What is the approximate quantity of harvest in sacs that you harvested in the following years during the dry season?

1. 2010 [ ] 2. 2011 [ ] 3. 2012 [ ] 4.2013 [ ] 5. 2014 [ ]

6. Unable to approximate [x]

3.4 Has the production/ yield reduced over time?

1. Yes [ ] 2. No [x]

If yes, give possible reason

....

....

Appendix 2: Questionnaire to the Key Respondents

SOUTH EASTERN KENYA UNIVERSITY

Msc. (ENVIRONMENTAL MANAGEMENT)

QUESTIONNAIRE FOR POLLUTION OF ATHI RIVER AND ITS IMPACT ON IRRIGATION WATER QUALITY IN ATHI RIVER

This is questionnaire is for the purpose of academics only. Any information given will be treated with utmost confidentiality. Your participation is highly appreciated.

Part A: – Respondent General Background Information

1.1 Respondent's Name (Optional)………………………………………………………

1.2 Organization:……………………………………………………………………

1.3 Position:…………………………………………………………………

Part B: Sources of water pollution in Athi River

2.1 Are the waters of Athi River polluted?

☐ Yes ☐ No

2.2 If yes what are the likely sources of pollution?

i) Industrial waste ☐

ii) Municipal waste water ☐

iii) Agricultural activities ☐

iv) Others (Specify)…………………………..

Part C: Monitoring and Mitigation measures

3.1 Have you ever received pollution complaints from the public?

i) Yes ☐

ii) No ☐

3.2 What is your monitoring frequency?

(i) Weekly ☐

(ii) Monthly ☐

(iii)Quarterly ☐

(iv) Annually ☐

(v) Other:…………………

(v) No monitoring program in place ☐

Appendix 3: NEMA Standards for Irrigation Water

STANDARDS FOR IRRIGATION WATER

Parameter	**Permissible Level**
pH	6.5-8.5
Aluminium	5 (mg/L)
Arsenic	0.1 (mg/L)
Boron	0.1 (mg/L)
Cadmium	0.5 (mg/L)
Chloride	0.01 (mg/L)
Chromium	1.5 (mg/L)
Cobalt	0.1 (mg/L)
Copper	0.05 (mg/L)
E.coli	Nil/100 ml
Fluoride	1.0 (mg/L)
Iron	1 (mg/L)
Lead	5 (mg/L)
Selenium	0.19 (mg/L)
Sodium Absorption Ratio (SAR)	6 (mg/L)
Total Dissolved Solids	1200 (mg/L)
Zinc	2 (mg/L)

Source: GOK (2006), The Environmental Management and Coordination, (Water Quality) Regulations 2006.

Appendix 4: FAO water quality standards for Irrigation

Laboratory Determinations Needed to Evaluate Common Irrigation Water Quality Problems

Water Parameter	Symbol	Unit	Usual Range in Irrigation water
SALINITY			
Salt Content			
Electrical Conductivity	EC_w	dS/m	0-3
or			0-2000
Dissolved Solids	TDS	mg/L	
Cations and Anions			
Calcium	Ca^{++}	mg/L	0-20
Magnesium	Mg^{++}	mg/L	0-5
Sodium	Na^{+}	mg/L	0-40
Carbonate	CO_3^{-}	mg/L	0-1
Bicarbonate	HCO_3^{-}	mg/L	0-10
Chloride	CL^{-}	mg/L	0-30
Sulphide	$SO4^{--}$	mg/L	0-20
NUTRIENTS			
Nitrate-Nitrogen	NO_3-N	mg/L	0-10
Ammonium-Nitrogen	NH_4-N	mg/L	0-5
Phosphate-Phosphorus	PO_4-P	mg/L	0-2
Potassium	K^{+}	mg/L	0-2
MISCELLANEOUS			
Boron	B	mg/L	0-2
Acid/Basicity	pH	1-4	6.0-8.5
Sodium Adsorption Ratio	SAR		0-15

Source: Ayers and Westcot (1994)

Appendix 5: FAO Guidelines for Interpretations of Water Quality for Irrigation

Potential Irrigation Problem				**Units**	**Degree of restriction of use**		
					None	**Slight to Moderate**	**Severe**
Salinity (*Affects water availability*)							
	EC_w			dS/m	<0.7	0.7-3.0	>3.0
	or						
	TDS			mg/L	<450	450-2000	>2000
Infiltration (Affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)							
SAR	=0-3	And EC_w	=		>0.7	0.7-0.2	<0.2
	=3-6		=		>1.2	1.2-0.3	<0.3
	=6-12		=		>1.9	1.9-0.5	<0.5
	=12-20		=		>2.9	2.9-1.3	<1.3
	=20-40		=		>5.0	5.0-2.9	<2.9
Specific Ion Toxicity *(affects sensitive crops)*							
	Sodium (Na)						
	Surface Irrigation			SAR	<3	3-9	>9
	Sprinkler Irrigation			me/L	<3	>3	
	Chloride (Cl)						
	Surface Irrigation			me/L	<4	4-10	>10
	Sprinkler Irrigation			me/L	<3	>3	
	Boron (B)			me/L	<0.7	0.7-3.0	>3
Miscellaneous Effects *(affects susceptible crops)*							
	Nitrogen (NO_3 - N)			me/L	<4	5-30	>30
	Bicarbonate (HCO_3)						
	(overhead sprinkling only)			me/L	<1.5	1.5-8.5	>8.5
	pH				Normal Range 6.5-8.4		

Source: Ayers and Westcot (1994)