LONGITUDINAL AND SEASONAL VARIATIONS IN PHYSICOCHEMICAL AND MICROBIOLOGICAL PROPERTIES OF WATER QUALITY OF SOSIANI RIVER, UASIN GISHU COUNTY, KENYA

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A thesis submitted to the Graduate School in partial fulfilment for the requirements of the Doctor of Philosophy Degree in Environmental Science of Egerton University

EGERTON UNIVERSITY

APRIL 2019

DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted or presented for examination in any other institution either in part or as a whole.

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Recommendation

This thesis has been submitted for examination with our approval as university supervisors

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DEDICATION

To my late parents Peris and Fred Masakha, my wife Joyce Cherotich Nyangwaria and our children: Sheila, Shanice, Sheena, Shaleen and Fred Masakha, for being a great source of joy and inspiration in my life.

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ABSTRACT

Water pollution is the change in physico-chemical and biological properties of water quality that is harmful to living things. It is caused by pollutants drawn from point and non point sources of pollution including industrial and agricultural effluents. It can also be attributed to inappropriate use of chemicals and haphazard disposal of waste. It has become a global concern due to the lethal and sublethal effects on fauna and flora. Sosiani River traverses Eldoret town, draining effluent openly discharged. This river is an important source of industrial and domestic water for residents living in Eldoret, Turbo and along the riparian. This study assessed longitudinal and seasonal variations in physicochemical and microbiological water quality. Composite water samples were collected from 13 effluent discharge points along Sosiani River for one year and analyzed using American Public Health Association water sampling and processing procedures. Medical data was collected from health facilities in Eldoret Township. Data was managed using Statistical Packages for Social Sciences version 20. Both descriptive and inferential statistics like analysis of variance, correlation and regression analysis were used in analysing the resultant data. Sosiani River exhibited high mean levels of turbidity at 64 ± 53.4 Nephelometric Turbidity Units, high biological oxygen demand at 122.8 ± 123.8mg/L, high chemical oxygen demand at 205.0 ± 190.2 mg/L, high total suspended solids at 173 ± 34.14 mg/L, high total dissolved solids at 171.3 ± 11.66mg/L, *Escherichia coli* at 57.0 ± 54.3mg/L Colony Forming Units /100ml, total coliforms at 135.1 ± 119.6CFU/100ml and cadmium at 0.048 ± 0.07mg/L above National Environment Management Authority (NEMA) guidelines. Sosiani River exhibited significant differences in seasonal and longitudinal variations in physico-chemical and microbiological properties of water quality at $P<0.005$. The river exhibited significant seasonal and longitudinal variation in levels of *Escherichia coli* at $F = 5.10$ and $P < 0.001$. However, prevalent water borne diseases in the study area; diarrhoea at $t = 0.6387$, $P < 0.5374$; dysentery at $t = 1.2839$ $P < 0.2281$ and typhoid at $t = 0.3588$, $P < 0.7272$ did not vary significantly during the dry and wet season. Water Resource Authority and NEMA should ensure all industries and hotels use constructed wetlands or are connected to the centralised sewerage system. The County Government should relocate Huruma dumpsite from the banks of the river and plant trees and grass along the river. Residents should treat drinking water sourced from Sosiani River at household level. Finally access to adequate sanitation should be increased to curb haphazard disposal of solid and liquid waste.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrophotometer
ANOVA	Analysis of Variance
APA	American Psychology Association Referencing System
APHA	American Public Health Association
BOD	Biological Oxygen Demand
CFU	Colony Forming Units
COD	Chemical Oxygen Demand
DEQ	Department of Environmental Quality USA
DO	Dissolved Oxygen
EC	*Escherichia coli* (*E. coli*)
ELDOWAS	Eldoret Water and Sanitation Company
EMCA	Environmental Management and Coordination Act
EPA	Environment Protection Agency of USA
FC	Faecal Coliforms
GLOWS	Global Water for Sustainable Programme USA
GoWA	Government of Western Australia
LVEMP	Lake Victoria Environmental Programme
MPN	Most Probable Number
MTRH	Moi Teaching and Referral Hospital
NEMA	National Environment Management Authority
NTU	Nephelometric Turbidity Units
PCB	Polychlorinated Biphenyls
RoK	Republic of Kenya
TC	Total Coliforms
TDS	Total Dissolved Substances
TSS	Total Suspended Solids
UGH	Uasin Gishu County Hospital
UNICEF	United Nations Children Emergency Fund
WASREB	Water Services Regulatory Board
WHO	World Health Organization
WRA	Water Resources Authority
WRUA	Water Resource Users Association

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Rivers and streams are vital sources of freshwater for both domestic and industrial use worldwide. They provide livelihood, freshwater resources, water for irrigation, hydropower and recreation purposes. Besides, rivers play a critical role in assimilation of municipal and industrial effluent through a complex process of influx of surface and ground water, hydrolysis, biological and chemical processes. These processes include; sedimentation, coagulation, volatization, precipitation of colloids and biological uptake by flora and fauna (Edward, 2000; McKinney & Schoch, 2003; David, 2008). Nevertheless, rivers have become susceptible to pollution as water bodies become limitless dumping grounds of effluent and solid waste. Rivers have been used as sinks for urban effluent hence becoming a pathway for heavy metal translocation worldwide (Edward, 2000; McKinney & Schoch, 2003; David, 2008). Aquatic organisms such as fish accumulate these pollutants directly from contaminated water and indirectly through bioaccumulation in the food chain posing a threat to human and ecosystem health. Apparently, owing to the large quantity of effluents discharged to the receiving waters, the natural processes of pathogen removal and reduction are inadequate to protect public health. Hence some rivers are unable to self purify as waters flow downstream (Alavi *et al.*, 2007; Maina *et al.*, 2010). By and large, water pollution has become a major global problem as effluent management deteriorates which is attributed to increasing populations, urbanization, industrialization and increased use of chemicals in agriculture and households (Burton & Robert, 2001; McKinney & Schoch, 2003; Hogan, 2010).

Haphazard effluent discharge alters the physico-chemical and bacteriological properties of water quality which interferes with vital and legitimate water use, ecosystem functions and human health. In light of this, water pollution can be defined as the change in physical, chemical and biological properties of water quality that has harmful effect on living things (WHO, 2016). Water is a critical resource that supports life and makes up to 50–97 per cent of plant and animal weight and 70 per cent of human body weight. Hence it is imperative that drinking water be clean and safe (Goel, 2006; Hogan, 2010; WHO, 2011). Most water resources are polluted by non-point source pollution where pollutants gradually diffuse or leach into rivers unlike point source pollution where pollutants are directly discharged from a single discrete source. Ultimately water pollution exacerbates water scarcity as it limits the use by, and or imposes a higher cost for treatment on downstream users. Hence deteriorating water quality has become a critical issue of environmental concern to both developed and developing countries in modern times (Goel, 2006; Hogan, 2010; WHO, 2017).

Water quality varies from place to place depending on seasonal changes, types of soils, rocks and surfaces through which it moves (Trivede *et al.*, 2010; Vaishali & Punita, 2013; Seth *et al.*, 2014; Thivya *et al.*, 2014). In addition anthropogenic activities alter the natural composition of water through disposal of chemicals and microbial matter, wastes, municipal effluent, industrial discharges, urban activities, and poor farming methods (Shaw, 2004; Moyo, 2013; Van, 2013; Govindarajan & Senthilnathan, 2014; Bello, 2015). Contaminated water contains pathogenic bacteria which cause waterborne diseases such as diarrhoea, typhoid, dysentery, poliomyelitis, respiratory diseases, meningitis, hepatitis and cholera. In addition, some water related diseases such as malaria, yellow fever and filariasis are transmitted by insects that have aquatic larvae (Burton & Robert, 2001; WHO, 2013; Liang *et al.*, 2006; Hogan, 2010; Obasohan *et al.*, 2010).

Nearly 1.1 billion people lack access to safe and clean drinking water worldwide due to water pollution. These accounts for the deaths of more than 1.8 million people every year due to diarrhoeal related diseases, 90% are children under the age of 5 years and mostly in developing countries (WHO, 2013). An estimated 2.4 billion people have no access to basic sanitation and 1 billion which is 15% still defecate in the open. Annually it is estimated that four million cases of diarrhoea with a corresponding 2.2 million infant mortality deaths for children under age of five years are reported due to use of contaminated water (WHO, 2017). It is also reported that 10 per cent of the people living in the developing world have intestinal worms due to contaminated water (WHO & UNICEF, 2010; WHO, 2017). Statistics from India alone indicate that nearly 580 people die every day as a result of diarrhoeal related diseases (Baosheng *et al*., 2004; Goel, 2006). One sixth of the world population do not have access to clean drinking water and nearly 80 per cent of this population is concentrated in Sub-Saharan Africa, Eastern Asia and Southern Asia (WHO & UNICEF, 2010). In Africa alone, over 300 million people lack access to safe drinking water while 85 per cent of diseases in children under the age of 5 years are attributed to water related diseases (WHO & UNICEF, 2010; WHO, 2017).

Rivers in Asia are perceived to be the most polluted in the world. They contain twenty times lead concentration and three times faecal coliforms than WHO standards (Evans *et al.*, 2012). The Ganges River in India is polluted by indiscriminate dumping of waste, cremated bodies and chromium from leather industries. Its coliforms content is over 2800 times higher than WHO standards (EPA, 2007). Similarly, textile industries in China discharge effluent containing reactive dyes, toxic heavy metals and chlorinated organic compounds into the Guangdong River (Baosheng *et al.*, 2004; Campbell, 2009). Moreover, it is reported that Bangladesh has the most polluted ground water in the world due to naturally occurring arsenic. Over 85% of ground water is polluted and 1.2 million people are exposed to arsenic poisoning which is a risk to their health (Evans *et al*., 2012). Hwang Ho River in China also known as Yellow River receives 4.29 billion tons of effluent and 1.6 billion tons of yellow silt from Loess plateau annually hence its name. This river receives 125.4kg of soil per cubic metre of water and is considered the world's muddiest river. Discharges from factories and sewage make a third of the Hwang Ho River water unfit for human consumption, aquaculture, industrial use or agriculture (Baosheng *et al.*, 2004). Over 60% of the people living in Asia have no access to clean water.

Similarly, 40 per cent of rivers in the USA are polluted to the extent that they are not even suitable for fishing, swimming or aquatic life. It is estimated that 4.5 trillion Litres of untreated sewage, storm water and industrial waste are discharged into USA waters annually. In Canada, an estimated 200 billion Litres of untreated sewage and storm water is reportedly discharged into Canadian waters annually (EPA, 2007). In the USA, 98.4 per cent of the 12442Km of rivers assessed were found unsuitable for recreation while 95% failed to meet water quality standards for polychlorinated biphenyls (PCB) and mercury in fish (EPA, 2007). In Michigan State alone, polluted rivers have more than doubled from 5405Km in 2008 to 11,636Km in 2012 which is attributed to leaking sewers, septic tanks, polluted storm water and animal manure (DEQ, 2013). On the other hand, the Amazon River in South America is threatened by agrochemicals and mercury from gold mining (Roulet *et al.*, 2001). Likewise, in Europe, saline discharges from mines in Germany make waters of the Rhine River unsuitable for gardening further downstream in the Netherlands (EPA, 2007). Elsewhere, King River in Australia is considered the most polluted river in the world as a result of acid mine drainage from copper mines in Mount Lyell. Water pH in King River ranges between 2.9 to 3.9 (Crawford, 2000; Laird, 2011).

In Africa 319 million people have no access to clean water which is the same as the population of USA by 2014. Similarly 695 million lack access to sanitation (WHO, 2016). Nile River in Egypt is polluted by heavy metals from industrial effluent, agrochemicals and oil spills (Ezzat, 2002; Scott, 2004) whereas Limpopo River in Southern Africa is polluted by acid mine drainage from coal mining and ore smelting (Ashton *et al.*, 2001). In West Africa crude oil is a threat to water quality in Niger River. It is estimated that this river receives 38 million Litres of crude oil annually (Ogwueleka, 2012; Ordinioha, 2013). In contrast, the Congo River in Central Africa is reported to be the least polluted river in the world which is attributed to the sparse population due to the dense Congo jungle and a rugged terrain (UNEP, 2011). In Eastern Africa, rivers draining into Lake Victoria are polluted by agrochemicals, untreated industrial effluent and sewage hence proliferation of water hyacinth (*Eichornia crassipes*) and algae bloom (Ching *et al.*, 2000; Aloyce *et al.*, 2001; MacDonald, 2001; COWI, 2002; LVEMP, 2003; Tole & Shitsama, 2003; Gichuki *et al.*, 2012).

It is estimated that 17 million Kenyans which is 43% of total population lack access to safe drinking water despite efforts made by the government through policy instruments to ensure sustainable access to safe drinking water and basic sanitation to all (RoK, 2008; Onyango & Angienda, 2010; Marshall, 2011). Indeed, Kenya is considered a water scarce country where demand exceeds renewable freshwater sources. Annual freshwater resources are estimated at 19,590 million m^3 of surface water and 619 million m^3 of groundwater. Water per capita has declined from 2399m^3 per year in 1963 to the current 647m^3. This is below 1000m^3 that the United Nations classifies as chronically water scarce as compared to Tanzania's 2940m^3 and Uganda's 2696m^3 (UNEP 2008). This is projected to drastically decline to 235m^3 by the year 2025 due to continued population growth (RoK, 2008; Marshall, 2011). Nationally, the coverage of improved water sources in the country is 61% with 83% in urban and 54% in rural areas. Similarly, the coverage of piped water provided by the Ministry of Water and Irrigation by the year 2011 was 20% nationally with 45% in the urban areas and as low as 12% in rural areas (WHO & UNICEF, 2013).

Most rivers in Kenya are polluted by poor sanitation, agrochemicals, siltation, leaking sewers, effluent discharge from municipalities and industries (RoK, 2009). Nairobi River which discharges into Athi River is contaminated by industrial effluents, untreated sewage and agrochemicals (Ndaruga *et al.*, 2004; Musyoki *et al.*, 2013). In the Lake basin, rivers flowing into Lake Victoria: Nyando, Sondu Miriu, Nzoia, Yala, Awach, Kibos, Sio, Gucha/Migori and Kasat have been found to be polluted by soil sediments from erosion, municipal effluent, open sewers, effluent from carwash, and agrochemicals from sugar industries. This effluent discharge has enhanced proliferation of the water hyacinth (*Eichhornia crassipes*) on Lake Victoria (Mwamburi, 2003; Bukhalama, 2010; Omutange, 2010; Akali *et al.*, 2011; Gichuki *et al.,* 2012). Likewise, Tana River is polluted by siltation and effluent from coffee factories and urban centres (WRA, 2010). Sosiani River which traverses Eldoret town drains effluent openly discharged into the environment which can affect the physico-chemical and microbiological properties of water quality. There is therefore growing concern among stakeholders over this river's water quality and freshwater resources. This is of major concern owing to the fact that Sosiani River water is used directly as a source of drinking water. It is against this background that a study was conceived to assess the Spatio-temporal variations in the physical, chemical and microbiological properties of water quality of Sosiani River, Kenya.

1.2 Statement of the Problem

Sosiani River traverses Eldoret town draining municipal effluent openly discharged into the environment from the county market, hotels, industries, effluent treatment plants, motor vehicle garages, slaughter houses, storm water and facilities along the riparian corridor. Further, it flows through informal settlements in Huruma and Langas estates where sanitation is poor. Eldoret town has experienced rapid urbanization and the population has more than tripled from 111882 people in 1989 to 392187 in 2017. This affects efficient provision of social amenities like sewerage services and garbage collection. Ultimately, this might affect the physicochemical and microbiological water quality which affects the river ecosystem functions, water use, human and environmental health. In 2014 there were 3525 cases of diarrhoea, 4962 cases of typhoid, 259 cases of dysentery, 144 cases of intestinal worms and 15883 cases of respiratory diseases treated in Uasin Gishu County Hospital alone. Pathogens in water cause waterborne diseases if such water is consumed untreated. On the other hand, increase in acidity and biological oxygen demand affects aquatic fauna like fish which cannot survive low dissolved oxygen below 4mg/l. Hence water for consumption should meet the standard guidelines set by National Environment Management Authority abbreviated as NEMA; World Health Organization; Kenya Bureau of Standards refered to as KEBS and Water Services Regulatory Board known as WASREB. Moreover, Sosiani River flows into Nzoia River which drains into Lake Victoria hence impacts of such effluent discharge can affect a larger water ecosystem and the dependant population. However, data on the spatial and seasonal variations in water quality of Sosiani River is sporadic, not well documented or is lacking. The paucity of data on water quality in this river persists despite increased anthropogenic signatures of pollution. Hence data on water quality is imperative for planning and management of water resources in the country and more specifically in Eldoret town.

1.3 Objectives

1.3.1 Broad Objective

To assess longitudinal and seasonal variations in physico-chemical and microbiological properties of water quality in Sosiani River and prevalent water related diseases in Eldoret Township.

1.3.2 Specific Objectives

i. To characterize sources of pollution along Sosiani River in Eldoret Township.
ii. To determine seasonal and longitudinal variations in selected physico-chemical properties of water quality of Sosiani River upstream, midstream and downstream of Eldoret town.
iii. To assess seasonal and longitudinal variations in selected four heavy metals cadmium, lead, zinc and chromium in Sosiani River upstream, midstream and downstream of Eldoret town.
iv. To analyse seasonal and longitudinal variations in total coliforms and *Escherichia coli* and prevalent water borne diseases treated in health facilities along Sosiani River in Eldoret Township.

1.4 Hypotheses

This research was premised on five hypotheses:

i. There is no significant difference in characteristics of pollutants discharged from effluent discharge points along Sosiani River.
ii. There is no significant difference in seasonal and longitudinal variations in selected physico-chemical properties of water quality in Sosiani River upstream, midstream and downstream of Eldoret town.
iii. There is no significant difference in seasonal and longitudinal variations in selected heavy metals in Sosiani River upstream, midstream and downstream of Eldoret town

iv. There is no significant difference in seasonal and longitudinal variations in total coliforms and *Escherichia coli in* Sosiani River and the prevalent water borne diseases treated in health facilities along Sosiani River in Eldoret Township.

1.5 Justification of the Study

Sosiani River is one of the main sources of freshwater for both domestic and industrial use by residents in Eldoret and Turbo townships and for communities living along the riparian corridor. Water from Sosiani River is also used for irrigation, carwash and recreational purposes by the residents of Eldoret and Turbo Townships. However, Sosiani River traverses Eldoret town draining effluent haphazardly discharged into the environment from several facilities located along the riparian corridor. They include industries like Eldoret steel mills, hotels, leaking sewers, carwash and hospitals. Other facilities are: Zena Flower Farm, Oldonyo Diaries, Wood industries like Rai Plywood and Wood Processing Plants for transmission poles, storm water and effluent from the county market and slums. Such effluent discharged affects water quality in Sosiani River. Hence the resourcefulness of this river as a source of drinking water, recreation and irrigation could be under threat.

The effluent could affect a larger population and ecosystem function since Sosiani River drains into Kipkaren River which is a sub-catchment of the larger Nzoia River basin. Nzoia River then discharges into Lake Victoria in Western Kenya, an important freshwater body in East Africa that supports millions of people and their economic activities. It is the second largest freshwater Lake in the world. Moreover, 17 million Kenyans lack access to safe water. The water per capita in Kenya is estimated at 461m^3 per year against the United Nations recommended water per capita of 1000m^3 per year. Hence Kenya is classified as a water scarce country (WHO, 2011). In this regard, this study sought to assess the physico-chemical and microbiological properties of water quality in Sosiani River that residents rely on as a source of drinking water. Water quality varies with the onset of the wet and dry seasons hence this study sought to determine the Spatio-temporal variations in water quality parameters. Further, this study is useful since heavy metals are known to be toxic, mutagenic and or carcinogenic and affect human health. On the other hand pathogens in contaminated water cause water related diseases like cholera, typhoid, diarrhoea, dysentery, poliomyelitis, meningitis, hepatitis, respiratory diseases, gastro enteritis and intestinal worms. Aquatic fauna like fish cannot survive low dissolved oxygen since they suffocate and die. Moreover, this survey is deemed necessary since in accordance with the law of mass balance all discharges from domestic and industrial processes end up in water and riverbeds as surface runoff.

Ultimately the physicochemical and microbiological water quality parameters will be useful to Water Resource Authority as they formulate and enforce water standards and regulate management and use of water resources; Water Services Regulatory Board and Eldoret Water and Sanitation Company as it will be used in the national database for water quality monitoring and water treatment which will benefit the local residents along Sosiani River to access clean and safe drinking water. Health workers will be able to use microbiological levels especially *Escherichia coli* (*E. coli*) in monitoring and surveillance of water related diseases among residents of Eldoret Township which will contribute to a healthy Nation as envisioned in Kenya's Vision 2030 Strategy and the Kenya Water Master Plan 2030. The goal is to provide clean and safe water for all Kenyans by 2030 for a healthy nation. They aim to provide good quality water in sufficient quantities to meet various water needs.

This study will also contribute to the global sustainable development goals. Goal number two on food security aims to provide unpolluted water which will contribute to sustainable agriculture. Goal number three purposes to ensure healthy lives for all by reducing preventable diseases like water borne diseases by providing safe drinking water and sanitation for all. Goal number four targets quality education hence this study will contribute to proper hygiene and sanitation practises among the residents. Similarly, sustainable development goal number six aims at sustainable management of water and access to adequate and equitable safe water, sanitation and hygiene for all. It aims at reducing pollution, eliminating dumping and minimizing release of hazardous chemical and materials reduce untreated wastewater and encourage recycling and safe reuse. Global sustainable development goal number eleven aims to make cities and human settlement safe and sustainable through sound solid waste management, manage mushrooming slums and reduce vulnerability to disasters.

The results will highlight water pollution threats to the residents of Eldoret who consume raw water sourced from Sosiani River. This might implore all stakeholders to take action to improve effluent management, and for residents to improve their hygiene and sanitation practises. Further, the Spatio-temporal variations in water parameters will contribute to new knowledge. Hence data on physico-chemical and microbiological properties of water quality is imperative for planning and management of water resources in rivers especially Sosiani River.

1.6 Scope and Limitation of the Study

1.6.1 Scope of the study

A sanitary survey 5Km along the riparian corridor of Sosiani River in Eldoret Township identified effluent discharge points. Then water samples were collected at effluent discharge points for laboratory analysis for selected water quality parameters. Composite water samples were collected every month upstream, midstream and downstream of Eldoret town for a period of one year. The objective was to determine seasonal and longitudinal variations in water quality during the dry and wet season. Composite samples were collected since pollutants in water are heterogeneous. Sampling commenced upstream at Two River dam in Kaptagat, Zena Flower Farm, Sukunanga Carwash, and midstream at Kapsabet Bridge, Huruma dumpsite, Huruma sewage plant and downstream at Turbo town. Water samples were analysed for total suspended solids, total dissolved solids, biological oxygen demand, chemical oxygen demand and four heavy metals. Temperature, turbidity and water pH were determined insitu. Four heavy metals cadmium, chromium, lead and zinc were analysed as they are commonly associated with industries in Eldoret such as textile mills, steel mills, motor vehicle garages, wood industries, Pole treatment plants and effluent from the Eldoret county market. *Escherichia coli* was used as indicator of presence of pathogens in the water since they are easy to isolate and enumerate. Data on water related diseases in Eldoret Township was collected from dispensaries and health centres along Sosiani River using pretested checklists. A survey of randomly selected households upstream midstream and downstream of Eldoret town using pretested questionnaires determined the socio-economic aspects of the study population.

1.6.2 Limitations of the Study

i. Pollutants are not homogenous in water which affects sample representativeness. Hence composite samples were collected 0.5m below surface level to avoid atmospheric interference. Depth is important as it represents a homogenous water layer free from riverbed sediments.
ii. Water quality changes fast through volatization or atmospheric air interference. Hence samples were kept in a cool box before transferring to a refrigerator and analysed

within 24 hours. Samples for heavy metals were acidified with concentrated nitric acid to pH ≤ 2 to minimize precipitation and adsorption of metals on container walls and to inhibit bacterial growth. Samples were stored in the dark since high temperatures lead to evaporation and enhance bacterial growth resulting in loss of metals (APHA, 2012).

iii. The results could be influenced by non-point source pollution which was not part of this study.

iv. Water related diseases are not only caused by contaminated water alone but by also contaminated food, poor hygiene and sanitation.

1.7 Assumptions of the Study

This study was premised on the assumption that the physico-chemical and microbiological properties of water quality keep varying in space and time. Hence the water samples were collected during the dry and wet seasons and at different locations along the river. Similarly this study assumes that effluent discharged in Eldoret town ends up in Sosiani River in accordance with the law of mass balance. This study also assumes that effluent discharge points along Sosiani River are the main sources of pollution since non-point sources are diffuse and discrete. Finally the study assumes that waterborne diseases reported in the study area are attributed to contaminated water and not contaminated food.

1.8 Operational Definition of Terms

Anthropogenic activities Human development activities along the riparian corridor of Sosiani River that discharge effluents into this river affecting its water quality parameters

Biological Oxygen Demand The amount of oxygen, microorganisms in water from Sosiani River require to decompose organic matter under standard aerobic conditions. It is used as a measure of organic matter in waters hence an indicator of water quality. Biological oxygen demand (BOD) is measured in mg/L (Clescerl, 2008; WHO, 2014)

Chemical Oxygen Demand Is a measure of the amount of overall biochemically oxidizable organic matter found in Sosiani River achieved by help of a very strong oxidizing agent, potassium dichromate in a strong acid media of concentrated sulphuric acid to ensure full oxidation of all organic compounds found in water and digested at 150°C. Chemical oxygen demand (COD) is measured in mg/L (Clescerl, 2008; WHO, 2014)

Coliforms Rod-shaped non-spore forming gram-negative bacteria, capable of growth in the presence of bile salts and ferments lactose at a specific temperature 35–37ºC with production of acid, gas and aldehyde within 24–48 hours (Prasai, 2007).

Downstream Section of Sosiani River below Eldoret town from Huruma sewage treatment plant up to the mouth in Turbo town where it discharges into Kipkaren River

Effluent Discharge Point Specific open point of discharge of waste water into Sosiani River from anthropogenic activities

Escherichia coli *E. coli* is a faecal coliform bacteria found in the gut of mammals. It is gram negative and non spore forming bacilli capable of fermenting lactose. They are facultative anaerobes determined at 44.5ºC. Some strains can cause diarrhoea and gastrointestinal tract infections. Also known as thermotolerant bacteria

Faecal Coliforms	A sub-group of coliforms found almost exclusively in the excreta of human and animal waste found in Sosiani River. They are thermotolerant bacteria, facultative anaerobes, rod shaped, gram negative bacteria which are an indicator of contaminated water with human waste or sewage. Faecal coliforms are determined at 44.5ºC and measured as Colony Forming Units (CFU)/100ml
Heavy Metals	Metals whose specific gravity is five times greater than that of water and in this study four metals associated with industries and hotels in Eldoret were selected namely: Cadmium, chromium, lead and zinc. Heavy metals are measured in mg/L
Microbiological quality	Microorganisms present in Sosiani River that cause water borne diseases: Microorganisms are determined by presence of total coliforms, faecal coliforms and *Escherichia coli*. They are measured in Colony Forming Units (CFU) /100ml.
Midstream	Section of Sosiani River within the central business district of Eldoret Town from Sukunanga carwash upto Huruma dumpsite.
Non-point Source	Diffuse water pollution sources without a specific point of origin like surface runoff after rain storms.
Open Reflux Method	Method of determining chemical oxygen demand in water through open boiling flow process.
Pathogens	Micro-organisms in Sosiani River like bacteria, virus, protozoa or helminthes that cause waterborne or water related diseases
Physico-chemical Quality	Physical properties of water like temperature, turbidity, total suspended solids and total dissolved solids and chemical properties like pH, chemical oxygen demand (COD), biological oxygen demand (BOD) and heavy metals in Sosiani River.
Point Source Pollution	This refers to direct discharge of effluent or pollutants into Sosiani River from a single discrete point of origin as evidenced by open drainage channel of the Eldoret county market.

Pollutants These are substances found in effluent like heavy metals and organic matter which alter the physical chemical and biological properties of water quality in Sosiani River

Riparian This refers to the land corridor along Sosiani River on either side of the river banks from the source in Kaptagat forest upto the mouth of the river in Turbo town where it discharges into Kipkaren River.

Sanitary Survey Physical observation of effluent discharge along the riparian corridor of Sosiani River from the source at Two River dam to Huruma dumpsite to determine point sources of pollution

Seasonal Variation Changes in the properties of water quality of Sosiani River during the dry and wet seasons

Spatial Variation Changes in water quality of Sosiani River along the longitudinal river profile from upstream in Kaptagat Forest downstream in Turbo town where the river discharges into Kipkaren River.

Suspended Solids Particles of solid material (pollutants) suspended or dispersed in water in Sosiani River like organic matter or soil particles which affect turbidity of water in Sosiani River. Total suspended solids are measured in mg/L

Total Coliforms Total coliforms are a large group of coliforms that are both thermotolerant, faecal and non faecal in origin. These coliforms could be from soil, organic matter or faecal matter. Total coliforms are measured in Colony Forming Units (CFU) per 100ml.

Turbidity This is a measure of light transmitting properties of water quality in Sosiani River. It is an optical property of water which refers to how clear or cloudy the water is in Sosiani River. Turbidity is caused by both suspended and colloidal matter in water and is measured in Nephelometric Turbidity Units (NTU).

Upstream This is the section of Sosiani River above Sukunanga Bridge on the Eldoret-Nairobi highway on the outskirts of Eldoret town upto the source of Sosiani River at Two River Dam in Kaptagat Forest.

Waterborne Diseases These are hygiene and sanitation diseases, caused by consumption of polluted water or preparing food with contaminated water containing disease causing pathogens like bacteria and viruses. Common Waterborne diseases include; typhoid, cholera, dysentery, diarrhoea meningitis, poliomyelitis and hepatitis (WHO, 2014).

Water Pollution This is the change in physical, chemical and microbiological properties of water quality in Sosiani River attributed to effluent discharged into the river from anthropogenic activities.

Water Related Diseases These are vector borne diseases associated with general water usage and stagnant water. The secondary hosts or called vectors which spread these diseases usually propagate in water at one stage of their life cycle like insects that have aquatic larvae. Common water related diseases include; malaria spread by female anopheles mosquito, yellow fever and dengue fever spread by Aedes mosquito, bilharzia (*Schistosomiasis*) spread by snails and river blindness spread by black flies (Hogan, 2010; WHO. 2014).

CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

Effluent discharge from uncontrolled anthropogenic activities usually affect water quality parameters such as temperature, turbidity, electrical conductivity, pH, dissolved and suspended substances, biological oxygen demand (Edward, 2000; McKinney & Schoch, 2003; David, 2008). Among these physico chemical parameters, variations in temperature, pH and electrical conductivity usually have the most profound or lethal effect on aquatic fauna and flora since they ultimately have a direct influence on the physico-chemical and biological functions of organisms (Alvarez, 2000; Prescott, 2002; Goel, 2006; Genevieve & James, 2008). Organic matter and dissolved substances discharged from anthropogenic activities increase electrical conductivity, biological oxygen demand (BOD) and turbidity of water which influences animal plant species or forms of life a river can support (Forrow & Maltby, 2000; Wetzel, 2001; Kaliff 2002; Prescott, 2002; Mosley *et al.*, 2004). As rivers become more acidic below pH 4, all vertebrates and most invertebrates are eliminated leaving only a few algae and bacteria to save the rivers from permanent sterility. Hence changes in water pH and biological oxygen demand can tip ecological balances of aquatic ecosystems whereas impaired water quality such as microbial quality can lead to sub lethal or lethal effects on human health (Wetzel, 2001; Kaliff, 2002; Mosley *et al.*, 2004; Pimentel *et al.*, 2004).

2.2 Physico-Chemical Parameters

2.2.1 Temperature

Temperature is one of the most important ecological and physical factors which have profound influence on living and non-living components of the environment as it affects organisms and functioning of ecosystems (Prescott, 2002; Bowman *et al.*, 2006; Perry *et al.*, 2007; David, 2008; Hogan, 2010). High water temperatures affect chemical and biochemical reaction rates, growth rate, reduce respiration rate, reproduction and ultimately survival of aquatic organisms (Edward, 2000; David, 2008). Similarly, elevated temperatures also affect solubility of gases, minerals, nutrients and pollutants in water. Moreover, high water temperatures contribute to decreased amounts of dissolved oxygen in water; affect taste, odour, colour and corrosion of water pipes. In addition, elevated temperatures increase evaporation and re-acidification of aquatic ecosystems. The saturation value of dissolved oxygen in water is inversely related to the temperature of water (Shaw, 2004; Bowman *et al.*, 2006; Perry *et al.*, 2007; David, 2008; Hogan, 2010).

In temperate climates, dissolved oxygen levels are higher during winter season and lower in the summer season. Variations in water temperature even as low as 0.8ºC have been found to be harmful and even lethal to some organisms in a very short time span (David, 2008; Hogan, 2010). Among aquatic species, fish have been shown to require more oxygen in warm water which is attributed to increased metabolic rate. Although temperature generally influences the overall quality of water, there is no guideline value recommended for drinking water by neither NEMA nor WHO standard guidelines refer to Appendices I & II.

2.2.2 Water pH

Water pH is the negative logarithm to base 10 of the hydrogen ion concentration in water. As the pH value decreases, acidity increases. Although many substances contribute to alkalinity of water, it is primarily the presence of salts of weak acids mainly bicarbonate, carbonate and hydroxide ions which contribute to high water pH and alkalinity. They are key water quality parameters that greatly influence chemical coagulation, disinfection, softening processes and corrosion control in water distribution pipe networks. Effective chemical coagulation of water for instance, occurs only within a specific pH range (Wetzel, 2001; Kaliff, 2002; Goel, 2006; David, 2008). The pH of most natural waters varies from 6.0 – 8.5 while pH for seawater varies from 7.5–8.4 Hence water pH depends on the acid base equilibrium achieved by various salts and gases dissolved in it (Goel, 2006; David, 2008).

In waters with high algae concentrations, pH varies diurnally, reaching values as high as 10 during the day when algae are using carbon dioxide in photosynthesis. Water pH drops during the night when the algae respire and produce carbon dioxide. When pH falls below 4, all vertebrates and most invertebrates are eliminated. Higher plants die leaving a few algae and bacteria to save rivers from permanent sterility (Prescott, 2002; McKinney & Schoch, 2003; Mosley *et al.*, 2004; Pimentel *et al.*, 2004; Salequzzaman *et al.*, 2008). When water becomes alkaline, only salt tolerant species like sea weed (*Enteromorphia spp*) can survive. Water pH affects solubility of many toxic and nutritive chemicals affecting the availability of these substances to aquatic organisms (Mosley *et al.*, 2004; Salequzzaman *et al.*, 2008). Water pH above 8.5 indicates that the water is hard. Most metals become more water soluble and more toxic with increase in acidity. Hence changes in water pH can tip ecological balances of aquatic ecosystems as most toxic metals become more soluble. Water can also become acidic as a consequence of carbon dioxide released by bacteria breaking down organic waste (Edward, 2000; Perry *et al.*, 2007).

2.2.3 Turbidity

Turbidity is an optical measurement that compares intensity of light scattered by a water sample and a standard reference suspension measured in Nephetometric Turbidity Units (NTU). The higher the intensity of light scattered, the higher the turbidity. It is caused by suspended matter like clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms (Edward, 2000; Smith & Davies-Calley, 2001; Wetzel, 2001; Kaliff, 2002; Perry *et al.*, 2007; David, 2008; Kudret & Ilker, 2011). High turbidity causes benthic smothering once the sediments settle out of the water column. However, the most visually and ecologically significant impact of suspended sediments is increased light attenuation through water. High turbidity decreases algal growth and productivity of aquatic ecosystems which affects feeding of aquatic fauna like fish. Turbidity also reduces photosynthesis and visual range of sighted animals. High turbidity, as a result of suspended solids, supports high numbers of foreign micro - biota in water bodies accelerating microbial pollution (Smith & Davies-Calley, 2001; Wetzel, 2001; Kaliff, 2002; Kudret & Ilker, 2011).

Decaying organic matter discharged into rivers affects odours of water due to increased amines and Hydrogen sulphide. Water is considered cloudy when turbidity levels exceed 50NTU. However, it is considered muddy when turbidity exceeds 500NTU. Turbidity is an important indicator of the possible presence of contaminants like bacteria which affect human health. Suspended solids offer shelter and food to bacteria as they are attached to the particles washed into the river (Coulter *et al.*, 2004; Obasohan *et al.*, 2010; Ayivor & Gordon, 2012). High turbidity in water for domestic use can reduce the efficiency of water disinfection as it offers protection to micro-organisms. To improve efficacy of disinfection, turbidity must be reduced below 1NTU through coagulation, sedimentation and filtration (WHO, 2011).

2.2.4 Total Dissolved Substances

Water dissolves a wide range of substances due to its bipolar properties. These total dissolved substances (TDS) beyond a certain concentration in water impair organoleptic and aesthetic properties of water giving it an earthy taste and changed water colour. Organic matter and dissolved substances discharged from anthropogenic activities increase electrical conductivity, biological oxygen demand (BOD) and turbidity of water which influences animal and plant species or other forms of life a river can support (Furrow & Maltby, 2000; Mosley *et al.*, 2004; Hogan, 2010). Water with TDS less than 600mg/L is considered palatable. Drinking water becomes significantly and increasingly unpalatable when total dissolved substances exceed 1000mg/L. High total dissolved substances cause excessive scaling in water pipes, heaters, boilers and household appliances. TDS also reduce crop yields if the water is used for irrigation (Nadia, 2006; WHO, 2011). Total dissolved substances and manure affect water odour and taste. Permissible WHO guideline for TDS in water is 1000mg/L and for TSS 600mg/L for good quality drinking water vide Appendix II.

2.2.5 Biological Oxygen Demand

Biological oxygen demand (BOD) is a measure of the amount of biologically oxidizable organic matter present in a water body (McKinney & Schoch, 2003; Mosley *et al.*, 2004; Goel, 2006; Perry *et al.*, 2007; Clescerl, 2008). It indicates the amount of oxygen that aerobic aquatic organisms could potentially consume in the process of metabolizing all the organic matter available to them. High BOD implies low levels of dissolved oxygen which stresses aquatic organisms and in extreme cases they suffocate and die (McKinney & Schoch, 2003; Mosley *et al.*, 2004; Goel, 2006; Perry *et al.*, 2007; Clescerl, 2008). Oxygen consumption is proportional to the size and number of fish in a given stream. Varying species and sizes of fish require different dissolved oxygen in warmer water than in cooler water due to their increased metabolic rate and lower dissolved oxygen in warmer water. Fish require a greater amount of oxygen after feeding due to increased metabolic rate while smaller fish use more oxygen per unit weight than larger fish (Goel, 2006; Perry *et al.*, 2007).

Biological oxygen demand (BOD_5) is the five day incubation period adopted as standard experimental procedure although 20 days incubation period is required for complete oxidation. BOD_5 avoids the contribution of nitrifying bacteria on oxygen demand (Clescerl, 2008; APHA, 2012). Another limitation of BOD is that industrial waste containing salts of heavy metals, chlorine, cyanide, phenols and pesticides are capable of inhibiting the activity of micro-organisms hence producing low BOD readings. High or low pH also lowers biological oxygen demand (Edward, 2000; Perry *et al.*, 2007; Clescerl, 2008; APHA, 2012). On the other hand, algae sulphur dioxide and Hydrogen sulphide increase biological oxygen demand. However, this is reduced by high dilutions in test tubes during analysis. The more the organic matter the more the bacteria and the greater the demand on oxygen. Aquatic species like fish cannot survive an increased BOD beyond 400mg/L (Edward, 2000; Furrow & Maltby, 2000; Pimentel *et al.*, 2004; Vanloon & Duffy, 2005; David, 2008; APHA, 2012).

2.2.6 Chemical Oxygen Demand

Chemical oxygen demand (COD) is a measure of both the amount of overall biologically degradable and chemically oxidizable organic matter in water samples under specific conditions. It is determined by the open reflux dichromate method using potassium dichromate as a very strong oxidizing agent, in a strong acidic media. Chemical oxygen demand measures all organic contaminants including those that are not biodegradable. High levels of COD imply the presence of greater amount of organic material in water which will reduce dissolved oxygen. A reduction in dissolved oxygen is deleterious to higher aquatic life forms as they suffocate and eventually die (McKinney & Schoch, 2003; Mosley *et al.*, 2004; Vanloon & Duffy, 2005; Goel, 2006; Perry *et al.*, 2007; Clescerl, 2008). The chemical oxygen demand test is often used as an alternate test to biological oxygen demand test since it takes only 2-3 hours to determine unlike BOD which takes upto 5 days and at most 20 days. When the ratio of BOD to COD is greater than 0.8, water is considered to be highly polluted. In normal water samples chemical oxygen demand is 2.5 times the value of biological oxygen demand. Hence chemical oxygen demand can be used to estimate amount of biological oxygen demand when time is a limiting factor. High chemical oxygen demand is also an indicator of presence of organic and inorganic matter which is not biodegradable (McKinney & Schoch, 2003; Clescerl, 2008).

2.2.7 Heavy Metals in Water

Heavy metals are chemical substances with a specific gravity that is at least five times the specific gravity of water. They occur naturally and their concentrations depend on local geology and pollution (Adriano, 2001; Cui *et al.*, 2004; Perry *et al.*, 2007; Zheng *et al.*, 2007). However, their distribution in water is governed by dilution, dispersion, sedimentation and adsorption processes. Heavy metals are among the major toxic pollutants in surface water. They have been found to be a problem in streams abutted by catchments with factories dealing with tanning, smelting, welding, renovation, manufacture and disposal of car batteries, petroleum and oil (Apostolis *et al.*, 2007; Luoma & Rainbow, 2008).

Heavy metals are considered an important water parameter as a result of their bio-accumulation, phytotoxicity and health related effects on human beings see Table 2.1. They have chronic and lethal effects and some are carcinogenic. Municipal effluent contains high concentrations of heavy metals which are toxic like zinc, cadmium, copper, lead, mercury, silver, chromium and nickel (Hammer & Hammer, 2001; McKinney & Schoch, 2003; UN, 2003; Nabulo *et al.*, 2008; Varshney, 2008; Suthar, 2012). Although food processing and textile industries produce effluent with high levels of heavy metals, domestic waste water is known to be the largest single source of heavy metals discharged in the environment. They contain high levels of copper, lead, zinc, and cadmium. Faecal matter contributes 60–70 per cent of the load of cadmium, zinc, copper and nickel in domestic wastewater. Faecal matter contains 250mg/kg zinc; 70mg/kg copper; 5mg/kg nickel; 2mg/kg cadmium and 10mg/kg lead. Other sources of heavy metals include body care products, pharmaceuticals and cleaning products (Adriano, 2001; European Commission, 2001; Woitke, 2003; Pacyna, 2005; Goel, 2006).

Mercury is the most serious environmental contaminant among the heavy metals and its deleterious effects are permanent. Mercury attacks the brain, kidneys and the central nervous system. The most disastrous large scale poisoning by mercury occurred in Minamata Kyushi Japan in 1953 where 700 people died and 9000 suffered paralysis and brain damage whereas 50000 people suffered mild symptoms after eating contaminated seafood. In Iraq, 459 people died and 6500 developed neurological problems after eating grain contaminated by methyl mercury fungicide in 1972 (Roulet *et al.*, 2001; Mahyar *et al.*, 2012).

Cadmium is a non-essential element which is both bio-available and toxic. It interferes with metabolic processes in plants and can bio-accumulate in aquatic organisms and enter the food chain. The principle long-term effects of low level exposure to cadmium are chronic obstructive pulmonary diseases; emphysema and chronic renal tubular diseases see Table 2.1. Ingestion of high concentration of cadmium leads to nausea, vomiting, and abdominal pain. Nearly three quarters of cadmium is used in batteries, especially nickel-cadmium batteries and a small proportion is used mainly for pigments, coatings and plating, and as stabilizers for plastics (Adriano, 2001; Apostolis *et al.*, 2007; Chennakrishnan *et al.*, 2008; Luoma & Rainbow, 2008). Cadmium derives its toxicological properties from its chemical similarity to zinc an essential micronutrient for plants, animals and humans. It is bio-persistent and once absorbed by an organism, remains resident for many years although it is eventually excreted. The presence of copper, lead, zinc and cadmium in fish is of serious health concern to human consumers (Apostolis *et al.*, 2007; Luoma & Rainbow, 2008).

Cadmium is found in rechargeable batteries, paints, photography, food products, detergents and body care products (Ulmgren, 2001; Perry *et al.*, 2007). It originates from launderettes, electroplating and coating shops, alloys, solders, pigments, enamels, glazes, artisanal shops, engraving, and garages. In Japan, water contamination by cadmium caused a disease called 'itai itai' where people had bone abnormalities and necroses of various organs. The water was found to contain 0.18ppm of cadmium and higher concentrations were found in aquatic food chain through biomagnifications (Adriano, 2001; David, 2008; Luoma & Rainbow, 2008). It accumulates primarily in kidneys and has a biological half-life of 10-35 years in human beings. It has acute and long term toxicity in mammals and it is a powerful mutagenic agent (WHO, 2011).

Chromium is widely distributed in the earth's crust. It can exist in the valences of +2 to +6. Chromium III is an essential nutrient for plants while chromium VI is carcinogenic (WHO, 2011). Hence guidelines are given for total chromium because of the difficulties in analyzing for the hexavalent form only. Chromium is present in alloys and is discharged from diffuse sources and products such as preservatives, dying, and tanning activities. It is widely used as a tanning agent in leather processing. Chromium poisoning causes skin allergy, it irritates the nose, lungs, stomach, intestines, convulsion, damage nose and lungs. Chromium causes non-cancer lung diseases, ulcers, kidney and liver damage see Table 2.1. It causes birth defects and is both carcinogenic and mutagenic. The WHO guideline value for chromium is 0.05mg/L (Ulmgren, 2001; Zheng, 2007; David, 2008; WHO, 2011).

Table 2.1: Sources and Health Impacts of Selected Heavy Metals

Heavy metal	Source	Impacts on Health
Cadmium	Batteries, paints, photography, food processing, detergents, body care products, launderettes, plastics, pigments, garages, municipal effluent, domestic wastewater	Pulmonary diseases, emphysema, chronic renal tubular disease, nausea, vomiting, colitis, anaemia, brain damage, carcinogenic
Chromium	Alloys, preservatives, dyes, tanning	Skin allergy, irritates nose, lungs, stomach, intestines, convulsion, non-cancer lung diseases, ulcers, kidney and liver damage, birth defects, carcinogenic and mutagenic.
Lead	Manufacturing, construction, and chemical industries, alkyl lead as an anti-knock agent in petrol	Anaemia, encephalopathy, renal malfunctioning, endocrine disorders, hallucination, poor memory and nephropathy
Zinc	Corrosion, leaching of plumbing, water proofing products, wood preservatives, deodorants, cosmetics, medicines, ointments, antiseptic, paints, pigments, galvanization, batteries, tyres, paper, textile, pharmaceuticals	Tissue hypoxia in fish, stomach and digestion problems, impaired muscular coordination, immune system damage and dehydration.

Source: WHO, 2011

The heavy metal zinc originates from various products commonly used such as: insecticides, fungicides, rat poison, wood preservatives, deodorants, cosmetics, medicines, ointments as antiseptic, paints, pigments, printing inks, colouring agent, ultra violet (UV) absorbent agent, galvanization processes, brass and bronze alloy production, tyres, batteries, plastics, rubber, paper, textiles and embalming fluid (Ulmgren, 2001; Zheng, 2007; David, 2008; WHO, 2011).

Acute toxicity from zinc results in tissue hypoxia as a consequence of cytological breakdown of gills in fish. Zinc imparts an undesirable stringent taste to water at a taste threshold concentration of 4mg/L. Water containing zinc concentrations in excess of 3–5mg/L may appear opalescent and develop a greasy film on boiling. Excessive ingestion causes stomach and digestion problems, impaired muscular coordination, immune system damage and dehydration (Burton & Robert, 2001; Zheng, 2007; David, 2008; WHO, 2011).

Lead is a highly toxic metal found in the manufacturing, construction and chemical industries. It is used primarily in production of Lead-acid batteries, solder and alloys. Organolead compounds such as tetraethyl and tetramethyl lead have been used as antiknock and lubricating agents in petrol and paint, though this has been phased out now. Lead poisoning causes neurodevelopment disorders, cardiovascular diseases, encephalopathy, anaemia, renal malfunctioning and various endocrinal disorders especially of the reproductive glands hence impaired fertility. The main source of lead pollution is in use of alkyl lead in petrol as an anti-knock agent and lead batteries. Although lead has a high profile in human toxicology it is of much lesser importance for aquatic life (Adriano, 2001; Cui *et al.*, 2004; Goel, 2006; Perry *et al.*, 2007; WHO, 2011).

Most recently, use of polluted water from Flint River in Flint, Michigan, USA in 2014 led to corrosion of lead pipes raising levels of lead in human blood. The water changed colour, taste and smell and had high levels of *Escherichia coli* and trihalomethanes (Flint Water Authority, 2016).

Therefore, four heavy metals commonly associated with municipal effluent and industries found in Eldoret; cadmium, chromium, lead, and zinc were investigated in this study.

2.3 Microbiological Properties of Water Quality

The most common and widespread health risk associated with drinking water is microbial contamination. Rivers exhibit seasonal fluctuations in bacterial population density and diversity. This spatial and temporal variability are rarely understood. Municipal effluent contains many pathogenic micro-organisms that pose a health hazard to mankind. These includes: *Salmonella* spp. *Shigella* spp. *Burkholderia pseudomallei*, *Cryptosporidium parvum*, *Giardia lamblia*, Novo virus, helminthes and mycobacterium (Burton & Robert, 2001; Maduka, 2004; Meays *et al.*, 2004; Gerardi & Zimmerman, 2005; WHO, 2011).

Untreated sewage contains pathogens in the genera *Clostridium, Pseudomonas, Proteus, Lactobacillus, Streptococci, Vibrio, Leptospira* and *Brucella* see Table 2.2. Pathogens in contaminated water cause water related diseases like gastro intestinal infections, diarrhoea, poliomyelitis, respiratory diseases, meningitis, hepatitis, typhoid, dysentery and cholera. Cholera is caused by a bacterium *Vibrio cholerae*. Viral diseases include poliomyelitis, meningitis, hepatitis and diarrhoea while bacteria diseases include typhoid, cholera, dysentery, gastro enteritis and diarrhoea. Diarrhoea is caused by many pathogens Vis avis: virus, bacteria and protozoa like *Giardia lamblia* (Burton & Robert, 2001; MacDonald *et al.*, 2001; Prescott, 2002; WHO, 2004; Hogan, 2010; Obasohan *et al.*, 2010).

In addition water related diseases are associated with general water use and are spread by vectors. They include: malaria caused by plasmodium parasites and spread by female anopheles mosquito, yellow fever a viral haemorrhage disease spread by *Aedes aegypti* mosquito, dengue fever caused by dengue virus and spread by *Aedes aegypti* mosquito, River blindness (*Onchocerciasis*) caused by a parasitic worm *Onchocerca volvulus* and spread by a black fly (*Simullium* sp.), bilharzia (*Schistosomiasis*) caused by a parasitic worm or fluke (trematodes) from the genus *Schistosoma* and spread by snails. Water related diseases are transmitted by insects that have part of their life cycle in water like the aquatic larvae of mosquitoes. The helminthes are source of tapeworms, guinea worms and *Schistosomiasis.* However, faecal indicator bacteria *Escherichia coli*, *Streptococcus faecalis* and *Clostridium perfingens* are used as indicator species of contamination although non-faecal coliforms like *Enterobacter, Citrobacter* and *Klebsiella* are easily detected (Burton & Robert, 2001; MacDonald *et al.*, 2001; Prescott, 2002; Hogan, 2010; Obasohan *et al.*, 2010; WHO, 2017).

Table 2.2: Microorganisms that Cause Water Related Diseases

Group	Organism	Water Related Diseases
Bacteria	*Salmonella typhimurium*	Typhoid
	Salmonella paratyphi	Paratyphoid fever
	Shigella spp.	Dysentery
	Vibrio cholerae	Cholera
	E. coli, Leptospira icterohaemorrhage	Gastro enteritis
Helminthes	*Diphyllobothrium latum, Fasciolapsis buski*	Tapeworms
	Schistosoma mansoni, S. haematibium S. japonicum,	*Schistosomiasis*(Bilharzia)
	Dracunculus medinensis	*Clonorchiasis* (trematodes), Guinea worms
Protozoa	*Entamoeba histolytica,*	Amoebic dysentery
	Giardia lamblia	Diarrhoea
Virus	Rotavirus	Diarrhoea
	Polio virus	Poliomyelitis
	Enterovirus	Respiratory diseases, Meningitis
	Hepatitis-A	Hepatitis

Source: Obasohan *et al.*, 2010; WHO, 2010

The coliform group is made up of a number of bacteria including the genera *Klebsiella*, *Escherichia*, *Serratia*, *Erwinia*, and *Enterobacter*. *Escherichia coli* test is a primary indicator of potability or suitability of water for consumption. *Escherichia coli* were chosen as a biological indicator of water since 1890s. They are used as an indicator of pathogens since they are easy to isolate and enumerate. They are a common micro biota present in intestines of warm blooded animals hence their presence is an indicator of fresh faecal matter disposed in water and hence a likely indicator of presence of pathogens in water (Ashbolt, 2004; Meays *et al.*, 2004; Chandra *et al.*, 2006; Prasai, 2007; Chioma *et al.*, 2014).

Coliform bacteria are not pathogenic and are safe to work with in the laboratory. If coliforms are present then there is a high likelihood of pathogens to be present. Hence it is not necessary to analyse drinking water for all pathogens. *Escherichia coli* surrogates are chosen because they are easier to analyse and due to deficiency of other methodologies. *Escherichia coli* is a common microbiota normally found in the intestines of warm blooded animals like livestock, wildlife and human beings (Edberg *et al.*, 2000; Burton & Robert, 2001; Prescott, 2002; Meays *et al.*, 2004; Gerardi & Zimmerman, 2005; Reynolds *et al.*, 2008; Hogan, 2010; Obasohan *et al.*, 2010).

However, some strains of *Escherichia coli* like the shiga toxin producing *E. coli* (STEC) have been confirmed to cause diseases in humans. Pathogenic serotypes such as *E. coli* 0157: H7 and *E. coli* 0104: H4 have been reported to cause diseases in humans like fever, abdominal cramps, diarrhoea, food poisoning, cystitis infection of the bladder, urinary tract infection and gastro intestinal infections. In extreme cases it can cause haemolytic uremic syndrome, a life threatening complication of the kidney which might lead to renal failure. It has been established that domestic and wildlife animals are the natural reservoirs of bacteria belonging to the family *Enterobacteriaceae* (Jain *et al.*, 2010; Van, 2013; Kamanula *et al.*, 2014).

2.4 Review of Related Research on River Water Pollution in Kenya and Worldwide

Studies on variations in physical chemical and microbiological water quality have been carried out worldwide. A survey on the temporal variations in the distribution of heavy metals in the environment has been done in the USA. It established that levels of all heavy metals were elevated into the environment during summer season than winter (Ikem *et al.*, 2003). Another study in the USA showed that use of animal manure in winter led to resurgence of algae blooms in Lake Erie (DEQ, 2013).

Dittmar *et al.* (2007) studied lateral and vertical distribution of arsenic in soils in Sreenagar, Bangladesh over one year cycle of irrigation and monsoon flooding and found that arsenic was highest at the inlet but decreased with length of the channel which he attributed to purification ability of paddy fields. Studies on spatial-temporal variations in water quality in rice fields in Brazil found very high levels of coliforms, calcium, magnesium, in irrigation water channels before the paddy fields and concentrations were lower after the paddy fields. Spatial patterns result from distribution of sampling points. The results confirm ability of paddy fields to filter out chemicals from irrigation water (Panizzon *et al.*, 2013; Reche *et al.*, 2016).

A study on the Niger delta showed that it is heavily polluted by oil spills and hydrocarbons attributed to major petroleum operations. Two million barrels of oil are extracted annually out of which 240000 barrels which is equivalent to 38 million Litres of oil spill into the Niger delta including carcinogens like polycyclic aromatic hydrocarbons. There are high levels of cadmium, lead, chromium, nickel and benzene which affect aquatic life (Ogwueleka, 2012; Ordinioha, 2013).

Many studies have been conducted on macro-invertebrates as bio-indicators of changing water quality in many streams, rivers and lakes worldwide. The studies revealed increased species composition and diversity as organic matter and nutrients increased with the onset of the rain season (Furrow & Maltby, 2000; King *et al.*, 2000; Efitre *et al.*, 2002; Handa *et al.*, 2002; Raburu, 2003; Wang, 2003; Fritz *et al.*, 2004; Rinella *et al.*, 2005; Bowman *et al.*, 2006; Kibichii *et al.*, 2007; Kasangaki *et al.*, 2008; Masese *et al.*, 2009; Odinga, 2009; Aura *et al.*, 2010; Patil *et al.*, 2012; Mbaka *et al.*, 2014; Orwa, *et al.*, 2014; Alhassan & Ofori, 2016). However, the current study focused on microbiological properties of water quality using total coliforms and *Escherichia coli* as indicator species.

Studies have also been conducted on ground water pollution using faecal coliforms as an indicator species in boreholes. Most boreholes had high faecal coliforms attributed to poor faecal disposal mechanisms (Mishra & Bhatt, 2008; Shyamala *et al.*, 2009; Mishra *et al.*, 2010; Desai, 2012; Parihar *et al.*, 2012; Niba & Chrysanthus, 2013; Shrivastava *et al.*, 2013; Palamuleni & Akoth, 2015; Sundar & Nirmala, 2015; Waithaka *et al.*, 2015).

Studies on pathogenic bacteria in contaminated water identified the following pathogenic bacteria in water that pose health risks: *Escherichia coli*, *Shigella flexeneri*, *Klebsiella* sp., *E. faecalis*, *Salmonella typhi* and *Vibrio cholera* (Byamuka *et al.*, 2000; Medema *et al.*, 2003; Oladiji *et al.*, 2004; Chandra *et al.*, 2006; Abraham *et al.*, 2007; Kiruki *et al.*, 2011; Kolawole *et al.*, 2011; Tabor *et al.*, 2011; Ateba *et al.*, 2012; Atieno *et al.*, 2013; Kamanula *et al.*, 2014).

Several studies have investigated presence of heavy metals in river water and in particular in soil sediments. These studies showed that heavy metals increased downstream and during rainy season. Some commonly studied metals were lead, zinc, copper, cadmium, chromium, arsenic and nickel (Ezzat *et al.*, 2002; Scott, 2004; Karikari & Ansa-Asare, 2006; Kouadion & Trefy, 2007; Campbell, 2009; Omutange, 2010; Fu Kaidao *et al.*, 2012; Mwangi *et al.*, 2014; Tamil *et al.*, 2014). Tamil *et al.* (2014) studied the spatial variability of heavy metals in estuary sediments of Sungai India while Omutange (2010) studied heay metals in sediments of Nzoia River.

In Cote devoire studies showed high spatial variations of heavy metal concentrations in excess of background levels in the soils of Ebre Lagoon (Kouadion & Trefy, 2007). Assessment of river water quality using an integrated approach with ecotoxicological approach has been done. These studies involved histopathological studies on fish in contaminated water, bacteriological analyses including total heterotrophic count, total coliforms and thermotolerant coliform counts. Histological investigations revealed significant alterations in tissue structure, and a comparative distinction of higher bacterial density in the intestine and liver tissues of fish in contaminated water (Mohammed & Gag, 2009; Kolawole *et al.*, 2011; Serpa *et al.*, 2014; Roig *et al.*, 2015).

Studies on physicochemical and microbiological characteristics of water have been done on several rivers and results showed that water quality declines downstream. In some cases, water quality parameters improved during flood seasons (Elisavet, *et al.*, 2007; Adekunle & Eniola, 2008; Omezuruike *et al.*, 2008; Shittu *et al.*, 2008; Kotut *et al.*, 2011; Tubatsi *et al.*, 2014; Palamuleni & Akoth, 2015). However, these studies did not focus on spatial-temporal variations of the water parameters. Similar studies on physical chemical & microbial water quality have been done but using nine scale factor (NSF) water quality index (Karikari & Ansa-Asare, 2006; Alobaidy *et al.*, 2010; Al-Bayatti *et al.*, 2012; Tahmasebi *et al.*, 2012; Marinez *et al.*, 2014). Water quality index (NSF) merges all the water parameters into one index. The current study uses specific water parameters and not the index method.

Comparative studies on physico-chemical and microbial quality of drinking water from different sources; rivers, lakes, streams, springs, wells, boreholes and tap water have been done. The studies revealed that most surface waters from rivers, streams and springs was more polluted than underground water and tap water (Vyas *et al.*, 2015). In Nepal, water quality has been determined from various water sources and microbial analysis showed high faecal coliforms as high as 94% due to poor faecal disposal (Prasai *et al.*, 2007; Warner *et al.*, 2007; Suthar *et al.*, 2012).

In Kenya, many studies have been conducted on river water pollution and found that rivers exhibit spatial temporal variations in physicochemical and microbiological water quality. A study on relationship between diversity and abundance of macro-invertebrates and change in water quality was done on Nyando River (Handa *et al.*, 2002). It provides insights into the response of macro-invertebrates to changing water quality. This study however did not look at heavy metal concentrations and microbiological properties. Studies on Lake Victoria showed increased diversity in distribution of lead zinc and mercury levels (Ochieng, 2007). In most stations on Lake Victoria, metal concentrations were above recommended values for drinking water (Tole & Shitsama, 2003). Similarly distribution of metals were also found to be high in Rivers Nyando, Sondu Miriu, Nzoia, Yala, Awach, Kibos and Kasat especially aluminiun, manganese and iron which also increased during rainy seasons (Mwamburi, 2003; Bukhalama, 2010).

A study on spatial distribution of metals along agro-industrial effluent sites along the riparian of River Nzoia revealed that zinc lead copper and cadmium displayed asymptotic trends with distance and were higher in sediments (Omutange, 2010). However, this study analysed soil sediments and not water samples. In a study to establish seasonal variations of nutrient fluxes into the Indian Ocean from River Sabaki, it was observed that both nitrates and phosphates increased during rainy seasons than dry seasons. Nitrates varied from 0.01 to 2.20mg/L in dry weather to 67.4 – 88.44mg/L during rainy seasons while phosphates increased to 25.3mg/L (Ohowa, 2000).

Studies have also been done on the influence of anthropogenic activities on microbial quality of surface water of Rivers Subukia and Momoi in Subukia town. It was established that pH values for Rivers Subukia and Momoi do not vary significantly but there was significant variation in temperature (Muchukuri *et al.*, 2014). This study did not look at other physico-chemical parameters like heavy metals. Studies on Njoro River showed high distribution of copper, lead, cadmium and arsenic along a gradient of human activities and increased during rainy seasons (Ndaruga *et al.*, 2004).

A study on qualitative microbial risk assessment at water abstraction points was done on Njoro River and it reported a significant positive correlation for TSS and bacteria density. Suspended solids and turbidity increased 2–3 times during wet season at most stream sites at the upper and middle reaches and 10 times more at the lower reaches downstream of Njoro town (Yillia *et al.*, 2009).

In addition, a study on Njoro River Watershed observed that Nakuru, Molo and Njoro Districts are endemic for diarrhoeal diseases attributed to poor water supply conditions (Tiwari & Jenkins, 2008). In a study on Lake Nakuru it was discerned that plankton composition and abundance are strongly influenced by changes in water volume in the Lake which affects water chemistry (Chepkiyeng *et al.*, 2010).

Studies on assessment of water quality of Dionsoyeyiet River in Kericho municipality established that the river is relatively polluted downstream than upstream which was attributed to influx of municipal sewage from the treatment plant. Dissolved oxygen was 1.21mg/L, BOD 84.13mg/L and COD 153.44mg/L (Koech, 2003). This study did not address faecal and total coliforms in the river. This study did not look at the impacts of this pollution on the river ecosystem and or human health. A study on water related bacteria pathogens in surface waters of Nairobi River and Health implications to the community downstream of the Arthi River was done. It determined that Athi and Nairobi Rivers are highly contaminated with human pathogenic bacteria particularly *Escherichia coli*, *Shigella flexineri*, *Klebsiella sp., E. faecalis, Salmonella typhi* and *Vibrio cholera* (Musyoki *et al.*, 2013).

2.5 Summary of Literature Reviewed

Effluent from anthropogenic activities alters water quality in rivers which affects ecosystem function and health (Edward, 2000; McKinney & Schoch, 2003; David, 2008). Elevated temperatures affect chemical and biochemical rates, growth rate and respiration rate (Edward, 2000; Shaw, 2004; Perry *et al.*, 2007; David, 2008).Water pH influences chemical coagulation, solubility of nutrients and heavy metals in water (Wetzel, 2001; Kaliff, 2002; Prescott, 2002; McKinney & Schoch, 2003; Mosley, 2004; Pimentel *et al.*, 2004; David, 2008; Salequzzaman *et al.*, 2008).

Suspended matter increases turbidity in water which causes benthic smothering, increased light attenuation, decreases algal growth and productivity of aquatic ecosystems affecting feeding of fauna (Smith & Davies-Calley, 2001; Wetzel, 2001; Kaliff, 2002; Perry *et al*., 2007; David, 2008; Kudret & Ilker, 2011; Ayivor & Gordon, 2012). Total dissolved substances impair organoleptic and aesthetic properties of water, increase electrical conductivity, BOD and turbidity of water. This affects fauna and flora in an ecosystem (Forrow & Maltby, 2000; Mosley, 2004; Nadia, 2006; Hogan, 2010). BOD is a measure of amount of biologically oxidizable organic matter in water. It indicates amount of oxygen that aerobic organisms could potentially consume in the process of metabolizing all organic matter. COD is a measure of overall biochemically oxidizable organic matter under a strong oxidizing agent and acidic media. High BOD implies low dissolved oxygen hence suffocating aquatic fauna like fish (McKinney & Schoch, 2003; Mosley *et al*., 2004; Goel, 2006; Perry *et al*., 2007; Clerscerl, 2008; Edward, 2008).

Heavy metals are toxic, bioaccumulate in the food chain, some are mutagenic and others are carcinogenic hence affect human health. Cadmium interferes with the metabolic process, causes chronic abstractive pulmonary diseases and emphysema. Chromium is both mutagenic and carcinogenic. It causes non cancer lung diseases, ulcer and kidney damage. Zinc causes tissue hypoxia and alters the taste of water. Lead is highly toxic. It can cause neurodevelopment disorders and cardiovascular diseases, encephalopathy, anaemia, renal malfunctioning and various endocrinal disorders (Adriano, 2001; Hammer & Hammer, 2001; McKinney & Schoch, 2003; Cui *et al*., 2004; Apostolis *et al*., 2007; Perry *et al*., 2007; Zheng *et al*., 2007; David, 2008; Luoma & Rainbow, 2008; Nabulo *et al*., 2008; Varshney, 2008; Suthar, 2012).

Municipal effluent contains pathogenic organisms like bacteria, helminthes, protozoa, and viruses which cause water related diseases Vis avis: dysentery, cholera, typhoid, hepatitis and meningitis among others. Coliforms especially *Escherichia coli* are used as indicator species of recent faecal pollution hence the likely presence of these pathogens in water (Maduka, 2000; MacDonald *et al*., 2001; Burton & Robert, 2001; Ashbolt, 2004; Meays, 2004; Gerardi & Zimmerman, 2005; Chandra *et al*., 2006; Prasai, 2007; Hogan, 2010; Obasohan *et al*., 2010; WHO, 2011; Van, 2013).

Finally, many studies carried out on several rivers in Kenya indicate that rivers exhibit spatial temporal variations in physical chemical and microbiological properties of water quality (Ohowa, 2000; Handa *et al*., 2002; Koech, 2003; Tole & Shitsama, 2003; Ndaruga *et al*., 2004; Ochieng, 2007; Tiwari & Jenkins, 2008; Yilia *et al*., 2008; Aura *et al*., 2010;

Chepkiyeng *et al*., 2010; Omutange, 2010; Chibole, 2013; Musyoka *et al*., 2013; Muchukuri *et al*., 2014; Ontumbi *et al.*, 2015; Waithaka *et al.*, 2015). Similarly, studies by other researchers outside Kenya have shown same results of spatial temporal variations in physical chemical and microbiological properties of water quality parameters (Furrow & Maltby, 2000; King *et al.*, 2000; Efitre *et al.*, 2002; Handa *et al.*, 2002; Wang, 2003; Fritz *et al.*, 2004; Rinella *et al.*, 2005; Bowman *et al.*, 2006; Kasangaki *et al.*, 2008; Patil *et al.*, 2012; Mbaka *et al.*, 2014; Alhassan & Ofori, 2016).

2.6 Gaps in Literature Reviewed

Several studies have been carried out on the influence of anthropogenic activities on physical chemical and microbiological water quality in many rivers and lakes worldwide. However, the results cannot be generalised on Sosiani River since rivers have different types and sources of pollution, characteristic effluent discharge, hence each river has unique physicochemical and microbiological water properties and ability to self purify. Previous studies on Sosiani River focused on impacts of phosphate and nitrate nutrients on benthic macroinvertebrate community structure (Marimba, 2003; Odinga, 2009; Osano *et al.*, 2009; Aura *et al*., 2010; Ontumbi *et al.*, 2015). They observed that macroinvertebrate species assemblage, composition and abundance decreased downstream as a response to changing water quality. Another study on Sosiani River focused on hydrological modelling and the water quality pollution at the catchment scale (Chibole, 2013). However, they did not examine Spatio-temporal variations in the physicochemical and microbiological water quality parameters. A study on metal concentrations in water obtained from Sosiani River established differential patterns that declined along the river channel from upstream to downstream (Marimba, 2003). However, this study did not analyse other physico-chemical and microbiological water properties of Sosiani River. They did not assess microbiological water quality of Sosiani River and the prevalent water borne diseases in Eldoret Township. Similarly, other studies focused on bioaccumulation of heavy metals in plants in Sosiani River but did not assess other physical chemical and microbiological properties of this river (Jepkoech, 2013) while others concentrated on ground water sources (Shyamala *et al.*, 2009; Waithaka *et al.*, 2015). On the other hand, other studies concentrated on heavy metal accumulation in soil sediments and not in the water (Omutange, 2010) while others used histopathological studies on Fish. The relationship between changing physico-chemical and micro biological properties of water quality in Sosiani River and prevalence of water related diseases in Eldoret township has not been established hence the need to fill this knowledge gap. Hence there was need to characterise the sources of effluent discharge and assess the longitudinal and seasonal variations in physico-chemical and microbiological properties of water quality in Sosiani River and prevalent water borne diseases in Eldoret Township.

2.7 Theoretical Framework

Increased economic growth results in generation of wastes from human production and consumption patterns that go beyond assimilative capacity of the natural environment. The effluent discharged ends up in rivers or lakes in accordance with the law of mass balance which affects the physico-chemical and biological properties of water quality since ecosystems must reach equilibrium (Burton & Robert, 2001; Goel, 2006; David, 2008). This study therefore was anchored on the theory that water is a universal solvent which dissolves most solutes in the effluent due to its bipolar properties. These dissolved substances influence water properties like pH, hardness, taste, dissolved oxygen, conductivity and water colour (Edward, 2000; Kaliff, 2002; Prescot, 2002). Hence there was need to determine the physico-chemical and microbiological properties of water quality in Sosiani River.

River ecosystem is best described by the river continuum concept as an ever changing ecosystem along its length in physico-chemical parameters hence the need to assess the spatio-temporal variations in water quality parameters of Sosiani River. Rivers are an open ecosystem with unique structures and sequences based on the concept of dynamic equilibrium that is in constant interaction with the environment (Vannotte *et al.*, 1980).

In general, water is a finite and vulnerable resource that is essential for human and ecosystem health. Hence potable water should contain nil coliforms due to water related diseases that pose a health risk to mankind (Maduka, 2004; WHO, 2010). As such, untreated municipal effluent is a threat to human health. Total coliforms and *E. coli* are used as an indicator of pathogens largely because they are easy to isolate and enumerate (Edberg, 2000; Prescott, 2002; Meays *et al.*, 2004). They are present in intestines of warm blooded animals hence an indicator of faecal matter and pathogens in water. The cause effect relationship of disease transmission and specifically faecally associated microbes was initially defined by Van Fritsch in1880 when he identified *Klebsiella* species in human and further developed by Escherich when he described *Bacillus coli* **(***Escherichia coli*) as an indicator of faecal pollution (Edberg, 2000; Prescott, 2002; Meays *et al.*, 2004). Hence this study assessed the total coliforms and *E. coli* in Sosiani River, their Spatio-temporal variations and their correlation with water related diseases.

Water sample properties change very fast as a result of atmospheric interference, volatilization and microbial activities hence holding time for samples collected should not exceed 24 hours. In this regard, water samples were refrigerated at 4ºC and stored in the dark. High water temperatures regulate various biochemical reaction rates that influence water quality. Elevated temperatures also increase evaporation and re-acidification of aquatic systems. Hence measurements for water pH and temperature were taken insitu since they change rapidly (Prescott, 2002; Bowman *et al.*, 2006; Yollanda & Zayas, 2007).

Heavy metals are phytotoxic even in trace elements. They exhibit specific characteristic wavelengths hence the samples were atomized at high temperatures and heavy metals present identified in the atomic absorption spectrophotometer (Adriano, 2001; Alavi *et al.*, 2007; Clescerl, 2008; Luoma & Rainbow, 2008). Standards with known analytes content were used to establish the relationship between measured absorbance and analyte concentration according to the Beer-Lambert law which states that absorbance is proportional to the concentration of the attenuating species in the material (Clescerl, 2008; APHA, 2012). A photoelectric detector measures the intensity of transmitted radiation. The inverse of the transmittance is related logarithmically to the absorbance, which is directly proportional to the number and density of vaporized ground-state atoms according to Beer-Lambert law (Clescerl, 2008; APHA, 2012). Pollutants in water vary with time and space hence this study sought to determine the spatial temporal variations of water quality and the self purification or cleansing ability of Sosiani River from upstream in Plateau further downstream in Turbo where it discharges into Kipkaren River. Composite samples were collected since pollutants are not homogenously distributed in water (Adriano, 2001; Alavi *et al.*, 2007; Clescerl, 2008).

Turbidity depends on suspended matter to absorb and scatter light. Hence it is an expression of optical property. Nephelometric apparatus are designed to measure forward scattering of light at 90º to the path of an incandescent light beam by a photoelectric detector. Suspended particles present in a water sample reflect a portion of the incident light off the particle surface (Smith & Davies, 2001; Bowman *et al.*, 2006; Goel, 2006; Aura *et al.*, 2010).

On the other hand, water pH is used to indicate the intensity of the acidic or alkaline condition of a solution. The alkalinity of water is its quantitative capacity to neutralize acids.

Water sampling was preferred to sampling sediments from the river bed or biological samples since it well represents episodic pollution from the effluent discharge than sediments or biota which are better for assessing cumulative pollution, bioaccumulation or non- point source pollution (Wang, 2001; Raburu, 2003; Njiru *et al.*, 2008; Masese *et al.*, 2009). However, the advantage with macroinvertebrates is that species diversity and abundance varies with changing water quality hence an important tool for monitoring the health of aquatic ecosystems (Smith & Davies, 2001; Bowman *et al.*, 2006; Goel, 2006; Aura *et al.*, 2010).

2.8 Conceptual Framework

2.8.1 DPSIR Conceptual Model

This study adopted the DPSIR (Drivers-Pressures-State-Impact-Response) conceptual model developed by OECD and the United Nations. DPSIR is a cause- effect relationship model linking interacting components of socio-economic and dynamics of the environmental systems and human health. It is a structured process that guides the understanding of relationships and interactions of components in a complex ecosystem and management options. The DPSIR conceptual model defines drivers as socio-economic factors that motivate human activities to fulfil basic human needs for water, shelter, health, security and culture. They are social demographic and economic developments in society which reflect corresponding changes in life styles (Wei, 2007; Moncheva & Doncheva, 2009; Bradley & Yee, 2015).

Drivers put pressure on the environment which leads to changes in the state of the environment. These are human activities that induce changes in the environment like discharge of effluent and storm water runoff. This pressure then causes the change in the state of the natural environment and built environment. Changing state could include quality, quantity of physical chemical and biological components of the ecosystem. Pressure and the state are considered intermediate variables. Changed state could have an impact on the ecosystem functioning, provision of ecosystem goods and services and affect human health. Hence drivers are the independent variable which predict amount of variation in dependent variables. The resultant impacts of this pressure are considered the dependent variables which warrant intervening measures to reduce the drivers and or pressures. Responses are considered as actions by groups or individuals in society and government to prevent, compensate, ameliorate or adapt to changes in the state of the environment. It could also involve modification of human behaviour that contributes to health risks, changes in land use management, Resource management, change of policies, discharge limitations, technical improvements, remediation, monitoring, restoring or outreach and education (Wei, 2007; Moncheva & Doncheva, 2009; Bradley & Yee, 2015).

This is a flexible conceptual framework model used in decision making process for alternative wise use of natural resources and or management of ecosystems for sustainable development (Wei, 2007; Moncheva & Doncheva, 2009; Bradley & Yee, 2015).

2.8.2 Conceptual Framework

In this Drivers-Pressures-State-Impact-Response conceptual framework (DPSIR), the basic driver affecting water quality in Sosiani River is the need for socio economic development like establishing industries, hotels, garages, carwash to generate income and housing estates along Sosiani River due to scarce land availability refer to Figure 2.1. These facilities located along the riparian corridor of Sosiani River discharge effluent in the open and into Sosiani River putting pressure on Sosiani River ecosystem. These drivers are also referred to as the independent variables of this study. Haphazard effluent discharged which is the pressure in this study, alters the state of the river by altering the physical chemical and microbiological properties of water quality in Sosiani River. The Pressure and state of the ecosystem are intermediate variables which explain the relationship in the causal pathway between independent and dependant variables. The resultant impact of changed water parameters is poor water quality which affects water use, Sosiani River ecosystem function and human health. Polluted water contains pathogens which cause water borne diseases like typhoid, cholera, dysentery, diarrhoea, poliomyelitis, meningitis and hepatitis.

The effluent discharged varies from each site along the river and with onset of the rainy season hence the study sought to assess the longitudinal and seasonal variations in water quality in Sosiani River. These changing water parameters are termed the dependent variables of this study. Consequently the impacts force the local communities, stakeholders and Government agencies to take action as intervening variables to manage or mitigate water pollution and its impacts. These include: Creating awareness by all stakeholders like National Environment Management Authority (NEMA), Water Resources Authority (WRA) and County government enforcing waste water management regulations; Eldoret Water and Sanitation company (ELDOWAS) connecting industries and hotels to discharge effluent into the sewer line; County government and residents to build toilets in unplanned residential areas; the National and County governments, National Environment Management Authority and Water Resource Authority relocating illegal structures on the riparian and constructing wetlands to manage the effluent discharged.

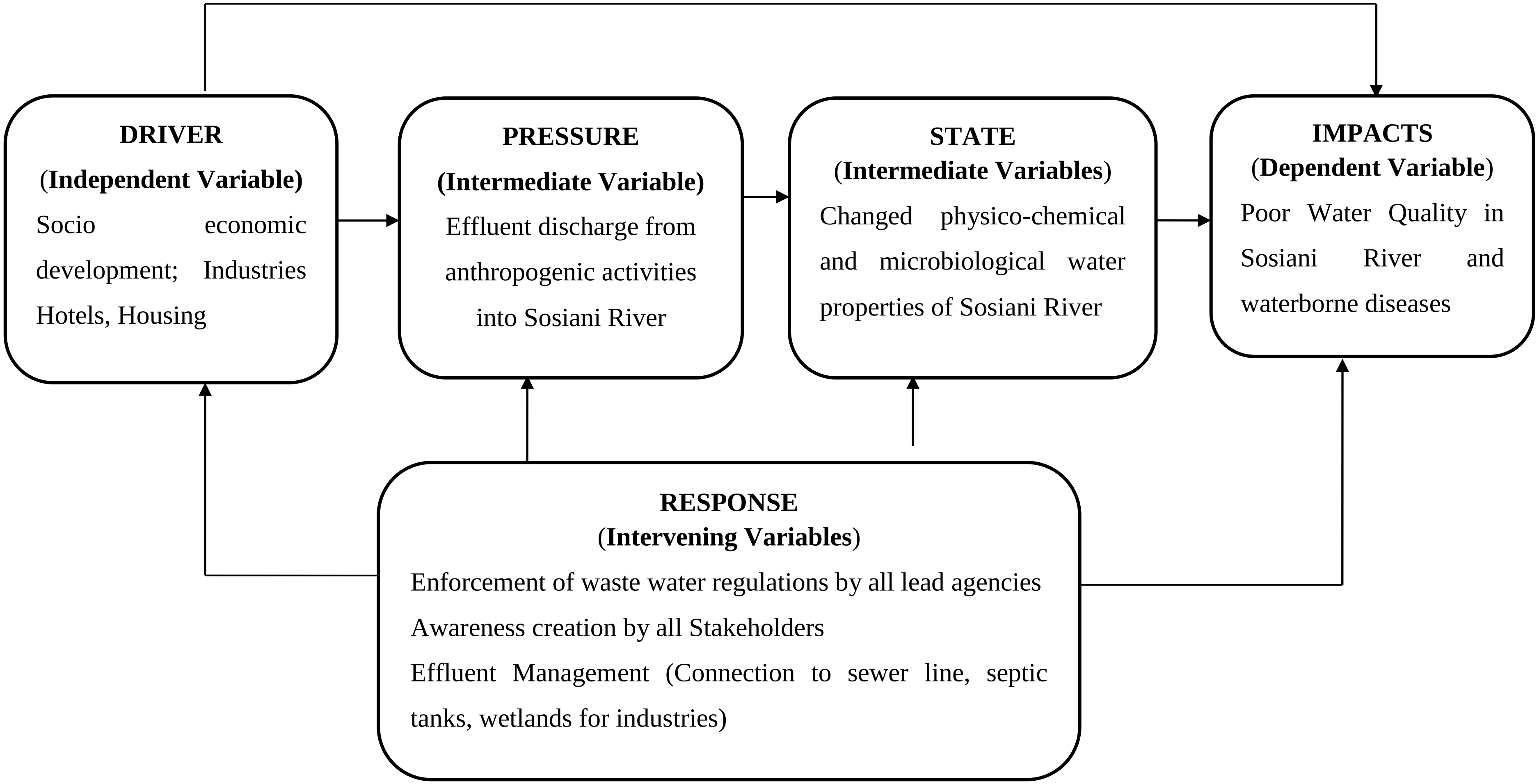

Figure 2.1: Conceptual Framework Adopted from OECD 1994

Source: Wei, 2007

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Description of the Study Area

This study was conducted along Sosiani River which traverses Eldoret town in Uasin Gishu County of Kenya. This river originates from the Two River dam in Kipkurgot, a confluent of two streams Elengerini and Endoroto whose source is Kaptagat forest in the highlands of Keyo escarpment (RoK, 2009). Sosiani River then flows through Eldoret town and discharges into Kipkaren River in Turbo town which subsequently drains into Nzoia River refer to Figure 3.1. The larger Nzoia River Basin then drains into Lake Victoria the largest Lake in Africa and the second largest freshwater Lake in the world (RoK, 2013). This study was therefore confined to a 44Km transect from the source of the river at Two River dam in Kaptagat through Eldoret town downstream to Turbo town. Sampling sites were selected at specific open effluent discharge points along the river at Kipkurgot, Sukunanga carwash, County Market effluent discharge point at Kapsabet Bridge, effluent discharge point from Huruma dumpsite, Huruma sewage treatment plant and finally downstream in Turbo where Sosiani River drains into Kipkaren River see Figure 3.1.

Eldoret town is located on a highland plateau rising upto 2080m above sea level which is dissected by Sosiani River. Hence Eldoret town can be described as a river valley town where surface runoff easily drains into Sosiani River. It is an agricultural town with large scale mechanized farming of wheat at 37500 ha, maize at 65758 ha and horticulture hence the use of agrochemicals is a major environmental concern to the ecosystem health of Sosiani River. Uasin Gishu County lies between latitude 00º 03´ South and 0º 55´ North and longitudes 34º 50´ East and 35º 17´ East see Figure 3.1 (RoK, 2013). Uasin Gishu County is a breadbasket of Kenya producing over 3 million bags of Maize per annum. The town is positioned on the great north road leading to the neighbouring Uganda in the west and Southern Sudan in the North and has attracted a lot of industrial investment. In this regard, Eldoret town is a hub of commercial activities in the North Rift region which has attracted a large urban population. Consequently, these urban migration constraints provision of social amenities like clean and safe drinking water and sewerage provision to residents of Eldoret town.

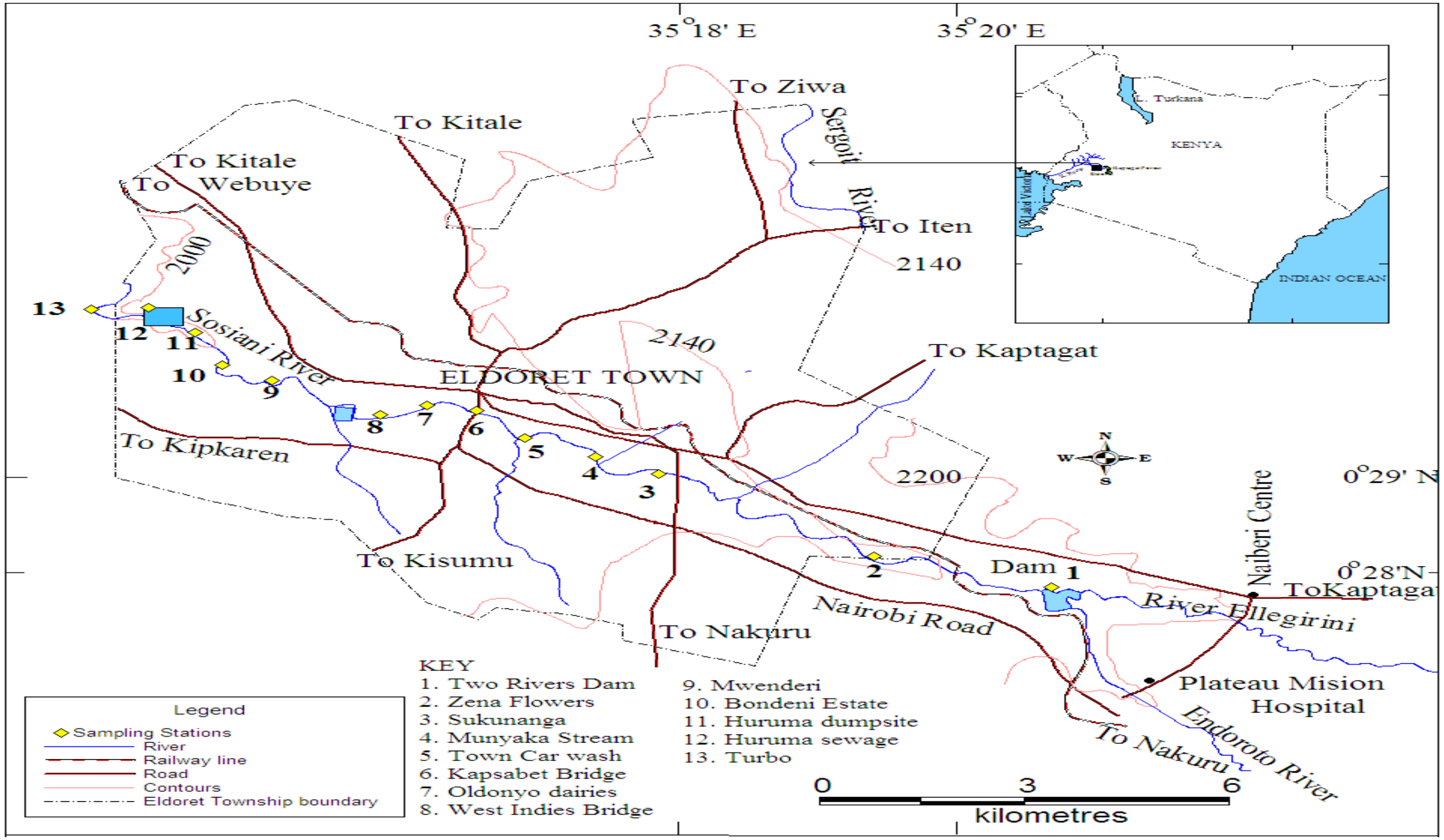

Figure 3.1: Map Showing Flow of Sosiani River

Source: Moi University Geography Department, 2019

Eldoret town is rated as one of the fastest growing towns and the fifth largest town in Kenya. The increased population growth in Eldoret town poses a threat to water quality if effluent and waste disposal are not well managed by relevant government agencies. Uasin Gishu County is located Midwest of the Rift Valley south of Cherangani hills. The name Uasin Gishu originates from a Maasai clan 'illwuasin Kishu' who grazed animals in this region in the early 1910. It is bordered by six Counties namely: Elgeyo-Marakwet in the East, Trans-Nzoia in the North, Kericho to the South, Baringo to the Southeast, Nandi to the Southwest and Kakamega to the West (RoK, 2009; 2013). Uasin Gishu County is divided into three administrative sub counties namely: Eldoret East, Eldoret West and Wareng sub counties. Eldoret town, which is the headquarters of Uasin Gishu County, is located at the centre of all the three sub-counties. The County is further subdivided into six administrative subdivisions namely: Turbo, Soy, Ainabkoi, Moiben, Kesses and Kapsaret. Uasin Gishu County covers a total land area of 3345.2Km^2. It had a population of 894179 people by 2009 which is projected to increase to 1211853 by 2017 with a nearly equal number of females 603346 to males 608,504. It is also observed that this County has a higher population growth rate of 3.8% than the national growth rate of 2.9 % (RoK, 2009; 2013).

3.1.1 Population and Water Demand

Eldoret town is one of the fastest growing towns in Kenya which is attributed to the many universities, industries and agricultural activities which have led to a significant increase in urban population. The population of Eldoret town has grown exponentially from 18,196 people in 1969 to 363486 people by 2015 at a population growth rate of 6% per annum see Figure 3.2. The population of Eldoret Township was projected to further increase to 392187 people by 2017 with a corresponding water demand of 53224m^3/day at a per capita water consumption of 100L/day (RoK, 2013). This will exert more pressure on water supply and sanitation in Eldoret. Furthermore, people are now living in unplanned settlements in Langas, Kamkunji, Bondeni and Huruma where sanitation and hygiene is poor. There are no sewer lines in these slums and pit latrine coverage is poor. Consequently, there is a constraint to provision of amenities like sewage reticulation system, clean drinking water and garbage collection leading to water pollution.

The increased population has led to an increase in water demand of 53224m^3/day with a water deficit of 13774m^3/day (WRA, 2010). Eldoret has a high urban rate of 38.6% which is higher than the national urban rate of 32% (RoK, 2013) which affects provision of amenities like sewer services. The residents of Eldoret town get piped drinking water from Chebara dam whose capacity is only 18000m^3/day. In addition, there are three dams on Sosiani River in use namely: Elengerini dam in Kaptagat with a capacity of 3450m^3/day, Two River dam 14950m^3/day, Sosiani treatment works 14950m^3/day and Kapsoya treatment works 500m^3/day. Water reticulation system is inadequate with only 180000 households within the municipality covered (RoK, 2005 & 2013). However, high water demand, water scarcity, water rationing, high water tariffs and poverty, have forced residents to use raw water from Sosiani River and boreholes. The unchecked population growth has also impacted negatively on the river catchment's water storage capacity both in quantity and quality. A part from increased water demand by the residents, deforestation of the water catchment in Kaptagat to give way to agriculture, settlement affect the water quality and quantity in this river (Sewe, 2009; RoK, 2013).

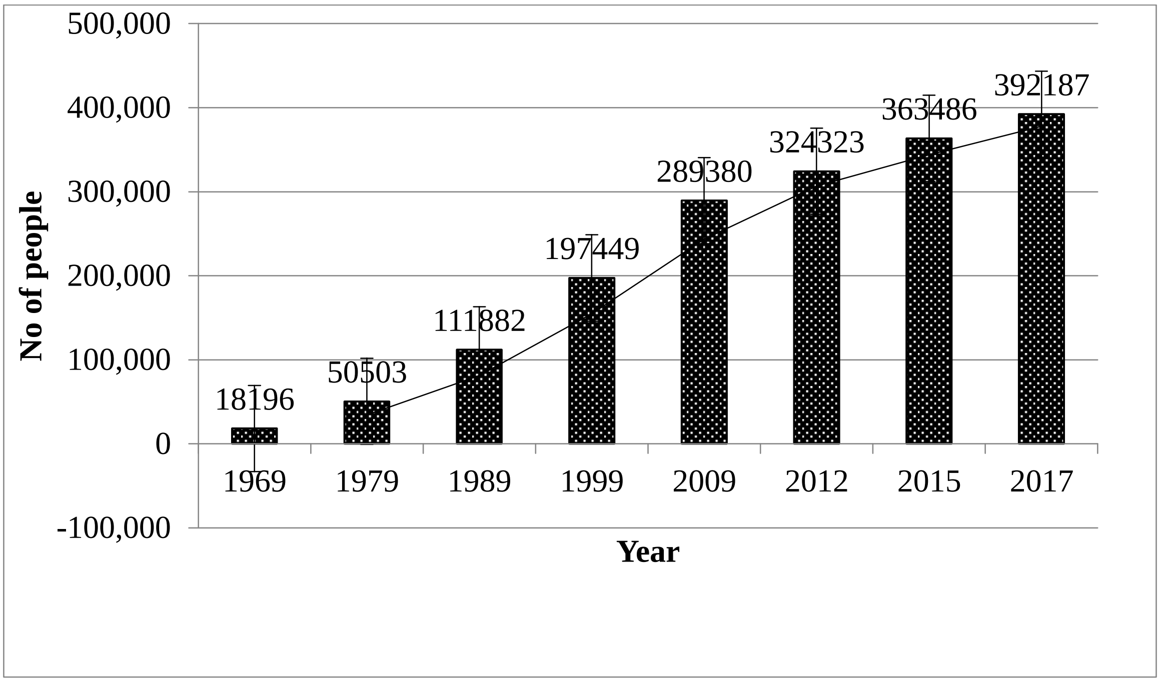

Figure 3.2: Population Trends and Projections for Eldoret Town from 1969 to 2017

Source: RoK, 2013

Eldoret Water and Sewage Company refered to as ELDOWAS is the main water services and sewerage provider in Eldoret town. It operates two wastewater treatment plants at Huruma 8000m^3/day and Kipkenyo 10000m^3/day Hence the total capacity of ELDOWAS sewerage treatment works is 18000m^3/day which is below the water demand and supply and sewerage generated (RoK, 2013).

3.1.2 Soils and Geology

Uasin Gishu County is predominantly covered by tertiary volcanic rock derived from basalt and phonolyte material. The soils are utisols or acrisols characterized by red or yellow argillic horizon. This is an alluvial horizon enriched with silicate clays. It is the stony bedrock of Sosiani River that is the source of the town's name in the Maasai dialect "Eldore" (RoK, 2009). Nevertheless, the soils have low Base Exchange capacity and are deficient in Phosphorous as a result of phosphorous fixation by aluminium III and iron III ions forming strengite and varcite respectively (RoK, 2009). In addition, the soils in Eldoret are poorly drained hence easily waterlogged during rainy season. Red loam soils are found in the northern parts of the County towards Turbo Moi's Bridge and lower Moiben. However, red clay soils occur in Soy, Upper Moiben and Nandi border while brown clay soils which are shallow and full of murram, are found in Upper Lessos plateau. Brown loam soils are found in high altitude areas in Ainabkoi and Kaptagat the source of Sosiani River where dense highland forests abound (RoK, 2013). Nevertheless, these forests have been degraded by human encroachment in search of land for settlement and agriculture. These poses a threat to Kaptagat water catchment tower and water quality in Sosiani River.

3.1.3 Topography

Uasin Gishu County is a highland plateau with a high altitude of 2700m above sea level towards Timboroa in the East. It then undulates gently to 1500m above sea level in Kipkaren in the west towards the Lake region (RoK, 2013). The county forms part of the Lake Victoria catchment hence all the major rivers in Uasin Gishu County drain into Lake Victoria in Western Kenya including: Sosiani, Elengerini, Endoroto, Kipkaren, Kerita, Moiben, Sergoit, Kipkuner, Nderugut, Daragwa and Samburu Rivers. The County is divided into three agro-ecological zones namely: Upper highlands in Timboroa, Upper midlands in Turbo and lower highlands in Moiben, Kesses, Soy and Kapsaret which affect land use, vegetation cover and drainage (RoK, 2013). Sosiani River dissects Eldoret town draining all effluent discharged in the open and surface runoff which affects the water quality.

3.1.4 Climate

The rainfall regime of Eldoret is nearly unimodal with long rainfall seasons and cold temperatures. The region receives mean annual rainfall of 1124mm which is high and evenly distributed throughout the year (RoK, 2009; 2013). It occurs in one long season from March to September with two distinct peaks of rainfall in May and August hence samples for wet season were collected within this period. The dry season begins from November to March. The average temperatures range from 18ºC during dry season to a mean minimum temperature of 8.4ºC in the coolest season which affects water temperatures. The coldest temperatures are recorded in the month of July while the hottest in February (RoK, 2009; 2013). The low temperatures are also attributed to the high altitude of Eldoret Township which is a highland plateau.

3.2 Research Design

This study was based on a social survey design. Sosiani River was stratified into three sections: upstream, midstream, and downstream of Eldoret town and composite water samples collected from thirteen effluent discharge points. The first sampling point at the source of the river, Two River Dam, served as the control of this study. Questionnaires and checklists were also used in the household survey see Appendix III and key institutions in Appendix IV to gather information on social aspects of water pollution and health impacts. Key informants selected were Eldoret water and Sanitation Company known as ELDOWAS, National Environment Management Authority abbreviated as NEMA, Water Resource Authority hereby refered as WRA and Health department purposely based on their national mandate in water management and public health. Medical data on cases of patients treated of water related diseases in Eldoret Township were collected from 5 health facilities located along Sosiani River namely: Ngelel-Terit Dispensary located upstream in Kipkurgot; Huruma Sub County Hospital, Sosiani Health Centre, and Kipkenyo Dispensary located midstream within Eldoret Township; Turbo Sub-County Hospital located downstream. Data was collected with the help of prepared checklists see Appendix V.

3.3 Study Sample Population, Sample Size and Sampling Frame

This survey was carried out with assistance from provincial administration who organized a public forum to sensitize the local community on this survey in the study area. The sample population in the household survey was drawn from the residents living along Sosiani River upstream in Kipkurgot sub location, midstream in Eldoret town and downstream in Turbo sub locations within a distance of 500m. A list of all households living along the river was acquired after canvassing the river with the help of the provincial administration and a research assistant. This formed the sampling frame of 227 households. The households on the list were numbered beginning from one to the last and a random sample selected using random numbers generated from Microsoft excel software. A total of 137 households were randomly selected from the sampling frame. A random sample of 40 households was selected upstream from population of 70 households, 57 households were selected midstream from a population of 91 households and 40 households were selected downstream from a population of 66 households based on the Cochran's formula see Table 3.1.

Table 3.1: Household Sample Sizes

Stream position	No of Households	Sample size
Upstream	70	40
Midstream	91	57
Downstream	66	40
Total	227	137

This is probability sampling which gives reliable estimates and every household has an equal chance of being selected. Pretested questionnaires were then administered with the help of a trained research assistant who works with the Sosiani River rehabilitation project refer to Appendix III. Cochran's formula was used since it is suitable for populations with continuous and categorical variables and one does not need to know the standard deviation of sample population (Mugenda & Mugenda, 2003; Michael & Douglas, 2004; Fuller, 2011).

Cochran's formula for determining sample sizes:

$$N = \frac{Z^2pq}{e^2}$$ ---------------------------------- Eq 3.1

Where Z-score = 1.96 at 95% confidence level, p is estimated proportion of attributes (0.5), q = 1- p and e is desired level of precision (α = 0.05).

Hence $N = \frac{(1.96)^2(0.5)(0.5)}{(0.05)^2} = 385$

This formula is used for large populations of over 10,000 households. For a small population the sample size is adjusted using the following formula:

$$n= \frac{no}{1+(no-1)/N} \text{ ------------------------- Eq 3.2}$$

Where n = New adjusted population size

n_o = Cochran's sample size calculated

N= Actual population size

Sample size adjusted upstream = $\frac{385}{1+(385-1)/70}$ = 40

Sample size adjusted midstream = $\frac{385}{1+(385-1)/91}$ = 57

Sample size adjusted downstream = $\frac{385}{1+(385-1)/66}$ = 40

Seven key institutions: Eldoret Water and Sanitation Company, Water Resource Authority, National Environment Management Authority, Health Department, Fisheries department, Veterinary department and County Government were selected based on their national mandates in matters water supply, hygiene and sanitation and public health. In water sampling, five composite water samples were collected every month from 13 sampling sites, upstream, midstream and downstream for a period of one year. Samples were collected for total suspended solids 1Litre, biological oxygen demand 1Litre, chemical oxygen demand 1Litre, heavy metals 250ml, and microbial analysis 200ml. Hence a total of 65 water samples were collected every day along Sosiani River per month on the same day for 12 months making it 780 water samples collected in a total of 12 months during the year of study in 2016.

3.4 Sampling Equipment

High density fluoropolymer bottles with Teflon lined caps were used to collect grab water samples for laboratory analysis from 13 sampling points along Sosiani River. The following specific equipment were used in water analysis: Turbidimeter HACH 2100A for measuring turbidity, Wagtech international portable meter for measuring water pH and temperature, GFC Whatman filters, autoclave for sterilizing bottles for microbial samples, atomic absorption spectrophotometer model AAS Spectronic 21D for heavy metal analysis, COD digester and a Geographical Positioning system for marking the exact sampling points along the river. The sampling points were selected based on open effluent discharge points identified along Sosiani River and marked using a GPS meter. This is useful in replicating the sampling at the same place. Samples were collected once every month.

3.5 Research Tools

The American Public Health Association (APHA, 2012) standard water sampling procedures were used to collect process and analyse water samples for the physico-chemical and microbiological properties of water quality of Sosiani River. Secondly a household survey was contacted using pretested questionnaires to collect socio-economic demographic data of the households and their perceptions of water quality of Sosiani River and the resultant impacts on their health. Prepared checklists were also used to collect views from key informants from selected government agencies see Appendix IV and in collecting secondary data on prevalent waterborne diseases treated in Turbo sub-county Hospital, Huruma Sub-county Hospital, Sosiani Health Centre, Ngelel-Terit Dispensary and Kipkenyo dispensary refer to Appendix V. Necessary research approvals were obtained from the Post-Graduate School see Appendix VI & VII, National Commission for Science Technology and Innovation also known as NACOSTI see Appendix VIII & IX, Institute of Research and Ethics Committee abbreviated as IREC in Appendix X and Moi Teaching and Referral Hospital known as MTRH vide Appendix XI.

3.6 Validity and Reliability of Research Tools

Validity is the accuracy and meaningfulness of inferences which is attributed to use of faulty instruments (Mugenda & Mugenda, 2003; Michael & Douglas, 2004). On the contrary, reliability is a measure of the degree to which instruments yield consistent data after repeated trials. It is inferred that data can be reliable but not valid when using faulty instruments (Mugenda & Mugenda, 2003; Michael & Douglas, 2004). Reliability was checked using the test-retest method and reliability coefficient of instruments computed before the study commenced. All sampling equipment were checked for any faults and calibrated with standard reference solutions to ensure accuracy. Heavy density fluoro-polymer bottles were used in water sampling to avoid leaking and or contamination of water samples. These bottles were cleaned with phosphate free detergent and dilute hydrochloric acid to avoid metal contamination (APHA, 2012). Samples collected were refrigerated but not frozen to minimize potential for volatilization or biodegradation. Freezing bottles crack and contaminate samples and also effects pH change. Samples were analysed within twenty four hours after collection to maintain sample integrity. Samples for heavy metals were acidified with concentrated nitric acid to minimize precipitation and adsorption of metals on container walls and to inhibit bacterial growth that could lead to loss of metals since the study analysed dissolved metals in water. Further, to check validity, field blanks were used to detect any sample contamination (APHA, 2012). In the household the questionnaires and checklists were also pretested on the sample population to ensure that they are accurate and that they illicit the right response from residents. Further, to ensure accuracy, the research assistant was trained on objectives of the research, how to use the research questionnaires to interview respondents and probability sampling.

3.7 Water Sampling and Analysis

Samples were collected at 13 effluent discharge points along Sosiani River once per month for a period of one year during the dry and wet seasons. The sampling sites were marked using a Geographic Positioning System abbreviated as GPS to enable replication see Appendix XII. Composite samples were collected using half litre metal free Van Dorn bottles at a depth of 0.5m below water surface. Depth was important as it represents a homogenous water layer free from riverbed sediments and avoided atmospheric air interference. Samples for heavy metals were acidified with concentrated nitric to pH ≤ 2 to minimize precipitation and adsorption of metals on container walls and to inhibit bacterial growth that could lead to loss of metals. Samples were refrigerated and stored in the dark since high temperatures lead to evaporation; enhance bacterial growth in solution and on the container surfaces resulting in loss of metals. In comparison, field blanks were used to determine extent of contamination or losses during field sampling and transportation (Vanloon & Duffy, 2005; Yolanda & Zayas, 2007; APHA, 2012).

3.7.1 Turbidity

Turbidity was measured insitu 1m below water surface to avoid ambient light using a HACH 2100A Turbidimeter with a photoelectric detector. Formazin polymer was used as a standard reference suspension. It has reproducible light scattering optical properties like particle size distribution, shape and refractive index. To ensure accuracy, this study avoided dirty glassware, air bubbles, minimized stray light using tungsten filament lamp and ensured that distance traversed by incident light and scattered light did not exceed 10cm (APHA, 2012).

3.7.2 Water pH

Water pH and temperature was measured in-situ using Wagtech international portable meter calibrated against a buffer solution of pH 4, 7 and 10 units. Electrode was rinsed with distilled water and dried before inserting into the water. Readings were taken one minute after the meter had stabilised (APHA, 2012).

3.7.3 Total Suspended Solids

Water sample of one litre was filtered using glass fibre filter of pore size 0.45µm and refrigerated at 1– 4°C. The total suspended solids abbreviated as TSS were determined by drying the filtrate at 103–105°C then weighed within 24 hours (APHA, 2012). Total suspended solids were computed using the formula:

$$\text{Suspended solids in mg/L} = \frac{Final\ weight - Initial\ weight \times 1000}{Volume\ of\ sample\ used} \text{ ---------------Eq. 3.3}$$

3.7.4 Total Dissolved Solids

One litre of the water sample was filtered through ordinary filter paper and water collected in an evaporating dish of known weight. The dish was heated totally evaporating the water. The dissolved solids which accumulated at the bottom of the dish were then weighed (APHA, 2012).

3.7.5 Biological Oxygen Demand

Biological oxygen demand abbreviated as BOD was determined in accordance with standard procedure 5210B (APHA 2012). Sample bottles were thoroughly cleaned and sterilized by autoclaving at 170°C for one hour. One litre of water sample was collected and refrigerated at 4°C. The sample was diluted and dissolved oxygen measured using a DO-meter. Nitrogen, phosphates and trace metals were added and seeded with microorganisms. A mixture of 150mg glucose/L and 150mg glutamic acid was added as a standard check solution. The sample was then saturated with air by shaking and incubated for five days at 20°C in the dark to prevent entry of light to avoid photosynthetic oxygen production refered to as BOD_5 test method. BOD was determined by measuring the difference in dissolved oxygen at dilution and after 5 days incubation period using a DO-meter. Biological oxygen demand was computed using the formula:

$$BOD = (DO_0 - DO_5) \times \text{dilution factor} \quad \text{--------------------Eq. 3.4}$$

Where DO_0 is Dissolved oxygen at dilution

DO_5; Dissolved oxygen after 5 days

3.7.6 Chemical Oxygen Demand

One litre of water sample was collected and preserved with sulphuric acid to pH < 2, refrigerated at 4°C and stored in the dark to avoid losing volatile materials. The chemical oxygen demand was determined by use of the open dichromate reflux method (APHA, 2012). A sample of 25ml of diluted water sample was titrated with potassium dichromate solution; 70ml concentrated sulphuric acid to remove nitrate interference, Silver sulphate as a catalyst, and mercury sulphate to remove chloride interference and digested at 150°C for two hours. Ferroin indicator was added to the digested sample. The remaining unreduced potassium dichromate was titrated with standard ferrous ammonium sulphate refered to as FAS to determine amount of chromate ion consumed vide Appendix XIII. The product of this reaction is a chromate ion with a sharp colour change from green-blue hue to reddish brown that is easily detected (Clescerl, 2008; APHA, 2012). Chemical oxygen demand was computed using the formula:

$$COD = \frac{8000(b-s)n}{sample\ Volume}$$ ------------------Eq. 3.5

Where: b is Volume of ferrous ammonium sulphate used in the blank sample; S is Volume of ferrous ammonium sulphate in the original sample and 'n' is normality of ferrous ammonium sulphate.

3.7.7 Total Dissolved Metals

Water sample was collected in fluoropolymer bottles pre- rinsed with nitric acid. The sample was digested with concentrated nitric to pH ≤ 2 to minimize precipitation and adsorption of metals on container walls and inhibit bacterial growth which otherwise leads to lose of analytes. Nitric acid was a preferred matrix as it reduces interference by organic matter and converts metals associated with particulates (APHA, 2012). A glass microfiber filter GFC Whatman filter of size 1.2µm was washed with water sample before and used to filter the acidified sample in the field. The sample was filtered after acid digestion since this analysis includes metals bound on particulate matter. Extra dilute nitric acid was again added to the filtered sample to ensure dissolution of any precipitates formed after filtration. Thereafter standard solutions of each metal were prepared and used for calibrating the atomic absorption spectrophotometer ASS-Spectronic 21D. They were then used to analyse heavy metals using the flame atomizer method.

3.7.8 Total Coliforms and *Escherichia coli*

Total coliforms and *Escherichia coli* were determined in accordance with standard method 9222D using the membrane filtration technique. Plastic bottles were washed in dilute hydrochloric acid, rinsed with distilled water and autoclaved. The bottles were then rinsed three times with the water sample before filling them. The sample was kept at 4°C and analysed within 24 hours. In the laboratory the sample was diluted 10 times of using distilled water due to high turbidity. The membrane filter technique was then used to filter 10ml of the diluted water sample through a sterile 0.45μm, 47mm, grid and sterile PallGN-6 membrane disc filter using an electric vacuum pump (APHA, 2012). After filtration, the filter was placed on an absorbent pad saturated with m-ColiBlue24 broth in a sterilized Petri dish. The petri dishes were inverted and incubated at 35°C for 24 hours for determination of total coliforms and 44.5°C for *Escherichia coli*. MColiBlue24 broth is a selective chromogenic medium for the simultaneous determination of total coliforms and *E. coli* (APHA, 2012). Total coliforms and *Escherichia coli* are differentiated by their enzyme activities β-galactosidase and β-glucuronidase respectively. A magnifier glass was then used to count the bacteria colony growth. Red and blue colonies indicate total coliforms while the blue colonies indicate *Escherichia coli*. Only dilutions that gave colony counts between 20 and 80 were considered. A simple computation was made to determine number of total coliforms and *Escherichia coli* colonies per 100ml of the sample analysed using the formula:

$TC = \frac{colonies\ counted}{volumeof\ sample} \times 100$ ---------------------Eq. 3.6

It is important to note that both total coliforms and *E. coli* were reported as colony forming units per 100ml of water sampled.

3.8 Data Analysis

Data collected was captured in Excel spreadsheet for Windows XP, and then organized, coded and summarized using descriptive statistics refer to Appendices XIV–XXVIII. The means, variance and standard error were used to analyse the spread of this data see Table 3.2. The data was analysed with the help of Statistical Packages for Social Sciences Statistics 20 abbreviated as SPSS. Data was tested for normal distribution by checking skewness and kurtosis. There was zero skewness and Kurtosis was 3. Skewness is a measure of horizontal departure of data from normal distribution which is zero for normal distribution. Kurtosis is a measure of vertical departure of data from normal distribution. Variations in water quality parameters were determined using inferential statistics (Mugenda & Mugenda, 2003; Michael & Douglas, 2004; Yolanda & Zayas, 2007).

Levene's test was used to determine homogeneity of variance before performing analysis of variance. The mean of parameters ±SE and one-way analysis of variance were used to determine and compare any significant differences among the mean values of water parameters along the Sosiani River. Where significant differences were found, the mean values were separated using post hoc Duncan's multiple range test and denoted using alphabetical letters. Means with the same alphabetical letter are not significantly different from each other. The differences in mean values were considered significant when calculated P-values were < 0.05. One way ANOVA using F-distribution partitioned total variation in water parameters along the river profile and seasons. F-distribution is used since we are comparing more than two means along the Sosiani River. Seasonal variations between means of dry and wet seasons were determined by use of the Students T-test (Mugenda & Mugenda, 2003; Michael & Douglas, 2004; Yolanda & Zayas, 2007). Correlation analysis showed the magnitude and direction of relationship between the water parameters. The correlation coefficient $r = +1$ implies a strong positive correlation while $r = -1$ implies a strong negative correlation. Regression analysis was performed to determine whether the independent variables of water quality predict or explain the changes in a dependent variable of water quality in Sosiani River. Effluent discharge points were marked using a Geographical Positioning System abbreviated as GPS and plotted using Arc-infor Geographical Information System software refered to as GIS.

Table 3.2: Data Analysis Summary Table

No	Research Hypothesis	Variables	Method of Analysis
1	There is no difference in characteristics of effluent discharged	Sources & types of pollutants discharged	Descriptive
2	There is no significant difference in longitudinal & seasonal variation in selected physico-chemical parameters	Eight selected parameters: BOD, pH, TSS, TDS, COD, Temperature, dissolved Oxygen & turbidity	Descriptive statistics One-way ANOVA, t-test for dry and wet season; Correlation and regression analysis of physicochemical parameters
3	There is no significant difference in longitudinal & seasonal variation in selected heavy metals	Four selected heavy metals namely: Lead, cadmium, chromium and zinc	Descriptive statistics One-way ANOVA. Correlation and regression analysis of 4 heavy metals and temperature, pH, TDS TSS & turbidity; Means of heavy metals, t-test for dry and wet season
4	There is no significant difference in longitudinal & seasonal variation in total coliforms, *E. coli* and prevalent waterborne diseases	*E. coli* and number of patients treated of waterborne diseases in health facilities along Sosiani River	Descriptive statistics, One-way ANOVA along sampling sites, t-test for dry and wet season; Correlation and regression analysis of *E. coli* and water borne diseases

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Characterisation of Sources of Water Pollution along Sosiani River in Eldoret Township

In this study, survey along Sosiani River identified many effluent discharge points from hotels and industries which are located along Sosiani River that affect the physico-chemical and microbiological properties of water quality of this river vide Appendix XXVI. The source of Sosiani River is Two River Dam which is threatened with siltation due to the destruction of Kaptagat forest water catchment in the highlands of Keiyo escarpment leading to soil erosion. Deforestation of this water tower is mainly due to poaching of trees for timber and firewood and conversion of the water catchment into agricultural farmlands for subsistence farming and wheat production. Kaptagat forest water catchment is the main source of water that flows in Sosiani River.

Sources of effluent discharged into Sosiani River contributing to water contamination include Zena Flower Farm which is located upstream of Eldoret town near Two River Dam in Kaptagat Forest the source of Sosiani River, followed by Carbacid factory, Sukunanga carwash along the Eldoret-Nairobi highway, Moi Teaching and Referral Hospital, St Lukes Hospital, several hotels, County market effluent discharge point at Kapsabet Bridge along the Eldoret-Kapsabet Highway, Eldoret Central Business District, town Carwash, motor vehicle garages at Bundaptai, Oldonyo-Lessos dairy factory, effluent discharge from Bondeni and Huruma Housing estates which are urban slums, Rai plywood wood processing factory, other wood treatment plants, Huruma solid waste dumpsite and Huruma sewage effluent treatment plant and finally Turbo discharge point where Sosiani River drains into Kipkaren River. These effluent discharge points were marked with the help of a Geographical Positioning System and mapped using Arc info Geographical Information System software as seen in Figure 4.1. These effluent discharge points (EDP) ultimately affect the physicochemical and microbiological properties of water quality of Sosiani River in Eldoret. Several streams drain into Sosiani River. These include Baharini stream, Cheplaskei stream Kapulut stream, Kapsoya stream, Marula stream, Kolol wetland, and Cherunya wetland.

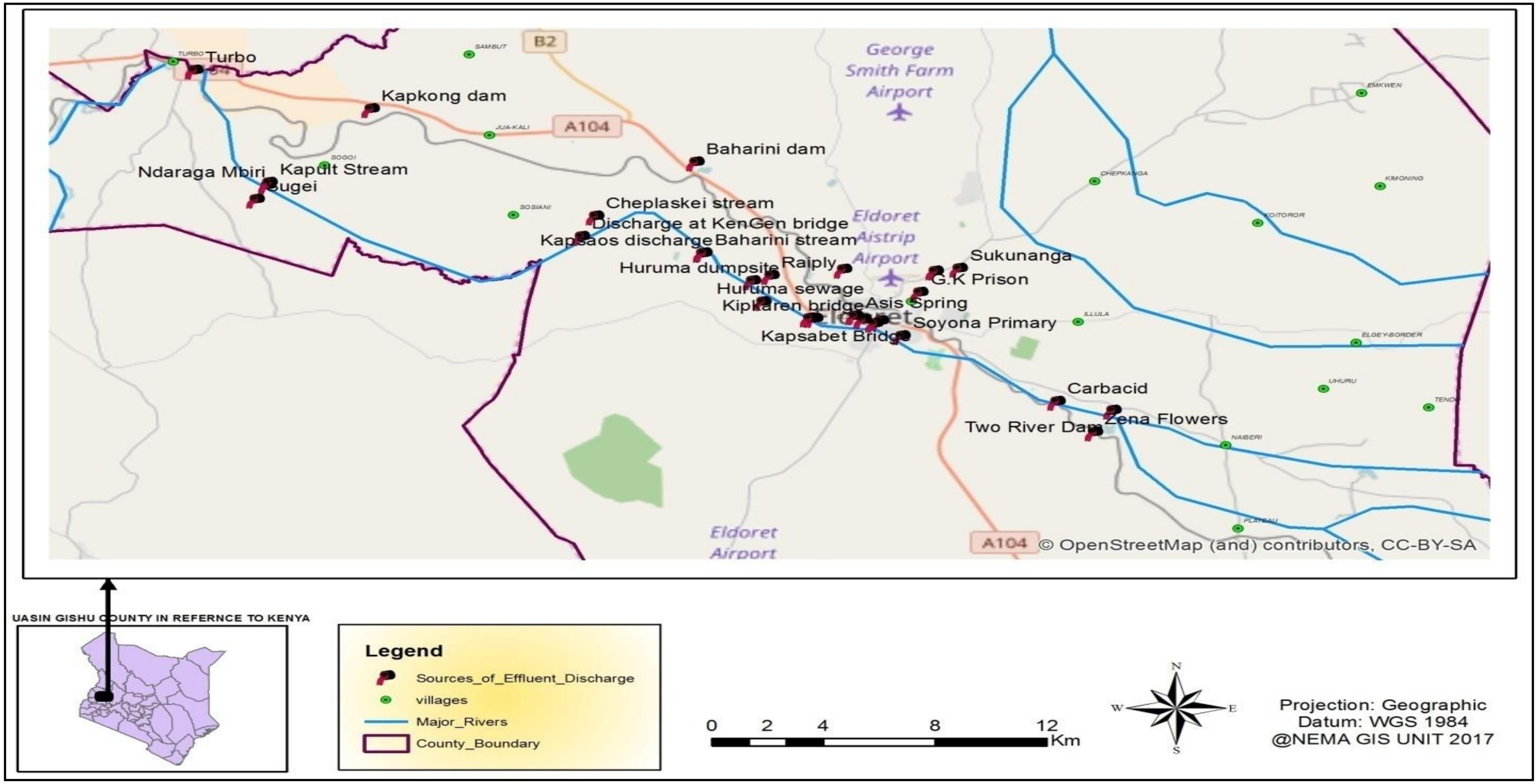

Figure 4.1: GIS Map Showing Effluent Discharge Points along Sosiani River in the Study Area

Source: NEMA, GIS Department, 2017

4.1.1 Characteristics of Two River Dam the Source of Sosiani River

Kaptagat forest is degraded as a result of increased pressure on land for settlement and agriculture. Moreover high demand for timber and charcoal has led to indiscriminate felling of trees in this water catchment of Sosiani River. As a result, this has led to soil erosion which ends up silting Two River dam the source of Sosiani River see Plate 4.1. Similarly, poor farming practices on slopes without erosion control measures and quarrying along the riparian corridor contributes to soil erosion.

Plate 4.1: Two River Dam in Kaptagat Forest the Source of Sosiani River Fenced and Protected from Human and Livestock Encroachment

The dam is fenced and protected from encroachment by the local residents hence little faecal pollution. However, there is soil erosion in the water catchment due to the degraded Kaptagat forest water catchment. These results corroborate the findings of Sewe (2009) who argued that the unchecked population growth has impacted negatively on Sosiani River catchment's water storage capacity both in terms of quantity and quality due to increased deforestation of the water catchment in Kaptagat. Indigenous wetland tree and grass species that filter the water in this dam were identified as *Carex aquatilis* (Water sedge), *Typha domigensis* (Cattail or Bulrushes), *Phragmites kaka* (common tall reed), *Cassia didymobotrya* ('Senetuet' in the local Nandi language) and *Cyperus papyrus* (Papyrus reed or nut grass). In addition, the residents living along Sosiani River water their livestock directly into this river. The urine and cow dung pollute the water since the dung is a source of faecal coliforms in water as seen in Plate 4.2.

Plate 4.2: Livestock Grazing and Watering Directly into Sosiani River in Kipkurgot Village a Source of Faecal Coliforms from the Cow dung

A similar study in the USA observed that use of animal Manure in winter let to resurgence of algae blooms in Lake Erie (DEQ, 2013).

4.1.2 Characteristics of Zena Fower Farm Effluent Discharge Point

The second sampling point was the point where Zena flower farm discharges effluent into Sosiani River in Kipkurgot village. The farm uses many agrochemicals used as herbicides, pesticides and fertilizers. It was also observed that Zena flower farm has no wetland to manage effluent discharged. Some of the agro-chemicals used as insecticides and herbicides include endosulfan, amitraz and chlorpyrofos. Sulphur is used as a fungicide and aluminium sulphate as post-harvest flower treatment. Glyphosate is used as a herbicide and deltamethrine as a pesticide against caterpillar's aphids and thrips. Organic fertilizers are used such as diammonium phosphate, Nitrogen Phosphate Potassium (NPK) and Potassium Nitrate.

4.1.3 Characteristics of Sukunanga Carwash Discharge Point

The residents of Eldoret town wash their cars at Sukunanga carwash next to the former East African Tanning and Extraction Company (EATEC) factory at the Sukunanga Bridge along the main Eldoret town-Nairobi city highway. Sukunanga Bridge effluent discharge point marks the beginning of the midstream section of Sosiani River in Eldoret Township in this study area as seen in Plate 4.3.

Plate 4.3: Vendors Washing Cars at Sukunanga Bridge along Eldoret-Nairobi Highway which Pollutes Sosiani River.

It was also observed that many indigenous trees have been planted at this site hence protecting the stream from surface discharges. Equally, the East African Tanning and Extraction Company was decommissioned in 2000 due to scarce Wattle trees (*Acacia mearnsii*) the source of tannin hence no more effluent discharges from this tanning factory at this site. Presence of *Gyrinus substriatus* (Whirligig beetle or *Chepkina* in the local Nandi language) is believed by the local residents to be an indicator of clean water in a river. Similar studies in rice fields of Brazil showed that paddy fields had purification ability on water quality. Studies on spatial-temporal variations in water quality in rice fields in Brazil showed lower levels of faecal coliforms, calcium and magnesium downstream in irrigation water channels than upstream (Dittmar *et al.*, 2007; Panizzon *et al.*, 2013; Reche *et al.*, 2016).

4.1.4 Characteristics of Munyaka Stream Discharge Point

This site is characterized by many motor vehicle garages located in Bundaptai section of Eldoret town along Sosiani River. Effluents from these garages are discharged into Munyaka stream which drains directly into Sosiani River. Sanitation is also poor as they have no public toilets.

4.1.5 Characteristics of Eldoret Carwash Discharge point

The Eldoret town carwash is located next to the Kapsabet bus stage near Kapsabet Bridge. This site has no public toilets hence poor sanitation. There were leaking municipal sewer lines near this carwash. There is a dumpsite with discarded old batteries from motor vehicle garages around hence a likely source of cadmium from rechargeable batteries (Ulmgren, 2001, Perry *et al.*, 2007). There are two wood treatment plants namely: Wood International and Tipsy wood treatment plants located near this sampling site, which are a likely source of cadmium and lead in Sosiani River.

4.1.6 Characteristics of Effluent Discharge Point at Kapsabet Bridge

Storm water from Eldoret town washes all solid waste carelessly dumped in Eldoret town is openly discharged into Sosiani River at Kapsabet Bridge. Street children live under Kapsabet Bridge with no sanitary facilities hence dispose faecal matter and solid wastes into Sosiani River see Plate 4.4.

Plate 4.4: Solid Waste from Eldoret Town Discharged into Sosiani River at Kapsabet Bridge on Eldoret-Kapsabet Road

Studies have shown that municipal effluent contains high concentrations of heavy metals which are toxic like zinc, cadmium, copper, lead, mercury, silver, chromium and nickel (Hammer & Hammer, 2001; McKinney & Schoch, 2003; UN, 2003; Suthar, 2012). It has also been observed that faecal matter contributes 60-70% of the load of cadmium, zinc, copper and nickel in domestic wastewater (European Commission, 2001).

4.1.7 Characteristics of Effluent Discharge Point at Oldonyo-Lessos Diaries

Effluent at this point comes from Oldonyo-Lessos Dairy processing plant. The water is whitish in colour. This could be attributed to waste water generated from Oldonyo-Lessos milk processing plant which contains waste milk. Waste water generated from food processing plants contains dissolved sugars, proteins, fats, fruit concentrate residues suitable for growth of pathogens (Efitre *et.al*. 2002).

4.1.8 Characteristics of Effluent Discharge Point at West Indies Bridge

Kipkaren housing estate is an informal settlement with poor sanitation within Eldoret town adjacent to West Indies Estate. Pit latrine coverage is poor and there is no sewer line. Waste water from Kipkaren housing estate is thus discharged into Sosiani River near the West Indies Bridge which contributes to the high faecal coliforms at this effluent discharge point. Domestic waste water is one of the largest single sources of heavy metals discharged into the environment (Woitke, 2003; Pacyna, 2005). They contain high levels of copper, lead, zinc, and cadmium (Goel, 2006). Downstream of West Indies Bridge, Sosiani River is choking with plastic bottles and other wastes refer to Plate 4.5.

Plate 4.5: Plastic Waste Bottles and Garbage pile up in Sosiani River after West Indies Bridge. Note the Green Algae Bloom in Sosiani River.

4.1.9 Characteristics of Effluent Discharge Point at Mwenderi Estate

Mwenderi effluent discharge point was characterized by discharges from wood processing factories mainly Rai plywood factory which discharges effluent containing chemical waste and sawdust vide Plate 4.6.

Plate 4.6: The Student and his Supervisor Identify Pollutants in Sosiani River at Mwenderi Effluent Discharge Point.

Rai Plwood factory utilizes Urea, paraformaldehyde, formic acid, caustic soda, melamine, Phenol formaldehyde, polypropylene granules, master batches and inks in wood processing and making mattresses and plastic packaging material. The mattress factory uses toluene di-Isocyanate, polymer propylene, methylene chloride, pigment and hydrochloric acid. Other wood treatment plants identified at this sampling site are Pioneer wood treatment plant, Bayete wood treatment plant and Trademark wood treatment plant. Wood preservatives used in the wood treatment plants are copper chrome arsenate which contains copper chromium and arsenic.

4.1.10 Characteristics of Effluent Discharge Point at Bondeni Estate

Bondeni and Kipkaren informal settlements are characterised by open effluent discharge. The estates have no public sewer lines and pit latrine coverage is poor hence poor faecal matter disposal in these slums. Studies have shown that domestic waste water is one of the largest single sources of heavy metals discharged into the environment (Woitke, 2003; Pacyna, 2005). They contain high levels of copper, lead, zinc, and cadmium (Goel, 2006). Water hyacinth (*Eichhornia crassipes*) has heavily infested Sosiani River at this sampling point refer to Plate 4.7.

Plate 4.7: Water Hyacinth Infestation into Sosiani River after Bondeni Estate due to Nutrient Load

4.1.11 Characteristics of Leachate Discharge Point from Huruma Dumpsite

Solid waste collected from Eldoret is ends up in Huruma open dumpsite located on the banks of Sosiani River. During wet season leachates from Huruma dumpsite drain into Sosiani River hence polluting the water quality. Both Huruma dumpsite and Huruma effluent treatment plant are located on the opposite banks of Sosiani River vide Plate 4.8.

Plate 4.8: NEMA Officials Inspect Water Pollution along Sosiani River between Huruma Dumpsite and Huruma Effluent Treatment Plant.

4.1.12 Characteristics of Huruma Sewage Effluent Discharge Point

Huruma sewage treatment plant discharges water that is not adequately treated see Plate 4.9. Furthermore, the waste stabilisation ponds are not fenced hence a risk to the residents and their livestock. The residents use this water discharged from the last maturation pond for making illegal brew which is a health risk. These findings are consistent with studies on Lake Victoria which showed the lake is polluted by agrochemicals, untreated industrial effluent and sewage hence proliferation of water hyacinth (*Eichhornia crassipes*) and algae bloom (Ching *et al.,* 2000; Aloyce *et al.*, 2001; MacDonald, 2001; COWI, 2002; LVEMP, 2003; Tole & Shitsama, 2003). Similar studies have shown that domestic wastewater is one of the largest single source of heavy metals discharged into the environment. They contain high levels of copper, lead, zinc, and cadmium (Woitke, 2003; Pacyna, 2005; Goel, 2006).

Plate 4.9: Algae Bloom in the Last Maturation Pond of Huruma Treatment Plant an Indicator of High Nutrients in Treated Effluent Water Discharged into Sosiani River.

Presence of algae bloom in the last maturation pond is an indicator of high nutrient content in the treated sewage water which is discharged back into Sosiani River. It was observed that water hyacinth weed has started invading this lagoon which could eventually end up blocking the sewage treatment plant see Plate 4.9. The poorly treated water is then discharged into Sosiani River at a very fast flow rate which is an indicator that there is reduced hydraulic retention time in the anaerobic, facultative and maturation ponds for sufficient and effective sewage treatment. This poorly treated sewage water ends up polluting water downstream in Sosiani River vide Plate 4.10. This observation corroborates findings of a study on assessment of water quality of Dionsoyeyiet River in Kericho municipality which showed that Dionsoyeyiet River is heavily polluted downstream due to influx of municipal sewage from the Kericho sewage treatment plant. Dionsoyeyiet River exhibited low Dissolved oxygen, high BOD and high COD (Koech, 2003).

Plate 4.10: Last Maturation Pond of Huruma Sewage Treatment Plant Discharging Poorly Treated Effluent Water into Sosiani River at a Fast Rate.

4.1.13 Characteristics of Turbo Discharge Point

Sosiani River drains into Kipkaren River and the water is very turbid at this sampling point. This last sampling point was characterised by brownish water due to soil sediments emanating from farmlands as a result of poor land use practice without soil erosion control measures. Sergoit River joins Sosiani River in Turbo at this point refer to Plate 4.11. This observation corroborates findings from other studies which showed poor farming methods lead to increased sediment load, increased carbon and organic matter in rivers (Shaw, 2004; Moyo, 2013; Van, 2013; Govindarajan & Senthilnathan, 2014; Bello, 2015).

Plate 4.11: High Turbidity at Turbo Sampling Point 50 Km Downstream due to Soil Erosion from Neighbouring Farmlands

4.2 Longitudinal and Seasonal Variations in Physico-Chemical Properties of Water Quality

Analysis of Physico-chemical water quality parameters shows a spatial variation along Sosiani River from the source of the river at Two River dam, downstream in Turbo town vide Table 4.1.

Table 4.1: Means of Physico-Chemical Parameters along Sosiani River

Site	TSS mg/L	TDS mg/L	TEMP ºC	pH pH Units	DO mg/L	TURB NTU	BOD mg/L	COD mg/L
Two River Dam	5.1 ± 2.8a	26.8 ± 8.7a	20.1 ± 1.5b	7.1 ± 0.1de	10.8 ± 2.1d	10.4 ± 4.3a	15.3 ± 5.9a	21 ± 8.2a
Zena Flower Farm	99.2 ± 40.6a	89.8 ± 27.7cd	20.0 ± 1.5b	7.0 ± 0.3cd	6.1 ± 1.8a	46.3 ± 26.6ab	72.8 ± 45.6ab	135.3 ± 11.6ab
Sukunanga Carwash	17.2 ± 9.3a	33.8 ± 6.2ab	22.6±1.1cd	7.2 ± 0.3fg	7.5 ±1.7abc	38.1±36.9ab	61.1 ± 47.9ab	88.8 ± 65.6ab
Munyaka Stream	53.7± 25.5a	120.3 ± 46.8d	23.0±1.0de	7.4 ± 0.2h	7.9 ± 1.2bc	39.4± 37.4ab	60.6 ± 53ab	120.7 ± 109ab
Town Carwash	1145.3± 76b	201.5 ± 76.6e	27.2 ± 0.8h	6.9 ± 0.2c	6.8 ± 1.5ab	58.1± 52bc	102.1 ± 94.4ab	200.7 ± 69.1bc
Kapsabet Bridge	16.3 ± 9.3a	43.4 ±17.4abc	19.6±0.2ab	7.2±0.2efg	7.6 ± 2.1abc	46.4±38.4ab	82.1 ± 72.6ab	191.2 ± 155.1bc
Oldonyo	53.4 ± 23.3a	58.4± 18.5abc	22.2 ± 1.0c	6.6 ± 0.2b	8.6 ± 1.8 c	59.1± 50.1bc	120.6 ±131.5b	214.8 ±119.9bce
West Indies Bridge	27.2 ±14.7a	50.5 ±20.6abc	27.6 ± 0.5h	7.5 ±0.1hi	7.3 ±1.9 abc	65.1± 79bc	133.5 ±161.9b	231.9± 271.5bce
Mwenderi	99.6 ± 38.5a	317.5 ± 90.1f	22.6±0.3cd	7.2±0.1efg	6.7 ± 1.8 ab	91.4± 46.5 cd	151.3 ± 72.3bc	309.2± 148.2cde
Bondeni Estate	39.8 ± 22.1a	363.8 ±105.4f	25.5 ± 0.8f	5.6 ± 0.1a	7.6 ±1.8 abc	97.3±52.2 cd	224.3±123.4cd	392.8 ± 193 e
Huruma Dumpsite	22.1 ± 8.9a	108.9 ± 38.6d	23.8 ± 0.9e	7.6 ± 0.1i	7.7 ±1.9 abc	108.5±45.9d	224 ± 106cd	314.8 ±197.2cde
Huruma Sewage	50.3 ± 23.6a	321.3 ± 89f	26.3 ± 0.7g	8.3 ± 0.1j	7.1± 1.6 abc	110.3±56.3d	286.4 ±184.1d	357.4 ± 182.8de
Turbo	41.8 ± 25a	80.5 ±37.4bcd	19.1 ± 0.8a	7.2 ± 0.1ef	11.5 ± 2.3d	61.6±41.9bc	61.8 ± 52.4ab	86.8 ± 71.7ab
Overall	**173 ± 34.14**	**171.3 ± 11.66**	**23.0 ± 3.0**	**7.1 ± 0.6**	**7.9 ± 2.3**	**64 ± 53.4**	**122.8 ± 123.8**	**205.0 ± 190.2**
F Statistic	**43.43**	**56.09**	**117.32**	**153.35**	**8.87**	**4.97**	**7.39**	**5.95**
P value	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**	**< .001**

Sites with the same letter notation do not differ significantly from one another. However, sites that have different letter notations differ significantly from one another. Where N = 156, F value is a statistic showing variations in means and P is the probability level.

4.2.1 Longitudinal Variations of Total Suspended Solids along Sosiani River

In general the total suspended solids in Sosiani River are above the NEMA/WHO guideline values of 30mg/L at all sampling sites refer to Figure 4.2. The mean TSS was 173 ± 34.14mg/L which is 5 times the NEMA standard guidelines as seen in Appendix I & II. However, the TSS was highest at town carwash reaching the highest value of 1261.9 ± 180.7mg/L which is fourty times the NEMA and WHO guidelines. This is attributed to municipal waste and soil erosion from upper Eldoret farming areas as seen in Table 4.1and Appendix I & II. The rest of the other sampling sites along Sosiani River exhibited significantly lower levels of total suspended solids than town carwash but above NEMA/ WHO guidelines see Figure 4.2. The TSS in Sosiani River varied significantly in space at F = 43.43, P < 0.001 since F-statistic is greater than F-critical at 99% confidence limit. However, the lowest mean TSS was recorded at Two River dam at 5.1 ± 2.8mg/L which could be attributed to few anthropogenic activities discharging sediments into Sosiani River at the source of the river see Table 4.1.

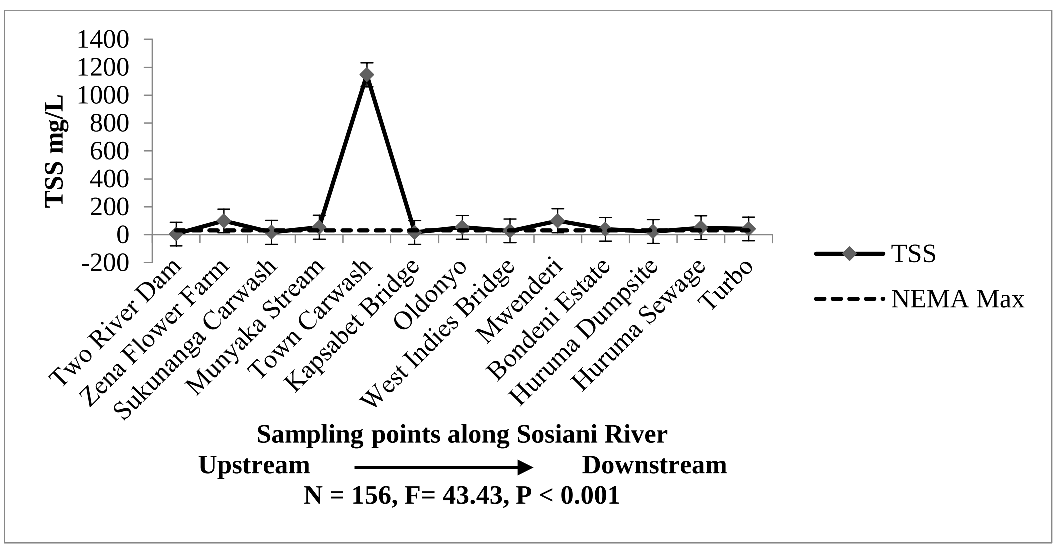

Figure 4.2: Longitudinal Variations of Total Suspended Solids along Sosiani River

However, as the river traverses through Eldoret town, many anthropogenic activities along the riparian discharge effluent increasing the total suspended solids. The mean TSS for Sosiani River at 135mg/L was above the NEMA water quality guidelines refer to Table 4.1. However, it was observed that there is significant positive correlation between temperature and TSS at r = 0.368 meaning increase in TSS increases water temperature as seen in Table 4.2.

Table 4.2: Correlation Analysis of Water Parameters in Sosiani River

	Independent Variables				
Dependent Variables	TEMP ºC	pH (pH Units)	TSS (mg/L)	TDS (mg/L)	TURB (TNU)
DO mg/L	- 0.175 (P<0.029)	- 0.035 (P<0.668)	- 0.225 (P<0.005)	- 0.44 (P<0.001)	- 0.65 (P<0.001)
BOD mg/L	0.262 (P<0.001)	0.059 (P<0.462)	0.033 (P<0.684)	0.627 (P<0.001)	0.904 (P<0.001)
COD mg/L	0.238 (P<0.003)	-0.087 (P<0.283)	0.099 (P<0.218)	0.639 (P<0.001)	0.885 (P<0.001)
TC (CFU/100mL)	0.141 (P<0.080)	0.059 (P<0.465)	0.189 (P<0.018)	0.384 (P<0.001)	0.488 (P<0.001)
EC (CFU/100mL)	0.147 (P<0.067)	- 0.039 (P<0.631)	0.374 (P<0.001)	0.377 (P <0.001)	0.475 (P <0.001)
Zn mg/L	0.257 (P<0.001)	0.499 (P<0.001)	- 0.066 (P<0.416)	0.057 (P<0.483)	0.295 (P <0.001)
Cd mg/L	0.206 (P<0.010)	- 0.151 (P<0.06)	0.443 (P <0.001)	0.22 (P<0.006)	0.241 (P<0.002)
Pb mg/L	- 0.045 (P<0.574)	- 0.47 (P<0.001)	0.302 (P <0.001)	0.165 (P<0.039)	0.134 (P<0.096)
Cr mg/L	0.004 (P<0.959)	- 0.036 (P<0.659)	0.069 (P<0.39)	0.49 (P<0.001)	0.27 (P<0.001)

Where N = 156, r is correlation coefficient and figures in brackets are probability levels

This correlation suggests that TSS increases as water temperature increases. Suspended solids in water absorb heat from solar radiation hence increasing the water temperature (Perry *et al.*, 2007; David, 2008; Hogan, 2010). These results corroborate the findings by Chibole *et al*. (2013) who observed that TSS in Sosiani River displayed a heterogonous spatial variation.

4.2.2 Seasonal Variations of Total Suspended Solids in Sosiani River

The mean total suspended solids for the wet season was 194mg/L which is higher than the TSS for the dry season of 76.1mg/L. T-statistic is greater than t-critical at t = 1.57 and $P < 0.014$ hence there was significant seasonal variation in TSS at 95% confidence limit as seen in Figure 4.3 and Table 4.4. Increase in total suspended solids during the onset of the rainy season could be attributed to increased surface run off. High total suspended solids clog respiratory surfaces and interfere with the feeding appendages of macro-invertebrates which suffocate and eventually die (Obasohan *et al.*, 2010). On average the mean monthly TSS for Sosiani River is above NEMA guidelines refer to Figure 4.3 and Appendices I &II. Similarly there was positive correlation between TSS and Turbidity at r = 0.985 which implies that increase in TSS increases turbidity of Sosiani River as seen in Table 4.2.

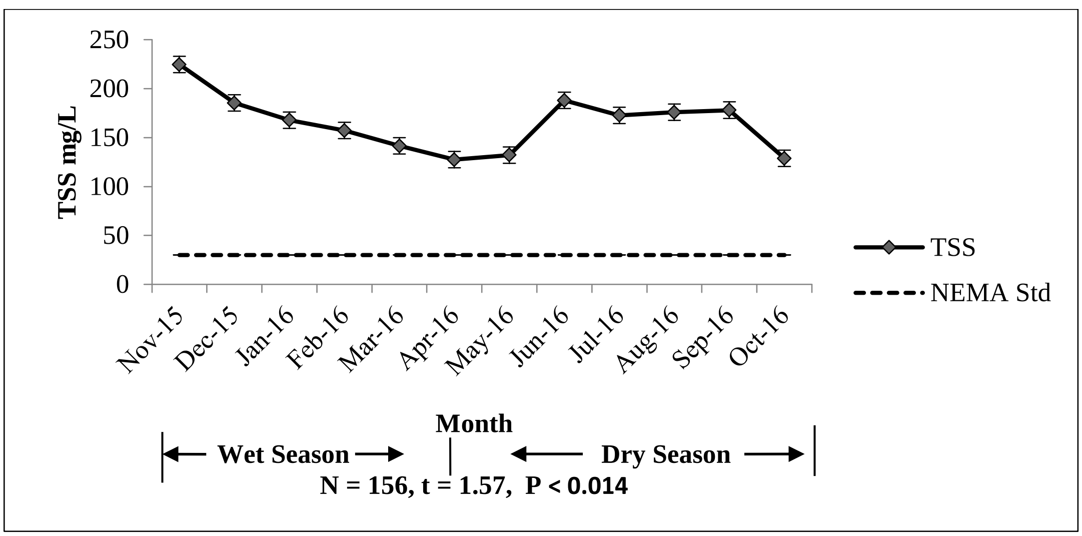

Figure 4.3: Seasonal Variations of Total Suspended Solids in Sosiani River

These findings corroborate results of a study on Njoro River which established that rains in Njoro River catchment led to increased total suspended solids and turbidity 2–3 times at most sampling sites (Yillia *et al.*, 2009).

Table 4.3: Monthly Means of Physico-Chemical Parameters in Sosiani River

Month	**TSS** mg/L	**TDS** mg/L	**TEMP** ºC	**pH**	**DO** mg/L	**TURB** (NTU)	**BOD** mg/L	**COD** mg/L
Nov-15	224.7 ± 160.05b	192.6 ± 43.63f	22.1 ± 3.2a	7.1 ± 0.7a	7.1 ± 1.8def	83.1 ± 63.7abc	122.5 ± 130.2ab	217.2 ± 206.2ab
Dec-15	185.4± 126.74ab	181.5 ± 42.72e	23.7 ± 2.9a	7.1 ± 0.6a	8.2 ± 2.2fg	51.8 ± 46.7ab	82.0 ± 82.9ab	131.2 ± 121.2a
Jan-16	167.9± 114.84ab	172.5 ± 41.8cde	23.6 ± 2.9a	7.1 ± 0.6a	9.1 ± 1.7g	34.7 ± 30a	57.8 ± 57.8a	91.5 ± 86.7a
Feb-16	157.2 ±109.05ab	164.1 ±41.17bc	23.8 ± 2.6a	7.2 ± 0.6a	9.8 ± 1.8efg	23.4 ± 20.7ab	45.0 ± 46.0ab	67.9 ± 64.3ab
Mar-16	141.5 ± 96.25a	156.8 ±40.15ab	23.8 ± 2.6a	7.2 ± 0.6a	10.6 ±1.7def	14.4 ± 12.2abc	30.7 ± 31.3ab	45.3 ± 43.6ab
Apr-16	127.5 ± 84.98a	151.1 ± 40.03a	23.6 ± 2.7a	7.2 ± 0.6a	9.5 ± 1.5cd	24.2 ± 16.2cd	43.2 ± 35.3abc	103.2 ± 105.1bc
May-16	132.2 ± 86.41a	155.9± 40.35ab	23.1 ± 2.9a	7.1 ± 0.5a	8.6 ± 1.9bc	39.6 ± 22.0de	76.2 ± 62.5cd	135.7 ± 103.2cd
Jun-16	188 ± 141.59ab	166.2 ± 41.17c	22.8 ± 3.3a	7.1 ± 0.6a	8.0 ± 1.7ab	57.0 ± 27.0ef	115.6 ± 82.0de	218.0 ± 149.7cd
Jul-16	172.8 ±119.47ab	170.5± 41.56cd	22.8 ± 3.3a	7.1 ± 0.6a	7.2 ± 1.6a	82.1 ± 38.7fg	171.4 ± 92.7de	312.5 ± 167.6d
Aug-16	175.9 ±120.49ab	173.3±41.87cde	22.4 ± 3.4a	7.1 ± 0.7a	6.4 ± 1.5a	96.6 ± 42.1g	218.2 ± 139.5e	341.8 ± 198.1d
Sep-16	178.1± 120.73ab	178.5 ± 42.74de	22.4 ± 3.3a	7.1 ± 0.7a	5.6 ± 1.3bc	120.9 ± 45.6de	240.2 ± 146.1bc	386.4 ± 205.6bc
Oct-16	128.8 ± 188.6b	202.7 ± 43.63f	22.3 ± 2.8a	7.2 ± 0.7a	5.0 ± 1.2bcd	140.1 ± 50.9bcd	270.3 ± 155ab	409.4 ± 211.5ab
Overall	**173 ± 34.14**	**171.3 ± 11.66**	**23.0 ± 3.0**	**7.1 ± 0.6**	**7.9 ± 2.3**	**64 ± 53.4**	**122.8 ± 123.8**	**205 ± 190.2**
F Statistic	**1.57**	**19.73**	**0.61**	**0.06**	**13.87**	**15.02**	**9.33**	**9.64**
P value	**0.014**	**< 0 .001**	**.8197**	**> .999**	**< .001**	**< .001**	**< .001**	**< .001**

Months with the same letter notation do not differ significantly from one another. Months with different letter notations differ significantly from one another.

Where N = 156, F is a statistic showing variations in means and P is the probability level

4.2.3 Longitudinal Variations of Total Dissolved Solids along Sosiani River

Sosiani River exhibited spatial variation in total dissolved substances. However, the mean total dissolved substances of 171.3 ± 11.66mg/L was below the NEMA and WHO standard guideline values for drinking water and irrigation refer to Figure 4.4 and Appendices I & II. The total dissolved substances increased midstream as the river flows through Eldoret town but decline further downstream. The F-statistic is greater than the F-critical at F = 59.09, $p < 0.001$. Hence there was significant variation in TDS at 99% confidence limit. The highest mean concentration of total dissolved substances was recorded at Bondeni estate at 363.8 ± 90.1mg/L but it is not significantly different from two other sites at Huruma sewage treatment plant at 321.3 ± 89mg/L and Mwenderi at 317.5 ± 90mg/L refer to Figure 4.4 and Table 4.1. High TDS affects water taste, odour, colour and hardness. Further, it causes corrosion of water pipes and scaling of household water appliances. However, low TDS contributes to palatability of water (Edward, 2000; David, 2008).

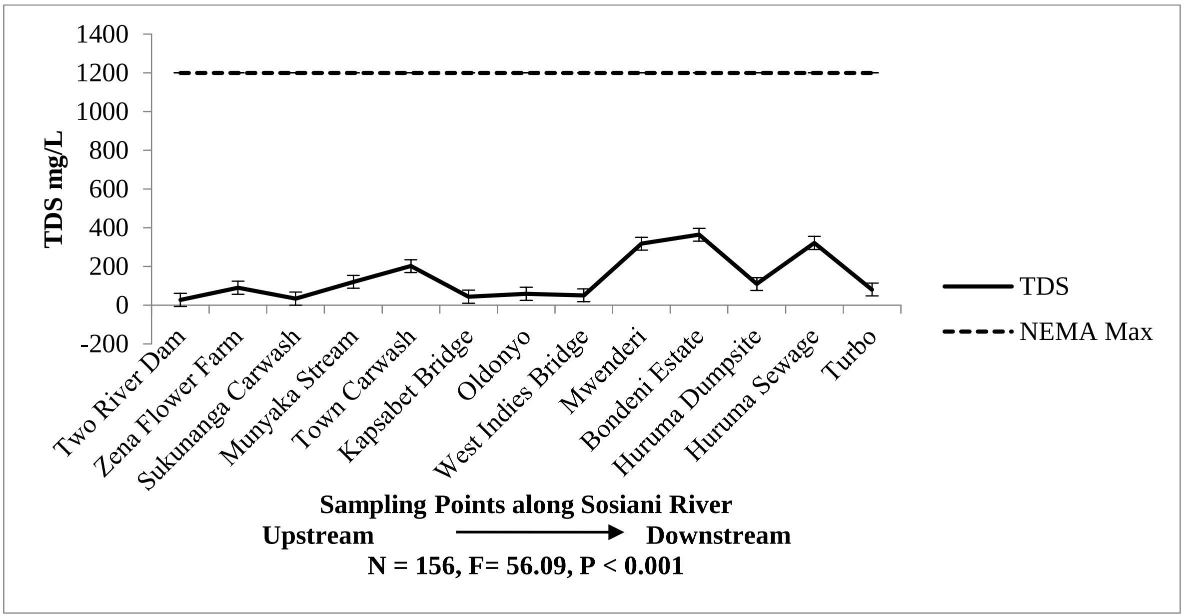

Figure 4.4: Longitudinal Variation of Total Dissolved Substances along Sosiani River

The lowest TDS of 26.3 ± 2.3mg/L was recorded at the first sampling point at Two River Dam which can be attributed to minimal effluent discharge in the dam apart from soil erosion upstream. At each point of increased activity such as flower farming, car wash and hotels or industries and human settlement there seemed to be a corresponding increase in TDS, perhaps evidence of pollution. There was a negative correlation between dissolved oxygen and dissolved substances at r = - 0.44 refer to Table 4.2. TDS increase matter in water which in turn increases bacteria activity hence leading to low dissolved oxygen. However there was a positive correlation between TDS and COD at r = 0.639 and BOD at r = 0.627. This implies that as TDS increases it increases the chemical and biological oxygen due to decreased dissolved oxygen. These findings are consistent with Muchukuri *et al.* (2014) who also observed that Njoro River exhibited heterogeneous spatial variation in total dissolved substances.

4.2.4 Seasonal Variations in Total Dissolved Substances in Sosiani River

The mean monthly TDS at 171.3mg/L was below the NEMA and WHO guidelines. The mean TDS during dry season was 98.2mg/L while TDS wet season was 178.9mg/L see Figure 4.5 and Appendices I & II. The t-statistic at t = 4.49, P < 0.001 is greater than t-critical. Hence there was significant variation in mean monthly total dissolved substances at 99% confidence limit. This could be attributed to increased surface runoff refer to Figure 4.5 and Table 4.4.

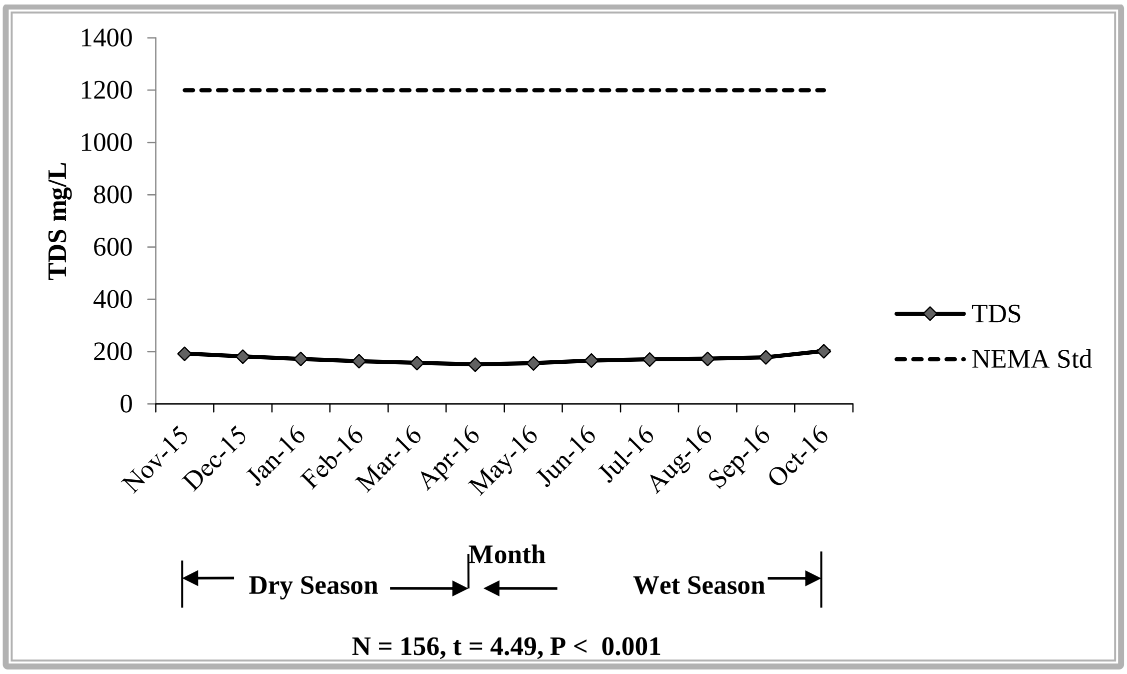

Figure 4.5: Seasonal Variations of Total Dissolved Substances in Sosiani River

High levels of dissolved substances impair organoleptic and aesthetic properties of water giving it a musty taste similar to earth or soil taste and changed water colour (Hogan, 2010). Dissolved substances increase electrical conductivity, BOD and turbidity of water which influences animal and plant species or forms of life a river can support (Forrow & Maltby, 2000; Mosley *et al.*, 2004). Palatability of water with TDS less than 600mg/L is considered suitable though no health based guidelines have been proposed for total dissolved solids (WHO, 2011). These findings are in agreement with Muchukuri *et al.* (2014) who observed that Njoro River exhibited heterogeneous spatial and temporal variation in total dissolved substances. Similar, studies have shown that rains increase TDS, TSS and turbidity in rivers (Chibole, 2013; Moyo, 2013; Van, 2013; Hadgu *et al*., 2014 and Bello *et al*., 2015).

Table 4.4: Comparison of Mean Parameters between Wet and Dry Season

Parameter	Season		Mean difference	t- Statistic	P value
	Mean Dry season	Mean Wet Season			
TEMP ºC	23.7 ± 2.6	22.7 ± 3.1	1.0 ± 0.9	4.39	0.001
pH (pH Units)	7.1 ± 0.6	7.1 ± 0.6	0.01 ± 0.05	0.19	0.849
DO mg/L	9.4 ± 2.0	7.2 ± 2.1	2.3 ± 0.6	12.7	< .001
TURB(NTU)	31.1 ± 32.6	80.5 ± 54.2	- 49.4 ± 20.1	- 8.86	< .001
BOD mg/L	53.9 ± 59.1	157.2 ± 133.2	- 103.3 ± 57.7	- 6.46	< .001
COD mg/L	84.0 ± 87.6	265.5 ± 198.9	- 181.5 ± 89.0	- 7.35	< .001
TC (CFU)	127.7 ± 121.4	138.9 ± 119.0	- 11.2 ± 28.1	- 1.44	< 0.017
EC (CFU)	43.1 ± 37.9	63.9 ± 59.8	- 20.7 ± 12.5	- 6.00	< .001
TSS mg/L	76.1 ± 196.2	194.6 ± 383.5	- 69.1 ± 158.8	- 1.57	<.0142
TDS mg/L	98.2 ± 87.5	178.9 ± 140.1	- 58.3 ± 46.9	- 4.49	< .001
Zn mg/L	0.198 ± 0.149	0.216 ± 0.156	- 0.018 ± 0.022	- 2.99	.011
Cd mg/L	0.040 ± 0.019	0.052 ± 0.040	- 0.013 ± 0.030	- 1.52	.023
Pb mg/L	0.016 ± 0.013	0.019 ± 0.013	- 0.003 ± 0.002	- 5.398	<0 .001
Cr mg/L	0.008 ± 0.015	0.010 ± 0.017	- 0.002 ± 0.002	- 2.96	0.012

N=156

4.2.5 Longitudinal Variations of Water Temperature in Sosiani River

Sosiani River displayed a spatial variation in its water temperature. However, the average water temperature of Sosiani River of 23.0 ± 3.0ºC is within the normal water range of rivers in the tropics of 20ºC–30ºC (Edward, 2000). There was significant longitudinal variation in water temperature at various sampling points along the river at F = 117.32, P < 0.001 since the F- statistic if greater than the F-critical at 99% confidence limit vide Figure 4.6 and Table 4.1. The river water was warmest at West Indies Bridge at 27.6 ± 0.5ºC followed by town carwash at 27.2 ± 0.8ºC but they were not significantly different from each other refer to Figure 4.6 and Table 4.3. On the other hand, the water was coolest at Two River dam, Kipkurgot, Kapsabet Bridge and Turbo. Water temperatures at these four sampling sites were not significantly different. These could be attributed to large forest cover at the source of the river in Kaptagat and downstream in Turbo town where forest plantation canopy insulates river water from solar radiation. These findings corroborate the results by Muchukuri *et al*. (2014) who observed significant spatial and temporal variation in water temperatures of Subukia River.

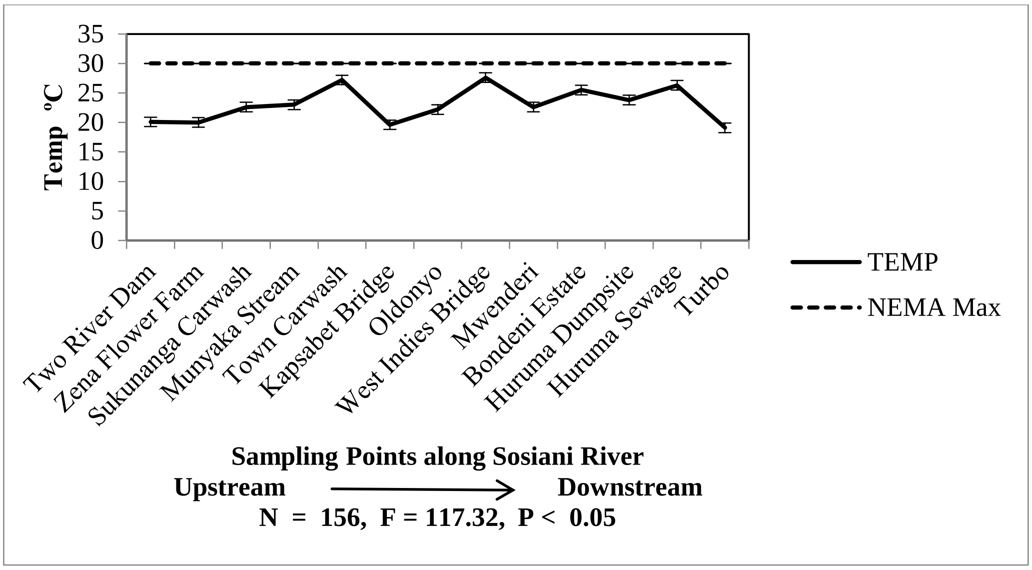

Figure 4.6: Longitudinal Variations of Water Temperature along Sosiani River

The low water temperatures upstream could be attributed to forest cover and high altitude. In a similar study it was observed that tree canopy cover protects river water from solar radiation hence ameliorating the water temperatures (Medema *et al.*, 2003; Kibichii *et al.*, 2007). The highest water temperatures recorded midstream at Kipkaren Bridge could be attributed to lack of vegetation canopy along the river as this is a built up residential area. Variations in water temperature even as low as 0.8ºC have been found to be harmful and even lethal to some organisms in a very short time span. There is significant negative correlation between temperature and dissolved oxygen at r = - 0.175, $P < 0.01$ see Table 4.2. However, there was a significant positive correlation between temperature and BOD at r = 0.262 and COD at r = 0.230.This implies that as the water temperatures in Sosiani River increase, less oxygen dissolves in this water. Low dissolved oxygen means an increase in Biological and oxygen demand. This can affect the health of aquatic species like fish which cannot survive low dissolved oxygen below 4mg/L (David, 2008). Elevated temperatures also affect solubility of gases, minerals, nutrients and pollutants in water (Perry *et al.*, 2007; David, 2008; Hogan, 2010).

4.2.6 Seasonal Variations of Water Temperature in Sosiani River

The mean monthly water temperature in Sosiani River during the dry season from November 2015 upto April 2016 was 23.7ºC. Mean temperature during the wet season from May 2016 to October 2016 was 22.7ºC. The t-statistic t = 4.39, $P < 0.001$ is greater than the t-critical at 99% confidence limit. Hence temperature in Sosiani River varied significantly from dry to wet season. This could be attributed to solar radiation since it is hot during the dry season see Figure 4.7 and Table 4.4.

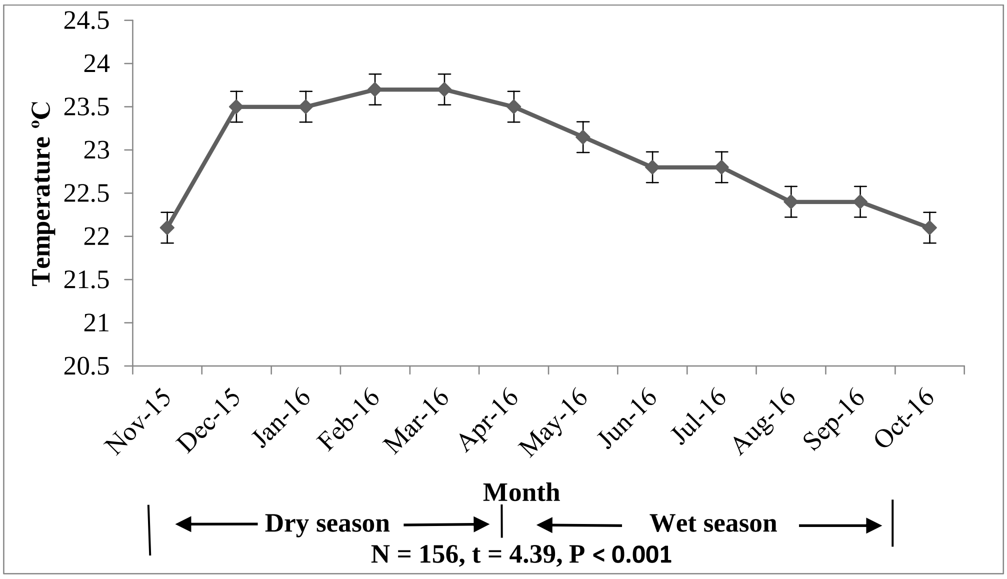

Figure 4.7: Seasonal Variations of Water Temperature in Sosiani River

These results are in agreement with Muchukuri, *et al*. (2014) whose study on Subukia River found out that the reduction in temperature from March to May was attributed to change in season as rains began in mid-April to May after a hot and dry period in March. The results are also consistent with those of GLOWS (2007) in a study along Mara River basin who found that water temperature was affected by season and time of the day.

4.2.7 Longitudinal Variations of Turbidity along Sosiani River

Sosiani River exhibits spatial variation in turbidity levels see Figure 4.8. The average turbidity of 64 ± 53.4NTU was above the NEMA guidelines for waters meant for recreational purposes refer to Appendix I. However, the NEMA and WHO guidelines are silent on standards of turbidity for drinking water and irrigation see Appendix II. In general, WHO guidelines recommend turbidity levels below 1 NTU for efficacy of water treatment. There was significant variation in turbidity levels along the sampling points at $F = 4.97$ $P < 0.001$ since the F-statistic is greater than the F-critical at 99% confidence limit vide Table 4.1. Turbidity levels were highest at Huruma sewage and treatment plant at 110 ± 56.3NTU which was significantly higher than any other sampling point along the river at $p < 0.001$ as seen in Figure 4.8. This could also be attributed to sediments washed down in the river from farming activities in Munyaka region in Eldoret town, car wash sites and municipal effluent washed down from the central business district. This high turbidity can cause benthic smothering, increased light attenuation, and reduces photosynthesis and visual range for sighted aquatic fauna and shelters bacteria (Smith & Davies-Calley, 2001).

Turbidity levels at Kipkurgot, Mwenderi and Bondeni estate sampling points are not significantly different. The three sampling points had a significantly lower turbidity than the site at town carwash but significantly lower than at other sampling points along the river refer to Figure 4.8. Hence water in Sosiani River can be described as cloudy since turbidity was in excess of 50NTU (Edward, 2000; Smith & Davies–Calley, 2001). The lowest mean turbidity was recorded at the first sampling point upstream at Two River Dam (10.4 ± 4.3NTU). This could be attributed to fencing off the dam to keep away influences of human activity and livestock. However, it was observed that there is significant negative correlation between turbidity and dissolved oxygen at $r = -0.65$ vide Table 4.2. Increase in turbidity is a result of dissolved and suspended matter in water which increases bacteria activity hence reducing dissolved oxygen. However, there was a strong positive correlation between Turbidity and BOD at $r = 0.904$, COD at r = t 0.885 and total coliforms at $r = 0.475$. Since reduction in dissolved oxygen leads to high biochemical oxygen demand while organic matter washed in the river is a source of coliforms. This suggests that as turbidity increases in Sosiani River, water temperature also increases. Suspended solids absorb heat from solar radiation hence increasing water temperature (Perry *et al.*, 2007; David, 2008; Hogan, 2010). Similarly, there was positive correlation between turbidity and *E. coli* at $r = 0.475$, turbidity and total coliform r = 0.488. This implies that as turbidity increases *E.coli* and total coliforms in Sosiani River also increase. These findings corroborate results of a study on Njoro River which established that rains in Njoro River catchment led to increased TSS and turbidity 2–3 times at most sampling sites (Yillia *et al.*, 2009).

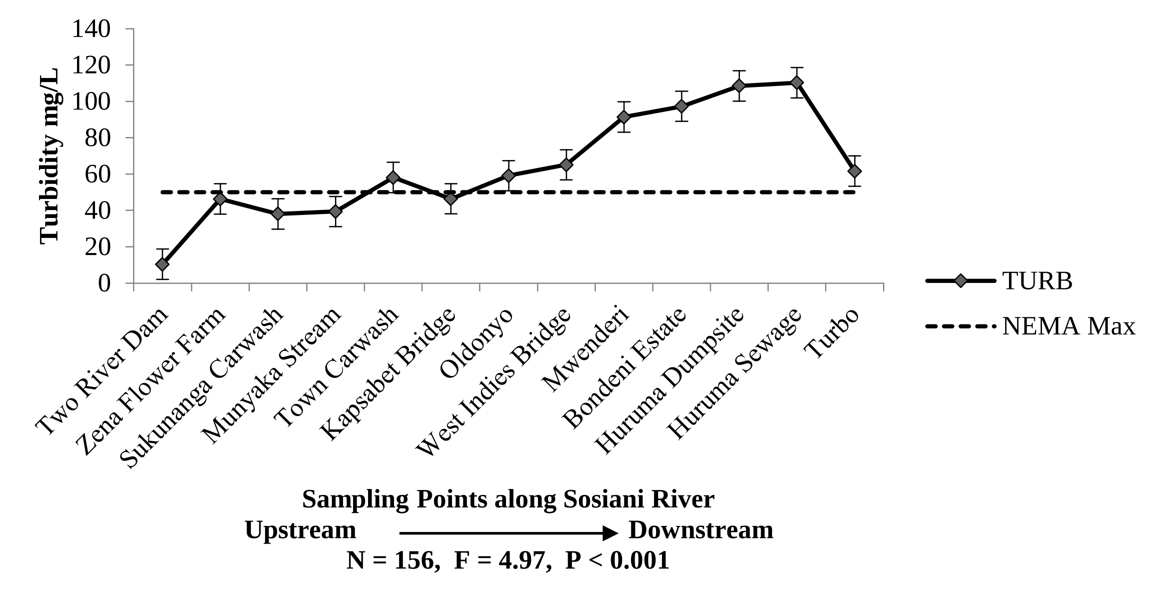

Figure 4.8: Longitudinal Variations of Turbidity along Sosiani River

4.2.8 Seasonal Variations of Turbidity in Sosiani River

Mean turbidity during the dry season from November 2015 to April 2016 was 31.1 ± 32.6NTU. Mean turbidity during the rainy season from May to October 2016 was 80.5 ± 54.2NTU. The t-statistic at t = 8.86, P < 0.001 is greater than the t-critical at 99% confidence limit since alpha is less than 0.001. Hence there was significant seasonal variation in turbidity during the dry and wet season in Sosiani River. This could be attributed to increased surface runoff refer to Figure 4.9 and Table 4.4. Increased surface runoff during the wet season washes down sediments into the river which increases suspended matter. Rainstorms also increase turbulence which takes bed sediments into suspension leading to relatively high concentrations of suspended mater in rivers like clay, silt, organic and inorganic matter and microorganisms (Correll *et al.*, 2001; Smith & Davies-Calley, 2001; Kudret & Ilker, 2011).

The increased sediment load along the river profile contributes significantly to low water quality and aesthetic value. High turbidity in water for domestic use can reduce the efficacy or efficiency of water treatment. To ensure efficiency of disinfection, turbidity should be below one NTU. High turbidity causes benthic smothering, reduces photosynthesis and productivity of aquatic ecosystems and visual range of sighted fauna (Smith & Davies-Calley, 2001; Kudret & Ilker, 2011).

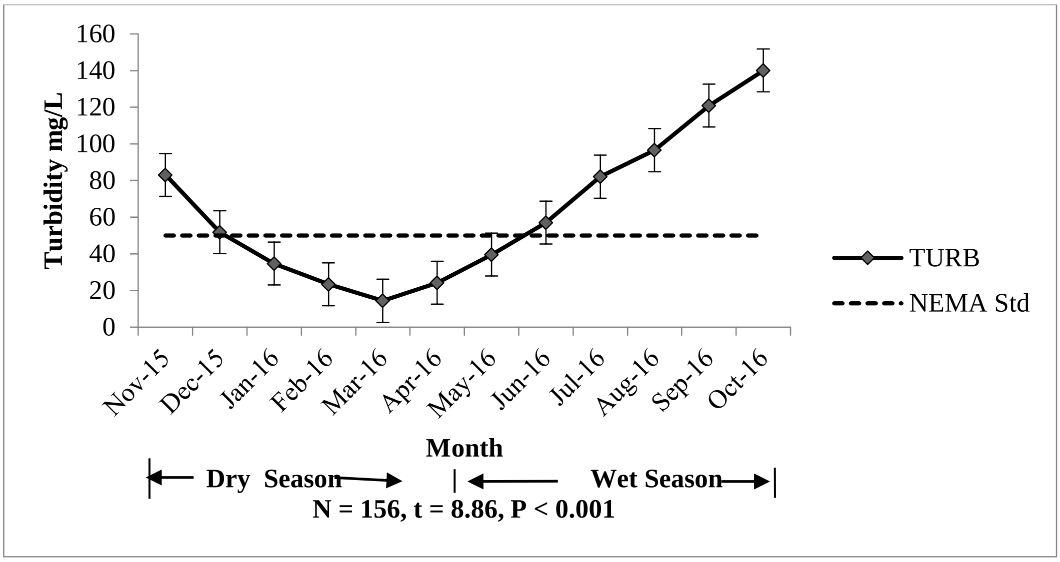

Figure 4.9: Seasonal Variations of Turbidity in Sosiani River

These results of seasonal variation in turbidity in Sosiani River corroborate findings of Long & Plummer (2004) who observed that turbidity levels in a small stream varies with changes in precipitation while Volk *et al.* (2002) established that turbidity levels in a stream could increase by as much as 300 fold following precipitation. These results are also consistent with findings of Muchukuri *et al.* (2014) who found out that the mean turbidity range for Subukia River increased with the onset of the rain season in May. Similarly, Yillia *et al.* (2009) found out that suspended solids and turbidity in Njoro River increased 2–3 times during wet season at most stream sites and 10 times more at the lower reaches downstream of Njoro town.

4.2.9 Longitudinal Variations of Water pH along Sosiani River

Sosiani River exhibited a spatial variation in its water pH. The F-statistic at F = 153.35 & P < 0.001 is greater than the F-critical at 99% confidence limit. Hence there was significant longitudinal variation in water pH along the sampling points. These could be attributed to effluent discharge at each sampling point. However, the mean water pH of Sosiani River was neutral at 7.1 ± 0.6 refer to Figure 4.10 and Table 4.1.

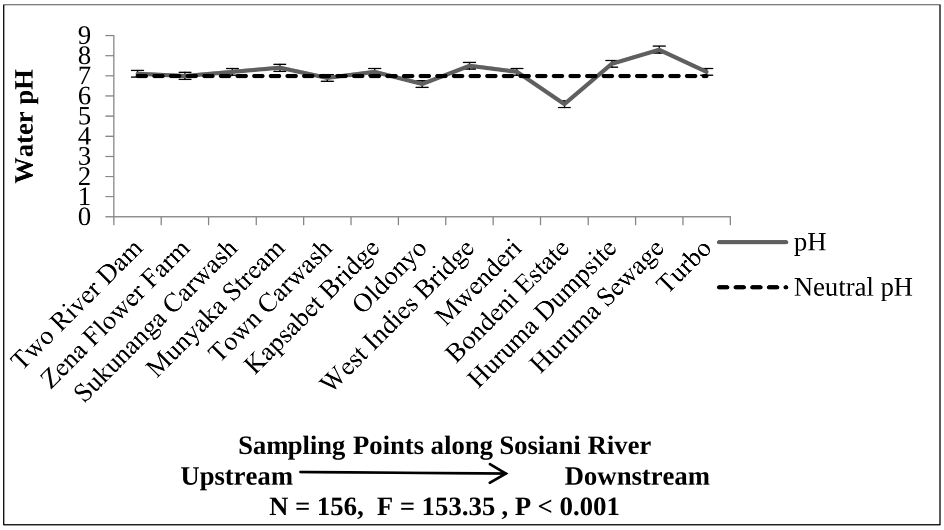

Figure 4.10: Longitudinal Variations of Water pH along Sosiani River

This river was most alkaline at Huruma sewage treatment plant with a pH 8.3 ± 0.1 and was significantly higher than at any other point along the river at $p < 0.05$. The water pH at Huruma dumpsite and Huruma sewage were significantly higher than any other sampling points along Sosiani River vide Figure 4.10. However, it is within the normal pH range from 6.5 to 8.5 according to the NEMA guidelines see Appendix I. However, the most acidic site along Sosiani River was Zena flower farm effluent discharge point which had the lowest pH 6.1 ± 1.8 which is below the NEMA recommended pH range of 6.5–6.8 refer to Figure 4.10; Table 4.1and Appendix I & II. This implies that water at this sampling site is acidic. This could be attributed to agrochemicals used as fertilizers, pesticides and herbicides in Zena flower farm and wheat farms upstream in Kipkurgot. The acidity of the river increases as the water pH decreases. The pH of water in Sosiani River was found to range between 6.1–8.6 which nearly falls within the normal range of water pH 6.0–8.5 as per the NEMA guidelines refer to Table 4.1 and Appendices I & II. However, the WHO guidelines are silent on permissible levels of pH of drinking water. Variations in water pH below 4 can affect the river ecosystem as more toxins become more soluble in acidic media. It also affects chemical coagulation, disinfection, softening process and corrosion of water pipes (Mosley *et al*., 2004; David, 2008; Salequzzaman *et al*., 2008). There was negative correlation between water pH and most water parameters. This implies that as water pH decreases or becomes acidic, most parameters like TDS and heavy metals increase. This is because metals become more soluble in acidic conditions like zinc at R = 0.449 vide Table 4.2. These findings are inconsistent with the findings of a study on Subukia and Momoi Rivers in Subukia town where it was established that pH values for Subukia River and Momoi River do not vary significantly along the river (Muchukuri *et al.*, 2014).

4.2.10 Seasonal Variations of Water pH in Sosiani River

Mean water pH during dry and the wet season was the same 7.1. The t- statistic at t = 0.19, P < 0.849 is less than the t-critical at 95% confidence limit. The P value is greater than the alpha value 0.05. Hence there was no significant seasonal variation in pH in Sosiani River refer to Figure 4.11and Table 4.4. This could be attributed to the acid base equilibrium of dissolved salts and gases in this water (David, 2008).

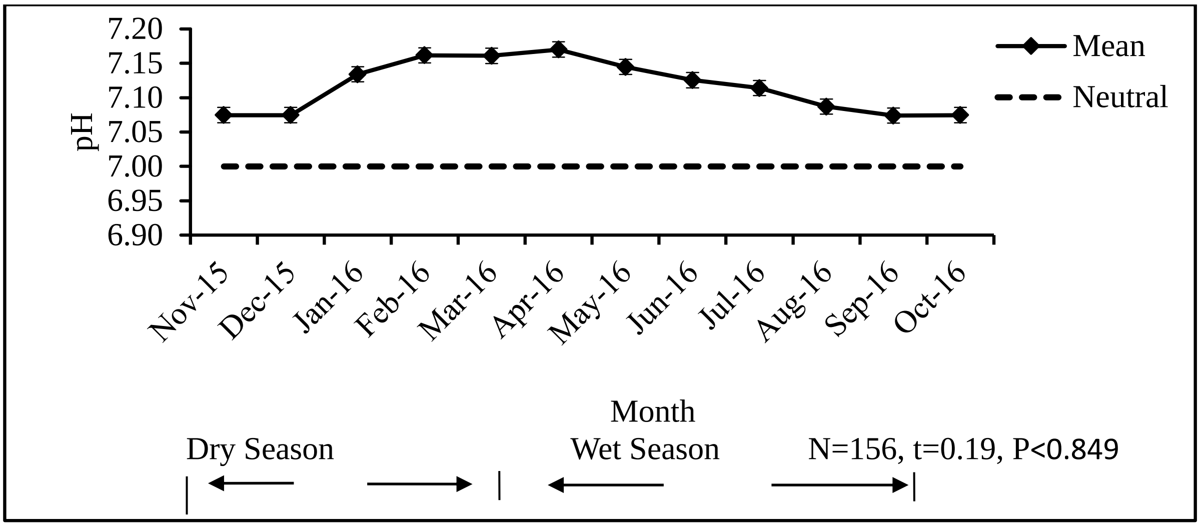

Figure 4.11: Seasonal Variations of Water pH in Sosiani River

These findings are consistent with the results of a study on Subukia and Momoi Rivers in Subukia town where it was established that water pH values for the two rivers do not exhibit any significant seasonal variation (Muchukuri *et al.*, 2014).

4.2.11 Longitudinal Variations in Biological Oxygen Demand along Sosiani River

The mean BOD in Sosiani River (122.8 ± 123.8 mg/L) was above the NEMA standard guidelines see Table 4.1 and Appendix II. High BOD implies a lot of biologically oxidizable organic matters from effluent discharged into the river see Figure 4.12. The F-statistic at F = 7.39 & P < 0.001 is greater than the F-critical at 99% confidence limit. Hence there was significant longitudinal variation in BOD.

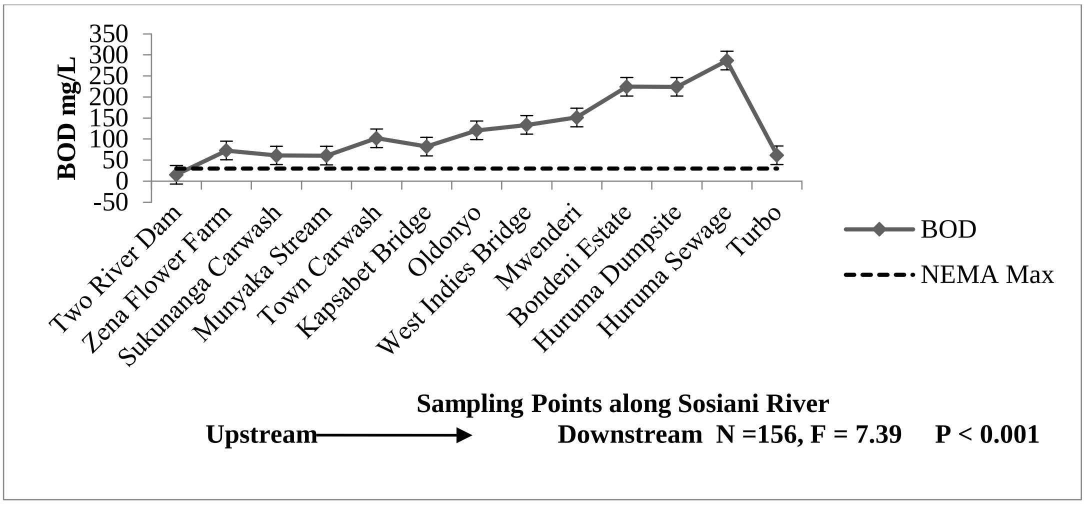

Figure 4.12: Longitudinal Variations in Biological Oxygen Demand along Sosiani River

There was a strong positive correlation between BOD and TDS at r = 0.627 and Turbidity r = 0.904 vide Table 4.2. Increase in TDS increased turbidity and BOD due to increased bacterial activity to break down organic matter. High BOD can be attributed to soil erosion upstream due to degradation of Kaptagat forest and farming activities. BOD increases midstream with the highest 286.4 ± 184.1mg/L recorded at Huruma sewage plant and 224.3 ± 123.4mg/L at Bondeni estate. This could be attributed to high sediments in the effluent discharged from the Sewage treatment plant, dumpsite and Bondeni housing estate in the slums and from the wood factories at these sampling points. Regression analysis shows that biological oxygen demand can be best predicted or explaned by turbidity at $P < 0.001$, temperature at $P < 0.001$, TSS at $P < 0.001$ and TDS at $P < 0.031$ more than any other variable see Table 4.5. Coefficient of determination $R^2 = 0.8493$ refer to Table 4.6. This implies that 84.93% of the variation in BOD can be explained by the variables in the equation:

$$BOD = 170.7727 + 6.0196temp + 3.3198pH - 0.0455TSS + 0.0950TDS + 1.9339Turb$$

Table 4.5: Regression Analysis of Physico-chemical Water Parameters

Outcome	Independent Variable	Coefficient	Std Error	t-Statistic	P Value	95 % Confidence Interval	
DO	TEMP	- 0.0090	0.0548	- 0.16	0.870	- 0.1173	0.0994
	pH	- 0.1206	0.2410	- 0.50	0.617	- 0.5968	0.3556
	TSS	- 0.0011	0.0005	- 2.37	0.019	- 0.0020	- 0.0002
	TDS	- 0.0006	0.0016	- 0.38	0.703	- 0.0037	0.0025
	TURB	- 0.0264	0.0034	- 7.78	0.000	- 0.0331	- 0.0197
	_CONS	10.9086	1.9044	5.73	0.000	7.1457	14.6715
BOD	TEMP	6.0196	1.5431	3.90	0.000	2.9706	9.0686
	pH	3.3198	6.7822	0.49	0.625	- 10.0813	16.7209
	TSS	- 0.0455	0.0128	- 3.55	0.001	- 0.0709	- 0.0202
	TDS	0.0950	0.0437	2.17	0.031	0.0087	0.1813
	TURB	1.9339	0.0954	20.27	0.000	1.7454	2.1224
	_CONS	- 170.7727	53.5928	- 3.19	0.002	- 276.6671	- 64.8783
COD	TEMP	7.1736	2.6102	2.75	0.007	2.0161	12.3310
	pH	- 37.5242	11.4724	- 3.27	0.001	- 60.1926	- 14.8558
	TSS	- 0.0329	0.0217	- 1.52	0.132	- 0.0757	0.0100
	TDS	0.1288	0.0739	1.74	0.083	- 0.0172	0.2748
	TURB	2.9456	0.1613	18.26	0.000	2.6268	3.2644
	_CONS	104.8629	90.6543	1.16	0.249	- 74.2615	283.9872
TC	TEMP	- 1.0634	3.2776	- 0.32	0.746	- 7.5397	5.4130
	pH	16.6686	14.4062	1.16	0.249	- 11.7966	45.1338
	TSS	0.0493	0.0272	1.81	0.072	-0.0045	0.1031
	TDS	0.1310	0.0928	1.41	0.160	-0.0524	0.3143
	TURB	0.8721	0.2026	4.30	0.000	0.4718	1.2724
EC	TEMP	- 1.2160	1.4180	- 0.86	0.392	- 4.0177	1.5857
	pH	0.2127	6.2323	0.03	0.973	- 12.1017	12.5272
	TSS	0.0554	0.0118	4.70	0.000	0.0321	0.0786
	TDS	0.0315	0.0401	0.79	0.434	- 0.0478	0.1108
	TURB	0.4139	0.0876	4.72	0.000	0.2407	0.5871
	_CONS	45.4454	49.2473	0.92	0.358	- 51.8626	142.7534

N =156, t is a statistic showing variations in means and P is the probability level

Regression analysis yields a statistic called coefficient of determination R^2. This is the amount of variation in the dependant variable explained or predicted by the independent variables in the regression equation. A variable is considered a significant predictor if $P < 0.05$ vide Table 4.6.

Table 4.6: Regression Analysis Summary

Outcome	n	RMSE	R^2	F value	P value
DO	156	1.736	0.4497	24.515	< 0.0001
BOD	156	48.850	0.8493	169.037	< 0.0001
COD	156	82.632	0.8174	134.323	< 0.0001
TC	156	103.762	0.2710	11.152	< 0.0001
EC	156	44.889	0.3386	15.361	< 0.0001
Zn	156	0.121	0.3810	18.469	< 0.0001
Cd	156	0.062	0.2511	10.057	< 0.0001
Pb	156	0.012	0.3245	14.414	< 0.0001
Cr	156	0.014	0.2905	12.283	< 0.0001

Where R2 is the coefficient of determination and N = 156

These findings are consistent with those of Karikari & Ansa-Asare (2006); Bukhalama (2007); Maina *et al.* (2010) and Chibole (2013) who all observed that COD and BOD increased downstream the river as more effluent is discharged which increases significantly with the onset of the rainy season. They attributed this to increased surface runoff which washes down soils, sediments, organic matter and nutrients from agricultural fields into rivers.

4.2.12 Seasonal Variations of Biological Oxygen Demand in Sosiani River

The mean BOD during the dry season from November 2015 to April 2016 was 53.9mg/L and in the wet season from May 2016 to October 2016 was 157.2mg/L. The t-statistic at $t = 6.46$, $p < 0.001$ is greater than the t-critical at 99% confidence limit. Hence there was significant variation in BOD at 99% confidence limit. This is attributed to high runoff during the wet season which washes organic matter into Sosiani River which increases bacteria activity to biodegrade the matter hence an increase in oxygen demand see Figure 4.13 and Table 4.4.

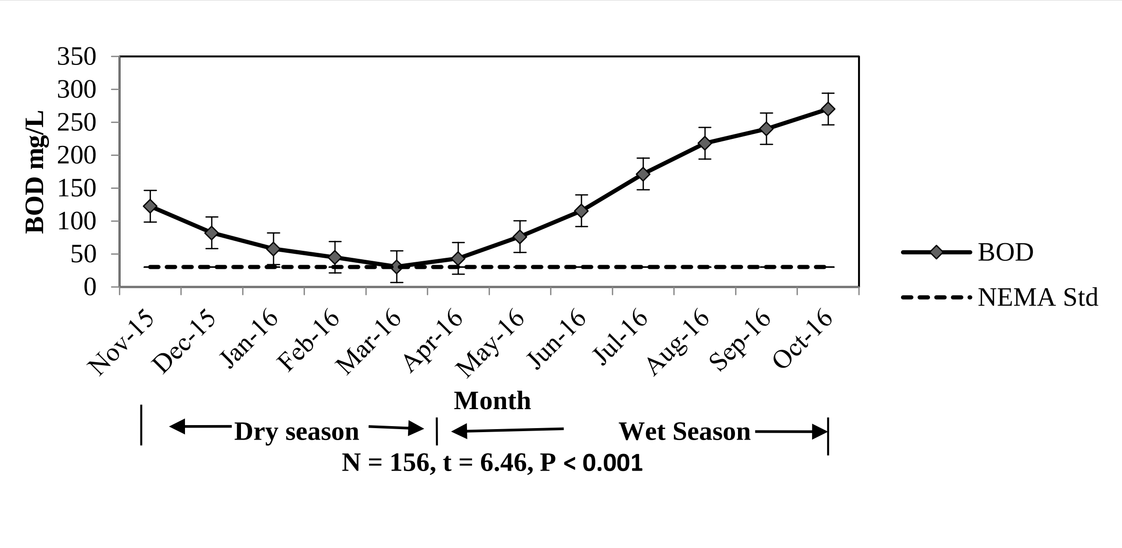

Figure 4.13: Seasonal Variation of Biological Oxygen Demand in Sosiani River

High biological oxygen demand stresses aquatic organisms and in extreme cases they suffocate and die and also interfere with reproductive functions of fish and other aquatic organisms (Clescerl, 2008). The onset of rainy season increases surface runoff that drains more sediments and organic matter into the river. This increases microbial activity to oxidize the excess organic matter drained into the river hence the increased biological oxygen demand. The NEMA and WHO guidelines are silent on standards in drinking water as it has no direct impact on human health see Appendix I & II.

These findings are consistent with those of Smith & Davies-Calley (2001); Karikari & Ansa-Asare (2006); Alavi *et al.* (2007); Bukhalama (2007); Maina *et al.* (2010); Kudret & Ilker (2011) and Hadgu *et al.* (2014). They all observed that chemical oxygen demand and biological oxygen demand increased downstream the river as more effluent is discharged which increases significantly with the onset of the rainy season. They attributed this to increased surface runoff which washes down soils, sediments, organic matter and nutrients from agricultural fields into rivers.

4.2.13 Longitudinal Variations of Chemical Oxygen Demand along Sosiani River

The mean chemical oxygen demand at all sampling sites along Sosiani River was high at 205.0 ± 190.2mg/L. The F-statistic at $F = 5.95$ & $P < 0.001$ is greater than the F-critical at

99% confidence limit. Hence Sosiani River exhibited significant longitudinal or spatial variation in chemical oxygen demand see Figure 4.14 and Table 4.1.

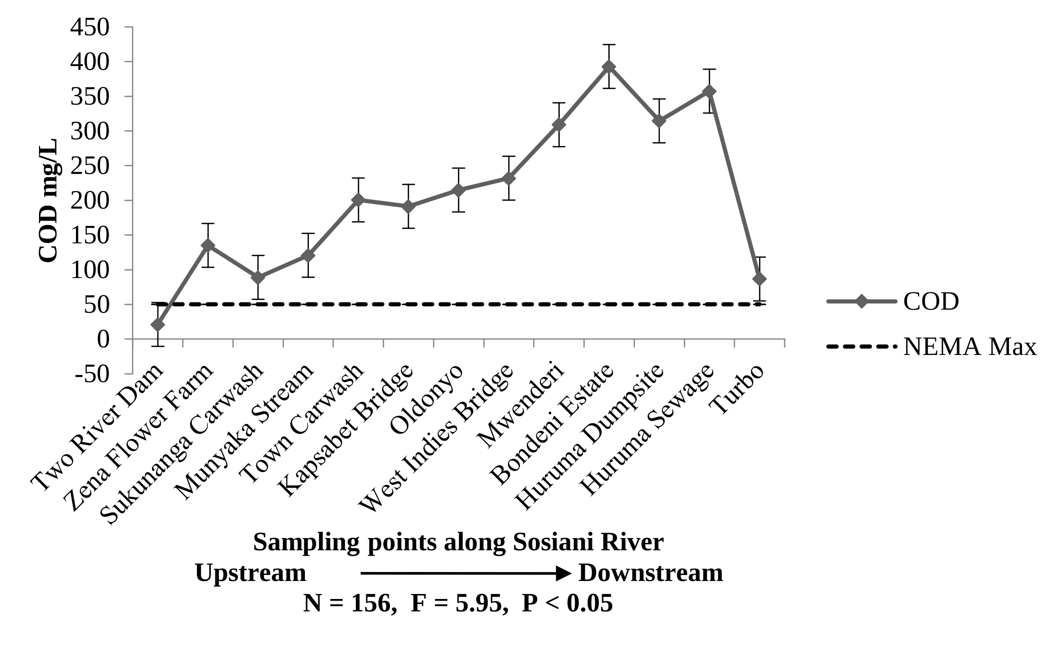

Figure 4.141: Longitudinal Variations of Chemical Oxygen Demand along Sosiani River

This high COD suggests that there is a lot of both biologically degradable and chemically oxidizable organic matter in Sosiani River which reduces dissolved oxygen available to aquatic fauna. Higher levels of COD above BOD, implies high levels of organic and inorganic matter in Sosiani River which is not biodegradable. A reduction in dissolved oxygen can lead to anaerobic conditions which is deleterious to higher aquatic life forms (Goel, 2006; Perry *et al.*, 2007; Clescerl, 2008). High COD upstream can be attributed to large scale farming activities where agrochemicals from large scale wheat and flower farms and soil erosion due to deforestation of Kaptagat water catchment increase organic matter in Sosiani River. The COD increases further as the river traverses Eldoret town midstream. The chemical oxygen demand was highest Mwenderi which could be attributed to many chemicals used as wood preservatives like acid copper chromate, creosote, chemicals used for making glue like urea formaldehyde, paints and chemicals used in making foam mattresses in industries around this site like Rai Plywood.

Correlation analysis showed that there is a strong positive correlation between chemical oxygen demand and turbidity at $r = 0.885$ and total dissolved substances at $r = 0.639$. This implies that increase in total dissolved substances in Sosiani River during the wet season increases COD as more matter becomes dissolved requiring more oxygen for oxidation process vide Table 4.2. Hence chemical oxygen demand can be used as an alternate to biological oxygen demand since it takes only 2 to 3 hours to determine unlike biological oxygen demand which takes 5 days and at most 20 days which is time consuming. Regression analysis shows that chemical oxygen demand can be best predicted by pH at $P < 0.001$ and turbidity at $P < 0.001$ than any other parameters studied see Table 4.5. Coefficient of determination of COD is 0.8174 vide Table 4.6. This implies that 81.74% of the variation in chemical oxygen demand can be explained by the variables in the equation:

$$COD = 104.8629 + 7.1736\, Temp - 37.5242\, pH - 0.0329\, TSS + 0.1288\, TDS + 2.9456\, Turb$$

These findings are consistent with those of Karikari & Ansa-Asare (2006); Alavi *et al.* (2007); Bukhalama (2007); Maina *et al.* (2010); Kudret & Ilker (2011) and Hadgu *et al.* (2014). They all observed that chemical oxygen demand and biological oxygen demand increased downstream as more effluent is discharged which increases significantly with the onset of the rainy season.

4.2.14 Seasonal Variations of Chemical Oxygen Demand in Sosiani River

The mean chemical oxygen demand for the dry season from November 2015 to April 2016 was 84.0mg/L and the mean COD during the wet season was 265.5mg/L. The t-statistic at $t = 7.35$, $P < 0.001$ is greater than the t-critical at 99% confidence limit. Hence there was significant seasonal variation in mean chemical oxygen demand in Sosiani River during the dry and wet seasons see Figure 4.15 and Table 4.3. This could be attributed to increased surface runoff washing in effluent and organic matter during the wet season. High chemical oxygen demand shows that there is high overall biologically degradable matter and chemically oxidizable organic matter refer to Table 4.1 and Figure 4.15.

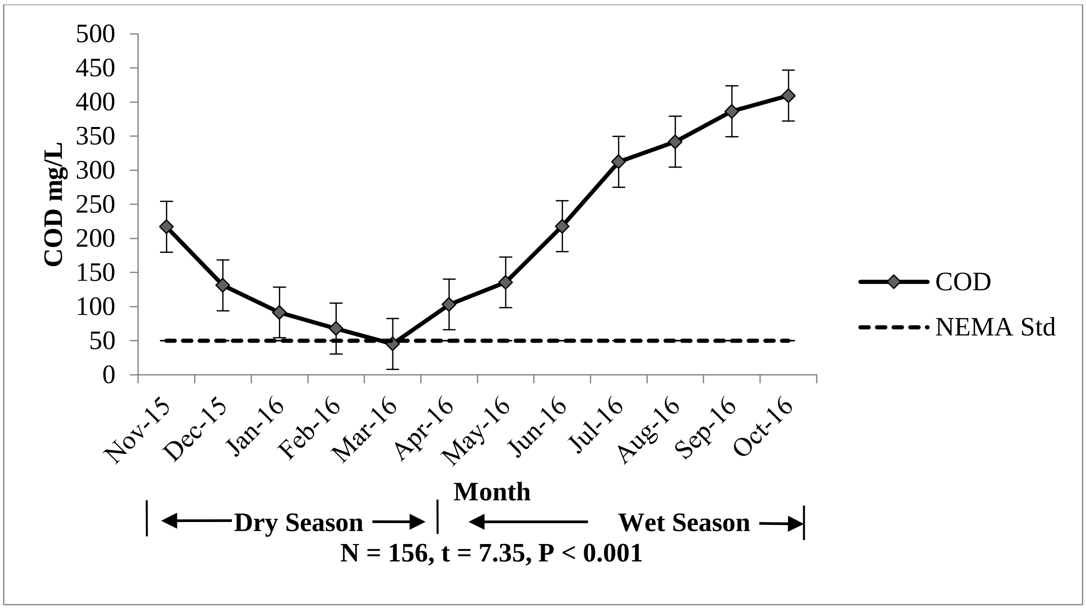

Figure 4.15: Seasonal Variations of Chemical Oxygen Demand in Sosiani River

4.2.15 Longitudinal Variations of Dissolved Oxygen in Sosiani River

The mean dissolved oxygen in Sosiani River was 7.9 ± 2.3mg/L which is above the NEMA/WHO minimum 4mg/L recommended to sustain aquatic live. The highest dissolved oxygen levels were recorded downstream in Turbo at 11.5mg/L and upstream at Two River dam at 10.4mg/L while the lowest dissolved oxygen was recorded at Zena flower farm discharge point see Figure 4.16. Dissolved oxygen increases downstream in Turbo. The F-statistic at $F = 8.87$ & $P < 0.001$ is greater than the F-critical at 99% confidence limit. Hence Sosiani River exhibited significant longitudinal variation in dissolved oxygen. Low dissolved oxygen at sampling points can be attributed to effluent discharged into Sosiani River, open and leaking sewer lines, organic matter as a result of soil erosion from agricultural farms along the river. Correlation analysis of dissolved oxygen and other water parameters indicate a negative correlation: Turbidity at $r = -0.65$; TSS at $r = -0.225$; TDS at $r = -0.44$; Temperature at $r = -0.175$ and pH at $r = -0.035$. This implies that as more total dissolved substances and total suspended substance increase in Sosiani River, bacterial activity increases to biodegrade them hence decreased dissolved oxygen. Similarly as temperatures increase dissolved oxygen decreases. This poses a challenge to aquatic fauna like fish. Regression analysis showed that TSS at $P < 0.019$ and turbidity at $P < 0.001$ can predict the variation in dissolved oxygen than any other water parameter refer to Table 4.5. Coefficient of determination R^2 is 0.4497 see Table 4.6. This implies that 44.97% of the variation in dissolved oxygen can be explained by the variables in the equation:

DO = 10.9086 - 0.009 Temp - 0.10206 pH - 0.0011 TSS - 0.0006 TDS - 0.0264 Turb

These findings are consistent with those of Karikari & Ansa-Asare (2006); Bukhalama (2007); Maina *et al.* (2010) and Chibole (2013) who observed that dissolved oxygen decreased with an increase in turbidity, total dissolved substances and total suspended substances in river water. They attributed this to increased surface runoff.

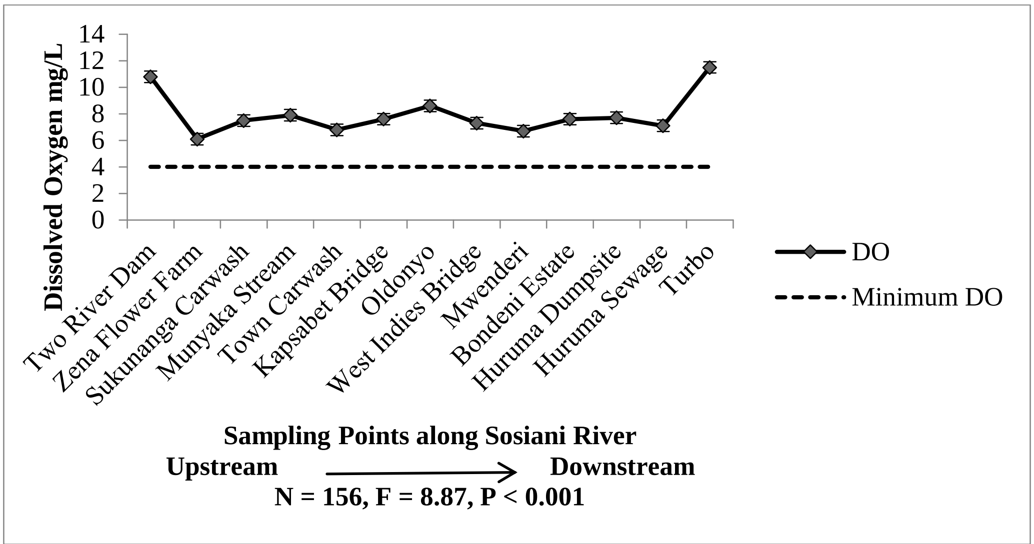

Figure 4.16: Longitudinal Variations of Dissolved Oxygen along Sosiani River

4.2.16 Seasonal Variations of Dissolved Oxygen in Sosiani River

The dissolved oxygen in Sosiani River varied with changes in rain season. The mean dissolved oxygen for the dry season from November 2015 to April 2016 was 9.4 ± 2.0mg/L and that of the wet season from May 2016 to October 2016 was 7.2 ± 2.1mg/L. The t-statistic at $t = 12.7$, $P < 0.001$ is greater than the t-critical at 99% confidence limit. Hence there was significant seasonal variation in dissolved oxygen in Sosiani River during the wet and dry season. Low dissolved oxygen in dry season could be attributed to increased temperatures which reduces dissolved oxygen in water refer to Table 4.3 and Figure 4.17. It was also observed that dissolved oxygen was lowest where biological oxygen demand, chemical ooxygen demand and Turbidity were highest. Hence they are inversely proportional. Studies on water quality in 'Majimoto Spring' meaning a hot spring in Nakuru showed low levels of dissolved oxygen which was attributed to high temperatures in the hot spring. The solubility of oxygen was affected none linearly by temperature and increased considerably in cold water (Wetzel, 2001; Kilonzi *et al.*, 2014). High temperatures reduce dissolved oxygen while turbidity reduces light penetration thus lowering primary productivity of aquatic ecosystems which in turn affects availability of dissolved oxygen (Kaliff, 2000). Low dissolved oxygen also interferes with reproductive function of aquatic organisms.

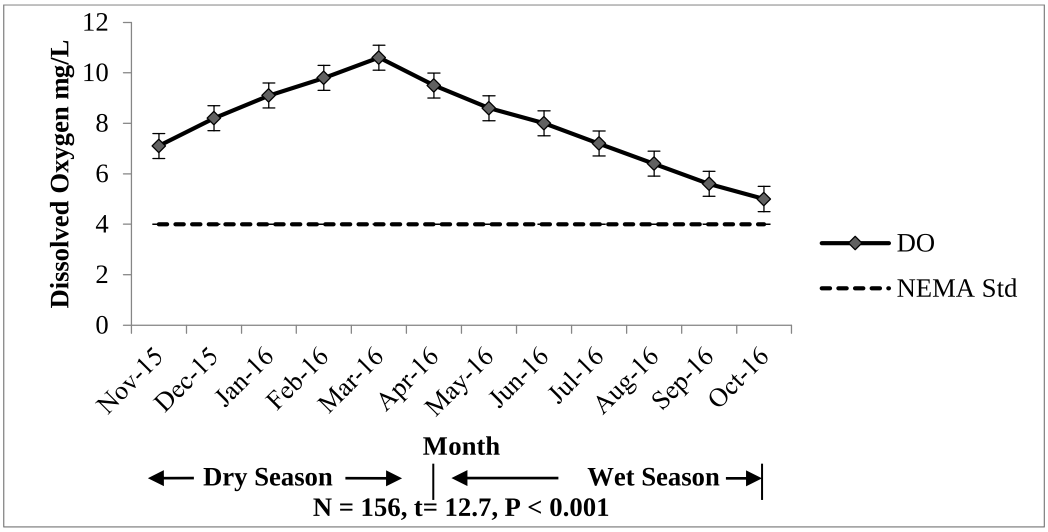

Figure 4.17: Seasonal Variations of Dissolved Oxygen in Sosiani River

4.3: Longitudinal and Seasonal Variations of Heavy Metals in Sosiani River

Analysis of water samples indicates presence of four selected heavy metals in Sosiani River namely: zinc, chromium, cadmium and lead. These heavy metals are associated with industries, wood treatment plants, storm water from Eldoret town and the county market and effluent from Huruma treatment works. These heavy metals exhibited both seasonal and longitudinal variations see Tables 4.7 & 4.9. It was also observed that the concentrations of the metals were lowest at the source of the river at Two River dam in Kaptagat forest but increased midstream in Eldoret town as effluent is discharged into the river from anthropogenic activities. However, the levels of these metals decline further downstream in Turbo town which could be attributed to dilution from incoming streams vide Table 4.9.

Table 4.7: Mean Concentrations of Heavy Metals along Sosiani River by Site

Site	Zn (mg/L	Cd (mg/L)	Pb (mg/L)	Cr (mg/L)
Two River Dam	0.097 ± 0.032b	0.015 ± 0.005a	0.014 ± 0.005b	0.002 ± 0.001a
Zena Flower Farm	0.093 ± 0.027b	0.034 ± 0.021a	0.017 ± 0.003bc	0.007 ±0.002bc
Sukunanga Carwash	0.042 ± 0.010a	0.045 ± 0.025a	0.021± 0.007c	0.002 ± 0.001a
Munyaka Stream	0.173 ± 0.039c	0.043 ± 0.025a	0.015 ± 0.004bc	0.004 ± 0.004ab
Town Carwash	0.165 ± 0.021c	0.137 ± 0.225b	0.032 ± 0.010e	0.010 ± 0.004c
Kapsabet Bridge	0.456 ± 0.026i	0.067 ± 0.011a	0.041 ± 0.009f	0.008 ± 0.003bc
Oldonyo	0.247± 0.065d	0.045 ± 0.033a	0.027 ± 0.005d	0.006 ± 0.003abc
West Indies Bridge	0.418 ± 0.038h	0.048 ± 0.020a	0.002 ± 0.001a	0.007 ± 0.002bc
Mwenderi	0.290 ± 0.022e	0.040 ± 0.028a	0.002 ± 0.001a	0.063 ±0 .015d
Bondeni Estate	0.034 ± 0.037a	0.070 ± 0.020a	0.037 ± 0.006f	0.008 ± 0.003bc
Huruma Dumpsite	0.324 ± 0.042f	0.028 ± 0.019a	0.007 ± 0.008a	0.002 ± 0.001a
Huruma Sewage	0.386 ± 0.019g	0.038 ± 0.030a	0.014 ± 0.004b	0.004 ± 0.003ab
Turbo	0.015 ± 0.004a	0.015 ± 0.010a	0.004 ± 0.010a	0.002 ± 0.001a
Overall	**0.211 ± 0.151**	**0.048 ± 0.07**	**0.018 ± 0.014**	**0.010 ± 0.016**
F Statistic	**258.89**	**2.70**	**51.87**	**126.78**
P value	**< .001**	**.003**	**< .001**	**< .001**

Sites with the same letter notation do not differ significantly from one another. Sites that have different letter notations differ significantly from one another.

Where N =156, F value is a statistic showing variations in means and P is the probability level

4.3.1 Longitudinal Variations of Zinc along Sosiani River

The mean concentration of zinc in Sosiani River was 0.211± 0.151 mg/L which is below the NEMA/WHO standard guideline of 1.5mg/L hence not a threat to human life. The F-statistic at F = 258.89, P < 0.001 is greater than the F-critical at 99% confidence limit. Hence there was significant longitudinal variation in concentrations of zinc along Sosiani River downstream. The highest concentration of zinc in Sosiani River was recorded at Kapsabet Bridge at 0.456 ± 0.0261mg/L but below NEMA guideline refer to Table 4.7; Figure 4.18 and Appendices I & II. This could be attributed to run off from Eldoret town and county market which is discharged into Sosiani River near this bridge. It contains discharges from motor vehicle garages, agrochemicals like insecticides, fungicides, wood preservatives, cosmetics, paints, printing ink, old batteries and plastics.

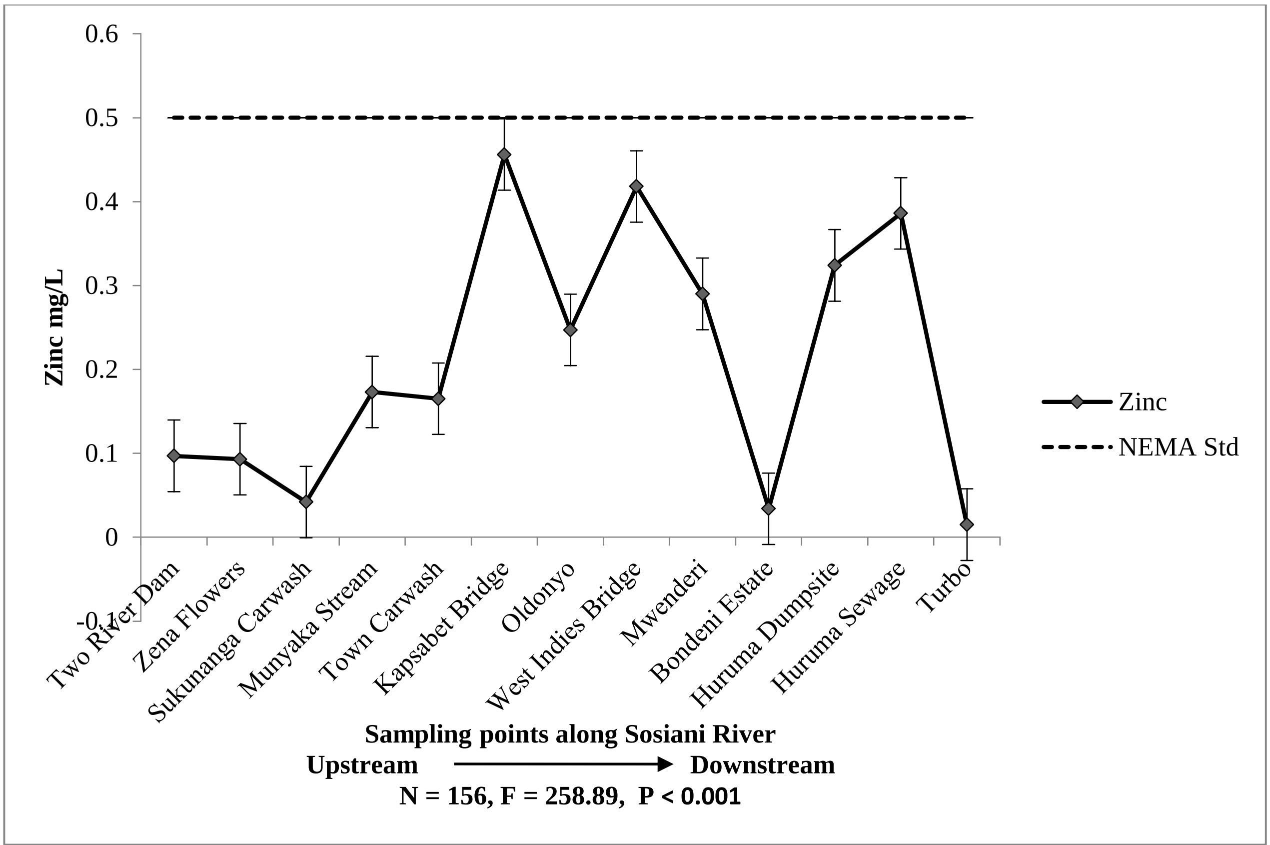

Figure 4.18: Longitudinal Variations in Levels of Zinc along Sosiani River

Sampling points exhibited moderately low concentrations of zinc below NEMA guidelines which was however, not significantly different from each other. The lowest concentration of zinc was recorded downstream at Turbo the last sampling point at 0.015 ± 0.001mg/L. This could be attributed to the fact that zinc is one of the most soluble and mobile metal cation in water which is easily assimilated by plants hence the river readily purifies itself (Jepkoech, 2013). However, the mean concentration of zinc in Sosiani River at 0.211 ± 0.151mg/L is below the NEMA and WHO guidelines refer to Table 4.7 and Appendices I & II. Similar studies have indicated that municipal effluent contains high concentrations of heavy metals especially zinc, cadmium, copper, lead and chromium (Hammer & Hammer, 2001). Further downstream in Turbo, the concentration of zinc significantly dropped to 0.015 ± 0.004 mg/L. This could be attributed to dilution from streams joining Sosiani River refer to Figure 4.18.

Correlation analysis of zinc and pH showed a significant negative correlation at r = -0.499 see Table 4.2. This implies that as the pH decreases, zinc becomes more soluble. This is in agreement with Mosley *et al.* (2004) who observed that water pH affects solubility of many toxic and nutritive chemicals hence affecting their availability to aquatic organisms. However, these results are inconsistent with the findings of Jepkoech (2013) who observed that there was no significant variation in levels of zinc in soil sediments along Sosiani Riverbed since zinc is one of the most soluble and mobile metal cation in water which is easily assimilated by plants hence low concentrations in soil sediments.

Multiple regression analysis of zinc as a dependent variable versus other independent variables showed that it can be predicted or explained by turbidity at $P < 0.001$, pH at $P < 0.001$ and temperature at $P < 0.001$ more than any other independent variable whose probability was higher than 0.05 see Table 4.8. The coefficient of determination of zinc R^2 was 0.3810 at $F = 18.469$ and $P < 0.0001$. This implies that 38.1% of the variation in zinc is explained or predicted in the regression equation. The rest 61.8% cannot be explained by the variables in the equation. The dependence of zinc can be expressed as a regression equation:

Zinc = - 0.8893 + 0.0140 Temp + 0.1048 pH - 0.0001TSS - 0.0002 TDS + 0.0010 Turb

Table 4.8: Regression Analysis of Heavy Metals at N=156

Outcome	Independent Variable	Coefficient	Std Error	t- Statistic	P Value	95 % ConfidenceInterval	
Zn	TEMP	0.0140	0.0038	3.67	0.000	0.0065	0.0216
	pH	0.1048	0.0168	6.24	0.000	0.0716	0.1380
	TSS	- 0.0001	0.0000	- 1.61	0.110	- 0.0001	0.0000
	TDS	- 0.0002	0.0001	- 1.61	0.109	- 0.0004	0.0000
	TURB	0.0010	0.0002	4.03	0.000	0.0005	0.0014
	_CONS	- 0.8893	0.1327	- 6.70	0.000	- 1.1515	- 0.6271
Cd	TEMP	0.0014	0.0019	0.71	0.481	- 0.0025	0.0052
	pH	- 0.0148	0.0086	- 1.72	0.087	- 0.0317	0.0022
	TSS	0.0001	0.0000	5.16	0.000	0.0001	0.0001
	TDS	0.0000	0.0001	- 0.64	0.521	- 0.0001	0.0001
	TURB	0.0003	0.0001	2.60	0.010	0.0001	0.0006
	_CONS	0.0958	0.0676	1.42	0.159	- 0.0378	0.2293
Pb	TEMP	- 0.0006	0.0004	- 1.68	0.095	- 0.0013	0.0001
	pH	- 0.0102	0.0016	- 6.30	0.000	- 0.0134	- 0.0070
	TSS	0.0000	0.0000	3.94	0.000	0.0000	0.0000
	TDS	0.0000	0.0000	- 0.38	0.707	0.0000	0.0000
	TURB	0.0000	0.0000	1.91	0.058	0.0000	0.0001
	_CONS	0.1008	0.0128	7.90	0.000	0.0756	0.1261
Cr	TEMP	- 0.0014	0.0004	- 3.04	0.003	- 0.0022	- .0005
	pH	0.0028	0.0020	1.45	0.149	- 0.0010	0.0067
	TSS	0.0000	0.0000	0.33	0.742	0.0000	0.0000
	TDS	0.0001	0.0000	6.68	0.000	0.0001	0.0001
	TURB	0.0000	0.0000	- 1.10	0.274	- 0.0001	0.0000
	_CONS	0.0105	0.0154	0.68	0.499	- 0.0200	0.0409

4.3.2 Seasonal Variations of Zinc Concentrations in Sosiani River

Mean levels of zinc during the dry season from November 2015 to April 2016 was 0.198 ± 0.149mg/L while in the wet season from May 2016 to October 2016 it was 0.216 ± 0.156mg/L. T-test shows that t- statistic at $t = 2.99$, $P < 0.011$ is greater than the t-critical at 95% confidence limit. Hence there was significant seasonal variation in levels of zinc in Sosiani River with the onset of the rainy season refer to Tables 4.4; 4.6 and Figure 4.19.

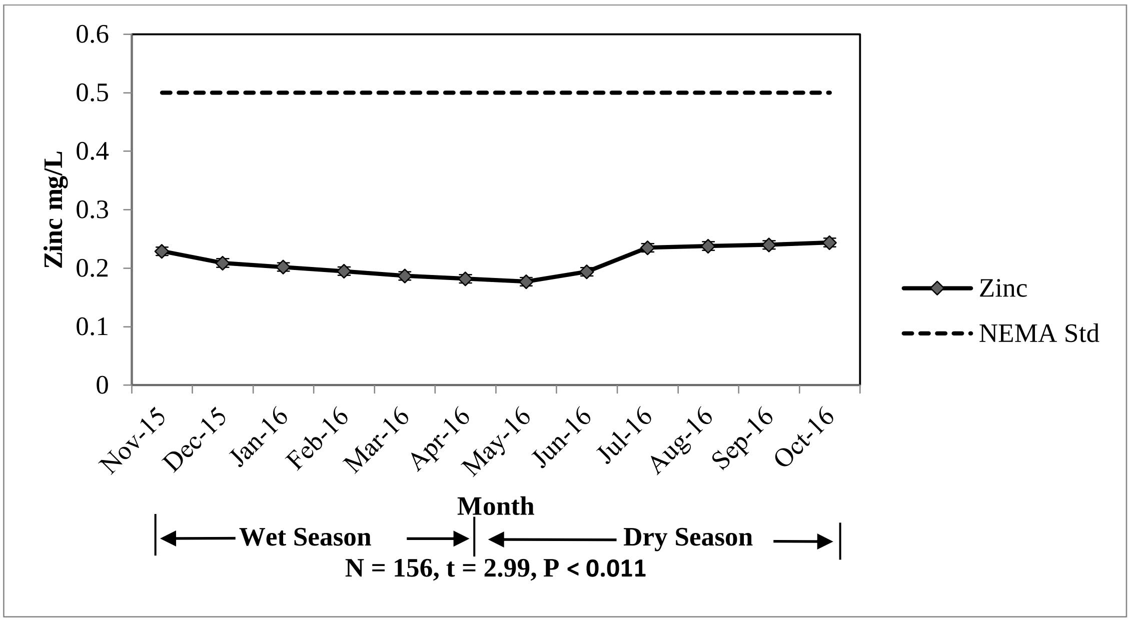

Figure 4.19: Seasonal Variations of Zinc in Sosiani River

This could be attributed to increased surface runoff draining effluent from Eldoret town and market into Sosiani River. High levels of zinc impart an undesirable astringent taste to water at a taste threshold beyond 4mg/L (WHO, 2011). Furthermore, water with high levels of zinc may appear opalescent and develop a greasy film on boiling (David, 2008; WHO, 2011). Moreover, zinc toxicity impairs muscular coordination and damages the immune systems of fauna. Similarly it can also cause tissue hypoxia as a result of cytological breakdown of gills in fish (Burton & Robert, 2001). These results of variations in zinc levels in Sosiani River are however inconsistent with the findings of Jepkoech (2013) whose study on bio-concentration of heavy metals in plants of Sosiani River showed no significant variations in mean concentrations of zinc in soil sediments along Sosiani Riverbed.

This was attributed to the fact that zinc is one of the most soluble and mobile metal cation in water which is easily assimilated by plants hence low concentrations in soil sediments (Jepkoech, 2013).

Table 4.9: Mean Monthly Concentrations of Heavy Metals in Sosiani River

Month	Zn (mg/L)	Cd (mg/L)	Pb (mg/L)	Cr (mg/L)
Nov-15	0.229 ± 0.0444e	0.061 ± 0.0084a	0.022 ± 0.0046f	0.013 ± 0.0057d
Dec-15	0.209 ± 0.0424d	0.046 ± 0.0064a	0.019 ± 0.004d	0.01 ± 0.0051cd
Jan-16	0.202 ± 0.0417cd	0.042 ± 0.0069a	0.017 ± 0.0037cd	0.009 ± 0.0043abcd
Feb-16	0.195 ± 0.041bcd	0.04 ± 0.0055a	0.014 ± 0.0034abc	0.007 ± 0.0036abc
Mar-16	0.187 ± 0.0404abc	0.031 ± 0.0049a	0.013 ± 0.0031ab	0.007 ± 0.0037ab
Apr-16	0.182 ± 0.04ab	0.025 ± 0.0049a	0.012 ± 0.0029a	0.006 ± 0.0029a
May-16	0.177 ± 0.042a	0.026 ± 0.0056a	0.012 ± 0.0027a	0.006 ± 0.0029a
June-16	0.191± 0.0439abc	0.033 ± 0.0073a	0.015 ± 0.0034bc	0.009 ± 0.0045bcd
July-16	0.235 ± 0.0441e	0.046 ± 0.0078a	0.019 ± 0.0038de	0.01 ± 0.0051bcd
Aug-16	0.238 ± 0.044e	0.048 ± 0.0073a	0.022 ± 0.0041ef	0.011 ± 0.005d
Sep-16	0.24 ± 0.044e	0.117 ± 0.0616b	0.023 ± 0.0042f	0.013 ± 0.0057d
Oct-16	0.244 ± 0.0471e	0.066 ± 0.0094a	0.027 ± 0.0017f	0.014 ± 0.0022d
Mean	**0.209 ± 0.012**	**0.048 ± 0.0056**	**0.017 ± 0.0011**	**0.01 ± 0.0013**
F value	**17.68**	**1.97**	**18.72**	**5.29**
P value	**< 0.001**	**0.036**	**< 0.001**	**< 0.001**
N = 156				

Months with the same letter notation do not differ significantly from one another. Months that have different letter notations differ significantly from one another. F is a statistic that shows variations in more than two means while P is the probability level

4.3.3 Longitudinal Variations in Levels of Cadmium along Sosiani River

The mean concentration of cadmium in Sosiani River was 0.048 ± 0.006mg/L which is above the WHO/NEMA standard guideline. This is a threat to the health of the residents in the study area refer to Table 4.5 and Appendix II. Cadmium is toxic, mutagenic and bio-persistent. It has acute and long term toxicity in mammals (Adriano, 2001; Apostolis *et al.*, 2007; Luoma & Rainbow, 2008). F-Statistic at $F = 2.71$, $P < 0.003$ is above the F-critical tabulated at 95% confidence limit. Hence Sosiani River displayed significant spatial variation in levels of cadmium along the river profile see Figure 4.20. Concentration of cadmium was highest at town carwash though it was not significantly higher than at Kapsabet Bridge; West Indies Bridge and Bondeni estate sampling points vide Figure 4.20. High concentrations of cadmium pose a health risk since cadmium is both toxic and mutagenic. Cadmium can cause chronic obstructive pulmonary diseases, emphysema and renal tubular diseases (WHO, 2011).There was a positive correlation between cadmium levels and turbidity at r = 0.241 and TDS at r = 0.22. This implies that as TDS and turbidity increase so does the level of cadmium increase in Sosiani River see Table 4.2. Regression analysis of cadmium shows that variations can best be predicted by TSS at $P < 0.001$ and turbidity at $P < 0.010$ than any other variables at 95% confidence limits vide Table 4.8. Coefficient of determination R2 = 0.2511which implies that only 25.11% of the variation in cadmium can be predicted or explained by the variables in the regression equation:

Cadmium = 0.0958 + 0.0014 Temp - 0.00148 pH + 0.0001 TSS + 0.0001 TDS + 0.0003Turb

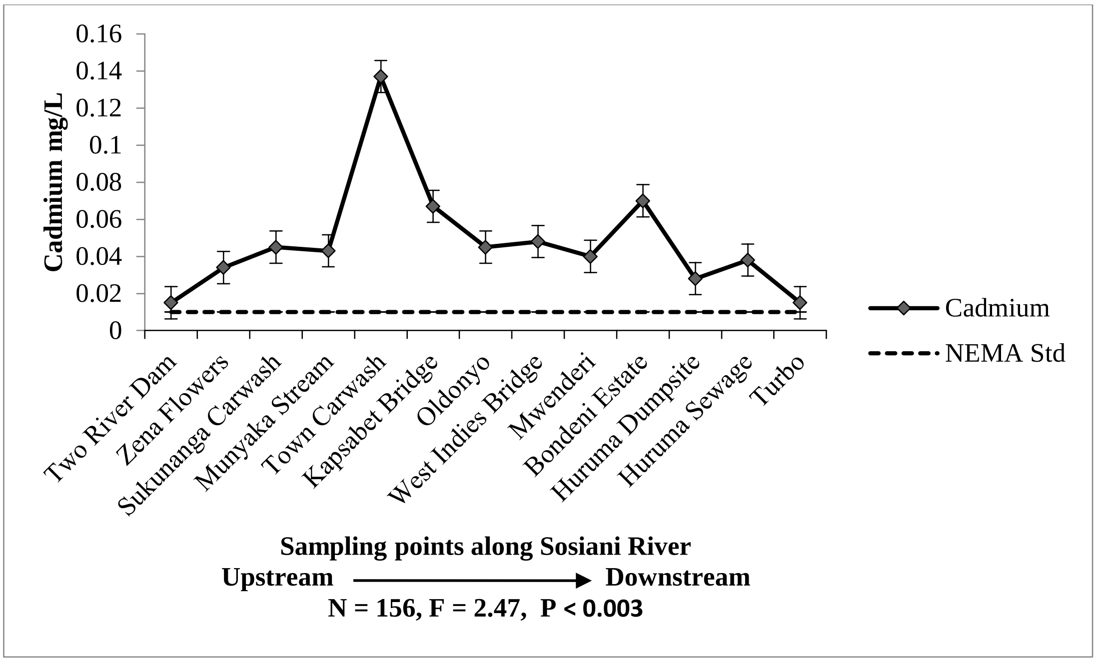

Figure 4.20: Longitudinal Variations of Cadmium along Sosiani River

These results are consistent with the findings of Mwamburi (2003); Omutange (2010); Chibole (2013); Mbaka *et al*. (2014) and Mwangi *et al*. (2014) whose studies on heavy metals in Nyando River, Nzoia River, Sosiani River, Naro Moru River and Kamiti River respectively showed characteristic spatial and temporal variations in heavy metals studied.

4.3.4 Seasonal Variations in Levels of Cadmium in Sosiani River

The mean concentrations of cadmium during the dry season from November 2015 to April 2016 was 0.040mg/L while the mean level of cadmium during the wet season from May 2016 to Octoberer 2016 was 0.052mg/L. The t-test indicates that t-statistic at t = 1.52, P < 0.023 is greater than the t-critical tabulated at 95% confidence limit. Hence there was significant variation in levels of cadmium during the dry and wet season. This could be attributed to increased surface runoff during the wet season refer to Figure 4.21 and Tables 4.5 & 4.6. High levels of cadmium could be attributed to effluent from garages and discarded old batteries. Cadmium is also found in municipal effluent washed off from many products like paints, photography, food products, detergents and body care products (Ulmgren, 2001; Perry *et al.*, 2007). This high level of cadmium is a health risk to the residents of Eldoret Township and those living along the riparian corridor whose main source of drinking water is Sosiani River.

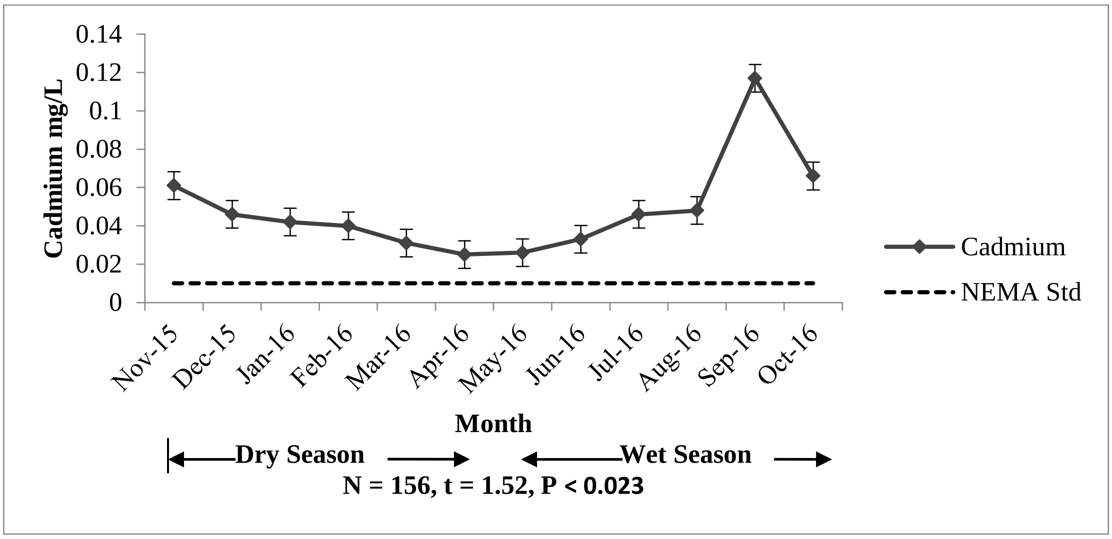

Figure 4.21: Seasonal Variations of Cadmium in Sosiani River

These results are consistent with the findings of Maina *et al*.(2010); Omutange (2010); Chibole (2013); Mbaka *et al*. (2014); Muchukuri *et al*. (2014) and Mwangi *et al*. (2014) whose studies on heavy metals in Njoro River, Nzoia River, Sosiani River, Naro Moru River; Subukia River and Kamiti River respectively showed characteristic spatial and temporal variations in heavy metals studied.

4.3.5 Longitudinal Variations in Levels of Lead in Sosiani River

Sosiani River is characterised by low mean concentrations of lead at 0.017 ± 0.001mg/L which is below the NEMA standard guidelines of 0.05mg/L but above the WHO standard guidelines refer to Table 4.5 and Appendix II. The F-statistic at F = 51.87, P < 0.001 is above the F-critical tabulated at 99% confidence limit. Hence Sosiani River displayed significant spatial variation in levels of lead along the river profile see Figure 4.22 and Table 4.5.

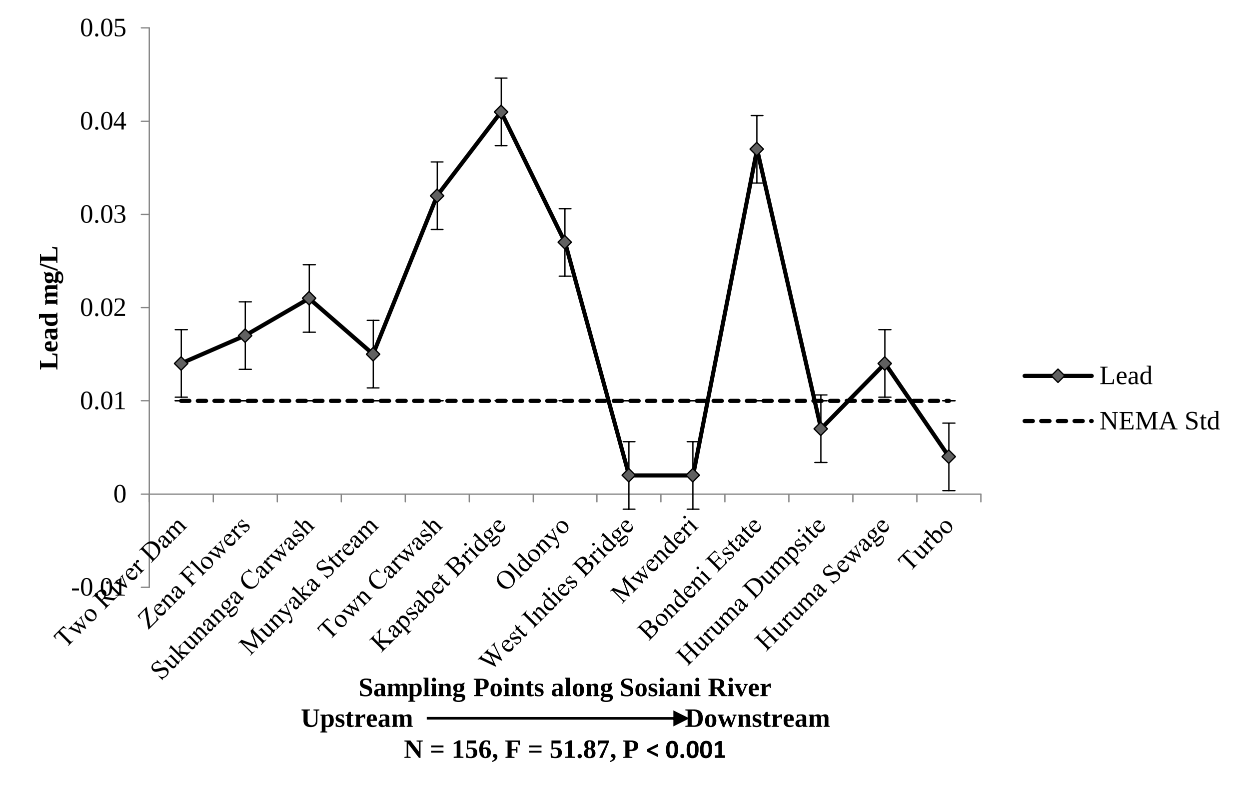

Figure 4.22: Longitudinal Variations in Levels of Lead along Sosiani River

Nevertheless, the highest concentration of lead in Sosiani River was recorded at the effluent discharge point at Kapsabet Bridge at 0.041 ± 0.009mg/L which perhaps could be attributed to heavy metals discharged from effluent in industries like Eldoret steel mills, motor vehicle garages and petrol stations along Sosiani River. The lowest concentration of lead was recorded downstream in Turbo town at 0.004 ± 0.010mg/L. This could be attributed to dilution from streams flowing into Sosiani River, through dispersion, sedimentation and adsorption processes (Apostolis *et al*., 2007; Luoma & Rainbow, 2008).There was positive correlation between lead levels and TSS at r = 0.322 and TDS at r = 0.165. This implies that as suspended and dissolved substances increase in Sosiani River they increase the levels of lead. However there was a negative correlation between lead and pH at r = - 0.47. This implies that as pH decreases, lead increases since it becomes more soluble in the acidic media in Sosiani River refer to Table 4.2. Regression analysis of lead shows that variations can best be predicted by TSS at $P < 0.001$ and pH at $P < 0.001$than any other dependant variable refer to Table 4.8. The Coefficient of determination of lead was $R^2 = 0.3245$ see Table 4.6. This implies that only 32.45% of the variation in lead can be predicted by the variables in the regression equation:

Lead = 0.1008 - 0.006 Temp - 0.0102 pH + 0.0001 TSS + 0.0001 Turb

These results are consistent with the findings of Maina *et al*. (2010); Omutange (2010); Chibole (2013); Mbaka *et al*.(2014); Muchukuri *et al*. (2014) and Mwangi *et al*. (2014) whose studies on heavy metals in Njoro River, Nzoia River, Sosiani River, Naro Moru River; Subukia River and Kamiti River respectively showed characteristic spatial and temporal variations in heavy metals studied.

4.3.6 Seasonal Variations in Levels of Lead in Sosiani River

The mean levels of lead during the dry season was 0.016 ± 0.013mg/L while the the level in wet season from May 2016 to October 2016 was 0.019mg/L which is below the NEMA/WHO standard guidelines. The t-test showed that the t-statistic at $t = 5.398$, $P < 0.001$ is greater than the t-critical tabulated at 99% confidence limit. Hence the mean concentrations of lead in Sosiani River varied significantly during the dry and wet seasons. This could be attributed to increased surface runoff during the wet season refer to Figure 4.23 and Tables 4.4 & 4.6. During wet season increased surface runoff washes effluent and discharges from anthropogenic activities into Sosiani River increasing heavy metal concentrations. High levels of lead above WHO standard guidelines is a health concern to the residents of Eldoret township and all those who source their drinking water from Sosiani River since lead is highly toxic. Lead poisoning causes neurodevelopment disorders, cardiovascular diseases, encephalopathy which is a brain disease, anaemia, renal malfunctioning and various endocrinal disorders especially of the reproductive glands hence impaired fertility (WHO, 2011).These results are consistent with the findings of Maina *et al*. (2010); Omutange (2010); Chibole (2013); Mbaka *et al*. (2014); Muchukuri *et al*. (2014) and Mwangi *et al*. (2014) whose studies on heavy metals in Njoro River, Nzoia River, Sosiani

River, Naro Moru River; Subukia River and Kamiti River respectively showed characteristic spatial and temporal variations in heavy metals studied.

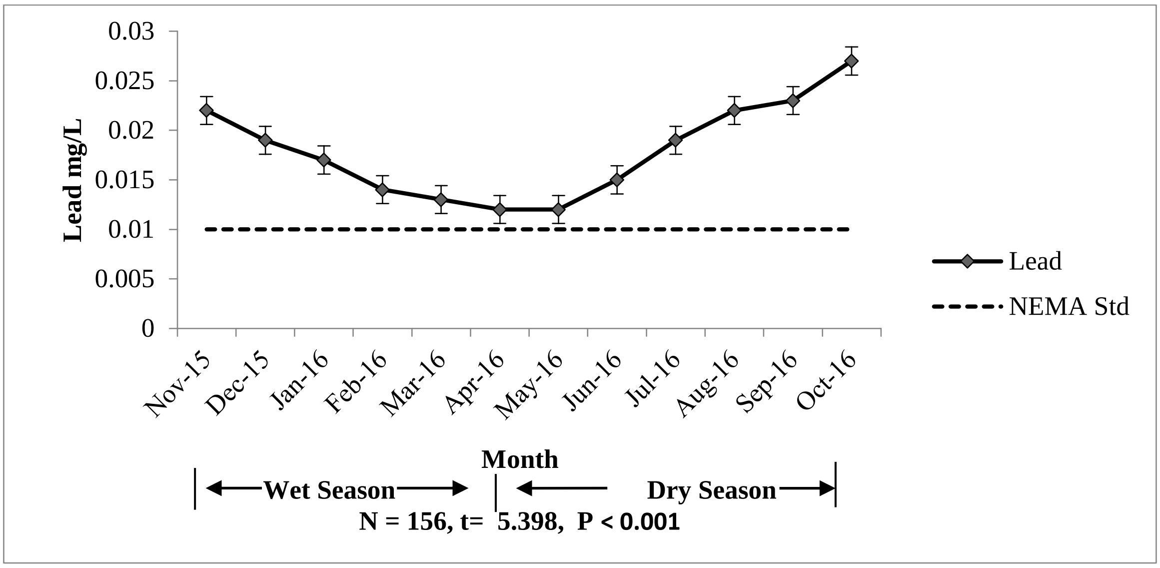

Figure 4.23: Seasonal Variations of Lead in Sosiani River

4.3.7 Longitudinal Variations in Chromium Levels along Sosiani River

Sosiani River exhibited low mean concentrations of chromium at 0.009 ± 0.0013mg/L which is below the NEMA and WHO standard guidelines refer to Table 4.5 and Appendix II. The NEMA guidelines are silent on permissible levels of chromium in drinking water but specify allowable limits of chromium in water for recreation purposes as 0.05mg/L refer to Appendix I. The F-statistic at $F = 126.78$, $P < 0.001$ is greater than the F-critical at 99% confidence limit see Figure 4.24. Hence there was significant longitudinal variation in the concentrations of chromium along Sosiani River. The highest levels of chromium were recorded at Mwenderi at 0.063 ± 0.015mg/L which is above the NEMA and WHO standard guidelines, while the lowest levels were recorded at Two River dam and Downstream in Turbo at 0.002 ± 0.001mg/L. High levels of chromium could be attributed to the effluent discharged from wood industries in this area. They contain wood preservatives like acid copper chromate and creosote, adhesive used for making plywood like urea formaldehyde and laminates. Chromium is also discharged from tanning industry, lubricants, oils, paints, pesticides, Eldoret steel mills, wet textile processing at Rivatex and RUPA mills. The levels of chromium declined further downstream in Turbo where Sosiani River discharges into Kipkaren River at 0.002 ± 0.001mg/L. There was a positive correlation between levels of chromium and TDS which implies that as TDS increases so does the level of chromium in

Sosiani River refer to Table 4.2. Chromium is both carcinogenic and mutagenic. It causes lung diseases, ulcers, kidney and liver damage and birth defects (David, 2008).

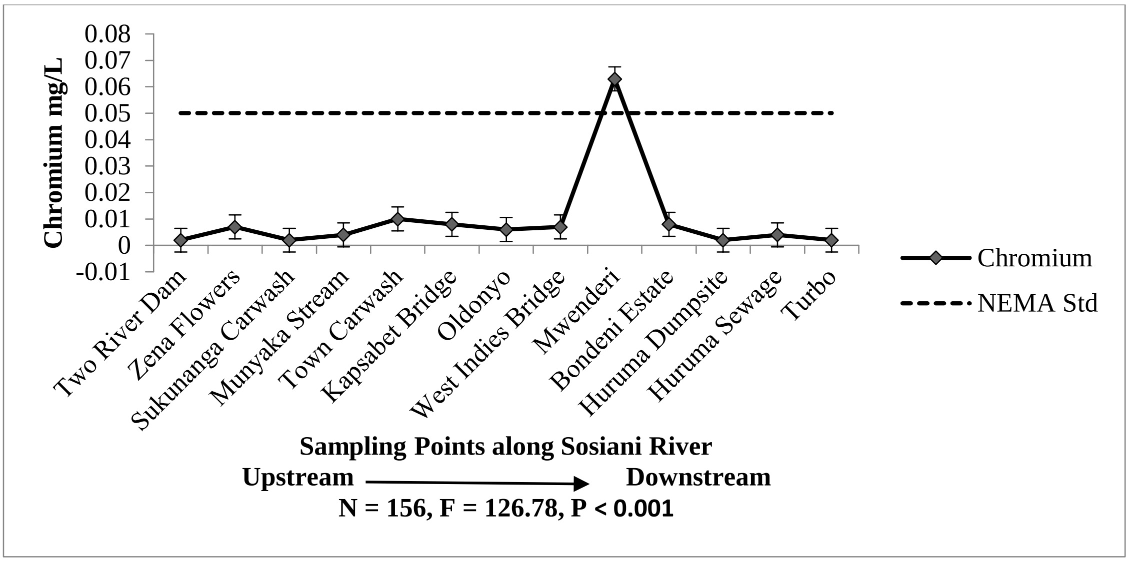

Figure 4.24: Longitudinal Variations of Chromium along Sosiani River

Regression analysis shows that variations in chromium can best be predicted or explained by TDS at $P < 0.001$ and temperatures at $P < 0.03$, than any other variables see Table 4.8. The coefficient of determination of chromium was $R^2 = 0.2905$ refer to Table 4.6. This implies that only 29% of the variation in chromium can be predicted by the variables in the regression equation:

Chromium = 0.0105 - 0.0014 Temp + 0.0028 pH + 0.001 TSS + 0.0001 Turb

These results are consistent with the findings of Maina *et al*. (2010); Omutange (2010); Chibole (2013); Mbaka *et al*. (2014); Muchukuri *et al*. (2014) and Mwangi *et al*. (2014) whose studies on heavy metals in Njoro River, Nzoia River, Sosiani River, Naro Moru River; Subukia River and Kamiti River respectively showed characteristic spatial and temporal variations in heavy metals studied along the rivers.

4.3.8 Seasonal Variations in Levels of Chromium in Sosiani River

The mean levels of chromium during the dry season from November 2015 to April 2016 was 0.008 ± 0.015mg/L while the mean concentration of chromium for the wet season from May 2016 to October 2016 was 0.010 ± 0.017mg/L . The t-test showed that t-statistic at $t = 2.96$ and $P < 0.012$ is greater than the t-critical at 95% confidence limit. Hence there was significant variation in the levels of chromium in Sosiani River during the dry and wet season refer to Figure 4.25 and Table 4.6. This could be attributed to increased surface runoff which drains effluent containing chromium from wood preservatives used in wood treatment at Tipsy wood international and Trade wood treatment plant, dyes and tanning. Increase of chromium in Sosiani River is a health concern since it is carcinogenic, mutagenic and causes birth defects.

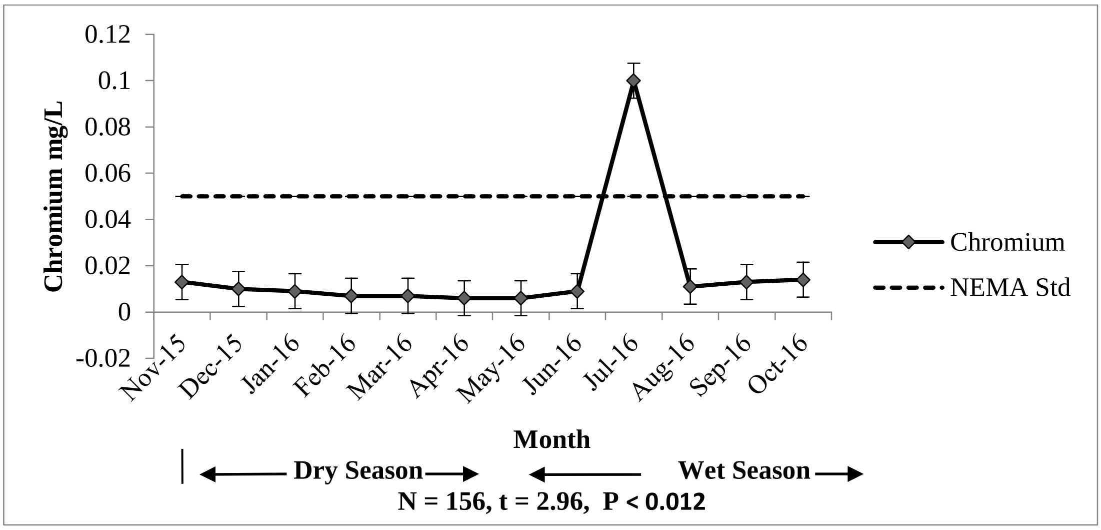

Figure 4.25: Seasonal Variations of Chromium Levels in Sosiani River

In general, these findings on heavy metals are consistent with similar studies on spatial distribution of metals along agro-industrial effluent sites along the riparian of Nzoia River where heavy metals: zinc, lead, copper and cadmium displayed asymptotic trends with distance and were higher in sediments (Omutange, 2010). Similarly, studies on Njoro River revealed high concentration of copper, lead, cadmium and arsenic along a gradient of human activities and increased during rainy seasons (Ndaruga *et al.*, 2004). The distribution of heavy metals were also found to be high in Rivers Nyando, Sondu Miriu, Nzoia, Yala, Awach, Kibos and Kasat especially aluminiun, manganese and iron which also increased during rainy seasons (Bukhalama, 2001; Mwamburi, 2003). The findings of this study also corroborate those of Marimba (2003) who established that heavy metals exhibited differential patterns that declined along Sosiani River downstream.

4.4: Longitudinal and Seasonal Variations in Levels of Total Coliforms and *Escherichia coli*

The levels of total coliforms and *Escherichia coli* in Sosiani River were high and above NEMA and WHO standard guideline of nil coliforms/100mL. The concentrations of these coliforms were lowest at the source of the river at Two River Dam in Kaptagat where the dam is protected and fenced keeping off the local residents and their livestock that contribute to total coliforms and *Escherichia coli* through faecal matter. However, the concentrations of the coliforms increased as Sosiani River traversed Eldoret town refer to Table 4.10. Coliforms are a large group of bacteria which are both thermotolerant, faecal and non faecal in origin. They could also be from soil or organic matter. They are made up of the genera *Klebsiella*, *Escherichia*, *Serratia*, *Erwina* and *Enterobacter*. Their presence is a primary indicator of pathogens in water which cause water related diseases. *Escherichia coli* is a common micro biota of intestines of warm blood mammals hence an indicator of recent faecal matter pollution (Burton & Robert, 2001; Prescott, 2002; Prasai, 2007; Hogan, 2010; Obasohan *et al*., 2010; Chioma *et al*., 2014).

Table 4.10: Means of Total Coliforms and *Escherichia coli* along Sosiani River

Sampling points	**Total Coliforms (**CFU/100ml)	***E. coli*** (CFU/100ml)
Two River Dam	5.5 ± 2 a	4.5 ± 2.1 a
Zena Flower Farm	107.3 ± 72.3 bcd	55.3 ± 33.2 bc
Sukunanga carwash	50.9 ± 26.9 ab	25.1 ± 14.8 ab
Munyaka Stream	71.0 ± 45.2 abc	40.5 ± 23.8 abc
Town carwash	180.3 ± 152.8 de	107.3 ± 100.5 d
Kapsabet Bridge	289.7 ± 119.6 f	104.6 ± 96.4 d
Oldonyo	119.9 ± 77.4 bcd	46.7 ± 26.1abc
West Indies Bridge	121.6 ± 81.8 bcd	49.3 ± 31.2 bc
Mwenderi	144.3 ± 104.5 cd	50.9 ± 25.5 bc
Bondeni Estate	180.3 ± 105.9 de	76.4 ± 54.1 cd
Huruma dumpsite	180.6 ± 111.4 de	75.7 ± 36.6 cd
Huruma sewage	248.9 ± 149 ef	80.5 ± 32.9 cd
Turbo	56.6 ± 27.6 ab	23.8 ± 12.7 ab
Mean	**135.1 ± 119.6**	**57.0 ± 54.3**
F value	**8.80**	**5.10**
P value	**< .001**	**< .001**
N=156		

Sites with the same letter notation do not differ significantly from one another. Sites that have different letter notations differ significantly from one another. F is a statistic showing variations in means and P is the probability level

4.4.1 Longitudinal Variations of Total Coliforms in Sosiani River

Sosiani River exhibited very high levels of mean total coliforms at 135.1 ± 119.6CFU/100ml above the NEMA and WHO standard guidelines see Table 4.10 and Appendix II. The F-statistic at F = 8.80, P < 0.0501is greater than the F-critical at 95% confidence limit. Hence there was significant longitudinal variation of total coliforms along Sosiani River vide Figure 4.26. The highest mean total coliforms were recorded at Kapsabet

Bridge, Huruma Sewage sampling points which varied significantly from all the other sampling sites. This could be attributed to soil erosion and poor faecal matter disposal. At Kapsabet Bridge, street children living under the bridge use the river as a public toilet and dumpsite. There was a significant positive correlation between total coliforms and turbidity at r = 0.772, total coliforms and total suspended solids at r = 0.758 and total coliforms and TDS at r = 0.378 see Table 4.2. This implies that total coliforms in Sosiani River increased as turbidity, total suspended and total dissolved solids also increased.

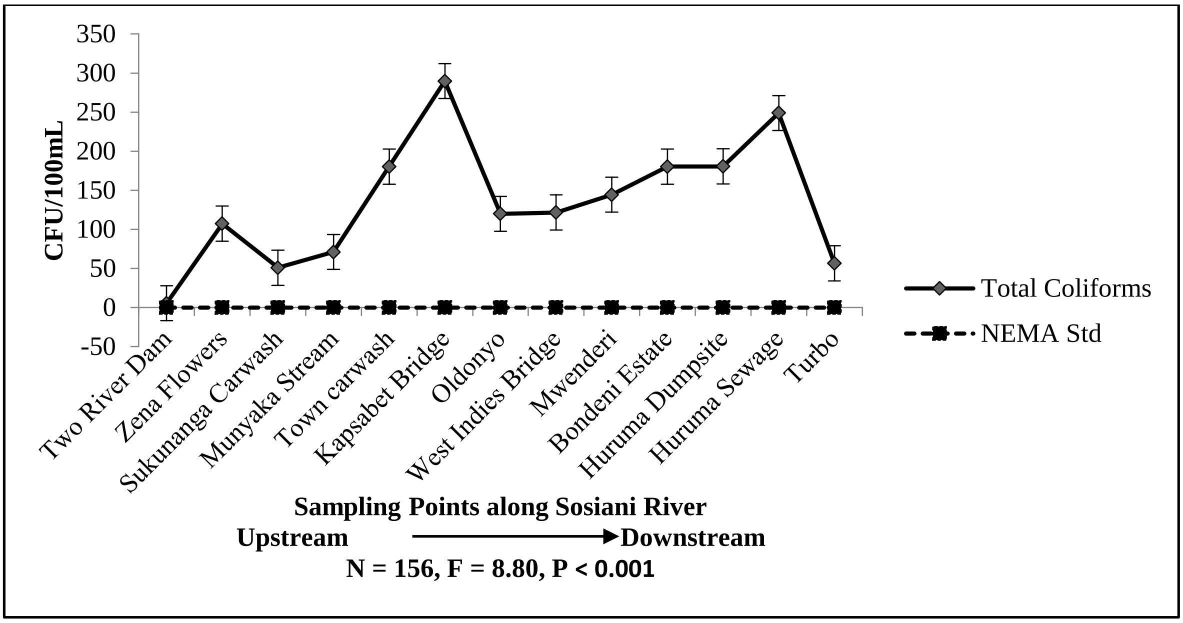

Figure 4.26: Longitudinal Variations of Total Coliforms along Sosiani River

The lowest total coliforms were recorded at Two River Dam which could be attributed to fencing of the dam and protecting it from human and animal encroachment. High level of total coliforms could be an indicator of presence of pathogens in Sosiani River like *Salmonella spp, Shigella spp, Burkholderia pseudomallei, Cryptosporidium parvum, Giardia lamblia*, *Novo* virus, helminthes and *Mycobacterium* which cause water related diseases (Burton & Robert, 2001; Maduka, 2004; Gerardi & Zimmerman, 2005).

4.4.2 Seasonal Variation of Total Coliforms in Sosiani River

The mean total coliforms in the dry season during the month of November 2015 to April 2016 were 127.7 CFU/100ml while mean total coliforms during the wet season from the month of May 2016 to October 2016 were 138.9CFU/100ml. The t-statistic at t = 1.44, P < 0.017 is greater than the t- critical at 95% confidence limit. Hence the mean total coliforms varied significantly during the dry and wet season. This is attributed to increased surface runoff with changes in the rainy season see Table 4.11 and Figure 4.27.

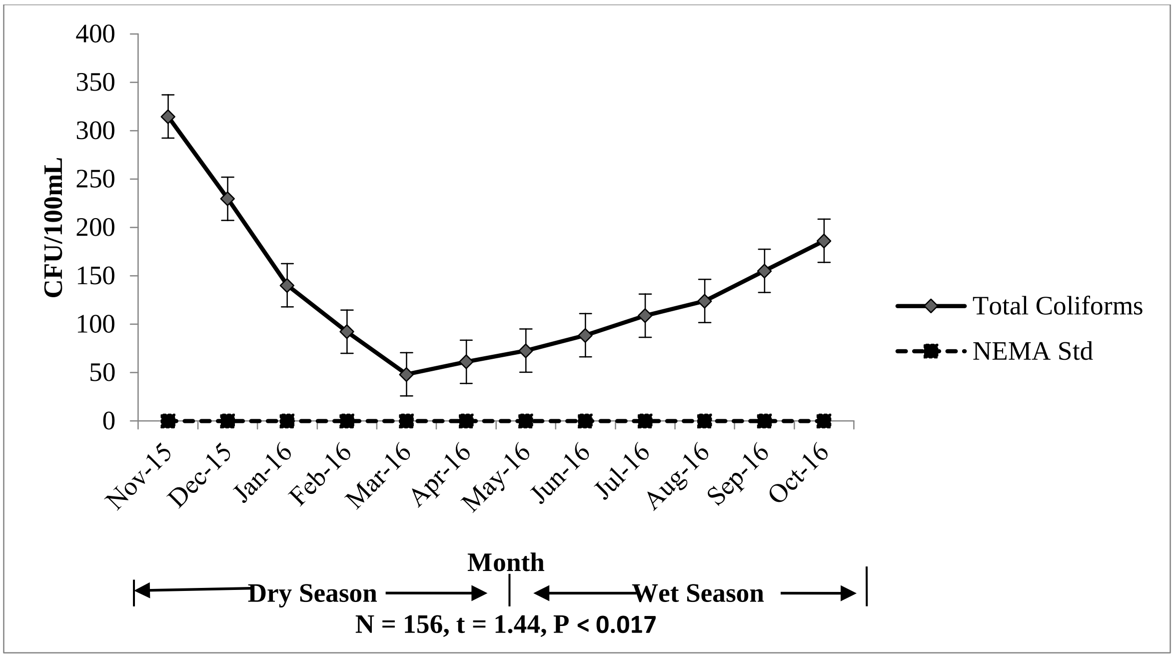

Figure 4.27: Seasonal Variations of Total Coliforms in Sosiani River

These findings are in agreement with Al-Bayatti *et al*. (2012); Musyoki *et al*. (2013); Muchukuri *et al*. (2014); Waithaka *et al*. (2015); Alhassan & Ofori (2016) whose microbial studies on Tigris River in Iraq, Nairobi River, Subukia River, Kandutura River and Black Volta in Ghana respectively showed that rivers exhibit seasonal and spatial fluctuations in bacterial population density and diversity.

4.4.3 Longitudinal Variations of *Escherichia coli* in Sosiani River

Sosiani River exhibited high mean levels of *Escherichia coli* at 57.0 ± 54.3CFU/100ml above the NEMA and WHO standard guidelines of nil coliforms see Table 4.10.The F-statistic at F = 5.10, P < 0.001 is greater than the F-critical at 99% confidence limit. Hence the *Escherichia coli* in Sosiani River varied significantly along the river downstream refer to Figure 4.28 and Table 4.10. The highest mean *Escherichia coli* content was recorded at effluent discharge points at town carwash at 107.3 ± 100.5CFU/100ml, Kapsabet Bridge at 104.6 ± 96.4CFU/100ml and Huruma sewage treatment plant at 80.5 ± 32.9CFU/100ml. This could be attributed to lack of public toilets and sanitary facilities at town car wash, discharge point of surface runoff from Eldoret town at Kapsabet Bridge and poorly treated sewage from Huruma sewage treatment plant being discharged into Sosiani River.

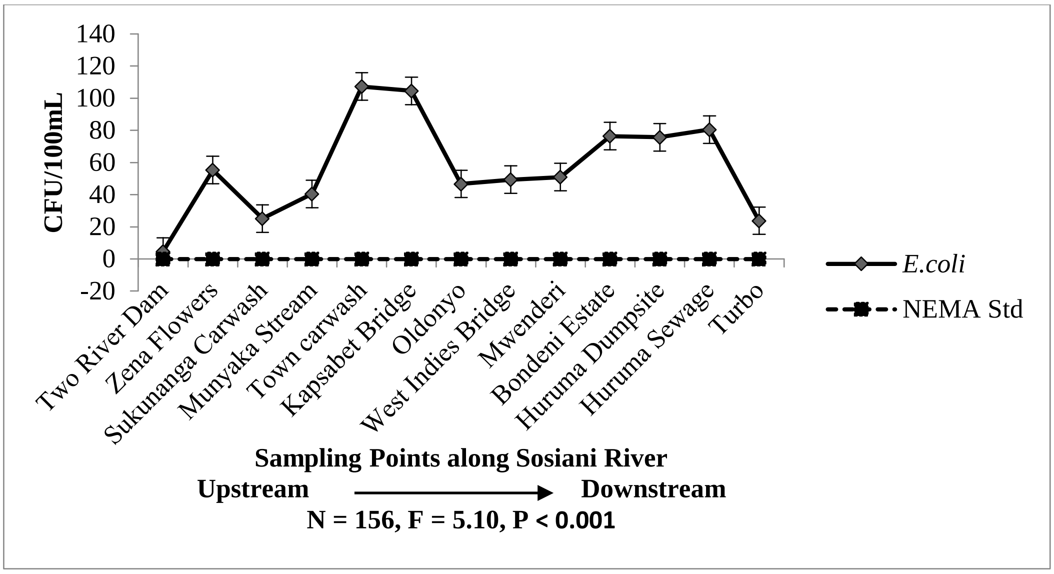

Figure 4.28: Longitudinal Variations of *E. coli* along Sosiani River

The high levels of *Escherichia coli* are attributed to poor sanitation, lack of toilets in slum areas along Sosiani River and leaking sewer lines. Presence of *Escherichia coli* is an indicator of recently discharged faecal matter hence a sign of likely presence of pathogens in Sosiani River. There was no significant difference in *Escherichia coli* at Two River dam, Zena Flower Farm and Munyaka stream. However, the lowest *E. coli* count was recorded at the source of the river at Two River Dam at 4.5 ± 2.1CFU/100ml. This could be attributed to fencing and protecting the dam from human and animal encroachment. There was significant positive correlation between *Escherichia coli* and turbidity at r = 0.858, *Escherichia coli* and TSS at r = 0.857 vide Table 4.2. This implies that *Escherichia coli* increased as TSS and turbidity increased in Sosiani River. Suspended solids facilitate survival and growth of faecal coliforms. They also protect coliforms from attack by bacteriophage and UV-radiation and provide organic and inorganic nutrient and attachment areas to the bacteria (Edward, 2000; David, 2008).

Table 4.11: Mean Monthly Total Coliforms and *E. coli* in Sosiani River

Month	Total Coliforms (CFU/100ml)	*E. coli* (CFU/100ml)
November-15	314.7 ± 196.1 bcd	136.8 ± 124 abcd
December-15	229.8 ± 152.7 abc	72.5 ± 49.5 abc

January-16	140.2 ± 109.5 a	49.8 ± 34 a
February-16	92.4 ± 77 ab	32.8 ± 24.4 b
March-16	48.2 ± 41.2 abc	17.4 ± 9.7 ab
April-16	61.2 ± 45.4 abc	23.3 ± 13.3 abcd
May-16	72.7 ± 48.9 abcd	28.1 ± 15.2 abcde
June-16	88.5 ± 55.3 abcd	39.8 ± 18.9 bcde
July-16	108.9 ± 62.7 cde	52.2 ± 22.9 de
August-16	123.9 ± 66.8 de	65.52 ± 7.7 e
September-16	155.1 ± 83.4 f	75.8 ± 31.3 f
October-16	186.2 ± 94.2 e	89.6 ± 41.5 cde
Mean	**135.1 ± 119.6**	**57 ± 54.3**
F value	**8.28**	**7.31**
P value	**< .001**	**< .001**
N=156		

Months with the same letter notation do not differ significantly from one another. Months that have different letter notations differ significantly from one another. F is a statistic showing variations in means of water parameters and P is the probability level.

The concentrations of total coliforms and *Escherichia coli* were highest during the wet season of May-October than in the dry season in November-April see Table 4.11.

4.4.4 Seasonal Variation of *Escherichia coli* in Sosiani River

The mean levels of *Escherichia coli* in the dry season during the month of November 2015 to April 2016 were 43.1CFU/100ml while the mean *Escherichia coli* in the wet season during the month of May 2016 to October 2016 were 63.9 CFU/100ml. The t-statistic at t = 6.00, P < 0.001 was greater than the t-critical at 99% confidence limit. Hence the mean *Escherichia coli* varied significantly during the dry and wet season refer to Tables 4.4; 4.8 and Figure 4.29. This could be attributed to increased surface runoff which drains faecal matter and effluent from Eldoret town into Sosiani River. These findings corroborate findings by Mehaffey *et al.* (2005) and Schoonover *et al.* (2005) who observed that high faecal coliform counts are related to inadequate provision of sewer services and poor waste management.

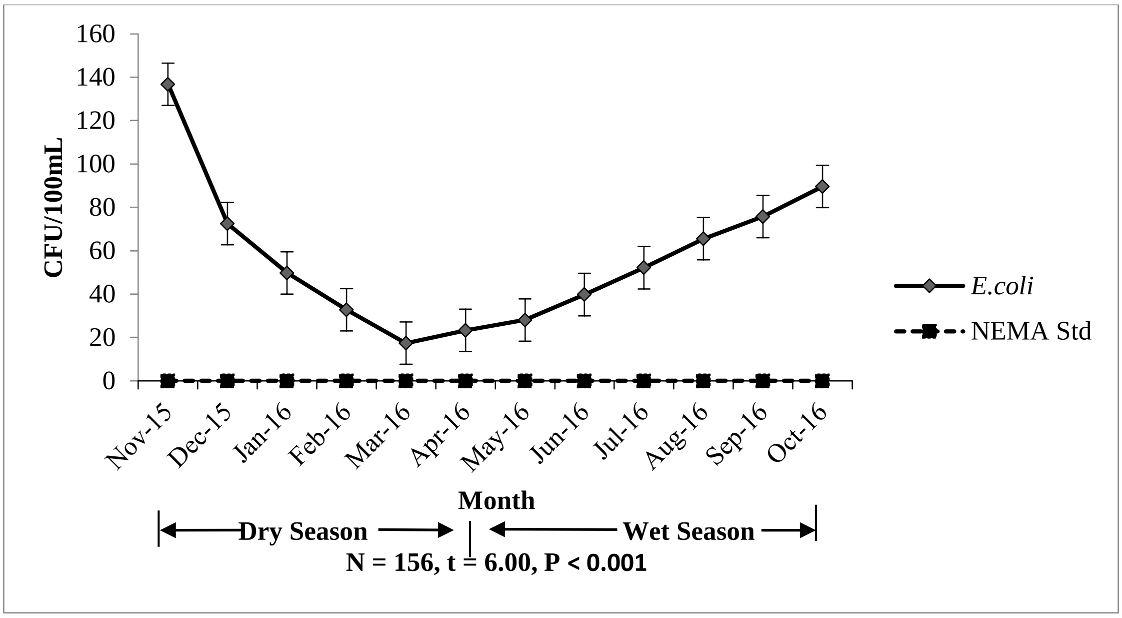

Figure 4.29: Seasonal Variations of *Escherichia coli* in Sosiani River

In general, the total coliforms and *Escherichia coli* content in Sosiani River were very high above the NEMA and WHO guidelines for drinking water, irrigation and recreation purposes refer to Appendices I & II. It was also observed that total coliforms at all sampling sites are higher than *Escherichia coli* since the later is a smaller group of feacal coliforms from faecal matter of warm blooded animals vide Figure 4.30. The levels of both total Coliforms and *Escherichia coli* were highest during the rainy season which is attributed to increased surface run off which drains faecal matter, soils and waste into Sosiani River. There is poor sanitation and faecal matter disposal in unplanned settlements of Huruma, Bondeni and Langas. High *Escherichia coli* counts have been positively related to poor urban planning and development, inadequate provision of sewer services and poor waste management (Mehaffey *et al.*, 2005; Schoonover *et al.*, 2005). Similarly Mallin *et al.* (2000) also found a strong correlation between population densities and mean faecal coliforms levels in surface waters.

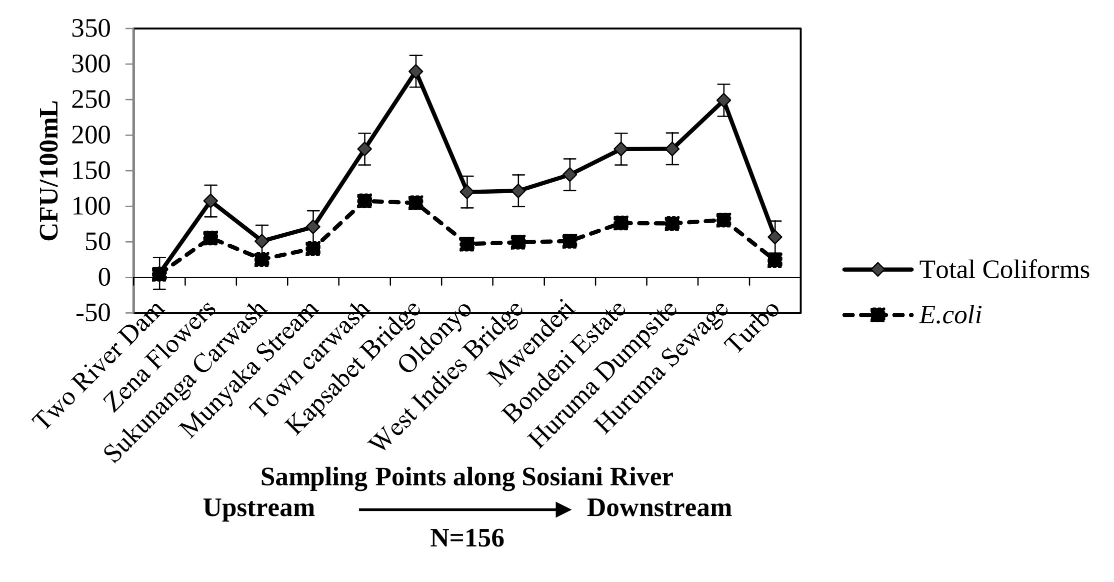

Figure 4.30: Comparison of Total Coliforms and *E. coli* along Sosiani River

These findings on total coliforms and *Escherichia coli* are consistent with a study on water related bacterial pathogens in surface waters of Arthi River and Nairobi River (Musyoki *et al.,* 2013). They observed that Athi and Nairobi Rivers were highly contaminated with human pathogenic bacteria mainly *Escherichia coli, Shigella flexineri, Klebsiella, Escherichia faecalis, Salmonella typhi* and *Vibrio cholerae* which significantly increased during the rainy season. This was attributed to increased surface runoff during the wet seasons. Similarly, It was also observed that bacterial counts in rivers tend to increase during high flows and decrease during base flows as a result of surface runoff (Medema *et al.*, 2003).

4.5 Prevalence of Water Related Diseases in Eldoret Township

4.5.1 Socio-Demographic Characteristics of Study Population

A survey of the study population shows that there were more females sampled in the study area than their male counterparts. This could be attributed to the fact that most females stay home taking care of household chores as males are away either looking after cattle, on their farms or managing their businesses refer to Table 4.12.

Table 4.12: Socio-Economic Data of Study Population

Characteristics of the study population	**Percentage %**
Females sampled	51.9
Males sampled	48.1

College level education	31.1
Secondary school level of education	49.6
Primary school level of education	16.3
No formal education	1.5
Average number of people/Household	5
Residents employed	22.2
Residents engaged in Business	28.9
Residents who are Farmers	19.3
Unemployed residents	26.7
Residents who rely on ELDOWAS Piped water	36.8
Residents who rely on wells for drinking water	26.3
Residents who rely on Sosiani River for drinking water	20
Residents who rely on Rainwater	16.8
Females who perceive contaminated water causes diseases	85
Males who perceive contaminated water causes diseases	48

N = 137

The survey revealed that most residents in the study area have attained formal education and are engaged in gainful employment. It also indicates that 98% of the study population have attained formal education which is characteristic of an urban population. Similarly 73% of this population are engaged in gainful employment. This is comparable to the estimated County literacy levels of 91% (GoK, 2013). Further, the study reveals that most of the residents in the study area source their drinking water from the piped water scheme managed by Eldoret Water and Sanitation Company, while 26% rely on hand dug wells, 20% source there drinking water from Sosiani River and 16% rely on rainwater harvested through roof catchments. However, Kimani, 2007 found out that most slum dwellers about 89% rely on shallow wells as a source of drinking water in Langas estate in Eldoret which is contaminated with faecal coliforms due close proximity to pit latrines. Most residents living downstream and upstream of Eldoret town source their drinking water from Sosiani River than those living midstream in Eldoret town. Residents living midstream within Eldoret town source their drinking water from the piped water scheme hence do not treat their drinking water see Table 4.13.

Table 4.13: Water Consumption Patterns among Residents along Sosiani River

Water Consumption patterns	Upstream %	Midstream %	Downstream %
Drinking water from Sosiani River	31.6	0.07	65
Drinking water from ELDOWAS	47.4	91.2	4.5
Drinking water from wells	26.3	8.8	87.5
Water from Sosiani River is polluted	47.3	87.7	25
Water from Sosiani causes diseases	31.6	61.4	32.5
Drinking water from Sosiani treated	73.7	36.9	80
Drinking water boiled	52.6	19.3	77.5
Chemical treatment	23.7	17.5	2.5
Livestock watered in Sosiani River	95	45	99

N = 137

Residents perceive water from Sosiani River to be polluted hence not safe for human consumption. However, most of the residents living downstream of Eldoret town source their drinking water from wells, Sosiani River and rainwater since most of them are not served by the ELDOWAS piped water scheme However, most residents living upstream of Eldoret town about 73.7% treat their drinking water sourced from Sosiani River by either boiling while others use chemical treatment by adding Sodium hypochlorite solution. Similarly, most residents living downstream of Eldoret town about 80% treat their drinking water sourced from Sosiani River. However, in the midstream of Eldoret town most residents source their drinking water from the already treated piped water from Eldoret Water and Sanitation Company.

4.5.2 Community Perceptions of Water Quality in Sosiani River

The household survey in the study area indicates that more than half of the local residents are not aware that use of contaminated water from Sosiani River can cause water related diseases. Nevertheless, only 31.6% of the households living upstream and 32.5% living downstream were aware that use of contaminated water could cause water related diseases vide Table 4.13. This could be attributed to lack of sanitation and hygiene information and awareness among the local residents living along the riparian corridor of Sosiani River. However, 85% of the females in the study area perceive that contaminated water from Sosiani River could cause water related diseases in the study area. Comparatively, 48% of the males interviewed were aware that water related diseases in the study area are associated with use of contaminated water and poor hygiene see Table 4.13. This could be attributed to the fact that females spend more time taking care of the household chores among this local community. Most of the residents living midstream of Eldoret town nearly 87.7% perceive water from Sosiani River to be polluted refer to Table 4.13. They attribute this to poor waste disposal, leaking sewers, industrial and municipal effluent discharge within Eldoret town. However, only 25% of those living downstream and 47.3% of those living upstream perceive water from Sosiani to be polluted.

The residents ranked diarrheoa, dysentery and typhoid as the most prevalent water related diseases in the study area. However, the survey indicates that cholera, hepatitis, poliomyelitis and meningitis are rare water related diseases in Eldoret Township. The only time there was an outbreak of cholera in Uasin Gishu County was during the post-election violence of 2008 when 50 people died of cholera in the internally displaced persons (IDP) camps (GoK, 2013). A Likert rank score was used to rank the most common water related diseases as perceived by the respondents in the study area refer to Figure 4.31. Rank score 10 was used to indicate the most prevalent water related disease and rank score 1 used for rare water related diseases. Community perception is important as it lays foundation for possible intervention measures by all stakeholders.

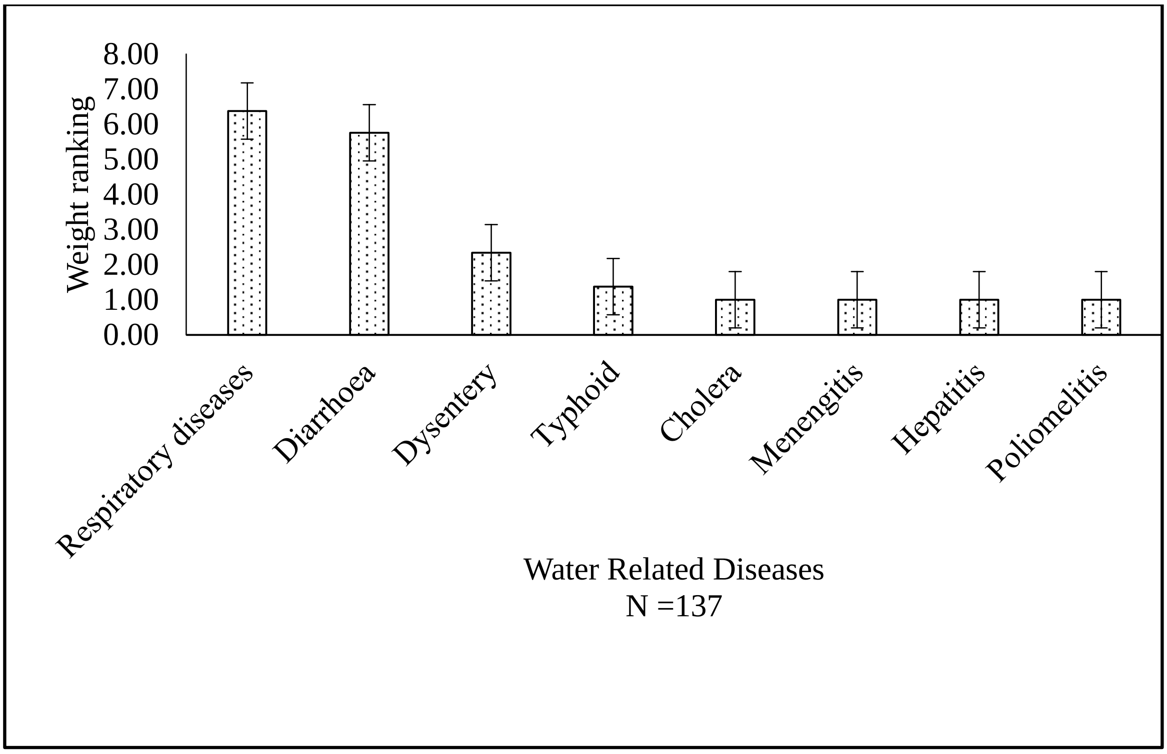

Figure 4.31: Likerts Rank Score on Water Related Diseases in Eldoret Township

4.5.3 Prevalence of Waterborne Diseases Treated in Health Facilities along Sosiani River

Medical data collected from sub county hospitals and dispensaries along Sosiani River indicate that the prevalent waterborne diseases in Eldoret Township are diarrhoea, typhoid and dysentery. However, no cases of menengitis, poliomyelitis, hepatitis and cholera were reported in the last 5 years from 2011 to 2016 refer to Appendices XXVII & XXVIII. In 2016, Ngelel-Terit dispensary recorded the highest cases of diarrhoea patients 5397 followed by Kipkenyo dispensary 728 patients and Sosiani Health centre 565. The highest cases of typhoid were recorded at Huruma sub county hospital 1685 cases followed by Turbo Sub-county hospital 1355 and Sosiani Health Centre 267 cases. Comparison of patients treated during the wet and dry season indicate that on typhoid varied significantly in Sosiani Health Centre and Huruma Sub-county Hospital see Table 4.14.

Table 4.14: Comparison of Means of *E. coli* and Waterborne Diseases by Season

	Parameter	Season		Combined	*t* Statistic	P value
		Dry	Wet			
E. coli		33.3 ± 16.2	53.5 ± 24.8	47.4 ± 23.7	-1.2712	.2394
Diarrhoea	Ngelel-Terit Dispensary	117 ± 48.3	615.8 ± 1521.4	449.8 ± 1238.5	-0.6387	.5374
	Kipkenyo Dispensary	48.0 ± 13.8	67.0 ± 15.8	60.7 ± 17.3	- 2.0405	.0686
	Sosiani Health Centre	47.5 ± 10.4	46.9 ± 11.5	47.1 ± 10.7	0.0910	.9293
	Huruma District Hospital	209.3 ± 144.2	95.5 ± 67.6	133.4 ± 108.2	1.9122	.0849
	Turbo Sub-County Hospital	3.5 ± 2.9	4.9 ± 5.1	4.4 ± 4.4	- 0.4901	.6346
Typhoid	Ngelel-Terit Dispensary	5.3 ± 3.0	4.4 ± 4.3	4.7 ± 3.8	0.3588	.7272
	Kipkenyo Dispensary	8.3 ± 4.8	6.4 ± 4.5	7.0 ± 6.2	0.4732	.6462
	Sosiani Health Centre	28.0 ± 12.8	19.4 ± 7.1	22.3 ± 9.7	1.5332	.1562
	Huruma District Hospital	278.3 ± 181.6	71.5 ± 59.8	104.4 ± 147.1	3.0329	.0126
	Turbo Sub-County Hospital	125.0 ± 71.5	106.8 ± 72.1	112.9 ± 69.1	0.4118	.6892
Dysentery	Ngelel-Terit Dispensary	1.0 ± 1.4	2.9 ± 2.7	2.3 ± 2.5	- 1.2839	.2281
	Huruma District Hospital	6.3 ± 5.4	9.0 ± 14.9	8.1 ± 12.3	- 0.3508	.7330
	Turbo Sub County Hospital	0.5 ± 1.0	0.9 ± 1.4	0.8 ± 1.2	- 0.4860	.6374

Where t is a statistic showing variations between two means and P is the probability level

4.5.3.1 Cases of Waterborne Diseases Treated at Turbo Sub-county Hospital

Turbo Sub-county Hospital treated a total of 53 patients of diarrhoea, 1355 of typhoid and only 27 cases of dysentery in 2016. There were no cases of poliomyelitis, meningitis or hepatitis reported in this hospital. Monthly average of waterborne diseases treated in 2016 were; 4 cases of diarrhoea, 113 cases of typhoid and only one case of dysentery see Figure 4.32. However there was no significant difference in number of cases treated during the wet and dry season for diarrhoea at $t = 0.4901$ & $P < 0.6346$ since t-statistic is less than t-critical and alpha is greater than 0.05: typhoid at $t = 0.4118$ & $P < 0.6892$ since t-statistic is less than t-critical and alpha is greater than 0.05: and dysentery at $t = 0.4860$ & $P < 0.6374$ since t-statistic is less than t-critical and alpha is greater than 0.05 see Table 4.16. Regression analysis of *Escherichia coli* and waterborne diseases gives a coefficient of determination for diarrhoea $R^2 = 0.0132$, typhoid $R^2 = 0.0504$ and dysentery $R^2 = 0.0815$ vide Table 4.17. This implies that only 1.3% of diarrhoea cases, 5% of typhoid and 8.1% of dysentery can be predicted by changes in *Escherichia coli* and changes in the wet and dry season.

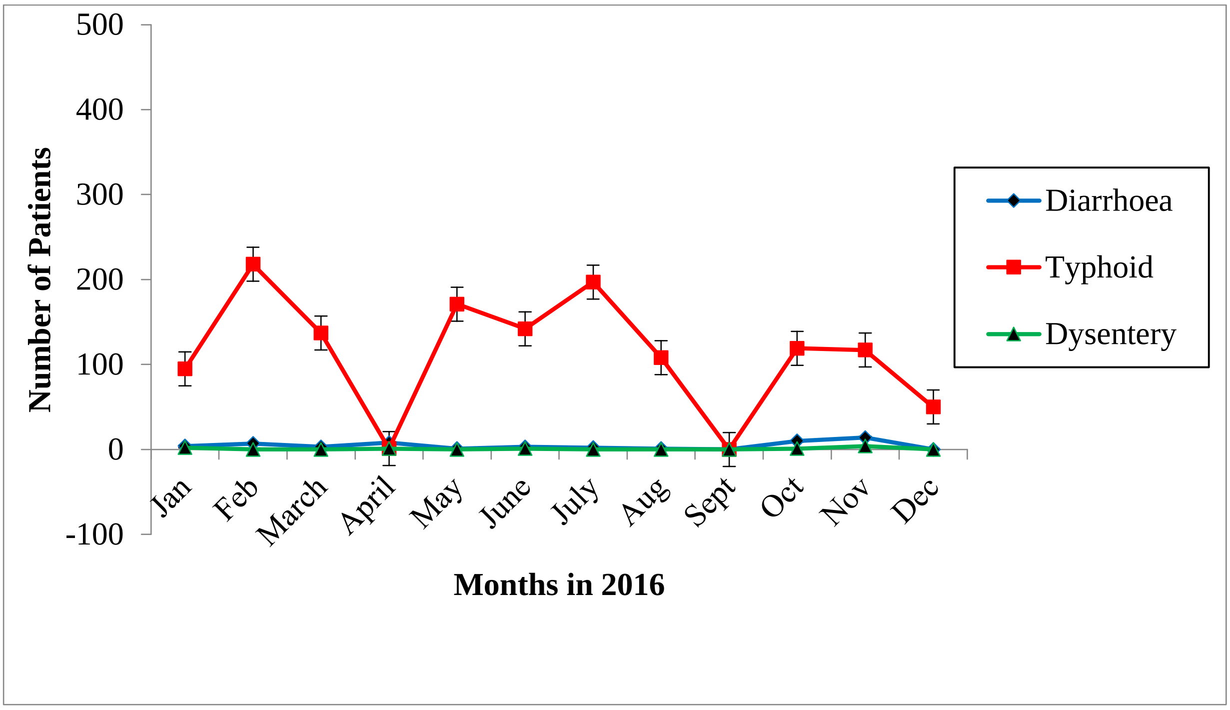

Figure 4.32: Monthly Prevalence of Waterborne Diseases in Turbo Sub-County Hospital in 2016

Generally, water related diseases are associated with poor sanitation and hygiene, lack of adequate water treatment mechanisms, poor water handling and hand washing practises at household level (Edward, 2000; WHO, 2016). Sanitation and hygiene is poor in unplanned settlements of Huruma, Langas, Kamukunji and Bondeni where sewer connectivity is very low 4–5% (RoK, 2009).

Table 4.15: Regression Analysis of *Escherichia coli* and Waterborne Diseases on Monthly Basis in Eldoret Township

	Hospital	Coefficient	R^2	F statistic	P value
E. coli		6.049	0.5957	11.7852	0.009
Diarrhoea	Ngelel-Terit Dispensary	124.291	0.0775	0.6720	0.436
	Kipkenyo Dispensary	1.115	0.0581	0.4939	0.502
	Sosiani Health Centre	0.558	0.0335	0.2770	0.613
	Huruma District Hospital	- 13.564	0.1231	1.1230	0.320
	Turbo Sub-County Hospital	-0.127	0.0132	0.1074	0.752
Typhoid	Ngelel-Terit Dispensary	-0.661	0.3038	3.4913	0.099
	Kipkenyo Dispensary	- 0.770	0.1332	1.2295	0.300
	Sosiani Health Centre	- 2.976	0.8388	41.6411	0.000
	Huruma District Hospital	- 40.982	0.6408	14.2718	0.005
	Turbo Sub-County Hospital	- 5.430	0.0504	0.4250	0.533
Dysentery	Ngelel-Terit Dispensary	0.376	0.1929	1.9115	0.204
	Huruma District Hospital	- 1.412	0.1010	0.8992	0.371
	Turbo Sub-County Hospital	- 0.067	0.0815	0.7097	0.424

Where F value is a statistic showing variations in means, P is the Probability level and R^2 is the Regression coefficient of determination.

4.5.3.2 Cases of Waterborne Diseases Treated at Huruma Sub-County Hospital

Huruma Sub-County Hospital treated a total of 1601 patients of diarrhoea, 1685 cases of typhoid and 97 cases of dysentery in 2016. There were no cases of poliomyelitis, meningitis or hepatitis treated in this Sub-County Hospital. On a monthly average, the hospital treated 133 patients of diarrhoea, 140 cases of typhoid and 8 cases of dysentery refer to Figure 4.33. There was a significant difference in cases of typhoid treated in this hospital during the dry and wet season at $t = 3.0329$ & $P < 0.0126$ since t- statistic is greater than t-critical and alpha is less than 0.05. Regression analysis between typhoid, *Escherichia coli* and changing season yields a coefficient of determination $R^2 = 0.6408$ at $P < 0.005$. This implies that 64% of the variations in typhoid at Huruma Sub–County Hospital can be predicted by changes in levels of *Escherichia coli* and changing rain season at 95% confidence limit. However, there was no significant difference in number of cases treated during the wet and dry season for diarrhoea at $t = 1.9122$ & $P < 0.0849$ since t-statistic is less than t-critical and alpha is greater than 0.05 see Table 4.16. Regression of *Escherichia coli* and waterborne diseases gives a coefficient of determination for diarrhoea $R^2 = 0.1231$ at $P < 0.320$ vide Table 4.17. This implies that only 12.3% of diarrhoea patients treated at Huruma Hospital can be predicted by *Escherichia coli* and changing rain season.

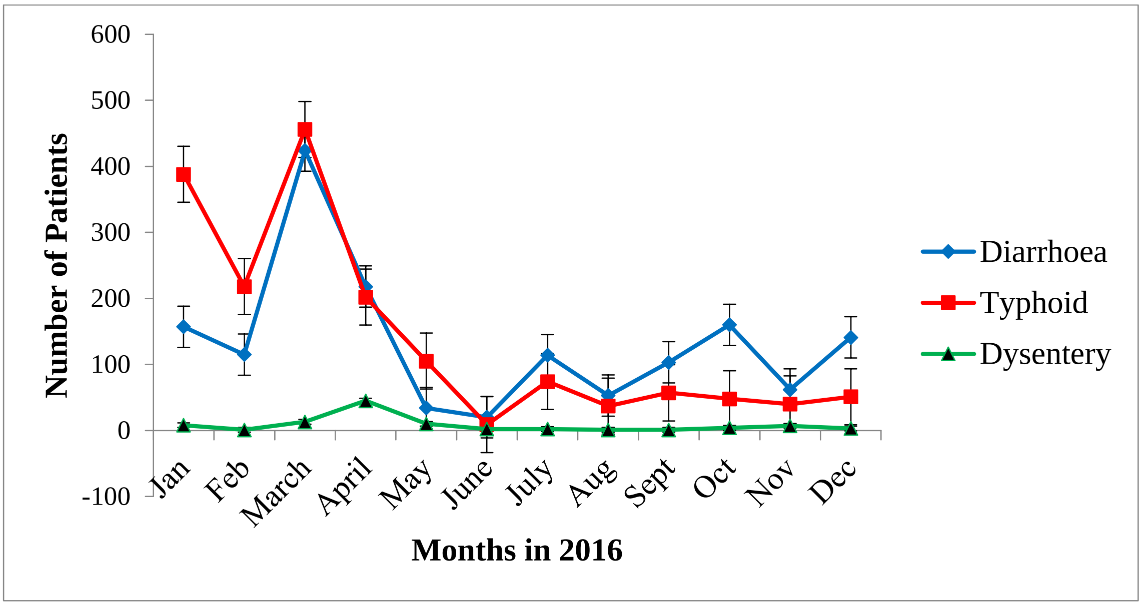

Figure 4.33: Monthly Waterborne Diseases in Huruma Sub-County Hospital in 2016

A similar study on quality of water slum dwellers use in Langas estate of Eldoret town revealed that 95% of the residents use wells as a source of drinking water which is polluted by faecal coliforms due to citing of pit latrines next to boreholes and wells against the water regulation (Kimani *et al.*, 2007).

4.5.3.3 Cases of Waterborne Diseases Treated at Sosiani Health Centre

Sosiani Health Centre recorded a total of 565 patients of diarrhoea and 267 patients of typhoid in 2016. There were no cases of dysentery, poliomyelitis, meningitis or hepatitis reported in this dispensary. On average, this dispensary treated 47 patients of diarrhoea, 22 cases of typhoid and no case of dysentery on monthly basis in 2016 see Figure 4.34. However there was no significant difference in number of cases treated during the wet and dry season for diarrhoea at $t = 0.0910$ & $P < 0.923$ since t-statistic is less than t-critical and alpha is greater than 0.05: similarly no significant variation in cases treated of typhoid at $t = 1.5332$ & $P < 0.1562$ since t-statistic is less than t-critical and alpha is greater than 0.05 see Table 4.16. Regression of *Escherichia coli* and waterborne diseases gives a coefficient of determination for diarrhoea $R^2 = 0.0335$ at $p < 0.613$, and typhoid at $R^2 = 0.8388$ & $P < 0.001$ vide Table 4.17. This implies that 83.88% of the variations in cases of typhoid can be predicted by changes in *Escherichia coli* and rain season at 99% confidence limit. However, only 3.35% of diarrhoea cases can be predicted by levels of *Escherichia coli* and changing rain season since alpha is greater than 0.05.

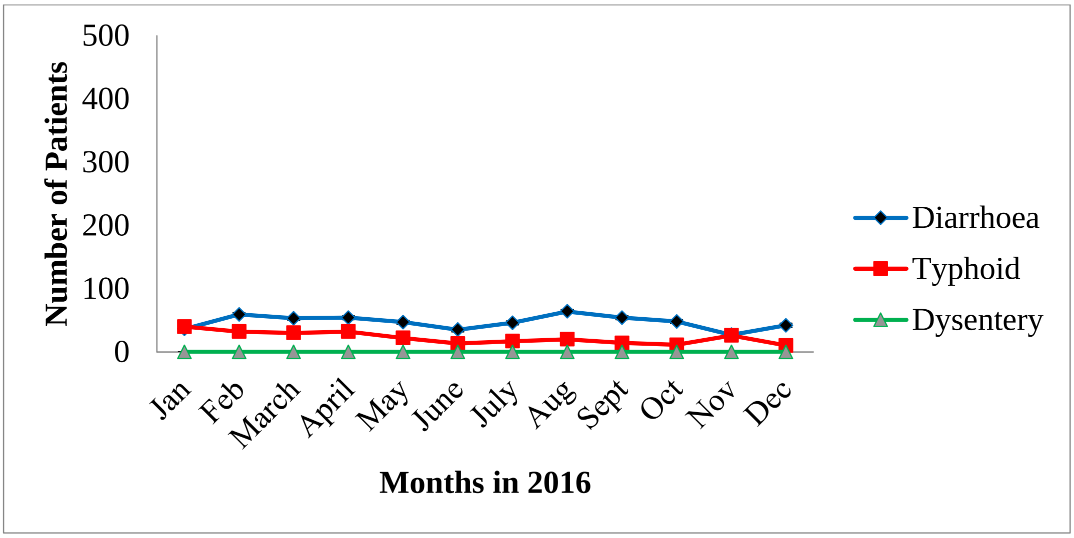

Figure 4.34: Monthly Waterborne Diseases Treated at Sosiani Health Centre in 2016

4.5.3.4 Cases of Waterborne Diseases Treated at Ngelel -Terit Dispensary

In 2016 Ngelel-Terit dispensary treated a total of 5397 patients of diarrhoea, 56 of typhoid and 27 of dysentery. There were no cases of poliomyelitis, meningitis or hepatitis reported in this dispensary. On average the dispensary treated 450 cases of diarrhoea, 5 cases of typhoid and 2 cases of dysentery monthly see Figure 4.35. However, there was no significant difference in number of cases treated during the wet and dry season for diarrhoea at t = 0.6387 & $P < 0.5314$ since t-statistic is less than t-critical and alpha is greater than 0.05: typhoid at t = 0.3588 & $P < 0.7272$ since t-statistic is less than t-critical and alpha is greater than 0.05: and dysentery at t = 1.2839 & $P < 0.2281$ since t-statistic is less than t-critical and alpha is greater than 0.05 see Table 4.16. Regression of *Escherichia coli* and waterborne diseases gives a coefficient of determination for diarrhoea $R^2 = 0.0775$, typhoid $R^2 = 0.3038$ and dysentery $R^2 = 0.1929$ vide Table 4.17. This implies that only 7.75% of diarrhoea cases, 30% of typhoid and 19% of dysentery can be predicted by *Escherichia coli* and changes in wet and dry season. A similar study on Njoro River showed that major enteric diseases faced by residents of Njoro town were identified as; cholera, hepatitis, *Amoebiasis*, bacillary dysentery and *Salmonellosis* due to poor water quality in Njoro River (Kimani & Ngindu, 2007; Kinuthia *et al.*, 2012).

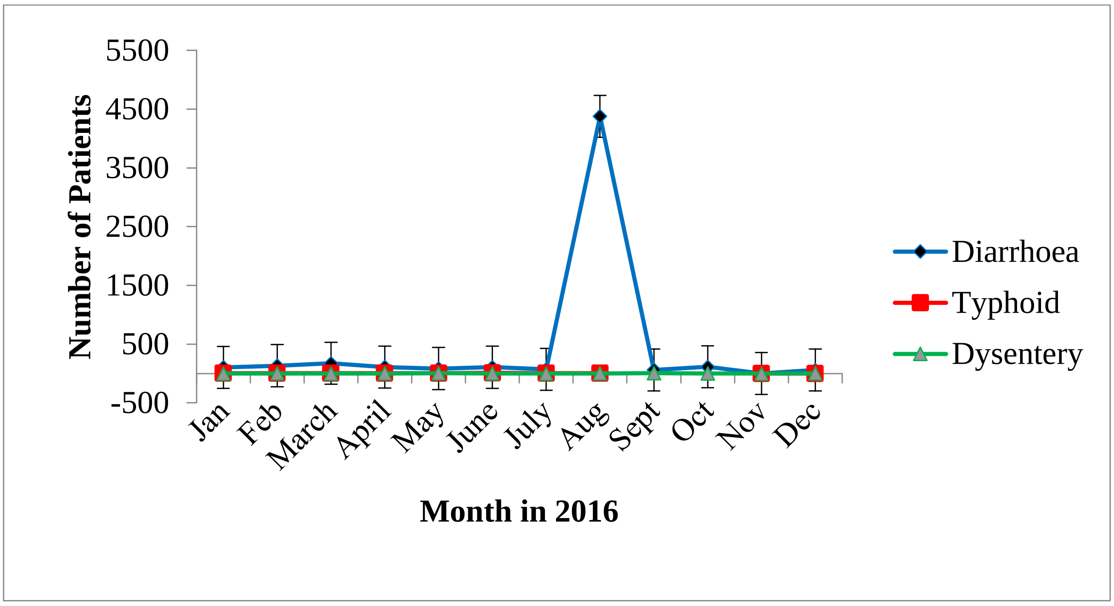

Figure 4.35: Monthly Waterborne Diseases Treated at Ngelel-Terit Dispensary in 2016

4.5.3.5 Cases of Waterborne Diseases Treated at Kipkenyo Dispensary

Kipkenyo dispensary treated a total of 728 patients of diarrhoea and 84 cases of typhoid in 2016. There were no cases treated of dysentery, poliomyelitis, meningitis or hepatitis reported in this dispensary during the study period. Monthly averages of cases treated at Kipkenyo dispensary were 60 patients for diarrhoea and only 7 cases of typhoid refer to Figure 4.36. The analysis shows that there was no significant difference in number of patients treated during the wet and dry season for diarrhoea at $t = 2.0405$ & $P < 0.0686$ since t-statistic is less than t-critical and alpha is greater than 0.05: and typhoid at $t = 0.4732$ & $P < 0.6462$ since t-statistic is less than t-critical and alpha is greater than 0.05 see Table 4.16. Regression analysis of *Escherichia coli* and waterborne diseases gives a coefficient of determination for diarrhoea $R^2 = 0.0581$ at $P < 0.502$ and for typhoid $R^2 = 0.1332$ at $P < 0.300$ see Table 4.17. This implies that levels of *Escherichia coli* and changes in wet and dry season can only predict 5.8% of the variations in number of patients treated of diarrhoea and 13.3% of typhoid cases.

These findings are consistent with those from studies on Njoro River Watershed which established that Nakuru, Molo and Njoro Districts are endemic for diarrhoeal related diseases as a result of poor water supply conditions. The residents in these rural and peri urban settings rely on this river for their domestic water supply (Tiwari & Jenkins, 2008).

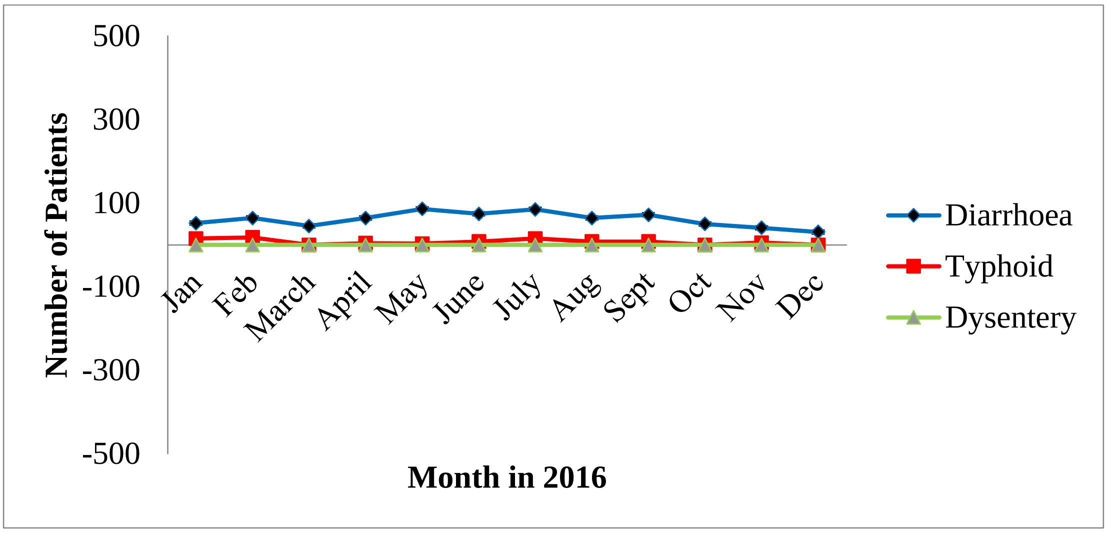

Figure 4.36: Monthly Waterborne Diseases in Kipkenyo Dispensary in 2016

4.5.4 Impacts of Polluted Water of Sosiani River on Fishery

Discussions with local residents and the County Director of Fisheries of Uasin Gishu County revealed that Sosiani River is not an important source of fish for residents of Eldoret town. Fish is mainly sourced from 143 fish farmers with 100 dams and 277 fish ponds across the County. The annual fish production from these farmers is 8000kg per annum while the rest of the fish demand comes from Lake Victoria in the western region. However, the residents reported that fish is found in some sections of the river upstream in Kaptagat, Kipkonen, and Kolol and downstream in Turbo where water quality is suitable. According to Fisheries department, one species of fish found in this river downstream is catfish (*Clarias gariepinus*). It is well adapted to surviving in polluted waters than other species of fish as seen in Plate 4.12.

Plate 4.12: Catfish (*Clarias gariepinus*) the main Fish Species Harvested by Local Residents from Sosiani River at Chemakil area

Sosiani River exhibited high biological oxygen demand and turbidity and perhaps this explains why the river is not an important source of fish for the local residents. High turbidity clogs respiratory organs of fish like gills affecting their survival hence only catfish thrives. Low dissolved oxygen also interferes with reproductive function of fish and other aquatic organisms. In particular, it affects spawning of fish. This stresses aquatic organisms and in extreme cases they suffocate and die (Clescerl, 2008). Fish have the highest oxygen need of the aquatic species. In very low dissolved oxygen valuable species of fish are replaced by catfish (*Clarias gariepinus*) and common carp (*Cyprinus carpio*). Histological studies have shown that heavy metals alter tissue structure in fish and moreover, fish cannot survive increased dissolved oxygen below 4mg/L (Edward, 2000; Kolawole *et al*., 2011; Serpa *et al*., 2014; Roig *et al*., 2015). Histopathological studies on fish (*Tillapia zillii* and *Solea vulgaris*) from polluted waters of Lake Qarun, Egpyt showed histological alterations in muscles including vacuolar degeneration and aggregation of necrosis in gills and inflammatory cells in hepatocytes of liver tissue (Thophon *et al*., 2003; Mohammed & Gag, 2009).

4.5.5 Impacts of Polluted Water of Sosiani River on Livestock Health.

Most of the residents who keep livestock observed that contaminated water from Sosiani River is a source of liver flukes and intestinal worms which affects the health of their livestock. This leads to low milk and beef production due to emaciated livestock. However, 95% of the residents interviewed were more concerned with tick borne diseases like East Coast Fever, Anaplasmosis and Anthrax which they perceive pose a major threat to livestock production than polluted water in the study area. According to the County Director of Veterinary Services in Uasin Gishu County, contaminated water leads to mull-absorption of food hence low yield production of beef and milk. He attributes watering animals directly into Sosiani River as a source of faecal coliforms from cow dung since coliforms are resident in intestines of warm blooded animals like livestock yet the residents are major livestock farmers. It was also observed that the Huruma sewage treatment ponds in Eldoret are not fenced which poses a major hazard to both the residents traversing the area and livestock grazing along the ponds. Livestock either drown in the ponds or drink the poorly treated water from the treatment ponds which are a health risk as seen in Plate 4.13. These findings are consistent with a study on dairy animals in the USA which showed that decaying organic matter, manure and total dissolved substances affect water odour and taste due to amines and hydrogen sulphide which suppresses water intake by Livestock. This suppresses feeding patterns leading to weight lose and low milk production (Ensley, 2001; Obahason *et al.*, 2010). The soil-borne microbes believed to be primarily responsible for foot rot can also be spread by consumption of contaminated water (Ensley, 2001; Wright, 2007; Mulugeta & Wassie, 2013). This observation also corroborates findings of a study on Lake Nakuru National park which observed that raw sewage discharged into the park was a threat to wildlife due to enteric pathogens (Kotut *et al.*, 2011).

Plate 4.13: Livestock Grazing along Sosiani River between Huruma Effluent Treatment Plant and Huruma Dumpsite

CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary of Key Findings

Objective1: To characterize sources of pollution along Sosiani River

Anthropogenic activities contributing to impairment of water quality in Sosiani River were identified upstream as agrochemicals from Zena flower farm effluent. Midstream were: waste oils from Sukunanga carwash, storm water from county market of Eldoret, Eldoret Town carwash, preservatives from wood processing factories, Hospital waste from MTRH and St Lukes hospitals, industries like Eldoret Steel Mills and hotels, waste oil and discarded old batteries at Bandaptai motor vehicle garages, leachates from Huruma solid waste dump site and discharge from Huruma effluent treatment plant. They discharge varying types of pollutants into Sosiani River affecting water quality.

Objective 2: To determine Seasonal and Longitudinal variations in selected Physico-chemical properties of water quality in Sosiani River.

The physico-chemical properties of water quality varied significantly along Sosiani River and with changing seasons. The physico-chemical water parameters increase in concentration as more effluent is discharged midstream in town centre but decline 50Km downstream in Turbo town. Turbidity, total suspended solids, chemical oxygen demand and biological oxygen demand were above the NEMA standard guidelines while total dissolved substances were below NEMA standard guidelines.

Objective 3: To determine Seasonal and Longitudinal variations in selected heavy metals in Sosiani River

There was significant seasonal and longitudinal variation in the four selected heavy metals. The mean of cadmium was above NEMA standards but zinc, lead, and chromium were below the NEMA standard guidelines.

Objective 4: To determine seasonal and longitudinal variations in Total coliforms and *Escherichia coli* and prevalent waterborne diseases

There was significant seasonal and longitudinal variation in total coliforms and *E. coli*. The mean levels of *Escherichia coli* and total coliforms were above the NEMA guidelines of nil coliforms/100ml. The prevalent waterborne diseases in Eldoret are diarrhoea, dysentery and typhoid. The number of patients treated of these waterborne diseases did not vary significantly during the dry and wet seasons in all the hospitals except for typhoid cases in Huruma Sub-County Hospital.

5.2 Conclusions

i. Effluent discharge points located midstream of Sosiani River release various types of pollutants into Sosiani River which lead to changes in physico-chemical properties of water quality.
ii. This study accepts the hypothesis that there is significant difference in seasonal and longitudinal variations in selected physico-chemical properties of water quality along Sosiani River.
iii. Findings support the hypothesis that there is significant difference in longitudinal and seasonal variations in concentrations of the selected four heavy metals along Sosiani River.
iv. This study accepts the hypothesis that there is significant difference in longitudinal and seasonal variations in *Escherichia coli* and total coliforms along Sosiani River, but rejects the hypothesis that there is significant difference in prevalence of water borne diseases during the dry and wet season in Eldoret town.

5.3 Recommendations

i. The County government of Uasin Gishu, Water Resource Authority and National Environment Management Authority should compel the owners of facilities discharging effluent into Sosiani River to channel it into the sewer lines or buid constructed wetlands. Eldoret water and sanitation Company should construct wetlands for tertiary treatment of the waste water from Huruma sewage treatment plant discharged into Sosiani River and relocate Huruma dumpsite away from the banks of Sosiani River to reduce leachates draining into this river.
ii. The County government, Water Resources Authority and NEMA should regularly monitor effluent discharge and enhance enforcement of the waste water management regulations.
iii. The County government of Uasin Gishu and Eldoret Water and Sanitation Company should channel storm water from Eldoret town into Huruma effluent treatment works for treatment before it is released into Sosiani River.
iv. ELDOWAS should extend sewerlines or build pit latrines in residential areas in informal settlements along Sosiani River to reduce faecal pollution. Residents should

treat drinking water sourced from Sosiani River at household level owing to the high levels of total coliforms and *Escherichia coli*. The County government of Uasin Gishu County, NEMA, WRA, Public health and all stakeholders should enhance community awareness campaign to improve hygiene and sanitation practises in the area.

5.4 Areas for Further Research

Finally, this study proposes a number of areas for further research on Sosiani River:

i. Other heavy metals that were not analysed like mercury which is associated with medical waste from hospitals and dispensaries and copper which is associated with agrochemicals used in large scale farming of wheat, maize and flowers in the study area.
ii. Efficiency of Huruma sewage treatment plant to treat effluent from Eldoret town due to algae bloom and pea soup discharged into Sosiani River from this facility.
iii. Specific pathogens found in Sosiani River which are associated with the water borne diseases identified in the study area.
iv. Effect of effluent discharge and resultant water pollution in Sosiani River on aquatic fauna and flora.
v. Determine whether Sosiani River has self purifying capacity between Huruma dumpsite effluent discharge point in Eldoret town and 50km downstream in Turbo town or it is a dilution factor since many streams join this river downstream.

REFERENCES

Abraham, W. R., Macedo, A. J., Gomes, L. H., & Tavares, F. C.(2007). Occurrence and Resistance of Pathogenic Bacteria along Tiete River, downstream of São Paulo Brazil. *Brazilian Journal of Biology*, *35 (4),* 339–347.

Adekunle, A. S., & Eniola, I. T. K.(2008). Industrial Effluents and Water Quality of Asa River within an Industrial Estate in Ilorin, Nigeria. *New York Science Journal, 1*, 17–21.

Adriano, D. C.(2001). *Trace Elements in Terrestrial Environments: Biochemistry, Bio–availability and Risks of Metals*. New York: John Wiley and Sons.

Ahmed, S. & Ismail, S. (2018). Water Pollution and Its Sources, Effects and Management: A Case Study of Delhi, India. *International Journal of Current Advanced Research, 7 (2),* 10436–10442.

Akali, N. M., Nyongesa, N. D., Masinde, N. E., & Miima, J. B.(2011). Effluent Discharge by Mumias Sugar Company in Kenya: An Empirical Investigation of Pollution in Nzoia River. *Journal of Environmental Studies, 1*, 1–30.

Alavi, A. N., Mirzai, M., Sajaadi, S. A. A., & Alamolhoda, A. A.(2007). *Surveying Jagoroad River Self Purification*. Teheran: Institute of Water and Energy.

Al-Bayatti, K. A., Al-Arajy, K. H., & Al-Nuaemy, S. B.(2012). Bacteriological and Physico-Chemical Studies on Tigris River near the Water Purification Stations within Baghdad Province. *Journal of Environmental and Public Health, 2012*, 1–8.

Alhassan, H. E., & Ofori, P. K.(2016). Relationship between Physico-chemical Factors & Plankton Abundance in Bui Reservoir on Black Volta, Ghana. *African Journal of Ecology, 36 (2),* 147–154.

Alobaidy, A. M. J., Monhood, B. K., & Kadhem, A. J.(2010). Evaluating Raw and treated Water Quality of Tigris River in Baghdad by Index Analysis. *Journal of Water Resources and Protection, 2,* 629–635.

Aloyce, R.C., Nduguru, J., Mjema, P., & Katagira, F.(2001). *Water Hyacinth (Eichhornia crassipes) Management in Lake Victoria: Update on Infestation Levels*. Paper presented at Regional Scientific Conference on Water Hyacinth. LVMP, Kisumu, December 2001. Nairobi: ICRAF.

Alvarez, C. M. (2000). Nutrient Dynamics and Eutrophication Patterns in a Semi arid Wetland: The Effects of Fluctuating Hydrology. *Water Air and Soil Pollution, 131*, 97–103.

APHA, (2012). *Standard Methods for the Examination of Water and Wastewater* (22nd Ed.). Washington DC: American Public Health Association 1360 pp

Apostolis, K. M., Braungrardt, C. B., Acheterberg, E. P., Elbaz- Poulichat, F. & Morley, N. H. (2007). Metal Geochemistry in a Mine Polluted Estuarine System in Spain. *Applied Geochemistry, 18,* 1757–71.

Ashbolt, N. J. (2004). Microbial Contamination of Drinking Water and Disease Outcomes in Developing Countries. *Journal of Toxicology, 1*, 229–238.

Ashton, P. J., Love, D., Mahachi, H., & Dirks, P. H. G. (2001). *An Overview of the Impacts of Mining and Mineral Processing Operations on Water Resources and Water quality in the Zambezi, Limpopo and Olifants Catchment in Southern Africa*: Contract Report to the Mining Minerals and Sustainable Development Project South Africa January 2001. Harare: Zimbabwe University.

Ateba, B. H., Nougang, M. E., & Noah, E. O. (2012). Occurrence of Salmonella in Surface Waters of Yaounde, Cameroon. *Journal of Environmental Science & Water Resources, 1*, 243–250.

Atieno, R. N., Okemo, P. O., & Ombori, O. (2013). Isolation of high Antibiotic Resistant Faecal Bacteria Indicators, Salmonella and Vibrio Species from Raw Abattoir Sewage in Peri-Urban Locations of Nairobi Kenya. *Green Journal of Biological Science, 3 (5)*, 172–178.

Augustine, U., Babula, A., & Joniec, J. (2016). Microbiological Indicators of the Quality of River Water used for Drinking Water Supply. *Pollution Journal of Environmental Studies*, *25 (2*), 511- 519.

Aura, C. M., Raburu, P. O., & Hermann, J. (2010). Macroinvertebrate Community Structure in Rivers Kipkaren and Sosiani in Nzoia basin Kenya. *Conserving the Natural Environment, 3 (2),* 39–46.

Ayivor, J. S. & Gordon, C. (2012). Impact of Land Use on River Systems in Ghana. *West African Journal of Applied Ecology*, *20 (3),* 2012.

Baosheng, W., Zhaoyin, W. & Changzhi, L. (2004). Yellow River Basin Management and Current Issues. *Journal of Geographical Science, 14,* 29–37.

Bello, O. O., Osho, A., Bankole, S. A., & Bello, T. K.(2015). Bacteriological and Physicochemical Analyses of Borehole and Well Water Sources in Ijebu-Ode South-Western Nigeria. *International Journal of Pharmacy and Biological Science, 8,* 18–25.

Bowman, M. T., Keith, M. C., Reid, R. A., & Scott, L. D.(2006). Temporal Response of Stream Benthic Macroinvertebrate Community to the Synergistic Effects of Anthropogenic Acidification and Natural Drought Events. *Journal of Freshwater Biology, 57*, 768–782.

Bradley, P. & Yee, S. (2015). *Using the DPSIR Framework to Develop a Conceptual Model*. Narragansett, USA: EPA.

Bukhalama, A. C. (2010). *Assessment of Pollution Loads in River Nyando* (Unpublished MSC Thesis). Moi University: Eldoret, Kenya.

Burton, A. Jr., & Robert, P. (2001). *Storm Water Effects Handbook: A Toolbox for Watershed Managers, Scientists, and Engineers.* New York: Lewis.

Byamuka, D., Kansime, F., Mach, R. L. & Farantiler, A. H. (2000). Determination of *Escherichia coli* Contamination with Chromocult Coliform Agar in Tropical Waters of Kampala, Uganda. *Journal of Applied Environmental Microbiology, 66*, 864–868.

Campbell, I. C. (2009). *Mekong Biophysical Environment of An International River Basin.* New York: Elsevier.

Chandra, R., Singh, S., & Raj, A. (2006). Seasonal Bacteriological Analysis of Gola River Water contaminated with Pulp Paper Mill Waste in Uttaranchal, India. *Journal of Environmental Monitoring and Assessment, 118*, 393–406.

Chennakrishnan, C., Stephen, A., Manju, T., & Raveen, R. (2008). Water Quality Status of Three vulnerable Freshwater Lakes of Suburban Chennai India. *Chemical Biological and Physical Sciences*, *5*, 3355–3360.

Chepkiyeng, J., Odour, S. O., & Yasindi, A. W. (2010). Influence of Water Level Fluctuations on Physico-chemical Parameters Plankton Composition and Structure in Lake Nakuru. *Egerton Journal of Science and Technology, 10 (1),* 25–30.

Chibole, O. K. (2013). Modelling Sosiani River Water Quality to Assess Human Impact on Water Resources. *European Regional Centre for Eco-hydrology of Polish Academy of Sciences*, *13*, 241–245.

Ching, O., Smithson, P., & Michele, S. (2000). *Assessment of Sediment and Nutrients in River Nyando in improved Land Management in Lake Victoria Basin*. Final Technical Report, 2000, LVEMP, Kisumu. Nairobi: ICRAF.

Chioma, C. O., Ogechukwu, W. M., Onyekwere, B. C., Onyewenjo, S. C., Ozurumba, A.V., Nwaehiri, L.V., & Nwaguih, F. (2014). Impacts of Disposal of Hospital Waste into

Nworie River in Imo State Nigeria. *International Journal of Environmental Monitoring and Protection, 1 (1),* 7–11.

Clescerl, L. S, (2008). *Standard Methods for Examination of Water and Wastewater* (20th Ed). Washington DC: American Public Health Association.

Correll, D. L., Jordan, T. E., &Weller, D. E. (2001). Effects of Precipitation, Air, Temperature and Land Use on Organic Carbon Discharges from Rhode Island River Watersheds. *Water Air and Soil Pollution, 128*, 139–159.

Coulter, C. B., Kolka, R. K., & Thompson, J. A. (2004). Water Quality in Agricultural, Urban and Mixed Land use Watersheds. *Journal of the American Water Resources Association, 40 (6),* 1593–1601.

COWI Consulting Engineers, (2002). *Integrated Water Quality/Limnology Studies of Lake Victoria*: Lake Victoria Environmental Management Project II Technical Report 2002. Nairobi: LVEMP.

Crawford, P. (2000). *King: Story of a River*. Australia: Montpellier.

Cui, Y. J., Zhu, Y. G., & Zhai, R. H. (2004). Transfer of Metals from Soil to Vegetables in an Area near a Smelter in Nanning China. *Environment International, 30,* 785–791.

David, N. (2008). *Chemistry of The Environment.* New York: Checkmark books.

Davies, N. M., Weaver, V., Parks, K., & Lydy, M. J. (2003). Assessment of Water Quality, Physical Habitat and Biological Integrity of an Urban Stream in Wichita, Kansas Prior to Restoration Improvements. *Archives of Environmental Contamination and Toxicology, 4 (3)*, 351–359.

DEQ, (2013). *Impaired Waters Report*. Michigan: Department of Environmental Quality

Desai, J. S. (2012). Studies on Physico-Chemical and Microbiological Characteristic of potable Water used in different areas of Ahmadabad in Gujarat. *Der Chemica Sinica, 3,* 503–507.

Dittmar, J., Voegelin, A., Roberts, L., Huz, J. J., Saha, G. C., Ali, M. A..,... & Kretzschmar, R. (2007). Spatial Distribution & Temporal Variability of Arsenic in Irrigated Rice Fields in Bangladesh & West Bengal from shallow wells used for Irrigation of Boro Rice. *Journal of Environmental Science Technology, 4, (17),* 5967–72.

Edberg, S. C., Rice, E.W., Karlin, R. J., & Allen, M. J. (2000). *Escherichia coli* the best Biological Drinking Water Indicator for Public Health Protection. *Journal of Applied Microbiology, 23,* 251–260.

Edokpayi, J., Odiyo, J.O, Popoola, E. O., & Msagati, T. A. M. (2015). Evaluation of Microbiological and Physico–chemical Parameters of Alternative Sources of Drinking Water: A Case Study of Nzhelele River, South Africa. *Open Microbiology Journal, 12,* 18–27.

Edward, A. (2000). *Aquatic Pollution: An Introductory Text*. New York: John Wiley and Sons.

Efitre, J. E., Capnan, L. J. & Makanga, B. (2002). Inshore Benthic Macroinvertebrates of Lake Nabugabo Uganda: Seasonal and spatial patterns. *African Zoology, 23 (5),* 123–125.

Elisavet, A., Kalliopi, A., Eleni, T., Foteini, K., Olga, P., & Lazarus, T. (2007). Physico-chemical and Microbiological Characteristics of Potable Water supply sources in Kozani, Western Macedonia. *Desalination, 213,* 1–8.

Ensley, S. M. (2001). *The Relationship of Drinking Water Quality to Production and Reproduction in Dairy Herds* (Unpublished PhD dissertation). Iowa: Iowa State University.

Environmental Protection Agency, (2007). *The National Water Quality Inventory:* Report to Congress for the 2002 Reporting Cycle. Washington, DC: EPA.

European Commission, (2001). *Pollutants in Urban Waste Water and Sewage Sludge*: European Commission Report, 2001. London: European Commission

Evans, A. E. V., Hanjra, M. A., Jiang, Y., Qadir, M. & Dreschel, P. (2012). Water Quality assessment of the Current Situation in Asia. *International Journal of Water Resources Development, 28 (2),* 195–216.

Ezzat, A. (2002). *Survey of Nile River Pollution Sources*. Water Policy Programme Report No. 64, 2002: Addis Ababa, Ethiopia: Ministry of Water.

Flint Water Authority, (2016). *Flint Water Advisory Task Force Final Report March 2016*. Michigan: Flint Water Authority.

Forrow, D. M. & Maltby, L. (2000). Towards a Mechanistic Understanding of Contaminant Induced hanges in Detritus Processing in Streams: Direct and Indirect Effects on Detritivore Feeding. *Environmental Toxicology and Chemistry, 19,* 2100–2106.

Fritz, K. M., Evans, M.A., & Feminella, J. W. (2004). Factors Affecting Biomass Allocation in the Riverine Macrophyte. *Justica American Aquatic Botany, 78,* 279–288.

Fu Kaidao, D., He, D. M., & Lu, X. X. (2012). Pollution Assessment of Heavy Metals along the Mekong River and Dam Effects. *Geographical Sciences, 22,* 874–884.

Fuller, W.A. (2011). *Sampling Statistics*. New Jersey: John Willey and Sons.

Genevieve, M. C., & James, P. N. (2008). *Water Quality for Ecosystem and Human Health* (22nd Ed): United Nations Environment Programme, Global Environment Monitoring System (GEMS) / Water Programme. GEMS. Ontario, Canada: UNEP.

Gerardi, M. H. & Zimmerman, M. C. (2005). *Wastewater Pathogens*. New Jersey: John Wiley & Sons pp. 3–4.

Gichana, Z. M., Njiru, M., Raburu, P. O., & Masese, F. O. (2014). Effects of Human Activities on Microbial Water Quality in Nyangores Stream Mara River Basin Kenya. *International Journal of Scientific & Technology Research, 3 (2),* 153–157.

Gichuki, J., Omondi, R., Boera, P., Okorut, T., Matano, A. S., Jembe, T., Ofulla, A. (2012). Water Hyacinth (*Eichhornia crassipes*): Dynamics and Succession in the Nyanza Gulf of Lake Victoria: Implications for Water Quality and Biodiversity Conservation. *Scientific World Journal, 2012*, 106–116

Global Water for Sustainability Programme (GLOWS, 2007). *Water Quality Baseline Assessment Report, Mara River Basin, Kenya- Tanzania 2007*: Miami: Florida International University.

Goel, P. K. (2006). *Water Pollution: Causes, Effects and Control*. New Delhi, India: New Age International.

Government of Western Australia (GoWA) (2009). *Standard Operating Procedures for Water Sampling Methods and Analysis.* Sydney, Australia: Water Division.

Govindarajan, M. & Senthilnathan, T. (2014). Groundwater Quality and Health Impact Analysis in an Industrial Area. *International Journal of Current Microbiology and Applied Science, 3*, 1028–1034.

Hacioglu, N. & Dulgar, B. (2009). Monthly Variation of Some Physico-chemical and Microbiological Parameters in Biga Stream Turkey. *African Journal of Biotechnology, 8 (9*), 211–226.

Hadgu, L.T., Nyadawa, M. O., Mwangi, J. K., & Kibetu, P. M. (2014). Assessment of Pollution in Ndarugu River attributed to run-off and agro-industrial wastewater disposal. *Journal of Agricultural Science and Technology, 16 (2),* 134–140.

Hammer, M. J. & Hammer, M. J. Jnr. (2001). *Water and Wastewater Technology* (4th Ed). New Delhi, India: Asoke K. Ghosh, Prentice Hall.

Handa, C., Nderitu, G. G., Gichuki, N. N., & Oyieke, H. A. (2002). Assessment of Biodiversity and Buffering Capacity of Nyando Delta Kenya. *Field Study Report. Centre for Biodiversity*. Nairobi, Kenya: National Museums of Kenya.

Hogan, M. (2010). *Water Pollution Encyclopaedia of Earth* Topic ed. Mark McGinley Ed in Chief Cleveland, Washington DC: National Council on Science and the Environment.

Ikem, L., Chiu-Weu, C., Hopkins, W., Jackson, P. & Snodgrass, J. W. (2003). Distribution and Accumulation of Heavy Metals in the Sediments off Florida Coast USA. *Chemosphere, 102*, 13–19.

Jain, C. K., Bandyopadhyay, A., & Bhadra, A. (2010). Assessment of Groundwater Quality for Drinking Water Purposes in District Nainital, Uttarakhand, India. *Journal of Environmental Monitoring and Assessment, 166*, 663–676.

Jepkoech, J. (2013). *Selected Heavy Metals in Water and Sediments and their Bio-concentration in Plants* (Unpublished Msc Thesis). University of Eldoret: Eldoret.

Kaliff, J. (2002). *Limnology: Inland Water Ecosystems*. New Jersey: Prentice Hall Inc.

Kamanula, J. F., Zambasa, O. J., & Masamba, W. R. L. (2014). Quality of Drinking Water and Cholera Prevalence in Ndirande Township, City of Blantyre, Malawi. *Journal of Physical Chemistry and Earth Sciences, 21*, 72–75.

Karikari, A.Y. & Ansa-Asare, O. D. (2006). Physico-chemical & Microbial Water Quality Assessment of Densu River Ghana. *West African Journal of Applied Ecology, 10 (1),* 235–241.

Kasangaki, A., Chapman, L. J., & Balirwa, J. (2008). Land use and the Ecology of Benthic Macroinvertebrate Assemblages of high altitude Rainforest Streams in Uganda. *Freshwater Journal of Ecology, 53*, 681–697.

Kibichii, S., Shivoga, W. A., Muchiri, M. & Miller, S. N. (2007). Macroinvertebrate Assemblages along a Land Use Gradient in the Upper River Njoro Watershed of Lake Nakuru Drainage Basin, Kenya. *Lakes and Reservoirs Research and Management, 12*, 107–117.

Kilonzi, C. M., Moturi, W. N., Ogendi, G. M., Koech, H. K. & Maina, J. (2014). Spatio-temporal Variations in Physico-chemical Parameters and Coliform Levels of Domestic Water Sources in Njoro District Kenya. *Egerton Journal of Environment Natural Resource Management and Society, 10*, 11–23.

Kimani, M., Wambui, E., & Ngindu, A. M. (2007). Quality of Water the Slum Dwellers Use: The case of a Kenyan slum. *Journal of Urban Health, 84 (6),* 829–838.

King, R. S., Nunnery, K. T. & Richardson, C. J. (2000). Macroinvertebrate Assemblage Response to Highway Crossings in Forested Wetlands: Implications for Biological Assessment. *Wetland Ecology and Management, 8,* 243–256.

Kinuthia, G. K., Afolayan, F. I. D., Ngure, V., & Anjili, C. O. (2012). Selected Practices among Rural Residents Versus the Prevalence of Amoebiasis and Giardiasis in Njoro District, Kenya. *African Journal of Health Science, 20,* 11–20.

Kiruki, S., Limo, K. M., Njagi, E. N., & Paul, O. O. (2011). Bacteriological Quality and Diarrhoeagenic Pathogens in River Njoro and Nakuru Municipal Water, Kenya. *International Journal of Biotechnology and Molecular Biology, 2 (9),* 150–162.

Koech, W. K. (2003). *Assessment of Water Quality Parameters and Concentrations of Selected Metals in Dionsoyeyiet River in Kericho Municipality* (Unpublished MSc Thesis). Moi University: Eldoret, Kenya.

Kolawole, O. M., Ajayi, K. T., Olayemi, A. B. & Okoh, A. I. (2011). Assessment of Water Quality in Asa River, Nigeria and its Indigenous *Clarias gariepinus* Fish. *International Journal of Environmental Resources and Public Health, 8 (11*), 4332–4352.

Kotut, K., Okemo, P., & Ngari, M. (2011). Potential Threat to Wildlife Posed by Enteric Pathogens from Nakuru Sewage Treatment Plant. *African Journal of Health Sciences, 18,* 85–95.

Kouadio, I. & Trefy, J. H. (2007). Sediment Trace Metal Contamination in Ivory Coast, West Africa. *Water Air and Soil Pollution Journal, 30,* 145–54.

Kudret, E. & Ilker, M. (2011). Water *Quality: Physical Chemical and Biological Characteristics*. Washington DC: Nova.

Laird, A. (2011). *Case Study Tailing Treatment at King River Delta Tasmania Australia*: Viro - Mine Technology Project Report April 2011. Tasmania, Australia: West Coast Council.

Lake Victoria Environment Management Project (LVEMP, 2003). *Lake Victoria Environment Management Project Phase I: Revised Draft Progress Report LVEMP 1 and Challenges for the Future*. Washington DC: World Bank.

Liang, J. L., Dziuban, E. J., Craun, G. F., Hill, V., Moore, M. R., & Gelting, R. J. (2006). Surveillance of Water Related Diseases and outbreaks associated with Drinking Water and Water that is not intended for Drinking in the United States of America, 2003–2004. In: *Morbidity and Mortality Weekly Report*. Atlanta: Centre for Disease Control and Prevention.

Long, S. C., & Plummer, J. D. (2004). Assessing Land Use Impacts on Water Quality Using Microbial Source Tracking. *Journal of the American Resources Association, 40 (6),* 1433-1448.

Luoma, S. N. & Rainbow, P. S. (2008). *Metal contamination in Aquatic Environment Science and Lateral Management*. Cambridge: Cambridge University Press.

MacDonald, M. & M & E Associates (2001). *Management of Industrial and Municipal Effluent and Urban Run off in the Lake Victoria Basin*. Final Report February 2001, LVEMP Progress Report. Cambridge, United Kingdom: Cambridge Press.

Maduka, H. C. C. (2004). *Water Pollution and Man's Health in Environmental Degradation, Reclamation, Conservation and Pollution Control for the Rural Women and the Youths*. Ado Ekiti, Nigeria: Green Line Publishers.

Mahyar, S., Ting, L. S., Houng, L. Y., Lim, S. K., Tahir, R., Adnan, F. A.,...... & Shah, M. D. (2012). Urban Effluent Discharge into Rivers: A Forensic Chemistry Approach to Evaluate Environmental Deterioration. *World Applied Sciences Journal, 20 (9),* 1227–1235.

Maina, C. W., Mutua, B. M., Oduor, S. O. & Randa, J. M. (2010). Water Quality and Self Purification Ability of Njoro River. *Egerton Journal of Science and Technology, 10,* 123–138.

Mallin, M. A., Williams, K. E., & Cartier, E. E. (2000). Effect of Human Development on Bacteriological Water Quality in Coastal Watersheds. *Ecological Applications, 10 (4),* 1047–1056.

Marimba, F. O. (2003). *Heavy Metal Concentrations in Water from Sosiani River in River Nzoia Basin.* Proceedings of Kenyatta University Conference on Water quality, April 2003, Nairobi, Kenya: Kenyatta University.

Marinez, S., Pinto, F. G. S., Fruet, T. K., Piana, P. A., & Moura, A. C. (2014). Water Quality Indicators for Environmental and Resistance Profile of *E. coli* Strains isolated in Rio Cascavel Parana Brazil. *Journal Engenharia Agricola, 34 (2),* 185–192.

Marshall, S. (2011). The Water Crisis in Kenya: Causes, Effects and Solutions. *Global Majority Environment Journal, 2 (2),* 31–45.

Masese, F. O., Muchiri, M., & Raburu, P. O. (2009). Macroinvertebrate Assemblage as Biological Indictors of Water quality in Moiben River Kenya. *African Journal of Aquatic Science, 34,* 15–26.

Mbaka, J. G., M'Erimba, C. M., Thiomo, H. K., & Mathoko, J. M. (2014) . Water and Habitat Quality Assessment in Honi and Naro Moru Rivers Kenya using Benthic Macroinvertebrate Assemblages and Qualitative Habitat Scores. *Agricultural Journal of Aquatic Science, 39 (4*), 385–392.

Mbuligwe, S. E. & Kaseva, M. E. (2005). Pollution and Self Cleansing Ability of an Urban River in a Developing Country: A Case Study of Dar Es Salaam, Tanzania. *Journal of Environmental Management, 36 (2),* 328–342.

McKinney, M. L. & Schoch, R. (2003). *Environmental Science Systems*. Burlington: Jones and Barlett.

Meays, C. L., Broersma, K., & Nordin, N. (2004). Source Tracking: Faecal Bacteria in Water: A Critical Review of Current Methods. *Journal of Environmental Management*, *73 (1),* 71–79.

Medema, G. J., Shaw, S., Waite, M., Snozzi, M., Morreau, A., & Grabow, W. (2003). Catchment Characterization and Source Water quality: In Dufour, A., Snozzi, M., Koster, W. (Eds). *Assessing Microbial Safety of drinking Water: Improving Approaches and Methods*. London: OECD, 111–158.

Mehaffey, M. H., Nash, M. S., & Wade, T. G. (2005). Linking Land Cover and Water Quality in New York City Water Supply Watersheds. *Environment Monitoring and Assessment*, *107*, 29–44.

Michael, E. G. & Douglas, E. J. (2004). *Statistical Tools for Environmental Quality Assessment.* New York: John Wiley and Sons.

Mishra, A. & Bhatt, V. (2008). Physico-chemical and Microbiological analysis of Underground Water in Nagar and nearby Places of Anand District, Gujarat, India. *Environmental Journal of Chemistry*, *5,* 487–492.

Mishra, A., Vasishta, D. B., Nirav, S., Pinal, S., Kirit, P. & Chaitanya, P. (2010). Comparative Study of Physico-Chemical and Microbial Parameters on Lotic and Groundwater in selected outlying Areas of Central Gujarat. *Journal of Chemistry and Pharmaceutical Research, 2,* 174–177.

Mohammed, F. A., & Gag, N. S. (2009). Environmental Pollution Induced Biochemical Changes in Tissues of *Tilapia zillii*, *Solea vulgaris* and *Mugil capito* from Lake Qarun, Egypt. *Global Veterinary Journal*, *2*, 327–336.

Moncheva, S. & Doncheva, V. (2009). *Application of DPSIR Indicator Model: A Conceptual Framework Towards Sustainable Development of the Bulgarian Black Sea Region*. Varna, Bulgaria: Institute of Oceanography.

Mosley, L., Sarabjeet, S., & Aalbersberg, B. (2004). *Water Quality Monitoring in Pacific Island Countries: Handbook for Water Quality Managers, Laboratories, Public Health Officers and Water Engineers*. Fiji Islands: University of the South Pacific Suva.

Moyo, N. A. G. (2013). Analysis of Chemical and Microbiological Quality of Groundwater from Boreholes and Shallow Wells in Zimbabwe. *Journal of Physics and Chemistry of the Earth*, *66*, 27–32.

Muchukuri, K. N., Ogendi, G. M., & Moturi, W. N. (2014). Influence of Anthropogenic activities on Microbial Quality of Surface Water in Subukia Town. *Egerton Journal of Environment Natural Resources Management and Society, 10*, 1–10.

Mugenda, O. M. & Mugenda, A. G. (2003). *Research Methods: Quantitative and Qualitative Approaches* (2nd Ed). Nairobi, Kenya: ACTS Press.

Mulugeta, Y., & Wassie, M. (2013). Prevalence, Risk factors and Major Bacterial causes of Bovine Mastitis in Wolaita Sodo, Southern Ethiopia. *African Journal of Microbiological Research, 7 (48),* 5400–5405.

Musyoki, A. M., Mbaruk, A. S., Mbithi, J. N., & Maingi, J. M. (2013). Water Related Bacteria Pathogens in Surface Waters of Nairobi River and Health Implications to Community downstream Athi River: *Life Science and Pharmaceutical Research, 3 (1),* 4–10.

Mwamburi, J. (2003). Variations in Trace Elements in bottom Sediments of Major Rivers in Lake Victoria Basin. *Lake Reservoir Research and Management, 8 (2),* 5–13.

Mwangi, J. W., Muthakia, G. K., Onindo, C. O., Nyamboka, H., & Ngila, J. C. (2014). Determination of Copper in Kamiti River along Coffee Farms in Kiambu County, Kenya. *Journal of Agricultural Science and Technology, 16 (2),* 195–202.

Nabulo, G., Origa, H. O., Nasinyama, G. W. & Cole, D. (2008). Assessment of Zinc, Copper, Lead, & Nickel contamination in Wetland Soils and Plants in Lake Victoria Basin. *International Journal of Environmental Science and Technology, 5 (1),* 24–29.

Nadia, M. A. (2006). *Study on Effluents from Selected Sugar Mills in Pakistan: Potential Environmental, Health, and Economic Consequences of an Excessive Pollution Load*. Islamabad, Pakistan: Sustainable Development Policy Institute.

Nazir, R., Khan, M., Masab, M., Rehman, H., Rauf, N., Shahab, S., …..Shaheen, Z. (2015). Accumulation of Heavy Metals in Soil Water and Plants and Analysis of Physico-chemical Parameters of Soil and Water Collected from Tanda Dam Kohat. *Journal of Pharmaceutical Sciences and Research, 7 (3*), 89– 97.

Ndaruga, A. M., Ndiritu, G. G., Gichuki, N. N., & Wamichwa, N. (2004). Impact of Water Quality Changes on Riverine Macroinvertebrate Assemblages along a Tropical Stream in Kenya. *African Journal of Ecology, 43*, 208–216.

Nelson, E. J. & Booth, D. B. (2002). Sediment Sources in an Urban Mixed Land-Use Watershed. *Journal of Hydrology, 264 (4),* 51–68.

NEMA, (2006). *Environmental Management and Coordination Act*: *Waste and Water Quality Management Regulations*. Nairobi, Kenya: Government Printers.

Niba, R. N. & Chrysanthus, N. (2013). Bacteriological Analysis of Well Water Sources in the Bambui Students Residential Area. *Journal of Water Resource Protection*, *5*, 1013–1017.

Njiru, M., Kazungu, J., Ngugu, C. C., Gichuki, J., & Muhozi, L. (2008). Overview of Current Status of Lake Victoria Fishery: Opportunities Challenges and Management Strategies. *Lakes Reserve Resources Management Journal, 13*, 1–12.

Nkechinyere, O. N. (2006). Seasonal Variations in Phytoplankton Populations in Ogulebe Lake: A Small Natural West African Lake. *Lake and Reservoir Research Management, 11*, 63–72.

Obasohan, E. E., Agbonlador, D. E., & Obano, E. E. (2010). Water Pollution: A Review of Microbial Quality and Health Concerns of Water, Sediments and Fish in the Aquatic System. *African Journal of Biotechnology, 9 (4*), 423–427.

Ochieng, E. O. (2007). *Limnological Aspects and Trace Element Analysis in Kenya's Natural Inland Waters* (Unpublished Msc Thesis). University of Nairobi: Nairobi Kenya.

Odinga, C. A. (2009). *Macroinvertebrates as Bioindicators of Water quality in Sosiani River* (Unpublished Msc Thesis). Moi University: Eldoret, Kenya.

Ogwueleka, T. C. (2012). Assessment of water quality and Identification of pollution Sources along Kadura River in Niger, Nigeria. *Water and Environment, 28 (1),* 31–37.

Ohowa, B. O. (2000). Seasonal Variations of Nutrient fluxes into the Indian Ocean from Sabaki River Kenya. *Discovery and Innovation Journal*, *8 (3)*, 257–260.

Oladiji, A.T., Adeyemi, O., & Abiola, O. O. (2004). Toxicological Evaluation of Surface Water of Amilegbe River using Rats. *Society Experimental Biology and Biochemistry Journal*, *16*, 94–101.

Omezuruike, O. I., Damilola, A. O., Adeola, A. O., Enobong, A., & Olufunke, S. (2008). Microbiological & Physicochemical Analysis of different Water Samples for Domestic purposes in Abeokuta & Ojota, Lagos, Nigeria. *Journal of African Biotechnology, 26, (4),* 265–272.

Omutange, E. S. (2010). *Spatial Distribution of Metals along Agro-industrial Effluent Sites in the Riparian of River Nzoia* (Unpublished doctoral dissertation). Moi University: Eldoret, Kenya.

Ontumbi, G., Obanio, J., & Ondieki, C. (2015). Influence of Agricultural Activities on Water Quality of Sosiani River in Uasin Gishu County. *International Journal of Resources in Agriculture Science*, *2 (1),* 34–40.

Onyango, D. M., & Angienda, P. O. (2010). Epidemiology of Water Related Diarrhoeal Diseases among Children aged 6-36 months old in Busia, Western Kenya. *International Journal of Biological and Life Sciences, 6 (2),* 92–99.

Ordinioha, B. (2013). Human Health Implication of Crude Oil Spillage in the Niger Delta. *Nigerian Medical Journal*, *54 (1),* 28–32.

Orwa, P. O., Raburu, P. O., Ngodhe, S. O., & Kipkorir, R. (2014). Impacts of Human activities on Macroinvertebrate Community Structure along Chepkoilel River Kenya. *International Journal of Water Resources and Environmental Engineering, 6 (10),* 253–262.

Osano, A., Cheruiyot, L., Chacha, J., Maghanga, J. & Maera, J. (2009). Role of Organic Nutrient Levels on the Distribution of Macroinvertebrates: A Case Study of Sosiani River, Eldoret Town, Kenya. *Agriculture, Pure and Applied Science and Technology, 4*, 2–38.

Pacyna, J. (2005). Sources and Emissions: In Symon, C., & Wilson, S. J. (Eds). *Heavy Metals in the Arctic*. Oslo, Norway: Arctic Monitoring and Assessment Programme.

Palamuleni, L. & Akoth, M. (2015). Physico - Chemical and Microbial Analysis of Selected Borehole Water in Mahikeng, South Africa. *International Journal of Environmental Research and Public Health, 12*, 8619–8630.

Panizzon, J. P., Macedo, V. R., Machado, V. & Fruza, L. M. (2013). Microbiological & Physico - chemical Water quality of the Rice Fields in Sonos River Basin, Brazil. *Journal of Environment Monitoring Assessment, 185 (3),* 2767–75.

Parihar, S. S., Kumar, A., Gupta, R. N., Pathak, M., Shrivastav, A. & Pandey, A. C. (2012). Physico-Chemical and Microbiological Analysis of Underground Water in and around Gwalior City, India. *Resource Journal of Recorded Science, 1*, 62–65.

Patil, S. G., Chonde, S. G., Jadhav, A. S. & Raut, P. D. (2012). Impacts of Physico-Chemical Characteristics of Shivaji University Lakes on Phytoplankton Communities, Kolhapur, India. *Resource Journal of Recorded Science, 1*, 56–60.

Perry, R. H., Green, D. W., & Maloney, J. O., (2007). *Perry's Chemical Engineers' Handbook* (7th Ed). New York: McGraw-Hill.

Pimentel, D., Houser, J., Preiss, E., & Omar, W. (2004). *Water Resources, Agriculture and the Environment Report*. Cornell University College of Agriculture and Life Sciences.

Prasai, T. (2007). *Microbial Analysis of Drinking Water for Kathmandu Valley Nepal*. Nepal: Academy of Science and Technology.

Prescott, L. M. (2002*). Introduction to Microbiology* (5th Ed). New York: McGraw-Hill.

Raburu, P. O. (2003). *Water Quality and Status of Aquatic Macroinvertebrates and Ichthyofauna in River Nyando Kenya* (Unpublished doctoral dissertation). Moi University: Eldoret, Kenya.

Reche, M. A., Machedo, V., Saul, D. A., Maledo, V. R., Marcolin, E., Knaak, N. & Fiuza, L. M. (2016). Microbial Physical and Chemical Properties of Irrigation Water in Rice Fields of Southern Brazil. *Journal Academia Bras Cienc, 88(1),* 361–75.

Reynolds, K. A., Mena, K. D. & Gerba, C. P. (2008). Risk of Water Related Illnesses via Drinking Water in the United States. *Environmental Contamination & Toxicology, 192,* 117–158.

Rinella, D. J. & Feminella, J.W. (2005). Comparison of Benthic Macro-invertebrates Colonizing Sand, Wood and Artificial Substrates in a Low Gradient Stream. *Journal of Freshwater Ecology, 20,* 209–220.

Roig, N., Sierra, J., Nadal, M., Moreno-Garrido, I., Nieto, E., Hampel, M., ... & Blasco, J. (2015). Assessment of Sediment Ecotoxicological Status as a Complementary Tool for Evaluation of Surface Water Quality, Ebro River Basin North- East Spain. *Journal of Science Total Environment, 15,* 269–78.

RoK, (2005). *Kenya Water Report*: Ministry of Water and Irrigation. Nairobi: Government Printers.

RoK, (2008). *Strategic Plan 2009–2012: Ministry of Water and Irrigation*. Nairobi: Government Printers.

RoK, (2009). *State of Environment Report: Uasin Gishu District*. Nairobi: Government Printers.

RoK, (2013). *Uasin Gishu County Development Profile*. Nairobi: Government Printers.

Roulet, M., Lucotte, M., Canuel, R., & Farella, N. (2001). Spatio-temporal Geochemistry of Mercury in Waters of the Tapajos and Amazon Rivers, Brazil. *Limnology and Oceanography, 46*, 1141–1157.

Salequzzaman, M. A., Islam, S. M. T., Tasnuva, A., Kashem, M. A. & Masud, M. M. (2008). Environmental Impact of Sugar Industry: Case Studies on Kushtia, Western Bangladesh. *Journal of Chemical Biological and Physical Sciences, 2*, 633–638.

Schoonover, J. E., Lockaby, B. G, & Shufen, P. (2005). Changes in Chemical and Physical Properties of Stream Water Across an Urban-Rural Gradient in Western Georgia. *Urban Ecosystems*, *8*, 107–124.

Scott, N. (2004). The Artificial Nile: The Aswan High Dam Destroyed a Fishery but Human Activities may have Revived it. *American Scientist*, *92*, 158–166.

Serpa, D., Keizer, J. J., Cassidy, J., Cuco, A., Silva, V., Gonclaves, F.,... & Abrantes, N. (2014). Assessment of River Water Quality Using an Integrated Physical Chemical Biological and Ecotoxicological Approach. *Environment Science progress Impacts, 16 (6)*, 1434–44.

Seth, O. N., Tagbor, T. A., & Bernard, O. (2014). Assessment of Chemical Quality of Groundwater Over some Rock types in Ashanti Region, Ghana. *American Journal of Science and Industrial Research, 5*, 1–6.

Sewe, P. O. (2009). *Textile Wastewater Treatment and Management in Eldoret* (Unpublished Msc Thesis). Moi University: Eldoret, Kenya.

Sharma, R., & Capoor, A. (2010). Seasonal Variations in Physical, Chemical and Biological Parameters of Lake Water of Patna Bird Sanctuary in Relation to Fish Productivity. *World Applied Sciences Journal, 8 (1*), 129–132.

Shaw, E. (2004). *Hydrology in Practice*. London, England: Stanley Thornes Publishers.

Shittu, O. B., Olaitan, J. O. & Amusa, T. S. (2008). Physico-chemical and Bacteriological Analyses of Water used for Drinking and Swimming Purposes in Abeokuta, Nigeria. *African Journal of Biomedical Research*, *11*, 285–290.

Shrivastava, N., Mishra, D. D., Mishra, P. K., & Bajpai, A. (2013). Water Quality Deterioration of Machna River attributed to Sewage Disposal, Betul, Madhya, Pradesh, India. *Journal of Environment and Earth Science, 3*, 1–5.

Shyamala, R., Shanthi, M. & Lalitha, P. (2009). Physicochemical Analysis of Borehole Water Samples of Telungupalayam Area in Coimbatore District, Tamil Nadu, India. *Journal of Chemistry*, *5*, 924–929.

Smith, D. G. & Davies-Colley, R. J. (2001). *If Visual Water Clarity is the Issue, Why Not Measure it?* New York: National Institute of Water and Atmospheric Research.

Sundar, S. B. & Nirmala, J. K. (2015). Case Study on Physico-chemical Properties of Groundwater in ID- Rollaram Industrial area Hydorabad India during 2010 Monsoon and 2013 summer. *American Journal of Microbiology Research*, *4*, 482–490.

Suthar, S., Singh, S., Sheoran, A., Garima, M. & Jai, S. (2012). Physical Chemical and Microbiological Characteristics of Water in Different Sites in Pali District, Rajasthan India. *Journal of Chemical Biological and Physical Sciences, 2*, 1061–1066.

Tabor, M., Kibret, M., & Bayeh, A. (2011). Bacteriological and Physico-chemical Quality of Drinking Water, Hygiene and Sanitation Practises of the Consumers in Bahir Dar City Ethiopia. *Ethiopian Journal of Health Science, 21 (1*), 19–26

Tahmasebi, S., Afkhami, M., & Takdastan, A. (2012). Study of Chemical Physical and Microbial Water Quality of Gargar River South West Iran, using NSF Water Quality Index. *Jundishapur Journal of Health Sciences, 3(1),* 62–72.

Tamil, T., Lias, K., Hanif, H. F., Norsila, D., Aesych, A., & Kamaruzzaman, B.Y. (2014). The Spatial Variability of Heavy Metal Concentration and Sedimentary Organic Matter in Estuary Sediment of Sungai, Malaysia. *Science Post, 1 (1),* 1–6.

Tariq, M., Ali, M., & Shah, Z. (2006). *Characteristics of Industrial Effluents and their Possible Impacts on Quality of Underground Water*. Peshawar, Pakistan: Soil Science Society of Pakistan.

Thivya, C., Chidambaram, S., Thilagavathi, R., Nepolian, M., & Adithya, V. S. (2014). Evaluation of Drinking Water Quality Index and its Seasonal Variations in hard Rock Aquifers of Madurai District, Tamil Nadu, India. *International Journal of Advanced Geosciences*, *2*, 48–52.

Thophon, S., Kruatrachue, M., Upathan, E. S., Pokethitiyook, P., Sahaphong, S., & Jarikhuan, S (2003). Histopathological Alterations of White Sea Bass, *Lates calcariferous* in Acute and Subchronic Cadmium Exposure. *Journal of Environmental Pollution, 121*, 307–320.

Tiwari, S. K. & Jenkins, M. W. (2008). Point of use Treatment Options for Improving Household Water Quality among Rural Populations in the Njoro River Watershed, Kenya. *Research Brief for Global Livestock Collaborative Research Support Programme April 2008*. Nairobi, Kenya: Global Livestock Collaborative Research Programme.

Tole, M. P., & Shitsama, J. (2003). *Concentration of Heavy Metals in Water, Fish and Sediments of the Winam Gulf, Lake Victoria Kenya*: Proceedings of the Climate- Food web Biodiversity and Integrated Management Conference 4–7 December 2003. Arusha, Tanzania: LVEMP.

Trivede, P., Bajpai, A., & Thareja, S. (2010). Comparative Study of Seasonal Variations in Physico-chemical Characteristics of Drinking Water quality in Kanpur, India. *Journal of Natural Science, 8*, 11–17.

Tubatsi, G., Bonyongo, M. C., & Gondwe, M. (2014). Water Quality Dynamics in the Roro-Thamalakane-Boteti River System Northern Botswana. *Agricultural Journal of Aquatic Science, 39 (4)*, 351–360.

Ulmgren, P. (2001). *Encyclopaedia of Industrial Chemistry*. New Jersey: John Wiley and Sons.

UN, (2003). *Water for People, Water for Life*: A Joint Report by the 23 UN Agencies on Freshwater, UN World Water Development Report at the 3rd World Water Forum in Kyoto Japan March 2003. Kyoto Japan: UNESCO, Berghahn.

UNEP, (2011). Water Issues in the Democratic Republic of Congo: Challenges and Opportunities: *Technical Report on Post-conflict Environmental Assessment of the Democratic Republic of Congo June 2011*. Nairobi, Kenya: UNEP.

UN-WATER/WWAP, (2006). *Kenya National Water Development Report: A Shared Responsibility*. Technical Report for the 2nd UN World Water Assessment Programme, UNESCO May 2006. Nairobi, Kenya: Government Printers.

Vaishali, P. & Punita, P. (2013). Assessment of Seasonal Variations in Water Quality of River Mini, Sindhrot, Vadodara India. *International Journal of Environmental Science, 3*, 1424–1436.

Van Vuuren, L. (2013). Institutional Conundrum Sinking Groundwater Supply in North West Town. *Water Wheel*, *12*, 17–19.

Vanloon, G. W. & Duffy, S. J. (2005). *Environmental Chemistry: A Global Perspective* (22nd Ed). Wiltshire: Antony Rowe.

Vannotte, R. L., Minshall, G.W., Cummins, K.W., Sedell, J. R., C. E. Gushing (1980). The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Science*, *37*, 130–137.

Varshney, C. K. (2008). *Water Pollution and Management* (2nd Ed). New Delhi, India: New Age International.

Volk, C., Larry, W. & Bruce, J. (2002). Monitoring Dissolved Organic Carbon in Surface and Drinking Waters. *Journal of Environmental Monitoring*, *4*, 43–47.

Vyas, V. G., Hassan, M. M., Vindhani, S. I., Parmar, H. J., & Rhalani, V. M. (2015). Physico-chemical and Microbiological Assessment of Drinking Water from Different Sources in Junagah City India. *American Journal of Microbiological Research*, *3 (4),* 148–154.

Waithaka, P. N., Maingi, S. M., & Nyamache, A. K. (2015). Physico-chemical Analysis, Microbial Isolation Sensitivity Test of the Isolates and Solar Disinfection of Water Running in Community Taps and River Kandutura in Nakuru South Sub-County Kenya. *Open Microbiology Journal, 9(1),* 56–63.

Wang, L., & Lyons, J. (2003). Fish and Benthic Macroinvertebrate Assemblage as Indicators of Stream Degradation in Urban Watersheds: In Simon, T.P. (Ed) *Biological Response Signatures: Indicator Patterns Using Aquatic Communities*. Boca Raton: CRC Printers.

Warner, N. R., Levy, J., Harpp, K., & Farrugia, F. (2007). Microbial Analysis of Drinking Water Quality in Kathmandu Valley Nepal. *Journal of Chemical Biological and Physical Sciences, 2*, 1020–124.

Wei, J. (2007). A Framework for Selecting Indicators to Assess the Sustainable Development of Natural Heritage Sites. *Journal of Mountain Science*, *4*, 321–330.

Wetzel, R. G. (2001). *Limnology, Lake and River Ecosystems* (3rd Ed). Cambridge: Cambridge Academic Press.

WHO & UNICEF, (2010). *Sanitation and Drinking Water in 2010: A Joint Monitoring Programme for Water Supply and Sanitation*. World Health Organization Progress Report March 2010. Geneva, Switzerland: WHO.

WHO & UNICEF, (2013). Progress on Sanitation and Drinking Water Update. *World Health Organization Report*. Geneva, Switzerland: WHO.

WHO, (2011). *Guidelines for Drinking Water Quality* (4th Ed). Geneva, Switzerland: WHO.

WHO, (2016). *The Situation of Water Related Infection Diseases in the Pan-European Region*. World Health Organization Report, August 2016. Geneva, Switzerland: WHO.

WHO, (2017). *Progress on Drinking Water Sanitation and Hygiene by 2015*. World Health Organization Report. Geneva, Switzerland: WHO.

Woitke, P. (2003). Analysis and Assessment of Heavy Metal Pollution in Suspended Solids and Sediments of River Danube. *Chemosphere, 51*, 633–642.

Wright, C. L. (2007). Management of Water Quality for Beef Cattle, Veterinary Clinics of North America. *Food Animal Practice, 23,* 91–103.

Water Resource Authority (2010). *Water Resource Authority Annual Report 2010*. Nairobi: Government Printers.

Yillia, P. T., Kreuzinger, N., Mathoko, J. M. & Ndomahina, E.T. (2009). Microbial Risk Assessment with the QAEL approach at Water Abstraction Points in Rural Kenya. *Journal of Physics and Chemistry of the Earth, 34 (13)*, 790–798.

Yolanda, M. & Zayas, Z. P. (2007). Water Sampling: Traditional Methods and New Approaches in Water Sampling Strategy. *Trends in Analytical Chemistry*, *26*, 986–991.

Zheng, N. (2007). Population Health Risk attributed to Dietary intake of Heavy Metals in the Industrial Area of Huludao City, China. *Science of the Total Environment*, *387*, 96–104.

APPENDICES

Appendix I: Water Quality Standard Guidelines by NEMA WHO and WASREB

Water Quality	NEMA Guidelines	WHO Guidelines	WASREB
BOD in mg/L	30	No guideline (use 4mg/L)	None
COD in mg/L	50	No guideline	None
Dissolved Oxygen mg/L	4	4	4
E. coli in CFU/100ml	Nil	Nil	Nil
pH in pH Units	6.5- 8.5	No guideline	6.5-8.5
TDS in mg/L	1200	No guideline (use 1000 in general)	1500
Temperature ºC	30	No guideline	None
TSS in mg/L	30	No guideline (Use 600 in general)	Nil
Turbidity in NTU	50	No guideline	5
Zinc in mg/L	1.5	3	5
Cadmium in mg/L	0.01	0.03	0.005
Chromium in mg/L	0.05	0.05	0.05
Lead in mg/L	0.01	0.01	0.05

Source: NEMA, 2006; WHO, 2011; WASREB 2016

Appendix II: NEMA Water Quality Standards for Various Uses

Water Parameter	Recreation Water	Irrigation Water	Drinking Water	Discharge in Public water
Arsenic in mg/L	0.05	0.1	0.01	0.02
Faecal Coliforms in CFU/100mL	500	Nil	Nil	Nil
Cadmium in mg/L	0.01	0.5	0.01	0.01
Chromium in mg/L	0.1	1.5	-	0.05
Turbidity in mg/L	50	-	-	-
pH in pH Units	6-9	6.5- 8.5	6.5- 8.5	-
Temperature in ^{0}C	30	-	-	-
TDS in mg/L	-	1200	1200	1200
TSS in mg/L	-	-	30	-
Lead in mg/L	-	-	0.05	0.01
Zinc in mg/L	-	-	1.5	0.5
BOD in mg/L	-	-	-	30
COD in mg/L	-	-	-	50

Source: NEMA, 2006

Appendix III: Questionnaire for Household Survey in Eldoret Township

1. Background Information

(I) Household number--

Gender (1) male ☐ (2) female ☐ Number of members in the household---
----

Estate---

Position on the river: (1). Upstream ☐ (2). Midstream ☐ (3).Downstream ☐

(ii) Level of Education: (1). Primary level ☐ (2). Secondary level ☐

(3). College level ☐ (4). None ☐

(iii) Occupation: (1). Employed ☐ (2) Unemployed ☐ (3) Businessman ☐

(4) Farmer ☐ (5) others please specify---

(IV) What is your main source of drinking water? (1) Borehole ☐ (2) Sosiani ☐
(3) Rainwater ☐ (4) ELDOWAS ☐
(5) others ---

(V) Do you use raw water from Sosiani River for drinking purposes? (1) Yes ☐ (2) No ☐

(VI) If not state why?---

(VI). If yes does raw water from Sosiani River affect your health? (1).Yes ☐ (2) No ☐

(VII). If yes what health effects have you observed? --

(VIII). Do you treat your drinking water if sourced from Sosiani River?

(1) Yes ☐ (2) No ☐

(IX). If yes how do you treat your drinking water?

(1). Boiling ☐ (2). Chemicals like chlorine ☐ (3).None ☐

(4).others specify --

(X) Do you water your animals in Sosiani River? 1. Yes ☐ 2. No ☐

(XI). If yes does the raw water from Sosiani River affect the health of your livestock health?

(1). Yes ☐ (2). No ☐

(XII).If yes, what are the effects on the health of Livestock? --
----
--------.---

(XIII) Is Sosiani River an important source of fish for the residents? (1). Yes ☐(2). No ☐

(XIV). Have there been any incidences of death of fish in this river?

(1) Yes ☐ (2) No ☐

(XV). If yes what was the main cause of the death of fish? ---
----

(XVI). Are water related diseases common in Eldoret (1). Yes ☐(2). No. ☐

(XVII) If yes what are the common water related diseases in Eldoret municipality--------------
----

(XVIII) Rank the following water related diseases in terms of the commonest on a scale of 1-10 (where 1 is Rare and 10 is most common)

Common Water Related Diseases in Eldoret	**Rank Score**
Diarrhoea	
Dysentery	
Cholera	
Typhoid fever	
Meningitis	
Hepatitis	
Respiratory diseases,	
Poliomyelitis,	

Appendix IV: Checklist for Key Informants

(WRMA, ELDOWAS, NEMA, Public Health, Fisheries, Veterinary departments and Schools**)**

1.Name of institution---
----

2. Key mandate---

3.What is the main source of drinking water for residents of Eldoret Municipality?-------------
----

----

4. Is water from Sosiani River used for domestic consumption? (1)Yes ☐ (2) No ☐

5. If yes, what volume of water does ELDOWAS abstract from Sosiani River daily for human consumption?---
----

----

6. If not, how is water from Sosiani River used?---

----

7. Have residents complained of any health effects when they consume raw water from Sosiani River? (1)Yes ☐ (2) No ☐ (3) Not Known ☐

8. If yes, how does this water affect human health? ---

----

9. How does this water affect livestock health?--

----

10. Is Sosiani River an important source of fish in Eldoret (1) Yes ☐ (2) No ☐

11. Have there been incidences of death of fish in Sosiani River? (1)Yes ☐ (2) No ☐

(3) Not Known ☐

12. If yes, which year(s)? --

----

13. What do you attribute the death of this fish to if any? ---
----

----

14. What are the potential sources of effluent discharge into Sosiani River?

----

15. What efforts have been put in place to protect Sosiani River from pollution -----------------
----

----

16 What are the challenges faced in protecting Sosiani River--
----

Appendix V: Checklist for Health Facilities along Sosiani River in Eldoret Township

1. Name of Institution--

2. What were the common water related diseases treated in this institution in the last ten years?---
----

3. What do you attribute these water related diseases to?---

----

4. How many cases of water related diseases were treated in the last 10 years in your institution? (Please fill table below)

	Number of Reported Cases										
Water related disease	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Cholera											
Diarrhoea											
Typhoid											
Dysentery											
Poliomyelitis											
Meningitis											
Hepatitis											
Gastro enteritis											
Respiratory diseases											
Intestinal worms											
Other water borne diseases											

5.Apart from those in the table above what other water related diseases were treated in the last 10 years--
----
----

6. What were the monthly cases of water related diseases treated in 2016? (Please fill table below)

	Number of Cases in 2016											
Water related diseases	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Cholera												
Diarrhoea												
Typhoid												
Dysentery												
Poliomyelitis												
Meningitis												
Hepatitis												
Gastro enteritis												
Respiratory diseases												
Intestinal worms												
Others												

Apart from those in the table above what other water related diseases were treated in 2016---- -- ---------

Appendix VI: Graduate School Approval

EGERTON UNIVERSITY

Tel: Pilot: 254-51-2217620
254-51-2217877
254-51-2217631
Dir.line/Fax: 254-51-2217847
Cell Phone
Extension; 3606

P.O. Box 536 - 20115
Egerton, Njoro, Kenya
Email: bpgs@egerton.ac.ke
www.egerton.ac.ke

OFFICE OF THE DIRECTOR GRADUATE SCHOOL

Ref: ND12/0421/14

Date: 20th May, 2016

Mr. Edward Juma Masakha
Dept. of Env. Sci.
Egerton University
P. O. Box 536
EGERTON

Dear Mr. Masakha

RE: CORRECTED PROPOSAL

This is to acknowledge receipt of two copies of your corrected proposal, entitled **"Longitudinal and Seasonal Variations in Physico-chemical and Microbiological Properties of Water Quality of Sosian River Uasin Gishu County, Kenya."**

You are now at liberty to commence your fieldwork. However note the following:

1. You must register each semester
2. Pay your fees every semester
3. Submit progress reports every four (4) months (Masters) or six (6) months (PHDs). Without this, your thesis/project will not be accepted. Forms are available at the Board
4. You are expected to publish one (1) paper (Masters) or two (2) papers (PhD) in peer-reviewed journal and present them before issuance of "Intent to submit Thesis/Project" forms by the board.

Thank you.

Yours sincerely,

DIRECTOR, BOARD OF POST GRADUATE STUDIES
20 MAY 2016
EGERTON UNIVERSITY P.O.

Prof. Dr-Ing. Benedict M. Mutua, PhD, Rer.Nat
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

c.c. Supervisors
COD, Env. Sci.
Dean, FERD

MAO/vk

"Transforming Lives Through Quality Education"
Egerton University is ISO 9001:2008 Certified

Appendix VII: Request for Research Permit

EGERTON UNIVERSITY

Tel: Pilot: 254-51-2217620
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P.O. Box 536 - 20115
Egerton, Njoro, Kenya
Email: bpgs@egerton.ac.ke
www.egerton.ac.ke

OFFICE OF THE DIRECTOR GRADUATE SCHOOL

Ref:..................
ND12/0421/14

Date:...............................
20th May, 2016

The Secretary,
National Commission for Science Technology and Innovation
P. O. Box 30623-00100,
NAIROBI.

Dear Sir,

RE: REQUEST FOR RESEARCH PERMIT – EDWARD JUMA MASAKHA. NO. ND12/0421/14

This is to introduce and confirm to you that the above named student is in the Department of Environmental Science, Faculty of Environment & Resource Development.

He is a bonafide registered PhD student in this University. His research topic is entitled **"Longitudinal and Seasonal Variations in Physico-chemical and Microbiological Properties of Water Quality of Sosian River Uasin Gishu County, Kenya."**

He is at the stage of collecting field data. Please issue him with a research permit to enable him undertake the studies.

Yours faithfully,

Prof. Dr-Ing. Benedict M. Mutua, PhD,Rer.Nat.
DIRECTOR, BOARD OF POSTGRADUATE STUDIES

BMM/vk

"Transforming Lives Through Quality Education"
Egerton University is ISO 9001:2008 Certified

Appendix VIII: NACOSTI Research Authorization

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471, 2241349,3310571,2219420
Fax:+254-20-318245,318249
Email:dg@nacosti.go.ke
Website: www.nacosti.go.ke
when replying please quote

9th Floor, Utalii House
Uhuru Highway
P.O. Box 30623-00100
NAIROBI-KENYA

Ref. No. **NACOSTI/P/16/49458/13219**

Date: **6th December, 2016**

Edward Juma Masakha
Egerton University
P.O. Box 536-20115
EGERTON.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Longitudinal and seasonal variations in physicochemical and microbiological water quality of Sosiani River in Uasin Gishu County,"*** I am pleased to inform you that you have been authorized to undertake research in **Uasin Gishu County** for the period ending **5th December, 2017.**

You are advised to report to **the County Commissioner and the County Director of Education, Uasin Gishu County** before embarking on the research project.

On completion of the research, you are expected to submit **two hard copies and one soft copy in pdf** of the research report/thesis to our office.

DR. STEPHEN K. KIBIRU, PhD.
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Uasin Gishu County.

The County Director of Education
Uasin Gishu County.

National Commission for Science, Technology and Innovation is ISO 9001:2008 Certified

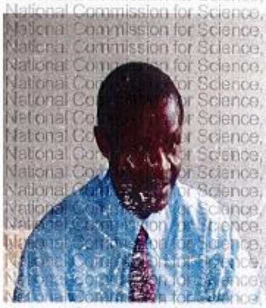
Appendix IX: NACOSTI Research Permit

THIS IS TO CERTIFY THAT:
MR. EDWARD JUMA MASAKHA
of EGERTON UNIVERSITY, 2660-30100
Eldoret,has been permitted to conduct
research in *Uasin-Gishu County*

on the topic: *LONGITUDINAL AND SEASONAL VARIATIONS IN PHYSICOCHEMICAL AND MICROBIOLOGICAL WATER QUALITY OF SOSIANI RIVER IN UASIN GISHU COUNTY*

for the period ending:
5th December,2017

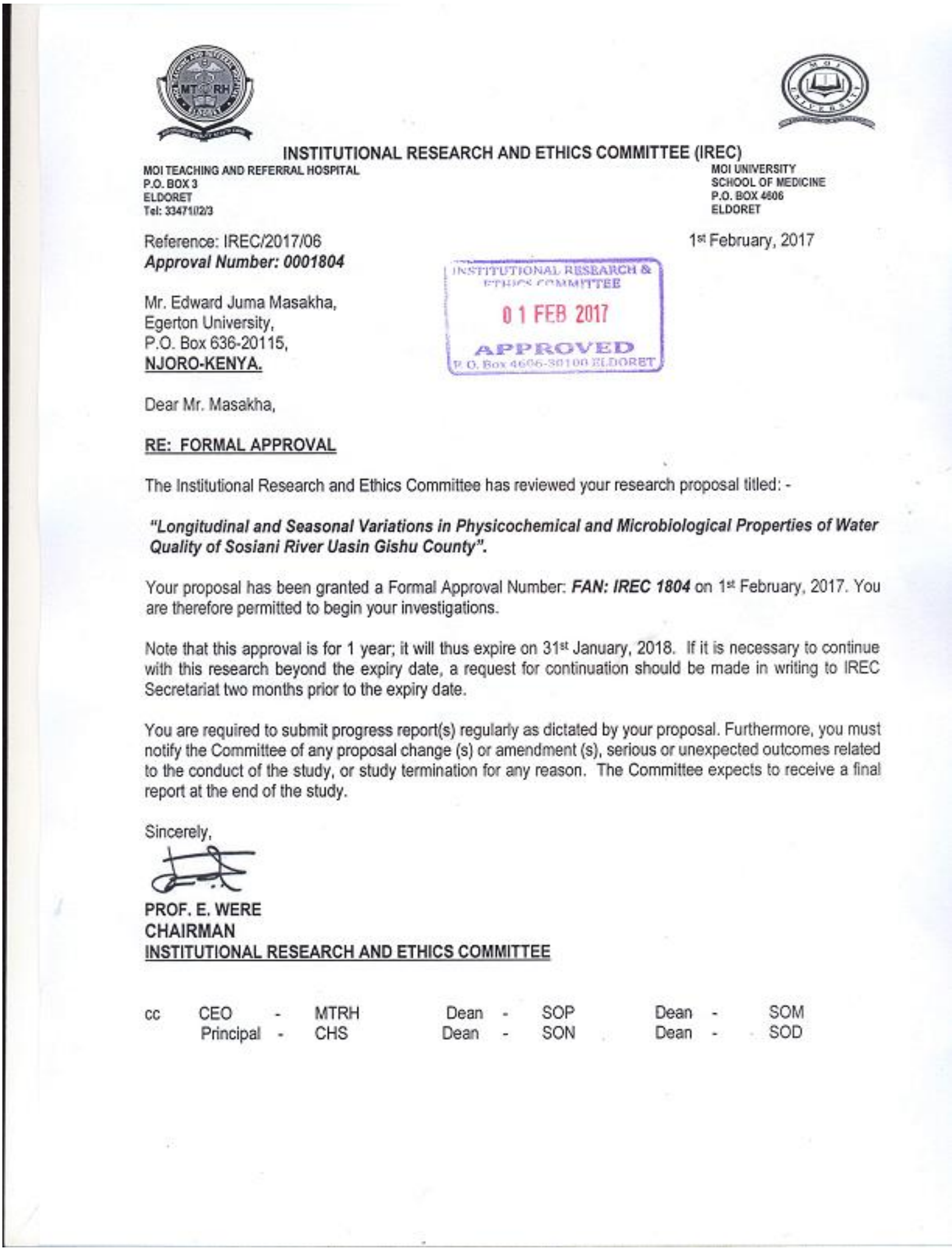
Permit No : NACOSTI/P/16/49458/13219
Date Of Issue : 6th December,2016
Fee Recieved :Ksh 2000



....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix X: Formal Approval IREC



INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE (IREC)

MOI TEACHING AND REFERRAL HOSPITAL
P.O. BOX 3
ELDORET
Tel: 33471//2/3

MOI UNIVERSITY
SCHOOL OF MEDICINE
P.O. BOX 4606
ELDORET

Reference: IREC/2017/06
Approval Number: 0001804

1st February, 2017

INSTITUTIONAL RESEARCH & ETHICS COMMITTEE
01 FEB 2017
APPROVED
P. O. Box 4606-30100 ELDORET

Mr. Edward Juma Masakha,
Egerton University,
P.O. Box 636-20115,
NJORO-KENYA.

Dear Mr. Masakha,

RE: FORMAL APPROVAL

The Institutional Research and Ethics Committee has reviewed your research proposal titled: -

"Longitudinal and Seasonal Variations in Physicochemical and Microbiological Properties of Water Quality of Sosiani River Uasin Gishu County".

Your proposal has been granted a Formal Approval Number: ***FAN: IREC 1804*** on 1st February, 2017. You are therefore permitted to begin your investigations.

Note that this approval is for 1 year; it will thus expire on 31st January, 2018. If it is necessary to continue with this research beyond the expiry date, a request for continuation should be made in writing to IREC Secretariat two months prior to the expiry date.

You are required to submit progress report(s) regularly as dictated by your proposal. Furthermore, you must notify the Committee of any proposal change (s) or amendment (s), serious or unexpected outcomes related to the conduct of the study, or study termination for any reason. The Committee expects to receive a final report at the end of the study.

Sincerely,

PROF. E. WERE
CHAIRMAN
INSTITUTIONAL RESEARCH AND ETHICS COMMITTEE

cc	CEO	-	MTRH	Dean	-	SOP	Dean	-	SOM
	Principal	-	CHS	Dean	-	SON	Dean	-	SOD

Appendix XI: Approval from MTRH

MOI TEACHING AND REFERRAL HOSPITAL

Telephone: 2033471/2/3/4
Fax: 61749
Email: director@mtrh.or.ke

P. O. Box 3
ELDORET

Ref: ELD/MTRH/R&P/10/2/V. II/2010

7th February, 2017

Mr. Edward Juma Masakha,
Egerton University,
P.O. Box 636-20115,
NAIROBI-KENYA.

RE: APPROVAL TO CONDUCT RESEARCH AT MTRH

Upon obtaining approval from the Institutional Research and Ethics Committee (IREC) to conduct your research proposal titled:-

"Longitudinal and Seasonal Variations in Physicochemical and Microbiological Properties of Water Quality of Sosiani River Uasin Gishu County".

You are hereby permitted to commence your investigation at Moi Teaching and Referral Hospital.

07/02/2017
DR. WILSON K. ARUASA
CHIEF EXECUTIVE OFFICER
MOI TEACHING AND REFERRAL HOSPITAL

CC - Deputy Director (CS)
- Chief Nurse
- HOD, HRISM

Appendix XII: GPS Coordinates of Effluent Discharge Points along Sosiani River

No.	Effluent Discharge Points	Longitude	Latitude
1	Zena flower farm	3534594	46713
2	Carbacid factory	3533396	48067
3	Sukunanga carwash	3530243	540124
4	St Lukes Hospital	28135	51151
5	Soyona primary School	3528404	50998
6	Munyaka stream draining effluent	3529473	53899
7	GK Prison	3528970	52947
8	Naivash supermarket	3527694	51671
9	Naivash car wash	3527527	51562
10	Effluent discharge at Kapsabet Bridge	3527136	51742
11	Asis spring discharge point	3526888	51892
12	Oldonyo Lessos Dairies discharge point	3526127	51762
13	Discharge at West Indies Bridge	3525581	51771
14	Rai ply wood Industries discharge point	3524171	53700
15	Bondeni housing estate discharge point	3526512	53973
16	Huruma dumpsite discharge point	3523515	53408
17	Huruma sewage discharge point	3523575	52466
18	Langas Housing estate discharge point	3525411	51807
19	Kapsaos Bridge discharge point	3521964	54692
20	Baharini stream discharge point	3522008	54707
21	Kengen Bridge discharge point	3518059	55449
22	Cheplaskei stream discharge point	3518511	56359
23	Baharini dam discharge point	3521743	58778
24	Ngaraga mbiri discharge point	3507955	57750
25	Sugoi discharge point	3507571	57119
26	Kapulut stream discharge point	350800	57862
27	Kapkong dam discharge point	3511291	61156
28	Turbo discharge point	3505600	62880

Appendix XIII: Reagents for COD Test

i. Open Reflux Method: Open boiling flow process of matter under certain chemical reaction conditions. Matter is oxidized under boiling mixture conditions openly in a conical flask (Erlenmeyer flask) (APHA, 2012)

ii. Closed Reflux method: This is a boiling process of matter under a closed system like in culture tubes for Volatile Organic Compounds (VOC). It takes a longer time for complete oxidation though it is an economical wise use of metallic salt reagents and generates less hazardous waste (APHA, 2012).

iii. Samples are refluxed in a COD digester in the presence of an oxidizing agent (Potassium dichromate) under an acidic media of conc., Sulphuric acid and a catalyst (Mercuric sulphate) (APHA, 2012)

iv. Ferroin indicator reagent: (Orthophenanthroline ferrous complex)

v. 1.485g 1, 10- Phenanthroline monohydrate added to 6.95g ferrous sulphate in distilled water

vi. Standard Potassium dichromate reagent

vii. Dissolve 12.259g standard primary grade Potassium dichromate previously dried at 150^0C for 2 hours in distilled water (6x 0.04167M= 0.25N)

viii. Mercuric Sulphate: 33.3g mercuric sulphate add 167 ml of concentrated sulphuric acid dissolved and cooled to room temperature and make up to 1000ml using distilled water

ix. Standard Ferrous Ammonium Sulphate solution

x. Ferrous Ammonium Sulphate crystals 98g dissolved in distilled water, 20 ml concentrated sulphuric acid added and make up to 1000ml (APHA, 2012)

Appendix XIV: Water Quality Analysis November 2015

Season: Wet Season Date: 15.11.2015

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	18.0	7.10	10.11	15.0	20	30	10	10	9	36	0.121	0.015	0.019	0.002
2	Zena Flower Farm	3534459	46713	19.0	6.90	3.80	79.0	87	174	252	98	141	121	0.110	0.020	0.022	0.010
3	Sukunanga Carwash	3530243	54012	21.6	7.25	6.45	23.0	26	39	82	41	27	60	0.055	0.020	0.029	0.004
4	Munyaka Stream	3527625	51533	21.7	7.00	6.50	27.6	34	64	179	90	85	175	0.210	0.050	0.019	0.005
5	Town Carwash	3527527	51562	27.0	6.50	6.50	130.0	59	295	600	395	2140	279	0.187	0.090	0.045	0.015
6	Kapsabet Bridge	3527136	51742	19.2	7.45	7.56	27.0	48	98	597	397	30	63	0.480	0.085	0.052	0.010
7	Oldonyo	3526127	51762	20.5	6.40	8.25	38.0	40	86	295	90	85	90	0.299	0.080	0.031	0.009
8	West Indies Bridge	3525581	51771	27.2	7.40	6.45	24.0	30	64	320	120	45	75	0.450	0.070	0.003	0.009
9	Mwenderi	3524171	53700	22.4	7.38	5.67	145.0	290	530	367	68	145	427	0.307	0.090	0.003	0.080
10	Bondeni Estate	3526512	53973	24.6	5.40	6.50	157.0	395	640	401	190	70	485	0.017	0.090	0.040	0.009
11	Huruma dumpsite	3523515	53408	22.7	7.75	7.15	167.0	258	358	327	137	35	170	0.320	0.060	0.004	0.004
12	Huruma sewage	3523575	52466	25.5	8.34	6.67	182.0	269	397	575	108	80	420	0.398	0.090	0.019	0.004
13	Turbo	3505600	62880	18.1	7.10	10.62	66.2	36	49	86	35	59	103	0.018	0.030	0.003	0.002

N = 156

Appendix XV: Water Quality Analysis December 2015

Season: Dry Season

20.12.2015

No	Sampling Point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	22.1	6.80	12.00	10.0	15	25	5	4	3	19	0.110	0.012	0.012	0.003
2	Zena Flower farm	3534459	46713	21.0	7.10	5.00	56.0	62	102	120	80	66	65	0.096	0.020	0.019	0.009
3	Sukunanga Carwash	3530243	54012	23.5	7.00	8..00	15.0	20	29	44	19	12	27	0.044	0.070	0.026	0.001
4	Munyaka Stream	3527625	51533	23.9	7.30	7.70	16.0	24	42	84	40	35	93	0.190	0.030	0.015	0.004
5	Town Carwash	3527527	51562	27.4	7.00	6.70	10.0	36	120	350	190	850	146	0.170	0.075	0.034	0.011
6	Kapsabet Bridge	3527136	51742	19.7	7.20	8.80	23.0	34	65	420	120	12	30	0.470	0.067	0.044	0.009
7	Oldonyo	3526127	51762	22.1	6.47	9.10	26.0	32	60	215	63	40	58	0.214	0.040	0.030	0.007
8	West Indies Bridge	3525581	51771	28.2	7.50	7.47	14	24	37	210	60	21	44	0.400	0.060	0.003	0.008
9	Mwenderi	3524171	53700	23.0	7.20	6.50	95.0	165	320	333	54	73	249	0.305	0.040	0.002	0.070
10	Bondeni Estate	3526512	53973	26.8	5.50	7.20	104.0	216	360	340	84	26	282	0.015	0.080	0.037	0.008
11	Huruma dumpsite	3523515	53408	24.2	7.60	8.10	124.0	224	268	366	105	20	100	0.310	0.030	0.003	0.002
12	Huruma sewage	3523575	52466	26.3	8.30	7.50	137.0	190	240	435	98	35	246	0.382	0.050	0.015	0.003
13	Turbo	3505600	62880	19.4	7.00	12.97	44.0	24	37	66	25	33	57	0.016	0.020	0.001	0.001

N = 156

Appendix XVI: Water Quality Analysis January 2016

Season: Dry Season

Date: 24.1.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	21.0	7.12	13.00	8.0	10	16	4	4	3	19	0.100	0.010	0.010	0.003
2	Zena Flower farm	3534459	46713	21.0	7.11	7.20	35.0	44	82	60	40	63	64	0.094	0.080	0.018	0.008
3	Sukunanga Carwash	3530243	54012	23.7	7.01	9.25	12.0	16	22	30	15	11	24	0.042	0.060	0.020	0.001
4	Munyaka Stream	3527625	51533	24.2	7.50	8.50	9.0	18	30	62	37	33	88	0.170	0.020	0.014	0.003
5	Town Carwash	3527527	51562	27.2	7.10	7.25	8.0	20	48	195	120	770	136	0.163	0.072	0.028	0.009
6	Kapsabet Bridge	3527136	51742	19.5	7.10	9.67	16.0	24	48	294	90	10	29	0.460	0.064	0.040	0.008
7	Oldonyo	3526127	51762	22.6	6.57	9.70	18.0	28	39	160	42	35	51	0.205	0.036	0.029	0.006
8	West Indies Bridge	3525581	51771	27.8	7.56	8.32	12.0	18	28	120	32	19	41	0.390	0.050	0.002	0.007
9	Mwenderi	3524171	53700	22.8	7.15	8.20	74.0	126	215	128	36	65	238	0.300	0.030	0.001	0.060
10	Bondeni Estate	3526512	53973	26.9	5.67	8.00	65.0	140	250	230	60	24	274	0.014	0.070	0.035	0.007
11	Huruma dumpsite	3523515	53408	24.4	7.57	9.00	86.0	148	196	123	85	18	84	0.297	0.020	0.003	0.002
12	Huruma sewage	3523575	52466	26.5	8.27	8.52	79.0	146	190	375	73	34	244	0.376	0.030	0.014	0.002
13	Turbo	3505600	62880	19.6	7.01	12.05	29.0	14	26	42	14	21	54	0.015	0.010	0.001	0.001

N = 156

Appendix XVII: Water Quality Analysis February 2016

Season: Dry Season

Date: 14.2.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	21.4	7.15	13.50	6.0	8	12	4	3	3	19	0.090	0.020	0.009	0.002
2	Zena Flower Farm	3534459	46713	22.1	7.12	8.50	18.0	27	59	42	28	60	62	0.094	0.060	0.015	0.007
3	Sukunanga Carwash	3530243	54012	23.9	7.10	9.15	9.0	12	18	26	13	10	22	0.040	0.050	0.015	0.001
4	Munyaka Stream	3527625	51533	24.6	7.56	9.00	6.0	14	26	38	21	30	76	0.156	0.050	0.012	0.002
5	Town Carwash	3527527	51562	26.9	7.12	8.00	6.0	18	32	120	80	730	130	0.150	0.068	0.025	0.007
6	Kapsabet Bridge	3527136	51742	20.0	7.10	10.53	10.0	16	32	272	72	9	28	0.440	0.062	0.037	0.007
7	Oldonyo Diaries	3526127	51762	23.1	6.75	10.70	12.0	24	30	80	24	31	47	0.199	0.020	0.024	0.004
8	West Indies Bridge	3525581	51771	27.7	7.57	9.15	8.0	12	22	72	21	15	34	0.385	0.040	0.002	0.006
9	Mwenderi	3524171	53700	22.8	7.16	9.50	46.0	101	166	96	19	62	231	0.297	0.030	0.001	0.050
10	Bondeni Estate	3526512	53973	26.1	5.68	9.30	42.0	108	180	116	27	20	266	0.012	0.060	0.033	0.006
11	Huruma dumpsite	3523515	53408	24.7	7.54	9.50	67.0	108	130	95	60	15	74	0.292	0.020	0.002	0.001
12	Huruma sewage	3523575	52466	26.7	8.24	7.43	50	125	156	214	49	29	239	0.370	0.025	0.012	0.001
13	Turbo	3505600	62880	20.0	7.01	13.01	24.0	12	20	26	10	19	45	0.014	0.010	0.001	0.001

N = 156

Appendix XVIII: Water Quality Analysis March 2016

Season: Dry Season

Date: 27.3.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	21.6	7.18	14.00	4.0	6	9	3	2	2	18	0.080	0.025	0.009	0.001
2	Zena Flower Farm	3534459	46713	22.4	7.10	9.30	12.0	18	30	26	12	59	62	0.093	0.040	0.014	0.005
3	Sukunanga Carwash	3530243	54012	24.2	7.08	10.21	6.0	20	30	15	9	10	21	0.040	0.030	0.013	0.001
4	Munyaka Stream	3527625	51533	24.0	7.55	10.16	6.3	12	18	23	13	28	72	0.123	0.015	0.010	0.001
5	Town Carwash	3527527	51562	26.3	7.09	9.10	6.5	12	16	67	32	645	121	0.143	0.060	0.023	0.005
6	Kapsabet Bridge	3527136	51742	19.8	7.00	10.41	12.0	12	18	160	33	8	26	0.425	0.060	0.032	0.006
7	Oldonyo Diaries	3526127	51762	23.2	7.00	11.20	10.0	12	18	38	14	30	43	0.190	0.010	0.022	0.003
8	West Indies Bridge	3525581	51771	28.0	7.60	10.30	6.0	8	12	34	17	13	28	0.380	0.040	0.001	0.005
9	Mwenderi	3524171	53700	22.5	7.18	9.20	24.0	40	86	42	20	60	228	0.283	0.020	0.001	0.050
10	Bondeni Estate	3526512	53973	25.8	5.50	10.10	26.0	76	137	68	14	17	256	0.011	0.050	0.032	0.005
11	Huruma dumpsite	3523515	53408	25.1	7.56	10.25	42.0	77	96	44	19	14	69	0.287	0.020	0.001	0.001
12	Huruma sewage	3523575	52466	26.8	8.21	9.26	30.0	96	103	88	32	28	231	0.367	0.020	0.010	0.001
13	Turbo	3505600	62880	19.6	7.04	14.10	2.0	10	16	18	9	8	34	0.012	0.010	0.001	0.001

N = 156

Appendix XIX: Water Quality Analysis April 2016

Season: Wet Season

Date: 27. 4.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	21.0	7.16	12.15	6.0	10	12	4	3	2	18	0.080	0.020	0.008	0.001
2	Zena Flower farm	3534459	46713	21.0	7.15	8.20	16.0	24	46	37	18	58	61	0.092	0.040	0.012	0.004
3	Sukunanga Carwash	3530243	54012	23.7	7.06	9.20	14.0	32	42	26	11	9	18	0.039	0.020	0.013	0.001
4	Munyaka Stream	3527625	51533	23.5	7.57	9.40	10.0	18	30	28	14	26	67	0.111	0.010	0.010	0.001
5	Town Carwash	3527527	51562	26.1	7.06	8.50	10.0	24	46	76	37	570	118	0.136	0.056	0.020	0.005
6	Kapsabet Bridge	3527136	51742	19.5	7.10	8.74	24.0	26	380	180	45	8	24	0.420	0.056	0.030	0.005
7	Oldonyo Diaries	3526127	51762	23.3	6.90	10.20	18.0	22	42	44	16	29	36	0.187	0.010	0.020	0.003
8	West Indies Bridge	3525581	51771	28.1	7.65	9.15	8.0	16	36	47	19	11	23	0.377	0.030	0.001	0.005
9	Mwenderi	3524171	53700	22.6	7.12	8.30	33.0	76	146	52	24	59	223	0.265	0.010	0.001	0.040
10	Bondeni Estate	3526512	53973	25.8	5.69	8.50	36.0	70	140	79	26	15	252	0.010	0.040	0.030	0.004
11	Huruma dumpsite	3523515	53408	24.6	7.42	9.20	56.0	88	160	80	27	11	66	0.282	0.010	0.001	0.001
12	Huruma sewage	3523575	52466	27.2	8.23	8.80	48.0	126	220	108	48	25	228	0.362	0.010	0.009	0.001
13	Turbo	3505600	62880	20.1	7.10	13.10	36.0	30	42	34	15	20	44	0.010	0.010	0.001	0.001

N =156

Appendix XX: Water Quality Analysis May 2016

Season: Wet Season

Date 28.5.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	19.1	7.13	10.40	8.0	14	18	4	3	3	19	0.085	0.020	0.008	0.001
2	Zena Flower farm	3534459	46713	20.0	7.19	6.00	24.0	46	96	42	20	59	68	0.012	0.050	0.013	0.005
3	Sukunanga Carwash	3530243	54012	22.3	7.05	7.50	26.0	48	98	37	15	10	19	0.029	0.020	0.014	0.001
4	Munyaka Stream	3527625	51533	23.1	7.57	8.40	18.0	24	68	32	18	30	71	0.112	0.010	0.010	0.001
5	Town Carwash	3527527	51562	25.9	7.01	7.30	40.0	62	96	80	42	581	121	0.140	0.057	0.016	0.005
6	Kapsabet Bridge	3527136	51742	19.4	7.11	7.15	36.0	38	76	198	49	9	28	0.430	0.065	0.029	0.005
7	Oldonyo Diaries	3526127	51762	23.5	6.95	9.57	42.0	38	88	53	21	30	37	0.190	0.010	0.020	0.003
8	West Indies Bridge	3525581	51771	27.5	7.50	8.10	16.0	32	78	55	24	12	26	0.380	0.030	0.001	0.005
9	Mwenderi	3524171	53700	22.7	7.11	7.30	58.0	90	188	64	31	60	224	0.260	0.010	0.001	0.040
10	Bondeni Estate	3526512	53973	25.7	5.70	9.50	74.0	186	328	82	36	18	256	0.010	0.040	0.029	0.004
11	Huruma dumpsite	3523515	53408	24.4	7.37	9.41	67.0	169	296	94	42	14	69	0.280	0.010	0.001	0.001
12	Huruma sewage	3523575	52466	27.3	8.14	8.25	72.0	187	286	128	52	27	235	0.360	0.010	0.009	0.001
13	Turbo	3505600	62880	20.0	7.05	13.50	34.0	56	48	76	12	29	49	0.010	0.010	0.001	0.001

N = 156

Appendix XXI: Water Quality Analysis June 2016

Season: Wet Season

Date: 20.6.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	21.2	7.16	10.15	10.0	16	18	5	4	5	32	0.012	0.010	0.015	0.001
2	Zena Flower farm	3534459	46713	18.6	6.89	5.80	38.0	76	126	86	37	121	106	0.096	0.020	0.016	0.005
3	Sukunanga Carwash	3530243	54012	21.4	7.37	7.00	32.3	86	146	42	18	11	34	0.020	0.060	0.015	0.002
4	Munyaka Stream	3527625	51533	22.1	7.30	8.01	30.6	74	120	48	30	63	150	0.186	0.070	0.017	0.017
5	Town Carwash	3527527	51562	28.7	6.97	7.00	56.0	98	156	106	49	1882	263	0.151	0.062	0.027	0.007
6	Kapsabet Bridge	3527136	51742	19.5	7.17	7.17	68.0	92	160	220	65	14	50	0.424	0.052	0.039	0.005
7	Oldonyo diaries	3526127	51762	22.1	6.55	8.50	62.7	68.4	196	75	37	58	57	0.202	0.010	0.024	0.005
8	West Indies Bridge	3525581	51771	27.7	7.35	7.50	28.6	64	126	74	36	23	58	0.426	0.010	0.001	0.008
9	Mwenderi	3524171	53700	22.3	7.12	6.45	78.0	120	296	88	43	127	385	0.241	0.020	0.001	0.061
10	Bondeni Estate	3526512	53973	25.1	5.63	8.63	84.0	201	450	108	53	49	436	0.011	0.060	0.031	0.006
11	Huruma dumpsite	3523515	53408	23.2	7.62	8.00	90.5	256	497	120	57	20	111	0.312	0.010	0.001	0.001
12	Huruma sewage	3523575	52466	26.4	8.15	7.45	96.1	291	423	146	68	53	388	0.386	0.010	0.013	0.001
13	Turbo	3505600	62880	18.4	7.35	12.50	66.8	60	120	32	20	38	92	0.014	0.000	0.001	0.001

N = 156

Appendix XXII: Water Quality Analysis July 2016

Season: Wet Season

Date: 30.7.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	20.0	7.10	9.80	11.0	18	22	6	5	6	33	0.118	0.010	0.017	0.001
2	Zena Flower Farm	3534459	46713	18.0	7.00	5.60	52.0	87	120	114	60	135	110	0.101	0.015	0.018	0.005
3	Sukunanga Carwash	3530243	54012	22.0	7.20	6.50	42.0	96	196	56	27	20	35	0.040	0.070	0.020	0.002
4	Munyaka Stream	3527625	51533	22.5	7.20	7.50	66.0	101	228	60	42	70	148	0.198	0.070	0.017	0.002
5	Town Carwash	3527527	51562	28.0	7.00	6.50	80.0	186	290	148	70	1600	269	0.181	0.078	0.037	0.009
6	Kapsabet Bridge	3527136	51742	20.0	7.20	6.25	46.0	134	286	242	72	18	55	0.475	0.065	0.040	0.007
7	Oldonyo Diaries	3526127	51762	22.0	6.50	7.55	90.0	250	447	86	42	69	61	0.290	0.075	0.024	0.007
8	West Indies Bridge	3525581	51771	28.0	7.40	6.50	102	296	520	90	45	35	62	0.445	0.040	0.001	0.006
9	Mwenderi	3524171	53700	23.0	7.18	5.65	140.0	186	425	106	65	130	390	0.301	0.040	0.001	0.070
10	Bondeni Estate	3526512	53973	25.0	5.50	7.50	98.0	180	396	148	74	53	447	0.091	0.080	0.040	0.007
11	Huruma dumpsite	3523515	53408	23.5	7.65	6.85	139.0	302	526	150	70	24	126	0.385	0.020	0.018	0.002
12	Huruma sewage	3523575	52466	26.0	8.20	6.50	120.8	296	486	168	80	68	390	0.408	0.020	0.015	0.007
13	Turbo	3505600	62880	18.0	7.35	11.25	81.0	96	120	42	26	49	103	0.018	0.010	0.001	0.002

N = 156

Appendix XXIII: Water Quality Analysis August 2016

Season: Wet Season

Date: 25.8.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	18.0	7.05	9.40	14.0	20	25	6	5	7	33	0.119	0.015	0.019	0.002
2	Zena Flower Farm	3534459	46713	18.5	6.50	5.20	60.0	97	456	140	80	138	115	0.105	0.018	0.020	0.008
3	Sukunanga Carwash	3530243	54012	21.5	7.47	6.01	58.0	106	135	70	35	23	37	0.045	0.020	0.025	0.002
4	Munyaka Stream	3527625	51533	22.3	7.19	7.20	80.4	120	256	82	53	74	150	0.203	0.060	0.019	0.002
5	Town Carwash	3527527	51562	27.8	6.83	5.10	95.0	220	402	102	82	1615	275	0.185	0.080	0.039	0.010
6	Kapsabet Bridge	3527136	51742	19.6	7.30	5.51	58.0	170	347	273	87	19	57	0.478	0.068	0.045	0.008
7	Oldonyo Diaries	3526127	51762	21.0	6.45	6.57	102.0	290	497	98	56	70	61	0.295	0.078	0.029	0.008
8	West Indies Bridge	3525581	51771	27.5	7.42	5.5	156.9	340	580	120	67	38	62	0.448	0.060	0.002	0.007
9	Mwenderi	3524171	53700	22.9	7.20	5.10	108.0	186	406	127	79	135	395	0.303	0.045	0.002	0.070
10	Bondeni Estate	3526512	53973	24.9	5.47	6.50	146.0	345	576	168	91	54	449	0.096	0.090	0.045	0.013
11	Huruma dumpsite	3523515	53408	23.0	7.69	6.10	138.0	316	57	167	86	25	129	0.387	0.030	0.019	0.003
12	Huruma sewage	3523575	52466	26.0	8.24	5.55	140.5	526	556	190	98	69	395	0.410	0.040	0.017	0.008
13	Turbo	3505600	62880	18.2	7.32	9.35	98.8	101	150	68	32	64	115	0.019	0.020	0.002	0.003

N = 156

Appendix XXIV: Water Quality Analysis September 2016

Season: Wet Season

Date: 28.9.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	18.5	6.90	8.15	16.0	22	30	7	5	8	35	0.119	0.010	0.019	0.003
2	Zena Flower Farm	3534459	46713	18.7	6.35	4.60	76.0	147	167	168	90	139	118	0.109	0.019	0.019	0.009
3	Sukunanga Carwash	3530243	54012	21.3	7.65	5.50	102.0	125	140	87	46	25	39	0.047	0.090	0.027	0.002
4	Munyaka Stream	3527625	51533	21.9	7.14	6.60	96.5	138	276	96	60	77	155	0.207	0.080	0.021	0.003
5	Town Carwash	3527527	51562	27.6	6.75	4.85	120.0	230	447	140	90	1620	281	0.187	0.850	0.040	0.011
6	Kapsabet Bridge	3527136	51742	19.4	7.40	4.90	108.0	180	377	300	100	21	59	0.479	0.069	0.046	0.009
7	Oldonyo Diaries	3526127	51762	20.9	6.42	6.00	134.0	302	527	127	72	76	65	0.298	0.079	0.030	0.009
8	West Indies Bridge	3525581	51771	27.4	7.39	4.84	196.3	356	629	148	74	39	68	0.449	0.070	0.003	0.008
9	Mwenderi	3524171	53700	22.7	7.36	4.41	138.0	198	456	140	86	139	400	0.305	0.049	0.003	0.080
10	Bondeni Estate	3526512	53973	25.0	5.43	4.90	156.0	372	606	184	102	57	467	0.099	0.090	0.047	0.015
11	Huruma dumpsite	3523515	53408	22.9	7.70	5.00	150.0	346	586	291	100	29	134	0.389	0.040	0.020	0.004
12	Huruma sewage	3523575	52466	25.9	8.27	4.60	170.5	576	596	240	120	64	402	0.412	0.050	0.019	0.009
13	Turbo	3505600	62880	18.5	7.20	8.00	108.7	131	186	88	40	72	127	0.019	0.020	0.002	0.002

N = 156

Appendix XXV: Water Quality Analysis October 2016

Season: Wet Season

Date: 29.10.2016

No	Sampling point	Longitude	Latitude	Temp	pH	DO	Turb	BOD	COD	TC	EC	TSS	TDS	Zn	Cd	Pb	Cr
1	Two River Dam	3535204	47675	18.8	7.20	7.40	17.0	25	35	8	6	10	40	0.125	0.018	0.020	0.003
2	Zena Flower Farm	3534459	46713	19.3	7.00	4.20	90.0	158	165	201	100	151	125	0.115	0.025	0.020	0.010
3	Sukunanga Carwash	3530243	54012	21.8	7.75	5.10	118.0	146	170	96	52	38	69	0.059	0.025	0.030	0.005
4	Munyaka Stream	3527625	51533	22.5	7.40	6.00	106.6	150	290	120	68	93	198	0.215	0.055	0.020	0.006
5	Town Carwash	3527527	51562	27.2	6.50	4.20	136.0	260	460	180	100	740	279	0.190	0.095	0.047	0.020
6	Kapsabet Bridge	3527136	51742	19.8	7.50	4.40	129.0	211	407	320	125	37	72	0.486	0.091	0.058	0.016
7	Oldonyo Diaries	3526127	51762	21.5	6.50	5.80	156.0	341	547	168	83	88	95	0.390	0.087	0.036	0.010
8	West Indies Bridge	3525581	51771	26.5	7.45	4.20	209.0	406	651	169	77	55	85	0.490	0.076	0.004	0.010
9	Mwenderi	3524171	53700	22.0	7.28	4.20	158.0	238	476	188	86	140	420	0.309	0.095	0.005	0.085
10	Bondeni Estate	3526512	53973	24.5	5.45	4.40	180.0	402	650	240	160	75	496	0.019	0.095	0.045	0.010
11	Huruma dumpsite	3523515	53408	22.4	7.80	4.30	176.0	396	607	310	120	40	175	0.350	0.065	0.005	0.005
12	Huruma sewage	3523575	52466	25.0	8.45	4.20	198.0	609	636	320	140	92	438	0.400	0.096	0.020	0.005
13	Turbo	3505600	62880	18.7	7.30	7.12	148.2	172	228	101	48	90	143	0.020	0.035	0.036	0.003

N = 156

Appendix XXVI: Sources of Pollution along Sosiani River in Eldoret Township

Category	**Source**	**Pollutants**
Agrochemicals	Wheat farms & Zena Flower farm	Heavy metals, sediments
Car wash & garages	Sukunanga & Naivash carwash, Garages around Bandaptai, Asis & FIMS	Cadmium, Lead
Food Industries	Arkay factory, Oldonyo dairies, CPC factory, KCC, Unga Ltd, Rift Valley bottlers & Bakeries.	Zinc
Wood industries	Rai plywood mills & Treatment of poles Tipsy	Chromium
Textile Industries	Rivatex, RUPA &Ken knit	Chromium, Nickel, Copper, Zinc, Cadmium
Steel mill	Eldoret steel rolling mills:	Cadmium
Laundries & Hotels	Laundries: Majimazuri, Theluji, Snowflakes, white Rose. Hotels: Boma inn, Sirikwa, Wagon, Highlands, White Castle, Miyako, Mahindi, SICADA, Horizon, Asis, Shakers, sports club and Sosiani	Heavy metals
Municipal effluent & sewage treatment	Municipal effluent, Huruma sewage treatment & dumpsite	Cadmium, Copper, Lead, Zinc, Mercury Silver, Chromium, Nickel & Pathogens

Appendix XXVII: Annual Waterborne Diseases in Health Facilities along Sosiani River in Eldoret Township between 2011 and 2016

Hospital	Disease	2011	2012	2013	2014	2015	2016
Turbo Sub county Hospital	Cholera	0	0	0	0	0	0
	Diarrheoa	507	90	317	213	169	53
	Typhoid	1305	719	647	1221	1797	1355
	Dysentery	8	20	20	12	17	9
Huruma Sub county Hospital	Cholera	0	0	0	0	0	0
	Diarrhoea	2356	2728	2078	3474	3314	1601
	Typhoid fever	1045	1441	2053	4118	3379	1685
	Dysentery	276	93	152	299	102	97
Ngelel Terit Dispensary	Cholera	0	0	0	0	0	0
	Diarrhoea	331	344	497	1189	1071	5397
	Typhoid fever	13	0	140	154	284	56
	Dysentery	6	3	0	3	8	27
Pioneer Health Centre	Cholera	0	0	0	0	0	0
	Diarrhoea	48	95	248	1382	811	868
	Typhoid fever	14	24	126	474	381	122
	Dysentery	0	0	1	1	7	4
Sosiani Health Centre	Cholera	0	0	0	0	0	0
	Diarrhoea	403	475	1083	746	735	565
	Typhoid fever	45	157	560	399	505	267
	Dysentery	3	0	2	2	0	0
Kipkenyo Dispensary	Cholera	0	0	0	0	0	0
	Diarrhoea	7	22	104	554	1038	728
	Typhoid fever	2	1	13	25	73	84

Source: Uasin Gishu County Hospital, 2017

Appendix XXVIII: Monthly Waterborne Diseases in Health Facilities along Sosiani River in Eldoret Township

Disease	Hospital/ Period	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16	Total
Cholera	Ngelel Terit Dispensary	0	0	0	0	0	0	0	0	0	0	0	0	0
	Kipkenyo Dispensary	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sosiani Health Centre	0	0	0	0	0	0	0	0	0	0	0	0	0
	Huruma District Hospital	0	0	0	0	0	0	0	0	0	0	0	0	0
	Turbo Sub County Hospital	0	0	0	0	0	0	0	0	0	0	0	0	0
Diarrhoea	Ngelel Terit Dispensary	105	133	174	110	84	107	70	4,380	62	113	0	59	5,397
	Kipkenyo Dispensary	52	64	45	64	86	74	85	64	72	50	41	31	728
	Sosiani Health Centre	36	59	53	54	47	35	46	64	54	48	27	42	565
	Huruma District Hospital	157	115	424	218	34	20	114	53	103	160	62	141	1,601
	Turbo Sub County Hospital	4	7	3	8	1	3	2	1	0	10	14	0	53
Typhoid fever	Ngelel Terit Dispensary	8	6	6	5	6	12	8	4	0	0	0	1	56
	Kipkenyo Dispensary	15	18	0	4	3	8	15	8	8	0	5	0	84
	Sosiani Health Centre	40	32	30	32	22	13	17	20	14	11	26	10	267
	Huruma District Hospital	388	218	456	202	105	9	74	37	57	48	40	51	1,685
	Turbo Sub County Hospital	95	218	137	1	171	142	197	108	0	119	117	50	1,355
Dysentery	Ngelel Terit Dispensary	0	1	0	3	5	3	0	3	8	1	0	3	27
	Kipkenyo Dispensary	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sosiani Health Centre	0	0	0	0	0	0	0	0	0	0	0	0	0
	Huruma District Hospital	8	1	13	45	10	2	2	1	1	4	7	3	97
	Turbo Sub County Hospital	2	0	0	1	0	1	0	0	0	1	4	0	9

Source: Uasin Gishu County Hospital, 2017