KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY COLLEGE OF SCIENCE

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EFFECTS OF ANTHROPOGENIC ACTIVITIES ON WATER QUALITY OF STREAMS: A CASE STUDY OF THE ONYASIA STREAM IN THE GREATER ACCRA REGION

A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY, KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY, KUMASI, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCE

BY FELISA BAABA ANDOH

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DECLARATION

I hereby declare that this submission is my own work towards the award of M.Sc. and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

Felisa Baaba Andoh (**PG 6503111**) …………………. …………………….

(Student)   Signature   Date

Certified by:

Dr. Bernard Fei-Baffoe   …………………. …………………….

(Supervisor)   Signature   Date

Certified by:

Rev. Stephen Akyeampong   …………………. …………………….

(Head of Department)   Signature   Date

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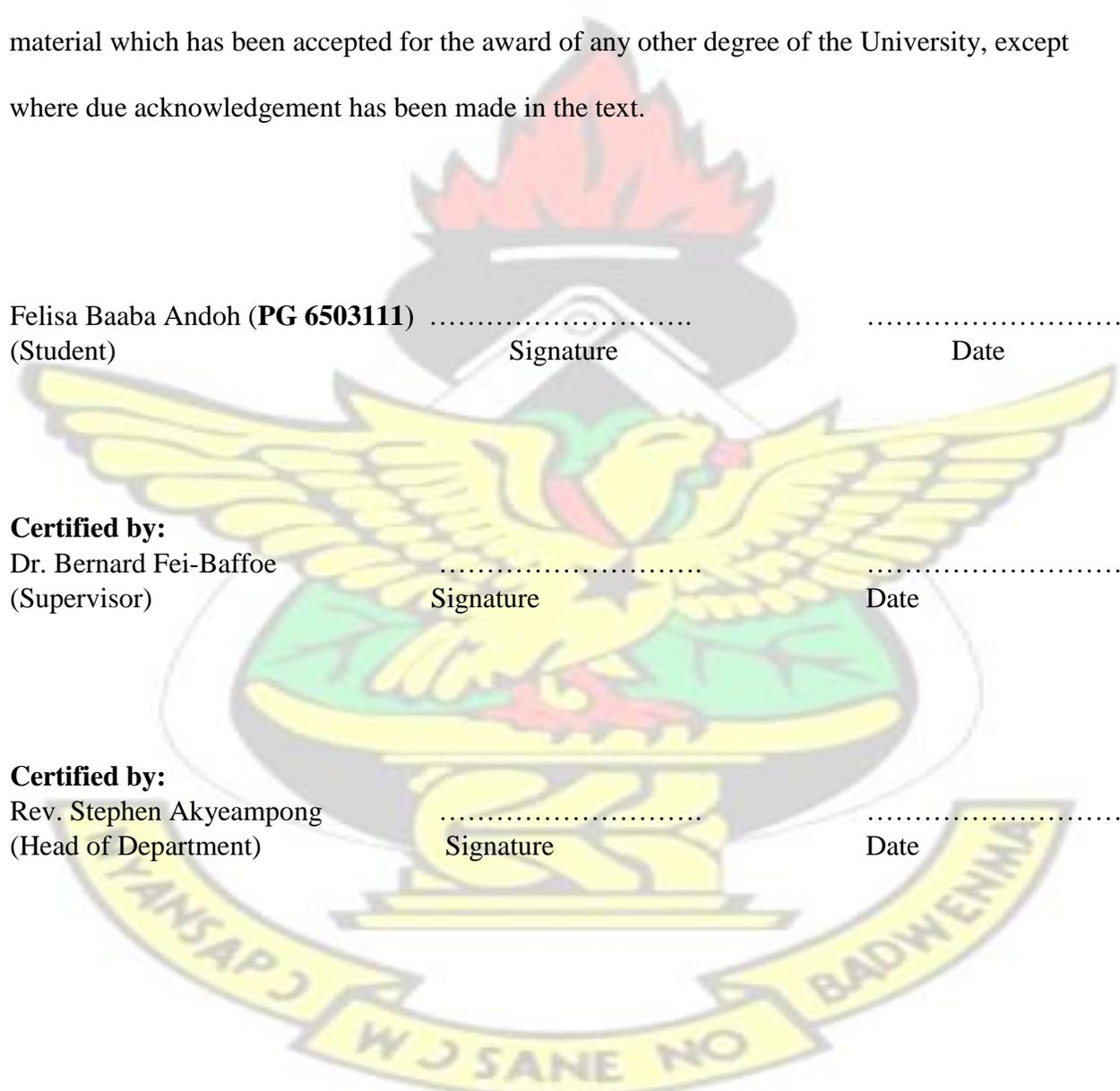
DEDICATION

I dedicate this piece of work to my dear mum, Mrs. Regina Akweley Andoh, who has been my backbone in achieving this degree. You have been my source of inspiration, thank you so much for your prayers and financial support.

Also to my dear husband, Sidney Owusu-Darko, my dad, Mr. Moses Botwe Andoh, my sister, Rebecca Aboagyewaa Andoh-Darko & husband Charles Tetteh Darko and my very own niece Jadelynn Ann Larko Darko, thank you so much for your prayers and unceasing support, that has brought me this far. God richly bless you.
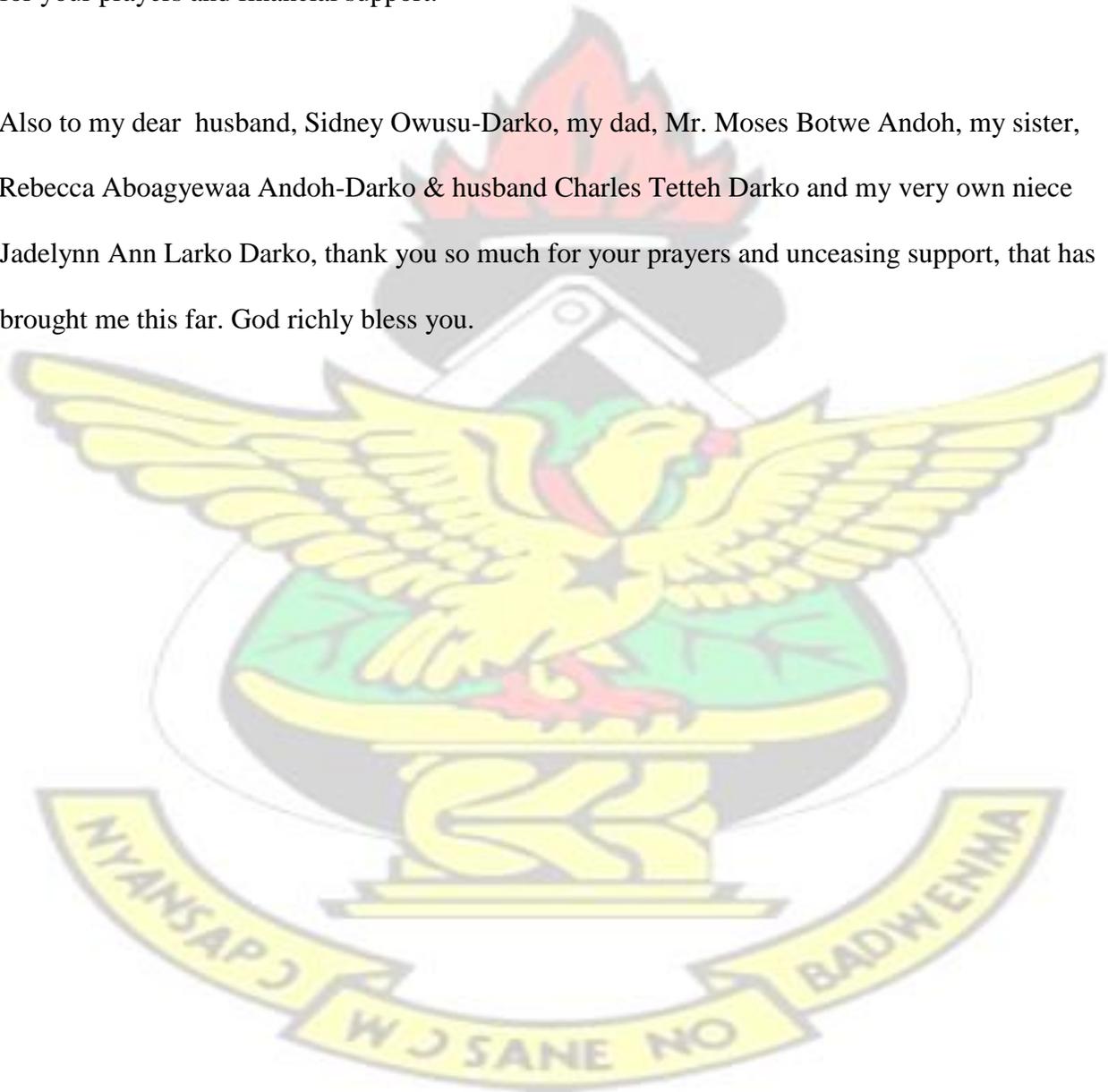
ABSTRACT

Indiscriminate disposal of waste, use of pesticides and fertilizer on farms along the Onyasia has been of great concern. This study assessed the water quality of the Onyasia stream in the Greater Accra Region. Composite water samples drawn from sections of the Onyasia stream from fifteen sampling points, five each from Upstream, midstream and downstream were analyzed in the laboratory for heavy metals (Al, Mn, Fe, Cd and Cu), selected nutrients (PO_4^{3-}, SO_4^{2-}, NO_3-N and NH_3-N) and Microbial counts (total and faecal coliforms). Physico-chemical parameters (pH, temperature, conductivity, turbidity, total dissolved solids and dissolved oxygen) were also analyzed in-situ using the Horiba water quality multi-checker. With the exception of turbidity (ranging from 68.86 to 129.24 NTU) which was far above the WHO limit of 5 NTU, all the other physical parameters (pH values ranging from 6.31 to 6.68, conductivity ranging from 1.31 to 1.71 μS/cm, TDS ranging from 0.76 to 0.97 mg/l and DO ranging 5.09 to 7.87mg/l) were below the WHO standards of 6.5-8.5, 1500μS/cm, 1000mg/l and 5mg/l respectively. With the exception of sulphate (47.00 to 76.40 mg/l), concentrations of phosphate (3.11 to 5.05 mg/l), nitratenitrogen (2.01 to 11.37 mg/l) and ammonia nitrogen (10.09 to 19.67 mg/l) the analyzed water samples were above the WHO limit of 250mg/l, 2.00mg/l, 3.00mg/l and 1.5mg/l respectively. There were high levels of Al (8.54-16.55mg/l) and Fe (0.81-2.5 mg/l) recorded compared to WHO limit of 0.05mg/l and 0.3 mg/l respectively; considerable concentrations of Mn, Cu and Cd (0.34-0.89, 1.36-2.80mg/l and 0.00-0.10mg/l) were recorded. The faecal coliform counts were significantly higher than the WHO standard for potable water of 0.00 cfu/100ml ($P<0.05$). Consequently, both total and faecal coliforms reached their maximum counts in the dry season when the stream turbulence is low and stream course choked with both organic and inorganic wastes. The study therefore concluded that the water from the Onyasia stream is not safe for human related activities.
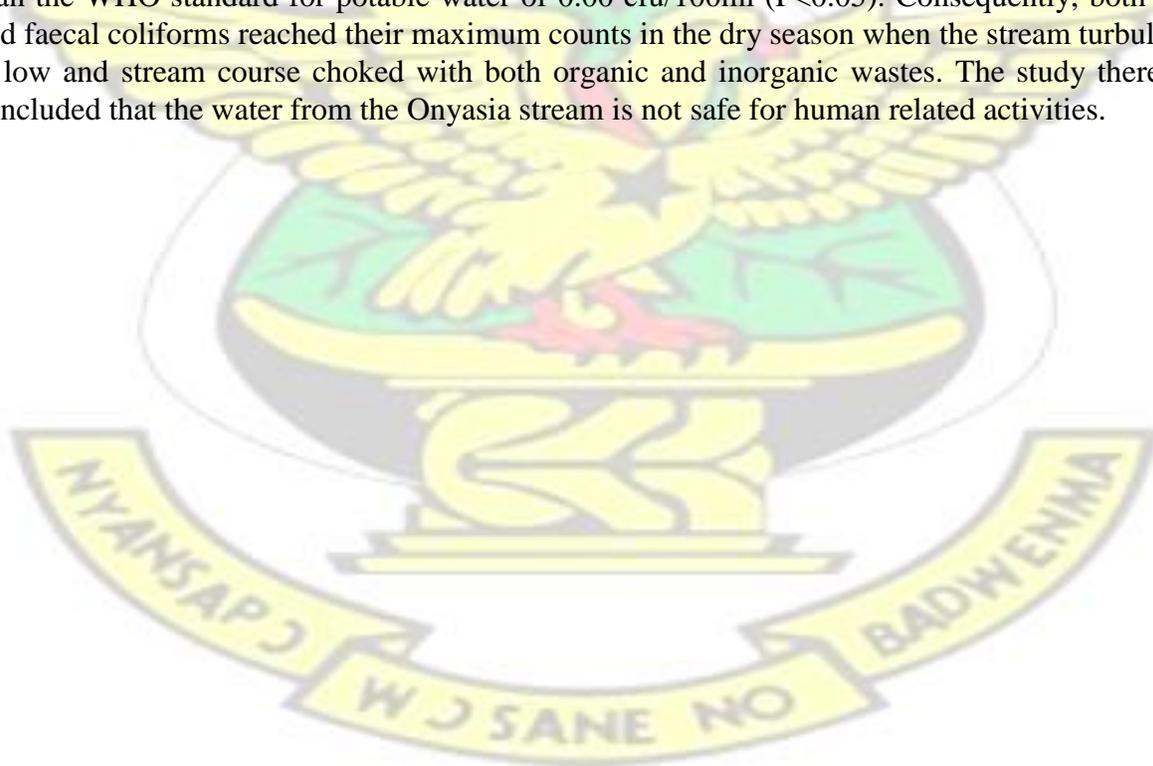
ACKNOWLEDGEMENT

I am very grateful to the Almighty God who kept me and strengthened me to accomplish this dream. To live is Christ indeed.

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LIST OF ABBREVIATIONS

AAS	-	Atomic Absorption Spectrophotometer
AMA	-	Accra Metropolitan Assemble
APHA	-	American Public Health Association
ATSDR	-	Agency for Toxic Substances & Disease Registry
BDL	-	Below Detection Limit
FAO	-	Food and Agricultural Organisation
IDPH	-	Illinois Department of Public Health
PAN	-	Pesticide Action Network
NTU	-	Nephelometric Turbidty Unit
TDS	-	Total Dissolved Solids
UNEP	-	United Nations Environment Program
UNEP/GEMS	-	UNEP/Global Environment Monitoring System
UN WWAP	-	United Nations World Water Assessment Programme
USGS	-	United States Geological Services
WHO	-	World Health Organisation
WRC	-	Water Resources Commission
WRI	-	World Resources Institute

CHAPTER ONE

INTRODUCTION

1.1 Background

The birth of industrial revolution and the rapid increase in human population has led to a large transformation of the natural environment. The environment has become hostile because of pollutants released into the environment by human activities posing threats to human health and welfare. It should therefore be made safe and turned to good use for better standards of living and wealth creation (Thomas, 1972).

Water quality can be defined by a range of variables which limit water use. Although many uses have some common requirements for certain variables, each use will have its own demands and influences on water quality (Meybeck *et al.,* 1996). The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life (Adefemi and Awokunmi 2009).

Most water sources have been subjected to detrimental anthropogenic activities especially in developing countries where stream water is used directly for washing vehicles and clothes, bathing, watering of livestock, and as a playground for children (Mathooko, 2001). Through these and other activities, inorganic and organic poisons, heavy metals and pesticides may find their way into running water systems. Furthermore, the need to produce more food for a growing population along the banks of rivers/streams impacts on the aquatic environment as it results in increased soil erosion, chemical pollution by fertilizers and pesticides, and pollution from animal operations (Novotny, 1999). Anthropogenic activities are very common within and along stream systems in

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tropical Africa (Mathooko, 2001) and they reduce water quality (Mokaya, 2000). Current farming practices in Ghana and the impact on streams depends to a great extent on the level of environmental awareness, knowledge and attitudes of farmers. In Ghana, decisions critical for the future of water bodies are taken with no concern of farmers‟ knowledge of the harmful effects of their practices and the ways they can overcome them. Furthermore, farmers‟ involvement in the formulation of environmental policies or implementation of management plans for wetlands has been totally ignored by the government. It has been assumed that rural people do not understand the issues relating to resource conservation and cannot, therefore, be entrusted with this responsibility (Beopoulous, 1996). Conserving streams, while at the same time maintaining the agricultural resource base by practicing environmentally compatible farming, is a necessity. For this to be realized, it is important that conservation policy makers and agricultural officers should have sufficient information on farmers‟ awareness of environmental issues, improve it, if possible, and make farmers in the district the key focus of a future wetland conservation programme.

According to UNEP and Pacific Institute (2010), every day, millions of tons of inadequately treated sewage and industrial and agricultural wastes are poured into the world‟s waters. Every year, water contamination of natural ecosystems affects humans directly by destroying fisheries or causing other impacts on biodiversity that affect food production. In the end, most polluted freshwater ends up in the oceans, causing serious damage to many coastal areas and fisheries and worsening our ocean and coastal resource management challenges (UNEP/Pacific Institute, 2010).

Clean, safe, and adequate freshwater is vital to the survival of all living organisms and the smooth functioning of ecosystems, communities, and economies. But the quality of the world‟s water is increasingly threatened as human populations grow, industrial and agricultural activities expand, and as climate change threatens to cause major alterations of the hydrologic cycle. Poor water

quality threatens the health of people and ecosystems, reduces the availability of safe water for drinking and other uses, and limits economic productivity and development opportunities. There is an urgent need for the global community – both the public and private sector – to join together to take on the challenge of protecting and improving the quality of water in our rivers, lakes, aquifers, and taps. There must commitments to prevent future water pollution, treating waters that are already contaminated, and restoring the quality and health of rivers, lakes, streams, and wetlands; this enables these waters to meet the broadest possible range of human and ecosystem needs. These actions will be felt all the way from the headwaters of our watersheds to the oceans, fisheries, and marine environments that help sustain humanity.

1.2   Problem Statement

Water is a commodity that many take for granted and allow it to be polluted to some extent. The industries, settlement areas, farming areas, markets, leaking sewer lines, poor hygiene practices are all potential sources of pollution. The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life (Adefemi and Awokunmi, 2009). As global exploitation of both stream water and groundwater increases, it is becoming more evident that managers need to develop an awareness of the linkages between these two systems, the roles that these linkages play in maintaining water quality, and how human activities may impair them (Hynes 1960, Johnson *et al.,* 1997, Townsend *et al.,* 1997). Humans have a great impact on ecosystems and biodiversity. Sometimes they can have a positive impact on ecosystems, but often their actions can have detrimental ecological consequences. Control and sustainable management of water bodies are major problems in Ghana as a result of human activities. The environmental issues arise from the improper management and control of domestic, municipal, agricultural, and

industrial waste which find their way into the water bodies (WRC, 2000). Agriculture plays a considerable role in the sustenance of the economy. Many people rely on the streams for irrigated farming and others even for domestic use. Irrigation is used mainly in vegetable farming, a common practice along the Onyasia stream and urban areas in Ghana all year round; while in the peril-urban areas it is used mainly during the major dry season.

The Onyasia stream, the focus of this research serves as one of the streams in the Greater Accra region that empties its effluent into the Odaw River and into the sea. For some time now, human activities such as farming, settlements, dumping of refuse, littering has had diverse impact on the stream and these activities continue to affect water resources within their catchment area. Vegetable production along the Onyasia stream typically occurs in intensely managed smallholder farms or irrigation schemes with relatively high inputs of agrochemicals. These farming activities if not carefully monitored can lead to pollution of inland waters and biomagnifications of chemicals.

Urbanization is one of the most significant trends in Africa. While the concentration of people in cities makes sense economically, the growth of cities has been unplanned and has overwhelmed public service providers, especially in slums, where poor residents "squat" on unclaimed land with no access to municipal provisions of water, energy, and sanitation services. Settlements along the stream as a result of rural urban migration do have adverse impact on streams.

Many people rely on the streams for irrigated farming and others even for domestic use. Irrigation is used mainly in vegetable farming, a common practice in urban areas in Ghana all year round; while in the peri-urban areas it is used mainly during the major dry season. Most of the lands being

cultivated are near riverbanks, along stream courses or close to open drains for easy access to water. The demand for conservation and regulation has necessitated the need to identify the various sources of contaminants carried into the stream by runoff and intentional dumping of refuse. Information on the levels of physical parameters, microbial and nutrient loads of the Onyasia stream will be useful for government and public intervention.

1.3   OBJECTIVES

The main objective of the present study therefore was to determine the effect of anthropogenic activities on the water quality of the Onyasia stream in Accra.

SPECIFIC OBJECTIVES

The specific objectives of this study were to determine:

i.   the presence and levels of heavy metals (Al, Cu, Mn, Cd and Fe) in the Onyasia stream

ii.   the physico-chemical parameters (pH, temperature, turbidity, conductivity, TDS, DO, sulphates, phosphates, nitrate-nitrogen and ammonia nitrogen) of the Onyasia stream and

iii.   the presence and levels of total and faecal coliforms in the Onyasia stream.

CHAPTER TWO

LITERATURE REVIEW

"Water quality" is a term used here to express the suitability of water to sustain various uses or processes. Any particular use will have certain requirements for the physical, chemical or biological characteristics of water. For example, limits on the concentrations of toxic substances for drinking water use, or restrictions on temperature and pH ranges for water supporting

invertebrate communities. Consequently, water quality can be defined by a range of variables which limit water use. Although many uses have some common requirements for certain variables, each use will have its own demands and influences on water quality. Quantity and quality demands of different users will not always be compatible, and the activities of one user may restrict the activities of another, either by demanding water of a quality outside the range required by the other user or by lowering quality during use of the water. Efforts to improve or maintain a certain water quality often compromise between the quality and quantity demands of different users. There is increasing recognition that natural ecosystems have a legitimate place in the consideration of options for water quality management. This is both for their intrinsic value and because they are sensitive indicators of changes or deterioration in overall water quality, providing a useful addition to physical, chemical and other information (Meybeck *et al.,* 1996). Worldwide, water bodies are the primary dump sites for disposal of waste, especially the effluents from industries that are near them. These effluents from industries have a great toxic influence on the pollution of the water body, as they can alter the physical, chemical and biological nature of the receiving water body (Sangodoyin, 1991; Adekunle and Eniola, 2008). The initial effect of waste is to degrade the physical quality of the water. Later biological degradation becomes evident in terms of number, variety and organization of the living organisms in the water (Ewa *et al.,* 2011)). Often the water bodies readily assimilate waste materials they receive without significant deterioration of some quality criteria; the extent of this is referred to as its assimilative capacity (Ewa *et al.,* 2011). Industrialization is considered the cornerstone of development strategies due to its significant contribution to the economic growth and human welfare. Water contamination weakens or destroys natural ecosystems that support human health, food production, and biodiversity. Studies have estimated that the value of ecosystem services is double the gross national product of the global

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economy, and the role of freshwater ecosystems in purifying water and assimilating wastes has been valued at US$ 400 billion (Costanza *et al.,* 1997).

Freshwater ecosystems are among the most degraded on the planet by worsening water quality and quantity (UN WWAP 2009). They have suffered proportionately greater species and habitat losses than terrestrial or marine ecosystems, from factors that will likely grow worse in coming years (Revengai *et al*., 2000).

From the earliest days, streams were among the most important natural resources sought after.

A stream is classified as a body of water that flows across the Earth's surface via a current and is contained within a narrow channel and banks. A stream also known as body of water with a current, confined within a bed and stream banks. Depending on its locale or certain characteristics, a stream may be referred to as a branch, brook beck, burn, creek, "crick", gill, kill, lick, rill, river, syke, bayou, rivulet, streamage, wash, run or runnel (Wikipedia). Streams are important as conduits in the water cycle, instruments in groundwater recharge, and corridors for fish and wildlife migration. The biological habitat in the immediate vicinity of a stream is called a riparian zone. Streams typically derive most of their water from precipitation in the form of rain. Most of this water re-enters the atmosphere by evaporation from soil and water bodies, or by the evapo-transpiration of plants. Some of the water proceeds to sink into the earth by infiltration and becomes groundwater, much of which eventually enters streams. The rest of the water flows off the land as runoff, the proportion of which varies according to many factors, such as wind, humidity, vegetation, rock types, and relief.

Water quality in streams and rivers is influenced by a variety of factors. Point sources of pollutants are important, but in many areas non-point sources such as agricultural and urban runoff are larger

and more intractable problems. There have been significant research efforts aimed at understanding the link between agricultural practices and water pollution (Smith *et al.*, 1997). Pollutants can enter surface waters from point sources, such as single source industrial discharges and waste-water treatment plants; however, most pollutants result from nonpoint source pollution activities, including runoff from agricultural lands, urban areas, construction and industrial sites, and failed septic tanks. These activities introduce harmful sediments, nutrients, bacteria, organic wastes, chemicals, and metals into surface waters (Ribaudo, 1986). Nonpoint source pollution can be difficult to control, measure, and monitor. In most cases, a combination of practices is required to address the problem. Pollution is a very general term and is defined as the befouling of the environment by man''s activities particularly by the disposal of solid, gaseous and liquid wastes (Velz, 1970). Inevitably, unsustainable and wasteful use of resources leads to the production and accumulation of unwanted materials which require disposal on land, sea and air. A subject that is becoming important today is achieving a balanced ecosystem. A balanced ecosystem is that in which living things and the environments interact for beneficial use to one another. Obviously water quality plays a critical role in this relationship. Often overlooked is the need to have a clean supply of water to centres of recreation like fountains, ponds and pools. Natural water bodies such as Lakes, Rivers and Streams should contain water of good quality because they are the only natural water sources (Mann and Williamson, 1986).

2.1   IMPORTANCE OF STREAM WATER

Water is the most important liquid found on earth and the most familiar to man. It is vital for sustaining all life and for economic and social development, including energy production,

agriculture, industry and domestic water supplies. Water is considered an economically vital resource and should be used efficiently, equitably and soundly (UNESCO, 1997).

Fresh water, the most precious of our planets natural resources is a basic ingredient for supporting all life; therefore its resources must be characterized as finite and irreplaceable although its availability varies widely with geographic location (Lamb, 1985).

WHO (1993) stated that water sources must be protected from contamination by human and animal waste. It is better to protect water from contamination than to treat it after it has been contaminated to ensure that the quality of the water is satisfactory for human consumption.

Clean, safe, and adequate freshwater is vital to the survival of all living organisms and the smooth functioning of ecosystems, communities, and economies. But the quality of the world"s water is increasingly threatened as human populations grow, industrial and agricultural activities expand, and as climate change threatens to cause major alterations of the hydrologic cycle. Poor water quality threatens the health of people and ecosystems, reduces the availability of safe water for drinking and other uses, and limits economic productivity and development opportunities.

There is an urgent need for the global community – both the public and private sector – to join together to take on the challenge of protecting and improving the quality of water in our rivers, lakes, aquifers, and taps. To do so we must commit to preventing future water pollution, treating waters that are already contaminated, and restoring the quality and health of rivers, lakes, aquifers, wetlands, and estuaries; this enables these waters to meet the broadest possible range of human and ecosystem needs (UNEP, 2010). Natural processes that occur in small streams and wetlands provide humans with a host of benefits, including flood control, maintenance of water quantity and quality, and habitat for a variety of animals.

2.1.1 Small Streams Provide Natural Flood Control

Floods are a natural part of every river. When small streams are in their natural state, they absorb significant amounts of rainwater and runoff before flooding. However, when a landscape is altered, such as housing development, the runoff can exceed the absorption capacity of small streams. Humans often alter both landscape and stream channels in ways that result in larger and more frequent floods downstream. A key feature of streams and rivers is their shape. Unlike a concrete drainage ditch, a natural streambed does not present a smooth surface for water flow. Natural streambeds are rough and bumpy in ways that slow the passage of water. Particularly in small narrow streams, friction produced by a stream"s gravel bed, rocks, and dams of leaf litter and twigs slows water as it moves downstream. Slower moving water is more likely to seep into a stream"s natural water storage system-its bed and banks-and to recharge groundwater. Slower moving water also has less power to erode stream banks and carry sediment and debris downstream. In watersheds that are not carefully protected against impacts of land development, stream channels often become enlarged and incised from increased runoff. Changed channels send water downstream more quickly, resulting in more flooding (Meyer *et al.,* 2003).

Urbanization has similar effects; paving previously-vegetated areas leads to greater storm runoff, which changes urban stream channels and ultimately sends water more quickly downstream. Covering the land with impermeable surfaces, such as roofs, roads, and parking lots, can increase by several times the amount of runoff from a rainstorm. If land uses change near headwater streams, effects are felt throughout the stream network. In an urban setting, runoff is channeled into storm sewers, which then rapidly discharge large volumes of water into nearby streams. The additional water causes the stream to pick up speed, because deeper water has less friction with

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the streambed. The faster the water moves, the less it can soak into the streambed and banks. Faster water also erodes channel banks and beds, changing the shape of a channel. The effect is magnified downstream, because larger rivers receive water from tens, sometimes hundreds, of small headwater basins. Such changes are made near headwater streams, downstream portion of the stream network experience bigger and more frequent flooding (Meyer *et al.,* 2003).

2.1.2 Small Streams Maintain Water Supplies

Headwater systems play a crucial role in ensuring a continual flow of water to downstream freshwater ecosystems. Water in streams and rivers comes from several sources: water held in the soil, runoff from precipitation, and groundwater. Water moves between the soil, streams and groundwater. Wetlands, even those without any obvious surface connection to streams, are also involved in such exchanges by storing and slowly releasing water into streams and groundwater, where it later resurfaces at springs. Because of these interactions, groundwater can contribute a significant portion of surface flow in streams and rivers; conversely, surface waters can also recharge groundwater. If connections between soil, water, surface waters, and groundwater are disrupted, streams, rivers, and wells can run dry (Meyer *et al.,* 2003).

2.1.3 Natural Cleansing Ability of Small Streams Protects Water Quality

Materials that wash into streams include everything from soil, leaves and dead insects to runoff from agricultural fields and animal pastures. One of the key ecosystem services that stream networks provide is the filtering and processing of such materials. Healthy aquatic ecosystems can transform natural materials like animal dung and chemicals such as fertilizers into less harmful substances. Small streams and their associated wetlands play a key role in both storing and

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modifying potential pollutants, ranging from chemical fertilizers to rotting salmon carcasses, in ways that maintain downstream water quality (Meyer *et al.,* 2003).

2.1.4 Habitat for some living organism

Perhaps the most important function of streams is their role as the primary collectors and processors of organic matter that is ultimately transported to downstream systems. Organic matter entering headwater systems consists of leaves, woody debris, detritus, and waste products of plants and animals. Microorganisms living in the stream use this material for food, transforming the organic matter from an unusable form (inorganic carbon) into food for other organisms (organic carbon). This process is the basis of the food web in freshwater ecosystems.

Headwater streams are unique and diverse habitats that can support hundreds to thousands of species, including bacteria, fungi, algae, higher plants, invertebrates, fish, amphibians, birds, and mammals. Some of these species are headwater specialists, meaning they are abundant in or restricted to headwaters, and sometimes extend over only a short distance along the length of the stream. These streams are important as spawning and nursery habitats, seasonal feeding areas and also refuge from predators and competitors (Cappiella *et al.,* 2007).

2.2   Human activities that affect water quality

A wide range of human and natural processes affect the biological, chemical, and physical characteristics of water, and thus impact water quality. Contamination by pathogenic organisms, trace metals, and human-produced and toxic chemicals; the introduction of non-native species; and changes in the acidity, temperature, and salinity of water can all harm aquatic ecosystems and make water unsuitable for human use.

Numerous human activities impact water quality, including agriculture, disposal of domestic and human waste, population growth and urbanization. Agriculture can cause nutrient and pesticide contamination and increased salinity. Nutrient enrichment has become one of the planet's most widespread water quality problems (UN WWAP, 2009), and worldwide, pesticide application is estimated to be over 2 million metric tonnes per year (PAN, 2009). Industrial activity releases about 300-400 million tons of heavy metals, solvents, toxic sludge, and other waste into the world's waters each year (UN WWAP Water and Industry 2009).

Industrial waste is the most common source of water pollution in the present day (Ogedengbe and Akinbile, 2004) and it increases yearly due to the fact that industries are increasing because most countries are getting industrialized. The extent of discharge of domestic and industrial waste is such that rivers receiving untreated effluent cannot give dilution necessary for their survival as good quality water sources. The transfer of unfavourable releases from industries is detrimental to human and animal health and safety (Sangodoyin, 1991). There is, thus, a challenge of providing water in adequate quantity and of the required quality to minimize hazards to human health and conserve the water bodies and the environment. Wastewater discharge from sewage and industries are major components of water pollution, contributing to oxygen demand and nutrient loading of the water bodies, promoting toxic algal blooms and leading to a destabilized aquatic ecosystem (Morrison *et al.*, 2001). As a result of the contamination of water bodies with heavy metals, persistent organic pollutants, faecal materials and nutrients, serious health problems have resulted in 80% of diseases in developing countries being water related (Feugo, 2008).

2.2.1 Agricultural Activities

The vast extent of agricultural activities around the world contributes significantly to both economic productivity and water-pollutant loads. Since the 1970s, there has been growing concern over the increases in nitrogen, phosphorus, and pesticide runoff into surface and groundwater (UNEP, 1996).

According to various surveys in India and Africa, 20-50 percent of wells contain nitrate levels greater than 50 milligrams per liter, and in some cases as high as several hundred milligrams per liter (FAO, 1996). Recent data from UNEP GEMS/Water shows that mean nitrate concentrations have increased in the last decade in watersheds in the Americas, Europe, Australasia, and most significantly, in Africa and the eastern Mediterranean.Agricultural activities are not pollution free. More nutrients (nitrogen and phosphorus) are commonly applied than plants can use. The excess runs off into streams or sinks into groundwater. Fertilizer and, to a lesser extent, municipal sludge and the seepage from on-lot sewage systems add still more nitrogen and phosphorus to soils. Much of the applied nitrogen is naturally converted to nitrates which can travel great distances through soil and bedrock to groundwater or to nearby surface streams. Much of the excess phosphorus can be held in place by the soil and is therefore less mobile than nitrogen. Pesticides and herbicides are in many instances applied at an average annual rate of 23 pounds per acre of cropland. Even in small concentrations pesticides and herbicides can be a public health concern (Shiklomanov, 1997).

2.2.2 Residential and Commercial Development

Many communities and industries are connected to treatment plants, in which case their wastewater is collected and treated prior to being discharged to nearby surface streams. However development

almost inevitably leads to increased runoff, which collects pollutants before reaching surface streams. Some businesses and industries generate wastes which, when stored, can leak or spill into surface streams or groundwater if they are not controlled. Low-to-medium density development brings a proliferation of private wells and on-lot wastewater systems which, if not controlled, can result in health concerns regarding pathogenic microorganisms or nitrates. Homeowners also tend to use excessive fertilizer and pesticide on lawns. Development can harm local surface and ground water so that it cannot safely be used as drinking water. When groundwater is found at shallow depths, pollutants from the surface are not filtered out before reaching the groundwater. Pollutants reaching groundwater sources are difficult to remove and may make groundwater supplies for water supply unattractive for future water supply development. Development can also cause problems with the quantity of surface and groundwater. When land is covered with pasture or forest, water sinks in and replenishes groundwater. Or it enters surface streams at a moderate rate so that flooding is reduced. When more land is covered with concrete and rooftops, water runs off more quickly and pollutants are not filtered out. Streams become degraded and provide poor habitat for fish and the small creatures that make up the food chain for fish. Stream banks erode more quickly, flood more often, and are shallower during dry spells (Shiklomanov, 1997).

2.2.3 Urbanization

Urbanization is often taken to mean an increase in the physical size of urban centers and urban population growth. The interaction between these two, i.e. urban population growth and the physical expansion depends on urban density. The former is often used as an indicator the of the impact of urbanization on environment, because of the potential for increase in the amount of land required for urban areas and the impact of activities such as waste generation that take place within urban centers. This phenomenon has also become associated with intensification of agriculture, especially urban agriculture and the growth and expansion of industries (Shiklomanov, 1997).

2.3   The Quality of Surface Water

The quality of surface water is constantly changing in response to daily, seasonal and climatic rhythms. The quality of natural surface waters is complex, and depends on the equilibrium reached with the normal physical, chemical and biological characteristics of the surrounding environment. Thus, all surface water will have different composition. To some extent, the surface water quality will depend on the type of vegetation covering the watershed, since the products of plant decay will find their way into the streams draining the area. Water draining coniferous forests tends to be acidic (Svobodova *et al.,* 1993). A number of factors influence water chemistry; rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry of surface water. These are examples of natural causes of differences in water quality (Gibbs, 1970). Some indication has already been given of the added impact that can be caused by man"s activities. Metal mining, by increasing the surface area of exposed rock to rainfall, can cause elevated concentrations of metals in draining water. Commercial forestry can cause an increase in the suspended mineral solids in the water after areas have been cleared by cutting and logging. Intensive agriculture can contribute fertilizers and pesticides applied to arable crops (Svobodova *et al.,* 1993).

2.4   Sources of Pollution

Water pollution is any physical, chemical, or biological change in the quality of water that has harmful effect on any living organism that drinks or uses or lives in the water. When humans drink polluted water it often has serious effects on their health. Water pollution involves the introduction

of anything which adversely and unreasonably impairs the beneficial use of water even though actual health hazard is not involved (Klein *et al.*, 1962).

Source of water pollution includes natural pollution source and manmade ones. The natural pollution sources generally include volcanoes, algal bloom, storms and earthquakes which cause major changes in water quality and ecological status of water bodies. Some water pollution comes from diffuse or non-point sources (Fish, 1995). For instance, airborne pollutants (from automobiles, factories and power plants) and waterborne pollutants (from cropland, feed lot, and logged forests, urban areas) can contribute significantly to stream basin pollution (WRI, 1992).

Apart from industrial and municipal wastes, which represent specific point sources, other specific sources of pollutants are bad land-use practices leading to soil erosion, the use of agricultural chemicals to increase yields, livestock and human waste when managed poorly add to the organic pollution of water bodies (Ogolla, 1989). Agriculture exists within a symbiosis of land and water. The FAO therefore suggested that appropriate steps be taken to ensure that agricultural activities do not adversely affect water quality so that subsequent uses of water for different purposes are not impaired (FAO, 1996).

2.5   Indicators of water quality

The quality of any water body is governed by its physicochemical and heavy metal factors. The monitoring of physicochemical characteristics of a water body is vital for both long term and short term evaluation of its quality (Ewa *et al*, 2011). In determining the quality of any water, the characteristics of the water must be clearly stated. For streams, it may include the following parameters, turbidity, temperature, conductivity, total dissolved solids, among others.

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2.6 WATER POLLUTANTS

2.6.1 Physical pollutants

Measurements of a stream"s physical attributes can serve as indicators of some forms of pollution. For example, changes in pH may indicate the presence of certain effluents such as metals, while changes in turbidity may indicate dredging in the area (Kortatsi, 2007). Other commonly measured physical characteristics of a stream include temperature, total dissolved solids, dissolved oxygen and conductivity.

pH

The most commonly measured chemical attribute of water is its acidity or pH. The pH of a solution is a measure of the acidic nature of that solution, thus, the concentration of the hydrogen ions present in that solution. The hydrogen ion (H^+) activity in a solution determines the pH. The pH scale ranges from 1 to 14, with 1 being the most acidic, 7 being neutral and 14 being the most basic. Most streams have a neutral to slightly basic pH of 6.5 to 8.5. If stream water has pH less than 5.5, it may be too acidic for fish survival whilst if stream water has a pH greater than 8.6 may be too basic (WHO, 2004). A change in stream water pH can also affect aquatic life indirectly by altering the other aspect of water chemistry. For example, low pH levels can increase the solubility of certain heavy metals. This allows the metals to be more easily absorbed by aquatic organisms. The WHO also set protection limits of pH from 6-9 for fisheries and other aquatic life (WHO, 2004).

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Alkaline water can act as a weak buffer solution, depending on the concentration of carbonates and bicarbonates. Therefore an acidic pollutant may be present in such water, yet may not cause a change in pH of the stream (APHA, 1998).

Turbidity

Turbidity in water is caused by the presence of suspended matter, such as clay, silt, fine particles of organic and inorganic matter, plankton and other microscopic organisms. The standard measure of turbidity is an expression of the optical property of a water sample which causes light to be scattered and absorbed rather than transmitted in straight lines through the sample. As the number of particles increases, more light is scattered, and higher turbidity readings are obtained (Shelton and Scibilia, 2005). High turbidity levels can reduce the efficiency of disinfection by creating a disinfection demand. The particles may also provide absorption sites for toxic substances in the water. It may protect pathogens from disinfection by absorbing or encasing them, and may interfere with total coliform analysis (USEPA, 1995).The measuring instrument is called a turbidimeter, and the readings are expressed as nephelometric turbidity units (NTU) or turbidity units (Shelton and Scibilia, 2005).

Temperature

Temperature impacts both the chemical and biological characteristics of surface water. It affects the dissolved oxygen level in the water, photosynthesis of aquatic plants, metabolic rates of aquatic organisms, and the sensitivity of these organisms to pollution, parasites and disease. Warm water is less capable of holding dissolved oxygen. For this reason, temperature should be measured at the same place within the stream at which dissolved oxygen is measured. This allows the correlation between the two parameters to be observed. The problem of low dissolved oxygen levels is magnified by the fact that the metabolic rates of aquatic plants increase as water

temperature rises, thus increasing their biochemical oxygen demand. Low dissolved oxygen levels leave aquatic organisms in a weakened physical state and more susceptible to disease, parasites, and other pollutants. Water temperature is measured with a thermometer in either degree Celsius (^{o}C) or degree Fahrenheit ($^{\circ}$F).

Conductivity

Conductivity is the ability of water to carry an electrical current. It indicates the presence of ions in the water. For example, when sodium chloride (NaCl) dissolves in water, it dissociates into Na^{+} and Cl^{-} ions. Generally, the conductivity of a stream is lowest at the source of its catchment and so as it flows along the course of the stream; it leaches ions from the soil and also pricks up organic materials from biota and its detritus (Ferrar, 1989), thereby increasing the electrical conductivity. The movement of these ions conducts electricity through the water. The dissociation of naturally-occurring, inorganic compounds is the main source of ions in stream water. Conductivity can also increase as a result of heavy metal ions released from pollutants such as acid mine drainage. The presence of inorganic compounds makes water exhibit high conductivities (Ntengwe, 2006). It is reported in micro Siemens per centimeter (µS/cm) using a conductivity meter. The average conductivity value of a typical, unpolluted stream is approximately 350µS/cm (Koning and Roos, 1999).

Total Dissolved Solids

TDS is the sum of all materials dissolved in the water. The presence of solids is partially responsible for both the apparent color and cloudiness or turbidity of a water source. These may

be organic impurities and may lend odor and taste to the water. They may also be inorganic in nature and may be responsible for high conductivity values of the water.

Measuring Total dissolved solids give a very good indication of the suitability of a water source for domestic use. High TDS values make the water salty and less palatable compared with one moderate minerals content. TDS has no health-based guideline value. The WHO has recommended a guideline value of 1000 mg/l for TDS based on taste and other aesthetic effect rather than health effects (WHO, 1996).

Dissolved Oxygen

Vital to aquatic life, oxygen enters the water by diffusion from the atmosphere or through plant photosynthesis. Actual solubility is directly proportional to the partial pressure in the gas phase, to salt concentration and temperature. The dissolved oxygen level in water is constantly changing and represents a balance between respiration and decomposition that deplete oxygen and photosynthetic activity that increases it. Organic waste may overload a natural system causing a serious depletion of the oxygen supply in the water that in turn leads to fish kills. Likewise, eutrophic waters, that are rich in nutrients, achieve the same result through causing massive proliferation of algae (algal blooms) whose eventual decomposition uses up the available dissolved oxygen (Alken Murray Corp.). The amount of oxygen that can dissolve in water is limited by physical conditions such as temperature and atmospheric pressure. Fish growth and activity usually require 5 - 6 mg/L of dissolved oxygen. Dissolved oxygen below 3 mg/L is stressful to most aquatic organisms. Levels below 2 mg/L will not support fish life at all. Low dissolved oxygen levels can be the result of elevated temperature and thus the inability of the water to hold the available oxygen. Low dissolved oxygen levels can also indicate an excessive demand on the oxygen in the system. Pollutants such as sewage and agricultural run-offs result in the buildup of organic matter in stream

water. Microbial decomposers use dissolved oxygen in the water to break down the organic matter during extra-cellular digestion (www.lenntech.com).

2.6.2 Chemical Pollutants

Assessment of water quality by its chemistry includes measurements of many elements and molecules dissolved or suspended in the water. Chemical measurements can be used to directly detect pollutants such as lead or mercury. Chemical measurements can also be used to detect imbalances within the ecosystem. Such imbalances may indicate the presence of certain pollutants. Commonly measured chemical parameters include nitrates, nitrites and ammonia, total phosphates, (APHA, 1998).

Phosphates

According to the United States Environmental Studies Board (2003), Phosphates come from fertilizers, pesticides, industry and cleaning compounds. Phosphates enter waterways from human and animal wastes, phosphate-rich rocks, and wastes from laundries, cleaning, industrial processes and farm fertilizers. Phosphates are also used widely in power plant boilers to prevent corrosion and the formation of scale (United States Geological Survey, 1970). Organic phosphates are important in nature. Their occurrence may result from the breakdown of organic pesticides which contain phosphates. They exist in solution as particles, loose fragments or in the bodies of aquatic organisms. Rainfall can cause varying amounts of phosphates to wash from farm soils into nearby waterways (USGS, 1970).

Phosphorus (P), like nitrogen (N, found in ammonia, nitrite, nitrate), is an important nutrient for plants and algae. Because phosphorus is in short supply in most fresh waters, even a modest

increase in phosphorus can cause excessive growth of plants and algae that deplete dissolved oxygen (DO) as they decompose. Excessive growth can also reduce the transparency of the water. Much of the excess phosphorus available to plants in the environment comes from farm and lawn fertilizers, runoff containing soil-bound phosphate, yard waste, and run-off from animal feedlots, storm water, and certain industrial wastewaters.

Sulphate

Sulphates (SO_4^{2-}) occur in almost all natural waters. Sources of sulphate in natural water systems can be from industrial wastes such as mining, from wood preservation and through atmospheric deposition as acid rain. However, the highest levels that occur in groundwater are from natural sources (WACAM, 2008).

The presence of sulphate in drinking water results in a noticeable change of taste. The lowest taste threshold concentration for sulphate is set to be approximately 250 mg/l whilst the aesthetic objective for sulphates in drinking water is set at 500 mg/l (Shelton, 2000). At levels above 600 mg/l, it may act as a purgative in humans. The physiological effects resulting from the intake of large quantities of sulphate in water may vary from catharsis, dehydration and gastrointestinal irritation. In addition, excess sulfate may also contribute to hardness of water and cause corrosion of drinking water distribution systems. Under anaerobic conditions, sulphate in water may be reduced to H_2S and this can give the water source an unpleasant or rotten eggs smell (Shelton, 2000).

Nitrate- Nitrogen

Nitrite and nitrate are sources of nitrogen (N), an important nutrient for plants and algae. As ammonia (NH_3) is broken down by bacterial action, nitrite is formed and is then converted to the

more stable, much less toxic nitrate through a process called "nitrification." The typically low natural levels of nitrate in surface water can be supplemented with nitrate from human sources. Nitrate from the fertilizer not taken up by crops in fields and grass in lawns can enter water bodies in runoff. Nitrate can also enter water bodies from wastewater discharge or runoff from feedlots. Once in the water, nitrates can stimulate excessive plant and algal bloom. Decomposition of the plant and algal material by bacteria can deplete dissolved oxygen (DO), adversely impacting fish and other aquatic animals (IWI, 2010).

Ammonia-nitrogen

Ammonia-nitrogen is an inorganic, dissolved form of nitrogen that can be found in water and is the preferred form for algae and plant growth. Ammonia is the most reduced form of nitrogen and is found in water where dissolved oxygen is lacking. When dissolved oxygen is readily available, bacteria quickly oxidize ammonia to nitrate through a process known as nitrification. Other types of bacteria produce ammonia as they decompose dead plant and animal matter. Depending on temperature and pH (a measurement of acidity), high levels of ammonia can be toxic to aquatic life. High pH and warmer temperatures increase the toxicity of a given ammonia concentration. High ammonia concentrations can stimulate excessive aquatic production and indicate pollution. Important sources of ammonia to lakes and streams can include: fertilizers, human and animal wastes, and byproducts from industrial manufacturing processes (Nitrogenous compounds; Ammonia Nitrogen) (IWI, 2010).

2.6.3 Heavy metals in water

Heavy metals are elements with atomic weights between 63.546 and 200.590 (Kennish, 1992), and a specific gravity > 4.0. They are required by living organisms in trace amounts. Examples include

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aluminium, manganese, copper, cadmium and iron. Heavy metal pollution of aquatic ecosystems is becoming a potential global problem. Third world countries such as Uganda, lack for mechanisms and sensitive tools to detect and monitor water quality and are therefore exposed to heavy metal poisoning (Ochieng *et al.*, 2008). Trace amounts of heavy metals are always present in fresh waters from terrigenous sources such as weathering of rocks resulting into geochemical recycling of heavy metal elements in these ecosystems (Muwanga, 1997; Zvinowanda *et al.,* 2009). Heavy metals may enter into aquatic ecosystems from anthropogenic sources, such as industrial wastewater discharges, sewage wastewater, fossil fuel combustion and atmospheric deposition (Linnik and Zubenko, 2000).

The content of heavy metals in waste is primarily a consequence of the intended use of heavy metals in industrial products. At the end of their useful life all products will end up in waste to the extent they are not attractive for recycling. Heavy metals may, however, also be lost to waste during production and use phases. Losses in the manufacturing process are often disposed of as manufacturing waste, while products may be exposed to wear and tear inclusive corrosion during the use phase (European Commission, 2002).

Excessive levels of these essential metals, however, can be detrimental to organisms, as they affect metabolic and other biological processes. Others referred to as non-essential heavy metals include arsenic, cadmium, chromium, lead and mercury (Kennish, 1992). These may originate from industrial discharges, wastewater effluent, run-off from city streets, and a variety of other sources. Agriculture also contributes heavy metals as these elements are contained in some pesticides or as trace elements in fertilizer products.

Aluminium

Aluminium is the third most abundant element in the earth's crust after oxygen and silicon. It occurs in nature in combination with other elements such as oxygen, silicon and fluoride. Traditionally aluminium has been considered as nontoxic to humans. However, in recent years, increased attention is being focused on possible adverse effects of aluminium on human health. Human exposure to aluminium is from its natural occurrence in the environment i.e. through food, water and air as well as from aluminium deliberately introduced into the environment by man (Gidde *et al.,* 2012). A silvery and ductile member of the poor metal group of elements, aluminium is found primarily as the ore bauxite and is remarkable for its resistance to oxidation (aluminium is actually almost always already oxidized, but is usable in this form unlike most metals), its strength, and its light weight. Aluminium is used in many industries to make millions of different products and is very important to the world economy. Structural components made from aluminium are vital to the aerospace industry and very important in other areas of transportation and building in which light weight, durability, and strength are needed. The use of aluminium exceeds that of any other metal except iron. Pure aluminium easily forms alloys with many elements such as copper, zinc, magnesium, manganese and silicon. The effects of aluminium have drawn our attention, mainly due to the acidifying problems. Aluminium may accumulate in plants and cause health problems for animals that consume these plants. High aluminium concentrations do not only cause effects upon fish, but also upon birds and other animals that consume contaminated fish and insects and upon animals that breathe in aluminium through air. The consequences for birds that consume contaminated fish are eggshell thinning and chicks with low birth-weights. The consequences for animals that breathe in aluminium through air may be lung problems, weight loss and a decline in activity. Another negative environmental effect of aluminium is that its ions can react with phosphates, which causes phosphates to be less available to water organisms. High concentrations

of aluminium may not only be found in acidified lakes and air, but also in the groundwater of acidified soils. There are strong indications that aluminium can damage the roots of trees when it is located in groundwater (http://www.lenntech.com/periodic/elements/al.htm).

Manganese

Manganese is a very common compound that can be found everywhere on earth. Manganese is one out of three essential but toxic trace elements, which means that it is not only necessary for humans to survive, but it is also toxic when too high concentrations are present in a human body. When people do not live up to the recommended daily allowances their health would decrease.

But when the uptake is too high health problems would also occur (http://www.lenntech.com/periodic/elements/mn.htm).

Manganese compounds exist naturally in the environment as solids in the soils and small particles in water. In air, manganese particles are present in dust particles. These usually settle to earth within a few days. Humans enhance manganese concentrations in the air by industrial activities and through burning fossil fuels. Manganese that derives from human sources can also enter surface water, groundwater and sewage water. For example, through the application of manganese containing pesticides, manganese would enter soils

 (http://www.lenntech.com/periodic/elements/mn.htm).

For animals manganese is an essential component of over thirty-six enzymes that are used for carbohydrate, protein and fat metabolism. Animals that eat too little manganese interference of normal growth, bone formation and reproduction will occur. In plants manganese ions are transported to the leaves after uptake from soils. When too little manganese is absorbed from the soil this causes disturbances in the plant‟s physiological mechanisms. For instance disturbance of the division of water to hydrogen and oxygen, in which manganese plays an important part

(http://www.lenntech.com/periodic/elements/mn.htm). Manganese can be both toxic and also cause deficiency symptoms in plants. When the pH of the soil is low manganese deficiencies are more common. Highly toxic concentrations of manganese in soils can cause swelling of cell walls, withering of leave and brown spots on leaves. Deficiencies can also cause these effects. Between toxic concentrations and concentrations that cause deficiencies a small area of concentrations for optimal plant growth can be detected

(http://www.lenntech.com/periodic/elements/mn.htm).

Cadmium

Cadmium is found in very low concentrations in most rocks, as well as in coal and petroleum. Mostly, cadmium is found in combination with zinc (WHO, 1992). Cadmium uses include electroplating, nickel-cadmium batteries, paint and pigments, plastic stabilizers (WHO, 1992). It is introduced into the environment from mining, smelting and industrial operations, including electroplating, reprocessing cadmium scrap and incinerating cadmium containing plastics. The remaining cadmium emissions are from fossil fuel use, fertilizer application, and sewage sludge disposal. Cadmium may enter drinking water as a result of corrosion of galvanized pipe. Landfill leachates are also an important source of cadmium in the environment (Wester *et al.,* 1992).

Acute and chronic exposure to cadmium in animals and humans result in kidney dysfunction, hypertension, anaemia, and liver damage (Wester *et al.*, 1992).

Cadmium may enter aquatic systems through weathering and erosion of soils and bedrock, atmospheric decomposition of direct discharges from industrial operations, leakage from landfills and contaminated sites and the dispersive use of sludge and fertilizers in agriculture. Much of the cadmium entering fresh waters from industrial sources may be rapidly adsorbed by particulate matter and thus sediment may be significant sink for cadmium emitted to the aquatic environment

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(WHO, 1992). Rivers containing excess cadmium can contaminate surrounding land, either through irrigation for agricultural purposes, dumping of dredged sediments or flooding. It has also been demonstrated that rivers can transport cadmium for considerable distance up to 50 km from the source (WHO, 1992).

Copper

Copper is a very common substance that occurs naturally in the environment and spreads through the environment through natural phenomena. Humans widely use copper. For instance it is applied in the industries and in agriculture. The production of copper has lifted over the last decades. Due to this, copper quantities in the environment have increased. The world's copper production is still rising due to this reason. This basically means that more and more copper ends up in the environment. Rivers are depositing sludge on their banks that is contaminated with copper, due to the disposal of copper-containing wastewater. Copper enters the air, mainly through release during the combustion of fossil fuels. Copper in air will remain there for an eminent period of time, before it settles when it starts to rain. It will then end up mainly in soils. As a result soils may also contain large quantities of copper after copper from the air has settled.

Copper can be released into the environment by both natural sources and human activities. Examples of natural sources are wind-blown dust, decaying vegetation, forest fires and sea spray. A few examples of human activities that contribute to copper release have already been named. Other examples are mining, metal production, wood production and phosphate fertilizer production. Because copper is released both naturally and through human activity it is very widespread in the environment. Copper is often found near mines, industrial settings, landfills and waste disposals (http://www.lenntech.com/periodic/elements/cu.htm).

Iron

According to Antonovics *et al.,* (1971), metallic iron occurs in the free state and is distributed and ranked in abundance among the entire elements in the earth‟s crust, next to aluminium. The combination of naturally occurring organic materials and iron can be found in shallow wells and surface. The type of iron is usually yellow or brown but may be colorless (IDPH, 1999). Dissolved iron that reaches surface water reacts with oxygen to form rust and precipitates out to the bottom of the stream. Dissolved iron is common in groundwater because dissolved oxygen is typically low. When groundwater with dissolved iron is brought to the surface in a well, the iron reacts with oxygen and is converted to visible red rust particles. It is also possible for iron to enter drinking water if it is dissolved from metal pipes (Sigler *et al*., 2011)

2.6.4 Bacteriological Indicators

Faecal Coliform and Total Coliform

Faecal Coliform

Faecal coliforms are bacteria that occur in the digestive tracts of warm-blooded animals which aids in the process of digestion. Faecal coliforms can enter stream by direct discharge from mammals and birds, from agricultural runoff, or from broken or open sewers. Faecal coliform is itself non-pathogenic. High levels of faecal coliform – greater than 200 colonies per 100 mL of water are

good indicator of the presence of pathogenic microorganisms. Health risks include induction of illness through exposure of recreational swimmers and boaters to pathogen and consumption of undercooked or raw food that have accumulated pathogens. They can result in health problems like common diarrhea and ear infections to deadly diseases like hepatitis, cholera and typhoid fever. Therefore, it is suggested that one does not have total body contact with water containing levels of faecal coliform greater than 200 colonies per 100 mL of water (WHO, 2004).

Total Coliform

These bacterial are used as an indicator of the microbiological quality of water. Their detection in drinking water indicates that, the source is probably environmental, and faecal contamination is not likely. Total coliform bacterial is the most common pollution in rainfall and runoff water (Hill *et al*., 2006) and direct heating to temperature of 65°C or above, reduces total coliform in naturally contaminated river water (Fjendbo *et al*., 1998). Total coliforms are used as indicators to measure the degree of pollution and sanitary quality of river water.

CHAPTER THREE

MATERIALS AND METHODS

3.1   DESCRIPTION OF STUDY AREA

The study was carried out within the Ayawaso West sub-metro in the Greater Accra Region. The sub-metro houses the Oponglo and Dzorwulu sections of the Onyasia Stream.

Accra is the capital of the Republic of Ghana and the Greater Accra Region was founded by the Ga people in the late 1600s. It is the country‟s most populous city and serves as the administrative,

communications, and economic heart of the country. Over 70% of Ghana‟s manufacturing capacity is located within this region.

The Accra metropolitan area has a total land size of 200 km^2 and lies within Longitude $0^o.03$ and $0^o.25$ West and Latitude $5^o.30$ and $5^o.53$ north. The city lies along the Atlantic coast and stretches north into the interior. It stretches from Botianor to Sakumo, and James Town to Oyarifa. Tema bounds it on the East, on the South by the sea, West by the Weija dam, and North by the Akwapim hills. The metroplolis is made up of eleven sub metros. These are Ablekuma Central, Ablekuma North, Ablekuma South, Ashiedu Keteke, Ayawaso Central, Ayawaso East, Ayawaso West-Wuogon, La, Okaikoi North, Okaikoi South, and Osu Klottey (AMA, 2006).

3.1.1 Demographic and Socio-economic Data of the Study Area

According to the Ghana Statistical Service (2002), the population of Accra has doubled between 1984 and 2000. The population of Accra has increased from 1,431,099 in March 1984 to 2,903,753 in March 2000. Recent statistics indicate 43.8% urban dwellers in 2000 as against 9% in 1931. Accra alone, according to the 2000 census, represents 25% of the urban dwellers in Ghana, increasing at 4.2% per annum. The population growth rate is estimated at 3.4% per annum in the city itself but up to 10% in its peri-urban districts (Ghana Statistical Service, 2002). The population as at 2010 had increased to 3,963,264.

The occupational structure of the region shows that 42.0% of the economically active population is engaged in sales and services, with professional, technical and their related workers comprising 10.8%. The industrial sector is dominated by wholesale and retail trade (30.4%) and manufacturing made up of 16.7% (Ghana Statistical Service, 2002).

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3.1.2 Rainfall

The rainfall of Accra is tropical and falls within the wet sub-equatorial type with two rainy seasons. The first occurs from April to July with peaks in May and June, about 19.8 mm average rainfall, and the second from September to November with the peak in October with 6.4 mm average rainfall. The yearly rainfall is 75 mm, which fall primarily during the two seasons. The coldest time of the year is between June and September, when the main rainfall occurs.

3.1.3 Temperature

There is very little variation in temperature throughout the year. Due to Accra‟s location adjacent to the ocean, the temperature is fairly stable from 24.7ºC in August, which is the coldest to 28°C in March, the hottest with an annual average of 26.8°C. The minimum temperature is about 23°C. The area is warm and comparatively dry. In between the rainy seasons, Accra experiences the harmattan, which is a hot dry desert wind, blowing from the northeast from December to March, lowering the humidity and creating hot days and cool nights in the north (AMA 2006).

3.1.4 Topography, Geology and Soil Type

The city is characterized by lowlands and occasional hills with an average altitude of 20m above sea level. The slopes are generally gentle with most slopes below 11 percent, except few places such as MaCarthy hills, the television transmitting station near Abokobi and Kwabenya hills, where slopes are above 22 percent. The water table varies between 4.80 m to 70 m below the surface at places like Ofankor, Kantamanso and Accra Brewery Limited bottling house in Accra. The geology of Accra consists of Precambrian Dahomeyan schists, granodiorites, granites gneiss and amphibolites to late Precambrian Togo series comprising mainly quartzite, phillites, phylitones and quartz breccias. Other formations found are the palaeozoic accraian sediments, that is,

sandstone, shales and interbedded sandstone-shale with gypsum lenses. The coastline of Accra comprises a series of resistant rock outcrops, platforms and sandy beaches near the mouth of the lagoons (AMA, 2006).

The soils in the metropolitan area can be divided into four main groups: drift materials resulting from deposits by windblown erosion; alluvial and marine motted clays of comparatively recent origin derived from underlying shales; residual clays and gravels derived from weathered quartzites, gneiss and schist rocks, and lateritic sandy clay soils derived from weathered Accraian sandstone bedrock formations. In many low lying poorly drained areas, pockets of alluvial „black cotton" soils are found. These soils have a heavy organic content, expand, and contract readily causing major problems with foundations and footings. In some areas, lateritic soils are strongly acidic and when saturated are prone to attack concrete foundations causing honeycombing. Near the foothills are the large areas of alluvial laterite gravels and sands. Many of these deposits are being exploited in an uncontrolled manner for constructional purposes (AMA, 2006).

3.1.5 Water Course and Drainage

The area is drained through by natural streams and valley network and artificial drains. Most of the streams like Odaw, Sakumo, Mahahuma, Lador, and Dzorwulu, take their source from the Akwapim range. The artificial drainage is mostly built-up structures that enable quick discharge of waste and storm water.

3.1.6 Land Use and Vegetation

There are three broad vegetation zones in the metropolitan area, namely, shrub land, grassland and coastal lands. The shrub land occurs more commonly in the western outskirts and in the north towards the Aburi hills. It consists of dense clusters of small trees and shrubs, which grow, to an

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average height of five metres. The grasses are a mixture of species found in the undergrowth of forests. They are short, and rarely grow beyond one metre. Ground herbs are found on the edge of the shrub. They include species, which normally flourish after fire. The coastal zone comprises two vegetation types, wetland and dunes. The coastal wetland zone is highly productive and an important habitat for marine and terrestrial, mainly bird life. Mangroves, comprising two dominant species, are found in the tidal zone of all estuaries sand lagoons. Salt tolerant grass species cover substantial low-lying areas surrounding the lagoons. In recent times, wetlands are however being encroached upon. Protection of the coastal wetland zone is very important to the long-term sustainability of the fish industry, which the Ga population of Accra depend upon.

The dune lands have been formed by a combination of wave action and wind. They are most unstable but stretch back several hundred meters in places. There are several shrub and grassland species, which grow and play an important role in stabilizing dunes. Neems, mangoes, cassias, avocados, and palms are prominent trees on the Accra landscape. Introduced shrubs like bougainvillea are also very prominent. These are being damaged by residential encroachment, bush fire, sand collection and illegal tree felling. Within the study area, food crops cultivated along the stream are mainly vegetables such a lettuce, carrots, cabbage and other vegetables.

Farmers along the stream use its water to irrigate the farms.

Plate 1a: Section of the Onyasia stream at Emmanuel Eye Clinic, East Legon
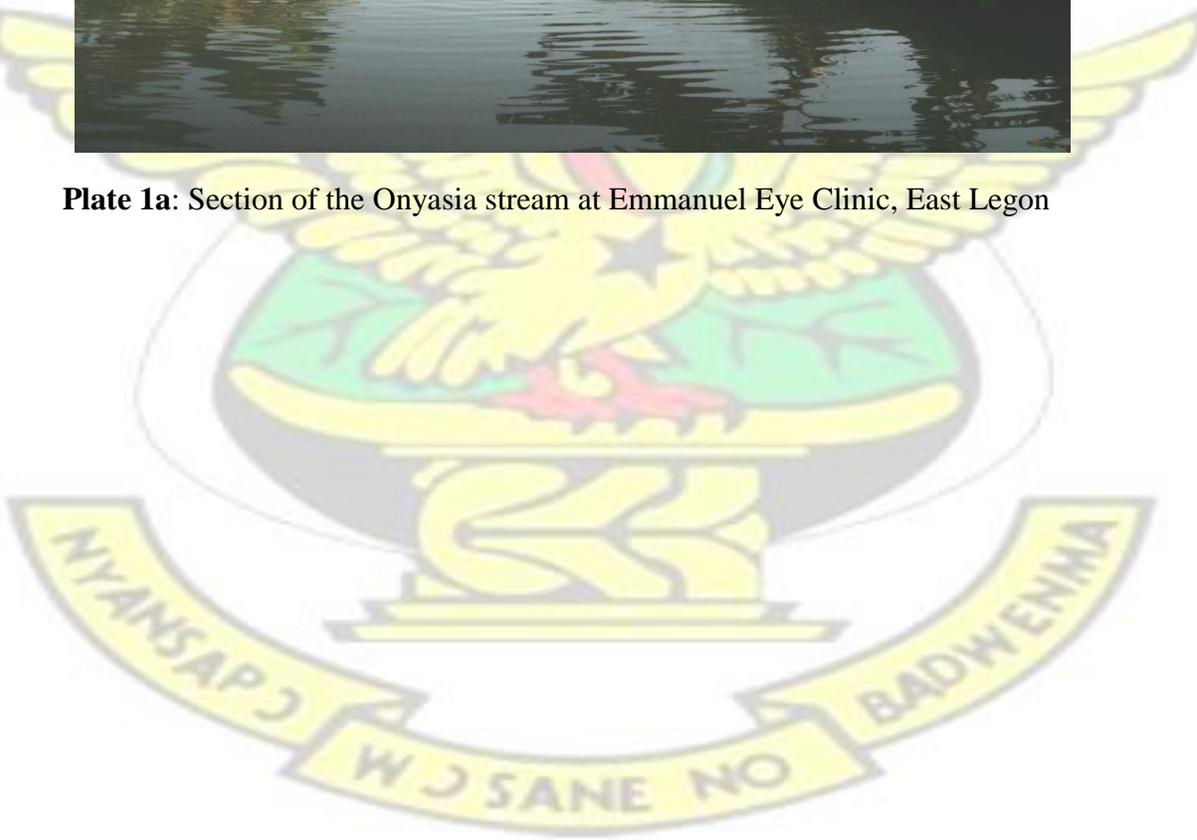
Plate 1b: Section of the Onyasia stream at Okponglo, East Legon

3.2   SAMPLING SITE

The study was carried out along the Onyasia stream which runs through some communities within Accra metropolis. A map showing the course of the Onyasia stream and the sample collection points is shown in Fig 1.

The Onyasia stream also known as the Nima creek which takes its source from the Akwapim mountain and flows through the Oponglo through Tetteh Quarshie, Dzorwulu and JA Plant Pool area, ends up joining the Odaw river was selected for the study, (Fig 1.). Sections of the Onyasia stream are shown in Plate 1a and 1b.

Five sampling sites located at different communities were selected for this study (Fig 1). These sites were chosen based on accessibility, activities along the stream. Sampling site and location of sampling site (community from which the samples were taken), and the Global Position System (GPS) readings of the locations are presented in Table 1.
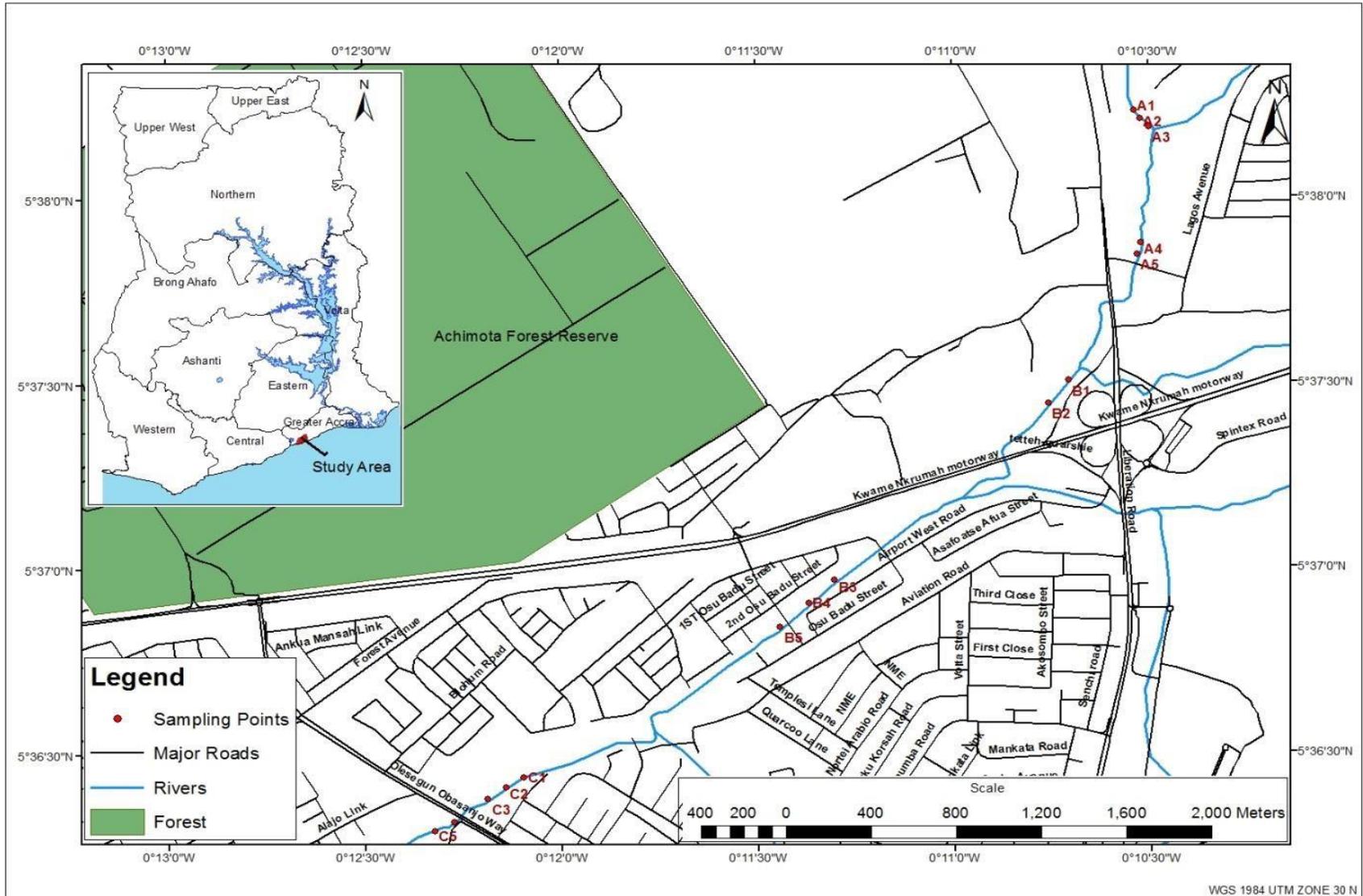
Fig 1: Map showing project location in Ghana and sampling sites along the Onyasia stream in the Greater Accra Region.

Table 1: Table showing the Global Positioning System (GPS) readings of sampling locations

Location	Sampling Code	GPS Reading	
		LATITUDE	LONGITUDE
OKPONGLO	A1	5.637203	-0.175676
	A2	5.636792	-0.175448
	A3	5.636367	-0.175238
	A4	5.631211	-0.175469
	A5	5.630734	-0.175542
TETTEH QUARSHIE CIRCLE (Area behind Tullow Head Office)	B1	5.625053	-0.178489
	B2	5.62403	-0.179331
	B3	5.616075	-0.18844
	B4	5.615091	-0.189563
	B5	5.61405	-0.190829

DZORWULU (Area behind ECG sub-station and JA plant pool)	C1	5.607255	-0.201658
	C2	5.606791	-0.202433
	C3	5.606293	-0.203191
	C4	5.605234	-0.204611
	C5	5.604826	-0.205432

3.3   COLLECTION OF WATER SAMPLES

To avoid contamination of the sample, the container used for collection of water samples were thoroughly cleaned with de-ionised water. Plastic containers of 0.5 litre size were used for the collection of water samples.

Five (5) samples each of water from upstream, midstream and downstream will be randomly collected from different points into 0.5 Litre bottles. The upstream being the area at Okponglo, midstream behind Tullow Head office & Tetteh Quarshie Circle and downstream, behind Dzorwulu ECG sub-station and J.A. plant pool (Fig.1).

3.3.1 Preparation of sampling containers

Sample containers were soaked in 4M nitric acid overnight and were washed with distilled water, rinsed with de-ionized water and dried in a drying cabinet (Anon, 2000). Sample bottles of volume 0.5 litre were rinsed with water from the respective sampling sites, thrice before actual sample collection was undertaken.

3.3.2 Sample containers labelling

Samples collected from the Okponglo area representing the upstream area was labelled as follows; A1, A2, A3, A4 and A5 for first, second, third, fourth and fifth sampling respectively. Samples from area behind Tullow Head Office, Tetteh Quarshie and part of Dzorwulu were labelled as B1, B2, B3, B4 and B5 for the sixth, seventh, eighth, ninth and tenth sampling respectively. Finally, samples taken from area from the Dzorwulu E.C.G sub-station area were labelled C1, C2, C3, C4 and C5 for eleventh, twelfth, thirteenth, fourteenth and fifteenth sampling respectively.

3.3.3 Duration and frequency of Sampling

Sampling was done in the dry season between December 2012 and January 2013 and during the wet season between May and June 2013. Samples were collected from morning to afternoon. A total of 60 samples were collected during that period.

3.4   MEASUREMENT OF PHYSICAL PARAMETERS

A 0.5-liter polyethylene bottles were filled with water at each site. This was subsequently used in the laboratory for ex-situ analysis. Water samples that were not analyzed immediately were stored in a refrigerator below 4 ^{0}C. Chemical parameters of the water samples were determined at the Ecological Laboratory of the University of Ghana. The chemical parameters determined were as follows: phosphate, sulphate, ammonia nitrogen, nitrate nitrogen, aluminium, manganese, cadmium, iron and copper. The analysis was carried out using a HACH DR/2010

Spectrophotometer and Perkin Elmer Atomic Absorption Spectrophotometer (AAS). All the Laboratory measurements were done under an established standard method (APHA, 1995).

3.4.1 Determination of Some Physico-Chemical Parameters

The pH, Conductivity, Turbidity, Temperature, Total Dissolved Solids and Dissolved Oxygen were determined using the Horiba multi-water quality checker on site.

The U-50 Series Horiba Multi water Quality checker (USA) features an integrated control unit and sensor probe. It is designed for ease on-site use, providing a wide variety of functions. The control unit has an easy to read LCD Display, which displays battery power and GPS, USB and probe unit connectivity. The sensor probe unit consists of sensors for measuring parameters such turbidity, dissolved oxygen, pH, conductivity, turbidity, temperature, total dissolve solid, salinity and water depth.

To measure these parameters, the sensor probe was lowered into the stream holding the control unit. After some few minutes, reading of pH, turbidity, conductivity, total dissolved solids and dissolved oxygen parameters were taken from the LCD display unit.

Plate 2: The Horiba multi water quality checker used for measuring physical parameters

3.5 LABORATORY ANALYSIS OF NUTRIENTS

3.5.1 Determination of phosphate

A 25 ml of water sample (the prepared sample) was placed in the sample cell. Phos Ver 3 Phosphate Powder pillow was added to the cell content and swirled immediately to mix. A twominute reaction period was allowed. A blue colouration of the mixture indicates the presence of phosphate. Another sample cell (the blank) was filled with 25 ml of sample and placed into the cell holder to calibrate it. After reaction period the prepared sample was placed into the cell holder and the level of phosphorus was determined at 890 nm. The Spectrophotometer displayed the results in mg/l PO_4^{3-} (HACH, 1996).

3.5.2 Determination of sulphate

Sulphate (SO_4^{2-}) is a naturally occurring ion and may be present in waters over wide concentration range. Acidic drainage may contribute large amounts of sulphate from oxidation of pyrite and other sulphide minerals. Increased levels of sulphate are usually the first indication of acid generation. The level of the sulphate in the sample was determined using Sula Ver 4 powder pillows in a direct reading HACH spectrophotometer Model DR. 2010. Twenty five (25) millilitres of the sample was measured into sample cell. One Sulpha 4 Reagent powder pillow was added to the sample and swirl to dissolve. A 5-minutes reaction period was allowed. Another sample cell (the blank) was filled with 25 ml of sample and placed into the cell holder to calibrate it. After the

reaction period the prepared sample was placed into the cell holder and the concentration of the phosphorus was determined at 450 nm. The Sulphate ions in the sample react with barium in the Sulfa Ver 4 Sulphate Reagent and form insoluble barium sulphate turbidity. The amount of turbidity formed is proportional to the sulphate concentration (HACH, 1996).

3.5.3 Determination of nitrate-nitrogen

The method used for the Nitrate analysis was the Cadmium Reduction Method (HACH, 1996). The nitrate level in each sample was measured using Nitrate Powder Pillows in a direct reading Hach spectrophotometer Model DR. 2010. Twenty five (25) ml of the sample was measured into sample cell of the Spectrophotometer. One Nitraver 5 Nitrate Reagent Powder Pillow was added to the sample. The mixture was then shaken vigorously for 1 minute. Five minutes was allowed for the solution react. An orange colour of the mixture indicates the presence of Nitrate. After five minutes, another cell was filled with 25 ml of only the sample (blank). The blank sample was placed in the spectrophotometer for calibration. Then the prepared sample was placed into the cell holder to determine the Nitrate concentration at 500 nm in mg/l (HACH, 1996).

3.5.4 Determination of ammonia nitrogen

Direct nesslerisation and spectrophotometric determination at wave length of 425 nm was used to determine ammonium-nitrogen. After distillation, 25 ml of the sample (the prepared sample) was measured using graduated mixing cylinder. A second graduated mixing cylinder was filled with the 25 ml of demineralised water (blank) .Three drops of Mineral Stabilizer was added to each of the cylinder, this complexes hardness in the sample. The solutions were inverted several times to mix. Three drops of Polyvinyl Alcohol Dispensing agent was added to each cylinder and inverted

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several times to mix to aid the colour formation in the reaction of Nessler reagent with ammonia ions. 1 ml of Nessler Reagent was pipetted into each cylinder. Stopper and inverted several times to mix. A 1-minute reaction period was allowed during which each solution was poured into respective blank and prepared cells. The blank was placed into the cell holder of the Spectrophotometer to calibrate it. The prepared sample was placed into the cell holder to determine the Nitrogen ammonia level at 425 nm. A yellow colour is formed proportional to the ammonia concentration (HACH, 1996).

Plate 3: Laboratory analysis of some physico-chemical parameters at the University of Ghana Ecolab.

3.6   HEAVY METAL DETERMINATION

3.6.1 Atomic Absorption Spectrometry method for heavy metals

This method was used for the determination of aluminium, manganese, cadmium, iron and copper. In flame atomic absorption spectrometry, a sample is aspirated into a flame and atomized. A light beam is directed through the flame, into a monochromator, and onto a detector that measures the amount of light absorbed by the atomized element in the flame. For some metals, atomic absorption exhibits superior sensitivity over flame emission. Because each metal has its own characteristic absorption wavelength, a source lamp composed of that element is used; this makes the method relatively free from spectral or radiation interferences. The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of the element in the sample over a limited concentration range. Most atomic absorption instruments also are equipped for operation in an emission mode (APHA, 1995).

3.7   BACTERIOLOGICAL ANALYSIS

The Most Probable Number (MPN) method was used to determine the total coliform and faecal coliform in the sample. Serial dilutions of 10^{-1} to 10^{-8} were prepared by picking 1 ml of the sample into 9 ml sterile distilled water. One milliliter aliquots from each of the dilutions were inoculated into 5 ml of MacConkey Broth at 35°C for total coliforms and 44°C faecal coliforms for 18-24 hours. Tubes showing colour change from purple to yellow after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100 ml were calculated from Most Probable Number (MPN) tables.

3.8   STATISTICAL ANALYSES

The data obtained in this study were subjected to descriptive statistical analyses using Microsoft Excel software and transported to IBM SPSS (version19). Descriptive summary statistics such as mean concentration, standard deviation of surface water data generated. The mean values were compared with the water quality criteria of World Health Organisation (WHO). Also, possible relationships between analyzed physico-chemical parameters and nutrient parameters taken from upstream, midstream and downstream of the Onyasia stream water samples were investigated using the Pearson"s correlation coefficient, r, $p<0.05$ and 0.01 significant levels. All tests were two-tailed.

CHAPTER FOUR

RESULTS

To achieve the objectives of this research, surface water was collected from three sampling sites along the Onyasia stream. These water samples were subjected to laboratory analyses to assess the water quality of the stream. The average physical, chemical and microbiological properties of the surface water samples including pH, conductivity, total dissolved solids, sulphates, phosphates, nitrates, ammonia nitrates, metal concentration, total and faecal coliform during the sampling period are presented with EPA, Ghana recommended limits for various parameters in surface water.

4.1   PHYSICO-CHEMICAL PARAMETERS OF THE ONYASIA STREAM

A summary of the results of the physico-chemical analyses are presented in Table 2.

pH

In general, mean pH levels in the surface water samples varied from pH 6.31±0.35 to 6.68±0.11 during the dry season and from pH 6.37±0.36 to 6.67±0.46 in the wet season. Throughout the period, the lowest pH for surface water was recorded upstream during the dry season whilst downstream recorded the highest during the dry season (Table 2). There was statistically significant difference (p=0.029) observed between the mean pH ranges at the sampling points.

Temperature

The temperatures of the water samples were normal. The average temperature ranged between 29.81±1.42 ℃ at upstream (Okponglo to) 32.20±0.37 ℃ at Dzorwulu ECG substation downstream during the dry season and 26.48±0.22 ℃ at Oponglo upstream to 27.78±0.12 ℃ during the wet

season (Table 2). The highest temperature (32.20±0.37 °C) was recorded at Dzorwulu ECG substation downstream during the dry season.

Conductivity

Conductivity is a direct measure of the ability of an aqueous solution to conduct current. It depends on the amount of dissolved ionic contaminants in the water. It can therefore give a fair indication of the extent of chemical pollution in a water body. Generally, the mean conductivity values of water samples collected from the Onyasia varied between 1.52±0.21 µS/cm to 1.64±0.0221 µS/cm during the dry season with the highest recorded during the dry season downstream (Table 2). In the wet season, mean conductivity ranged from 1.31±0.0821µS/cm to 1.71±0.0321µS/cm with the highest recorded downstream.

Turbidity

Turbidity is a measure of water clarity how much the material suspended in water decreases the passage of light through the water (USEPA, 2012). Mean turbidity values ranged from a maximum of 129±64.64 NTU during the dry season upstream and a minimum of 68.86±8.89 NTU during the wet season downstream(Table 2). These values grossly exceeded their background levels for WHO 2003 limits. There was statistically significant difference (p=0.005) between the data obtained at the sampling points.

Total Dissolved Solids

Mean Total Dissolved Solids (TDS) concentrations ranged during the dry season from 0.86±0.12 (mg/l) to 0.94±0.02 (mg/l) and during the wet season from 0.76±0.02 (mg/l) to 0.97±0.01 (mg/l) with the highest mean value recorded at 0.97±0.01 (mg/l) downstream during the wet season (Table 2). The total dissolved solids were within the WHO acceptable limit of 1000 mg/l. There was statistically significant difference (p=0.005) between the mean concentrations of TDS at the sampling points.
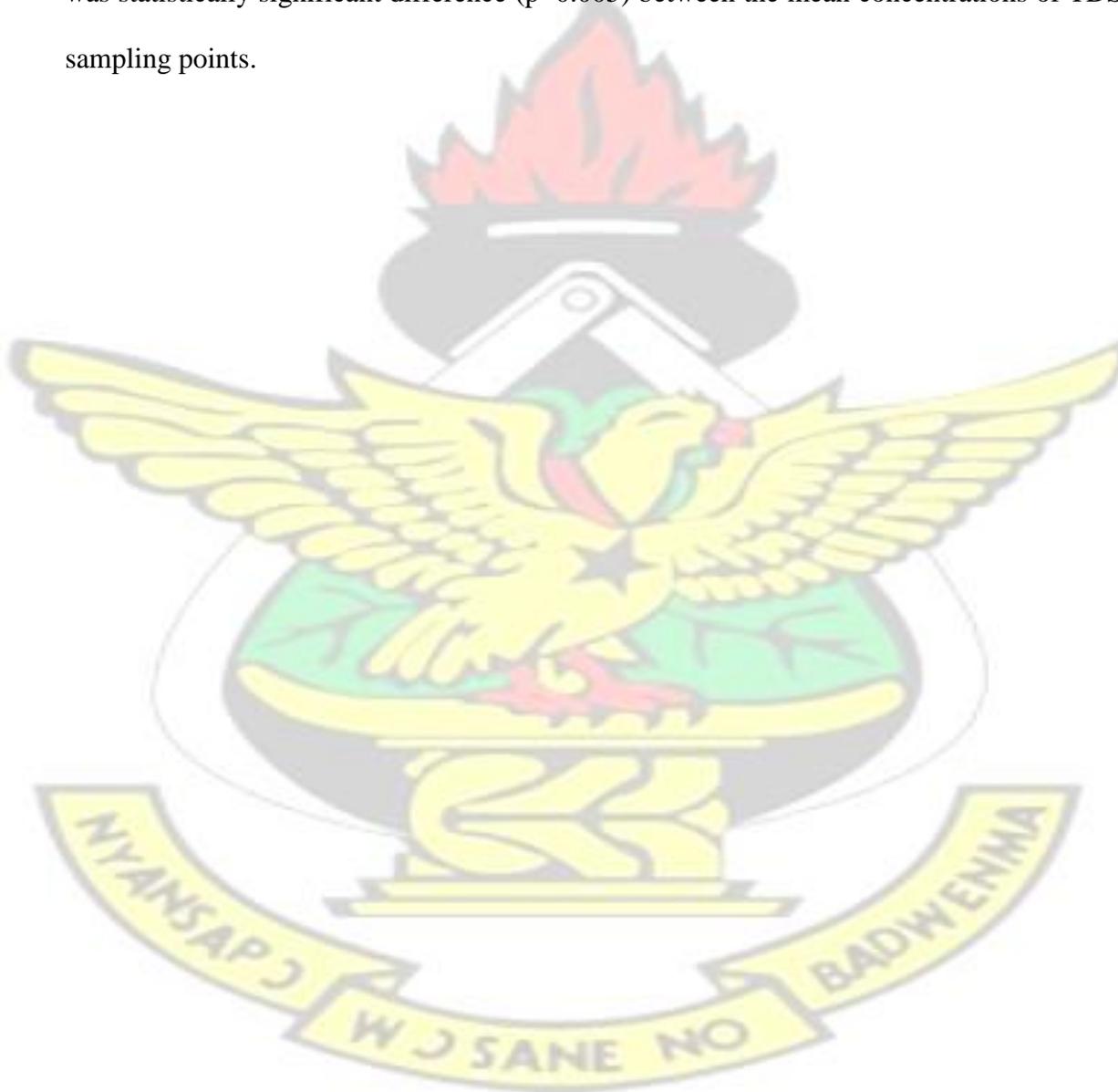
Table 2: Some physico-chemical qualities of the water samples from the various sampling points of the Onyasia stream and the Corresponding WHO limit

LOCATION	SEASON	pH	Temperature (°C)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)
WHO values		**6.5-8.5**		**1500**	**5.00**	**1000**	**5.00**
UPSTREAM	Dry Season	6.31±0.35	29.81±1.42	1.52±0.21	111.42±29.86	0.86±0.12	5.89±2.01
	Wet Season	6.37±0.70	26.48±0.22	1.31±0.08	129.24±64.64	0.76±0.02	6.60±1.50
MIDSTREAM	Dry Season	6.32±0.36	31.10±0.34	1.63±0.04	102.74±22.22	0.94±0.02	6.85±0.56
	Wet Season	6.38±0.61	27.73±0.52	1.61±0.07	123.80±18.04	0.89±0.02	5.09±1.89
DOWNSTREAM	Dry Season	6.68±0.11	32.20±0.37	1.64±0.02	107.91±15.52	0.94±0.02	7.87±0.41
	Wet Season	6.67±0.46	27.78±0.12	1.71±0.03	68.86±8.89	0.97±0.01	7.29±1.18

Dissolved oxygen

Mean dissolved oxygen (DO) concentrations ranged from 5.89±2.01 to 7.87±0.41 mg/l in the dry season whilst mean concentrations during the wet season ranged from 5.09±1.89 to 7.29±1.18 mg/l (Table 2). The highest value occurred downstream with a value of 7.87±0.41 mg/l in the dry season and lowest value occurred midstream at a value of 5.09±1.89 mg/l during the wet season. There was no statistically significant difference (p=0.328) between data obtained at the different sampling sites.

4.1.1 Interrelations of physico-chemical parameters in upstream surface water samples

The Pearson''s correlation matrix for levels of physico-chemical parameters in the water sampled upstream is presented in Table 3. There was a negative correlation between turbidity and pH with r value of (-0.803) at P 0.01 level of significance. Conductivity showed positive correlation with temperature (r=0.751) at P 0.05 level. TDS exhibited positive correlation with Temperature (r=0.757) at level P 0.05 and a strong positive correlation with Conductivity(r=0.965) at P 0.01 level. From Table 3, there was a weak correlation between temperature-pH, conductivity- pH, TDS-pH, DO-pH, DO-conductivity, DO-TDS. There were also no significant correlations between turbidity and temperature, turbidity and conductivity, TDS and turbidity, DO and temperature and DO and turbidity.

Table 3: Correlation matrix for physico-chemical parameters of upstream surface water samples of the Onyasia stream

	pH (Units)	Temperature (ºC)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)
pH (Units)	**1.000**					
Temperature (ºC)	0.066	**1.000**				
Conductivity	0.187	**0.751***	**1.000**			
Turbidity (NTU)	**-0.803****	-0.243	-0.322	**1.000**		
TDS (mg/l)	0.066	**0.757***	**0.965****	-0.203	**1.000**	

	pH (Units)	Temperature (ºC)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)
DO (mg/l)	0.201	-0.014	0.154	-0.512	0.217	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).

**.Correlation is significant at the 0.01 level (2-tailed).

4.1.2   Interrelations of physico-chemical parameters in midstream surface water samples

The Pearson''s correlation matrix for levels of physico-chemical parameters in the water sampled midstream is presented in Table 4. There was a positive correlation between TDS and DO with r value of (0.695) at 0.05 level. There were weak correlations between temperature-pH, conductivity-pH, conductivity-temperature, turbidity-pH, turbidity-conductivity, TDS-temperature, TDS-conductivities, DO-pH, DO-temperature and DO-conductivity. There was no significant correlation between turbidity-temperature, TDS-pH, TDS-turbidity and DO-turbidity.

Table 4: Correlation matrix for physico-chemical parameters of midstream surface water samples of the Onyasia stream

	pH (Units)	Temperature (ºC)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)
pH (Units)	**1.000**					
Temperature (ºC)	0.077	**1.000**				
Conductivity	0.533	0.367	**1.000**			
Turbidity (NTU)	0.273	-0.452	0.114	**1.000**		

	pH (Units)	Temperature (ºC)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)
TDS (mg/l)	-0.074	0.622	0.279	-0.207	**1.000**	
DO (mg/l)	0.321	0.565	0.475	-0.016	**0.695***	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).
**.Correlation is significant at the 0.01 level (2-tailed).

4.1.3   Interrelations of physico-chemical parameters in downstream surface water samples

The Pearson‟s correlation matrix for levels of physico-chemical parameters in the water sampled midstream is presented in Table 5. There was strong positive correlation between TurbidityTemperature and TDS-Conductivity with r value of (0.862) and (0.906) respectively at 0.01 level. DO showed a positive correlation with pH (r=0.647) at the 0.05 level. Conductivity – Temperature showed a strong negative correlation with r value (-0.771) at 0.01 level whilst TDS-Temperature also showed a negative correlation (-0.647) at 0.01 level significance. There were weak correlations between temperature-pH, DO-temperature and DO-turbidity. There were no significant correlations between conductivity-pH, turbidity-pH, turbidity-conductivity, TDS-pH, TDS-turbidity, DO-conductivity and DO-TDS as shown in Table 5.

Table 5: Correlation matrix for physico-chemical parameters of downstream surface water samples of the Onyasia stream

	pH (Units)	Temperature (ºC)	Conductivity (µS/cm)	Turbidity (NTU)	TDS (mg/l)	DO (mg/l)
pH (Units)	**1.000**					
Temperature (ºC)	0.012	**1.000**				

Conductivity	-0.353	**-0.771****	**1.000**			
Turbidity (NTU)	-0.002	**0.862****	-0.585	**1.000**		
TDS (mg/l)	-0.391	**-0.647***	**0.906****	-0.419	**1.000**	
DO (mg/l)	**0.647***	0.378	-0.438	0.345	-0.287	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

4.2   CONCENTRATION OF NUTRIENTS IN WATER SAMPLES FROM THE ONYASIA STREAM

The mean concentrations of the nutrients (PO_4^{2-}, SO_2^{2-}, NO_3^--N, NH_3-N) upstream, midstream and downstream of the Onyasia stream are shown in Table 6;

Phosphate

Mean phosphate concentration varied between 3.11±0.41mg/l and 5.05±0.64 mg/l during the dry season in the samples and 3.11±0.31 to 4.86±1.27 mg/l in the wet season (Table 6). The highest mean concentration in the samples occurred upstream at a concentration of 5.05±0.64 mg/l and lowest mean concentration midstream was 3.11±0.41 during the dry season. Also during the wet season, the highest was measured upstream was 4.86±1.27 mg/l and lowest midstream was 3.11±0.31mg/l.

Sulphate

In the dry season, mean sulphate concentration ranged from 58.4±10.1 mg/l to 76.40±4.21 mg/l with the highest recorded at upstream and lowest downstream. During the wet season, mean

concentration ranged from 47±3.53 mg/l to 75.20±6.53 mg/l with the highest recorded upstream and lowest downstream (Table 6).

Nitrate – Nitrogen

Mean nitrate-nitrogen concentration in surface water samples ranged from 2.41±0.43 mg/l to 11.37±7.41 mg/l during the dry season. Samples from upstream recorded the highest level of nitrate-nitrogen concentration of 11.37±7.41 mg/l and lowest recorded midstream with a value of 2.41 mg/l (Table 6). During the wet season, mean concentration varied between 2.01±0.50 mg/l to 10.14±4.52 mg/l with the highest recorded upstream concentration of 10.14±4.52 mg/l and lowest recorded midstream concentration of 2.01±0.50 mg/l.

Table 6: Record of the mean levels of the indicated chemical parameters in Onyasia stream

LOCATION	SEASON	PHOSPHATE (mg/l)	SULPHATE (mg/l)	NITRATE-N (mg/l)	AMMONIA-N (mg/l)
WHO Limits		**2.00**	**250**	**3.00**	**1.5**
UPSTREAM	Dry Season	5.05±0.64	76.40±4.21	11.37±7.41	18.53±6.23
	Wet Season	4.86±1.27	75.20±6.53	10.14±4.52	14.35±3.21
MIDSTREAM	Dry Season	3.11±0.41	67.20±5.31	2.41±0.43	10.60±0.71
	Wet Season	3.11±0.31	66.70±10.53	2.01±0.50	10.09±1.66
DOWNSTREAM	Dry Season	4.35±2.00	58.4±10.1	2.91±0.15	19.67±1.49
	Wet Season	4.73±0.70	47.00±3.53	2.63±0.62	14.67±1.91

Ammonia Nitrogen

The mean level of ammonia-nitrogen in the samples analyzed for the dry period ranged from 10.60±0.71 mg/l to 19.67±1.49 mg/l (Table 6). The highest value of 19.67±1.49 mg/l was recorded downstream and midstream recorded the lowest value of 10.60±0.71 mg/l. In the wet season, mean concentrations varied from 10.09±1.66 mg/l to 14.67±1.91 mg/l. Samples taken from downstream recorded the highest concentration of 14.67±1.66 mg/l whilst midstream water samples recorded the lowest value of 10.09±1.66 mg/l (Table 6).
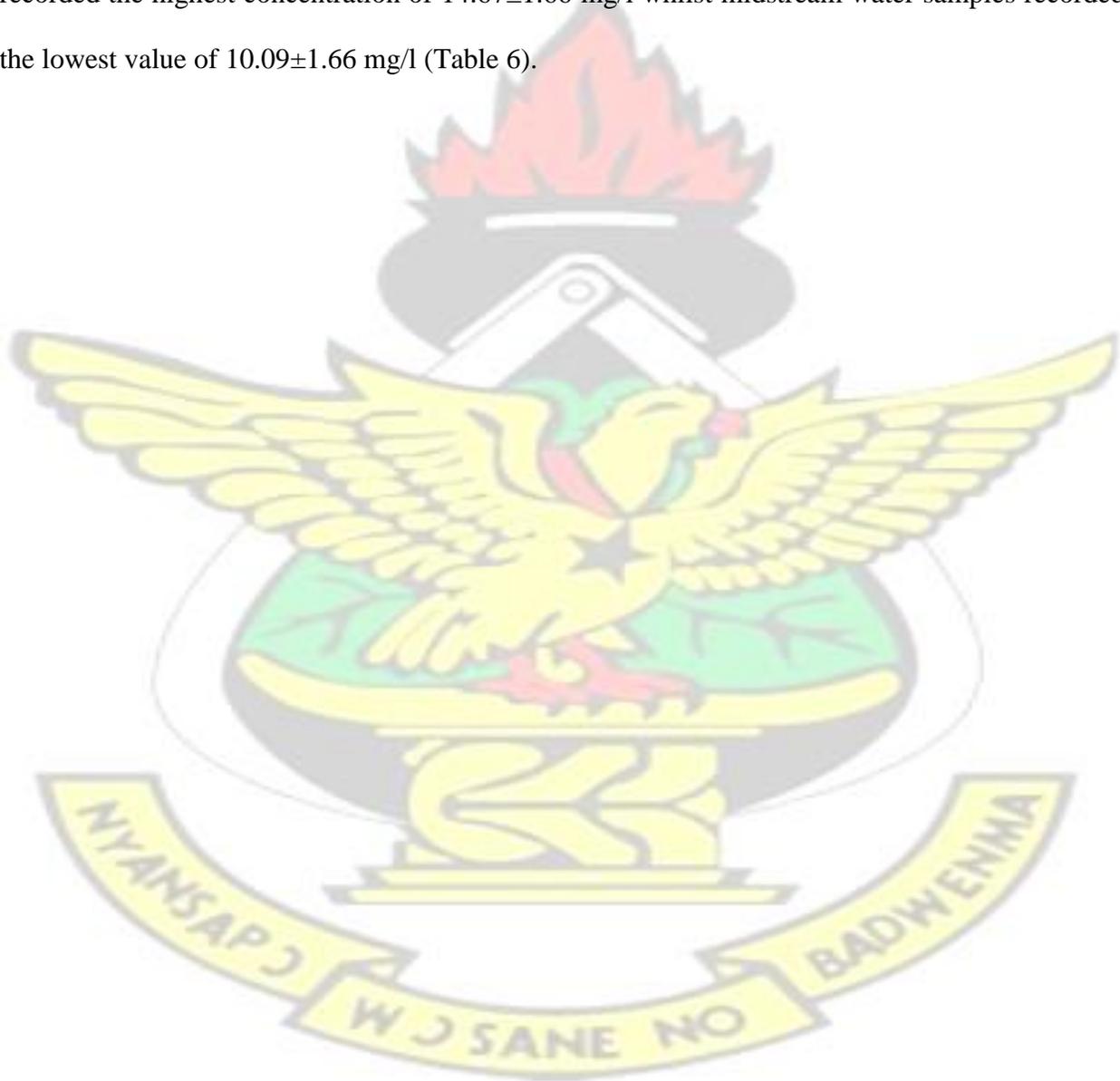
4.2.1 Correlations between mean nutrient concentrations from upstream sampling points

Possible Nutrient-Nutrient relationships were investigated using the Pearson"s correlation coefficient, r, p<0.05 and 0.01 significant levels to ascertain whether they have any relationship apart from occurring in the river. The mean nutrient concentrations for the four nutrient parameters for the sampling locations were used. The Pearson"s correlation matrix for nutrient levels in the water samples at the different sampling points is presented in Table 7. The Table indicates that Ammonia nitrogen correlated positively with nitrate nitrogen (r=0.681) at the p=0.05 significant level. In table 7, there was a weak correlation between nitrate nitrogen and phosphate, nitrate nitrogen and sulphate and ammonia-nitrogen and phosphate. There was no significant correlation between sulphate-phosphate and ammonia nitrogen-sulphate.

Table 7: Pearson"s correlation matrix of r-values of mean nutrient data of upstream surface water samples of the Onyasia stream

	Phosphate (mg/l)	Sulphate (mg/l)	Nitrate nitrogen (mg/l)	Ammonia nitrogen (mg/l)
Phosphate (mg/l)	**1.000**			
Sulphate (mg/l)	-0.030	**1.000**		
Nitrate nitrogen (mg/l)	0.485	0.021	**1.000**	
Ammonia-nitrogen (mg/l)	0.112	-0.307	**0.681***	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).
**.Correlation is significant at the 0.01 level (2-tailed).

4.2.2 Correlation between mean nutrient concentrations of sampling points from midstream of Oyansia stream

Possible nutrient-nutrient relationships investigated for midstream sampling points, using the Pearson''s correlation coefficient indicated that there were weak correlations among nitrate nitrogen and phosphate, ammonia nitrogen and phosphate and ammonia nitrogen and nitrate nitrogen (Table 8). Table 8 shows that, there was no significant correlation between sulphate and phosphate, nitrate nitrogen and sulphate and ammonia nitrogen and sulphate.

Table 8: Pearson''s correlation matrix for nutrient data of midstream surface water samples of the Onyasia stream

	Phosphate (mg/l)	Sulphate (mg/l)	Nitrate nitrogen (mg/l)	Ammonia nitrogen (mg/l)
Phosphate (mg/l)	**1.000**			
Sulphate (mg/l)	-0.538	**1.000**		
Nitrate nitrogen (mg/l)	0.029	-0.089	**1.000**	
Ammonia-nitrogen (mg/l)	0.628	-0.118	0.400	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).
**.Correlation is significant at the 0.01 level (2-tailed).

4.2.3 Correlation between mean nutrient concentrations from downstream sampling points

The nutrient-nutrient relationship investigated for water samples analyzed downstream showed weak correlation between sulphate-phosphate, nitrate nitrogen-sulphate and ammonia nitrogennitrate nitrogen as indicated in Table 9. Table 9 shows that, there was no significant correlation between nitrate nitrogen-phosphate and ammonia nitrogen-phosphate.

Table 9: Pearson‟s correlation matrix for nutrient data of downstream surface water samples of the Onyasia.

	Phosphate (mg/l)	Sulphate (mg/l)	Nitrate nitrogen (mg/l)	Ammonia nitrogen (mg/l)
Phosphate (mg/l)	**1.000**			
Sulphate (mg/l)	0.034	**1.000**		
Nitrate nitrogen (mg/l)	-0.080	0.072	**1.000**	
Ammonia-nitrogen (mg/l)	-0.071	0.444	0.282	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).
**.Correlation is significant at the 0.01 level (2-tailed).

4.3 HEAVY METAL CONCENTRATIONS OF ANALYSED WATER SAMPLES IN ONYASIA STREAM

The mean concentrations of heavy metals (Al, Mn, Cd, Fe and Cu) from upstream, midstream and downstream of the Onyasia are presented in Table 10.

Aluminium

The mean concentrations of the surface water sampled for Aluminium varied from 8.54±4.09 mg/l to 12.58±1.15 mg/l during the dry season with the highest level recorded downstream. In the wet season, the mean concentration level ranged from 10.79±4.23 mg/l to 16.55±1.86 mg/l with the highest level recorded downstream and the lowest recorded upstream (Table 10).

Manganese

Manganese concentration levels in the surface water sampled ranged from 0.34±0.08 mg/l to 0.49±0.20 mg/l during the dry season. Midstream recorded the highest level at 0.49±0.20 mg/l whilst downstream recorded lowest level. In the wet season, mean levels ranged from 0.5±0.09 mg/l to 0.89±0.34 mg/l with the lowest value recorded downstream and highest value recorded midstream (Table 10).

Cadmium

Mean cadmium concentration during the dry season ranged from 0.05±0.10 mg/l to 0.10±0.20 mg/l with its highest value in the surface water recorded downstream (Table 10). Cadmium in the midstream was below detection level. During the wet season, all the cadmium concentrations were below detection level. Cadmium correlated negatively with iron at p=0.05 level downstream.

Iron

In the dry season, iron concentration values ranged from 0.81±0.78 mg/l to 1.04±0.91mg/l (Table

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10). The highest mean value was recorded midstream (1.04±0.91mg/l) and lowest upstream (0.81±0.78 mg/l). In the wet season, mean values varied from 1.95±1.02 mg/l to 2.50±0.72 mg/l with the highest mean value recorded midstream and lowest mean value recorded upstream.

Table 10: Mean heavy metals values of water samples from the Onyasia stream and their corresponding WHO limits

LOCATION	SEASON	Al (mg/l)	Mn (mg/l)	Cd (mg/l)	Fe (mg/l)	Cu (mg/l)
WHO Limit		**0.05**	**0.40**	**0.003**	**0.300**	**2.0**
UPSTREAM	Dry Season	8.54±4.09	0.39±0.28	0.05±0.10	0.81±0.78	2.39±3.03
	Wet Season	10.79±4.23	0.5±0.43	0.00±0.00	1.95±1.02	2.80±3.13
MIDSTREAM	Dry Season	11.24±4.13	0.49±0.20	0.00±0.00	1.04±0.91	1.55±1.45
	Wet Season	14.10±4.53	0.89±0.34	0.00±0.00	2.5±0.72	2.44±2.29
DOWNSTREAM	Dry Season	12.58±1.15	0.34±0.08	0.10±0.20	1.03±0.74	1.26±1.82
	Wet Season	16.55±1.86	0.50±0.09	0.00±0.00	2.46±0.52	1.36±1.93

Copper

Mean copper concentration of surface water varied from 1.26±1.82 to 2.39±3.03 mg/l during the dry season. Copper concentration was highest upstream with a value of 2.39±3.03 mg/l whilst the lowest was recorded midstream (1.55±1.45 mg/l). During the wet season, the mean copper concentration ranged from 1.36±1.93 to 2.80±3.13 mg/l. The highest concentration of copper was recorded upstream whilst downstream water samples recorded lowest value for copper during the wet season (Table 10).

4.3.1 Correlations between mean heavy metals concentrations from upstream water samples

The Pearson"s correlation matrix for levels of heavy metals concentration in the water samples taken from upstream are presented in Table 11. There was a positive correlation between Manganese and Aluminium with r values of (0.758) at P 0.05 levels. There were weak correlations between iron-cadmium and copper-manganese. There were no significant correlations between cadmium-aluminium, cadmium-manganese, iron-aluminium, ironmanganese, copper-aluminium, copper-cadmium and copper-iron as shown in Table 11.

Table 11: Pearson"s correlation matrix for heavy metal of upstream surface water samples of the Onyasia.

	Aluminium (mg/l)	Manganese (mg/l)	Cadmium (mg/l)	Iron (mg/l)	Copper (mg/l)
Aluminium (mg/l)	**1.000**				
Manganese (mg/l)	**0.758***	**1.000**			
Cadmium (mg/l)	-0.240	-0.109	**1.000**		
Iron (mg/l)	-0.137	-0.156	0.211	**1.000**	
Copper (mg/l)	-0.272	0.056	-0.226	-0.156	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).
**.Correlation is significant at the 0.01 level (2-tailed).

4.3.2 Correlations between mean heavy metals concentrations from midstream water samples

The Pearson"s correlation matrix for heavy metal concentrations in the water sampled at the midstream are presented in the Table 12. There was a strong positive correlation between iron and aluminium (r = 0.812) at P 0.01 level. Iron also showed a negative correlation with cadmium (r=-0.706) at the P 0.05 level (Table 12). Table 12 also shows that, there were weak correlations between iron-manganese, copper-aluminium, copper-manganese and copper-iron. There were no significant differences between manganese-aluminium, cadmium-aluminium, cadmiummanganese and copper-cadmium (Table 12).

Table 12: Pearson"s correlation matrix for heavy metal of midstream surface water samples of the Onyasia

	Aluminium (mg/l)	Manganese (mg/l)	Cadmium (mg/l)	Iron (mg/l)	Copper (mg/l)
Aluminium (mg/l)	**1.000**				
Manganese (mg/l)	-0.291	**1.000**			
Cadmium (mg/l)	-0.345	-0.622	**1.000**		

Iron (mg/l)	**0.812****	0.176	**-0.706***	**1.000**	
Copper (mg/l)	0.345	0.011	-0.252	0.575	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).

**.Correlation is significant at the 0.01 level (2-tailed).

4.3.3 Correlations between mean heavy metals concentrations from downstream water samples

The Pearson‟s correlation matrix for heavy metal concentration in the water sampled at the midstream is presented in Table 13. Manganese showed a positive correlation with Aluminium (r=0.665) at P=0.05 level; Iron also showed a strong positive correlation with manganese (r=0.867) at P=0.01 significant level. There were weak correlations between iron-aluminium, copper-manganese and copper-iron while there was no significant correlation between cadmiumaluminium, cadmium-manganese, iron-cadmium, copper-aluminium, and copper-cadmium (Table 13).

Table 13: Pearson‟s correlation matrix for heavy metal of downstream surface water samples of the Onyasia

	Aluminium	Manganese	Cadmium	Iron	Copper
Aluminium	**1.000**				
Manganese	**0.665***	**1.000**			
Cadmium	-0.275	-0.226	**1.000**		
Iron	0.623	**0.867****	-0.129	**1.000**	
Copper	-0.001	0.331	-0.224	0.123	**1.000**

*.Correlation is significant at the 0.05 level (2-tailed).
**.Correlation is significant at the 0.01 level (2-tailed).

4.4 MICROBIOLOGICAL ANALYSIS

Table 14 summarises results obtained in the microbiological analysis. All the water samples from

the stream showed the presence of coliform far above the WHO limits.

Table 14: Mean Log of Faecal and Total Coliforms identified in water samples from the Onyasia stream and the corresponding WHO limits

LOCATION	SEASON	Mean Log of Total Coliform (cfu/100ml)	Mean Log of Faecal Coliform (cfu/100ml)
WHO LIMITS		0.00	0.00
UPSTREAM	Dry Season	8.07	6.45
	Wet Season	4.16	2.92
MIDSTREAM	Dry Season	8.15	6.37
	Wet Season	3.65	2.49
DOWNSTREAM	Dry Season	8.32	6.40
	Wet Season	3.42	3.93

Total Coliforms identified in the water samples under study

Total coliforms were found in high concentrations in the water samples. During the dry season, the total coliform ranged from a log of 7.60 to 8.63 cfu/100ml with mean log of 8.19 cfu/100ml. In the wet season, total coliform ranged from a log of 3.04 to 5.18 with an average log of 3.86 cfu/100ml. Analysis revealed that downstream was most polluted with highest total coliform (8.32 cfu/100ml) during the dry season whilst upstream recorded least (8.07 cfu/100ml). However, during the wet season, upstream recorded the highest total coliform of 4.16 cfu/100ml whilst downstream recorded lowest total coliform of 3.42 (Table 14).

Faecal Coliforms identified in the water samples under study

Analysis of the sample data for faecal coliforms revealed that faecal coliform ranged from a log of 5.60 to 6.97 cfu/100ml in the dry season with an average log of 6.41 cfu/100ml. However, it was ascertained that the faecal coliform levels reduced drastically during the raining season with a log range of 0.18 to 4.73 cfu/100ml and mean log of 3.51 cfu/100ml recorded. Among the three (3) sampling locations, the highest faecal coliform was recorded upstream (6.45 cfu/100ml) whilst midstream recorded lowest (6.37 cfu/100ml). In the wet season, however, downstream recorded the highest faecal coliform count, 3.93 cfu/100ml, whiles the midstream recorded the lowest (2.49 cfu/100 ml) (Table 14).

CHAPTER FIVE

DISCUSSIONS

5.1   ANALYSIS OF PHYSICAL PARAMETERS

5.1.1 pH

The pH of a sample of water is a measure of the concentration of hydrogen ions. The water analysis of the Onyasia stream was below the WHO (2003) limit (slightly acidic) with a mean pH range of 6.31 to 6.37 units for both dry season & wet season upstream and midstream whilst the pH values downstream (6.67 to 6.68) were within the range of 6.5-8.5 suitable for drinking and domestic purposes (WHO, 1993). The mean pH value shows that the water is generally neutral though it tends to be weakly acidic upstream and midstream (Table 2), attributable to solid waste dump along the stream, as reported by Tubonimi *et al.,* (2010). A high natural production of humic acids associated with detritus loadings could contribute to the slight acidic nature downstream. These naturally occurring acids can lower the pH to levels below standards. There was however no evidence of seasonal variation supported by data from this project. There was a negative correlation between pH – turbidity and pH – DO.

5.1.2 Temperature

Temperature is a measurement of the intensity or degree of heat present in a substance. It is the primary influencing factor on water density. Temperature affects solubility of many chemical compounds and can therefore influence the effect of pollutants on aquatic life (Resources Inventry Committee, 1998). The temperatures of the water ranged from 29.81 to 32.20 ℃ during the dry season and 26.48 to 27.78℃ during the wet season. The relatively low sampling temperatures in

the wet season could be attributed to the fact that during the rainy season, temperatures are relatively lower than the dry season. There is no guideline set by the World

Health Organisation for temperature. Temperature correlated positively with conductivity and TDS at P 0.05 level.

5.1.3 Conductivity

Conductivity is the numerical expression of an aqueous solution to carry electrical current and it is a useful indicator of the mineralization in water sample (Jain *et al.,* 2005); it also gives an indication of all dissolved ions in solution. The conductivity values during the dry season varied from 1.52±0.21 to 1.64±0.02 µS/cm and 1.31±0.08 to 1.71±0.03 µS/cm during the wet season. The dry season values of conductivity were generally higher than the wet season values. It can be conjectured that high litter fall during the dry season decompose to increased water conductivity during the dry season as proposed by Singh *et al.,* (2013). There was an increase in conductivity values along the stream and downstream recorded highest value (Table 2). Karikari and Ansa-Asare, (2006) indicated that, generally, the conductivity of a river is lowest at the source of its catchments, and as it flows along the course of the river, it leaches ions from soils and also picks up organic material from the biota and its detritus This could have attributed to the relative increase in the mean concentration of the water samples. The WHO limit of conductivity is 1500 µS/cm (WHO, 1992). According to Koning & Roos, (1999) the average value of conductivity for a typical and unpolluted river is 350 µS/cm. Consequently, the conductivity values recorded for water samples from the Onyasia stream should present no obvious problem to domestic users as their average conductivity were lower than 350 µS/cm during both seasons. A positive correlation was observed with between conductivity and TDS at P=0.01 level and temperature at P=0.05 level.

5.1.4 Turbidity

The mean turbidity values recorded for the water samples were all above the WHO (2003) limit for surface water. It varied between 102.74 and 111.42 NTU during the dry season and 68.86 to 129.24 NTU during the wet season. The high turbidity values could be due to runoff and soil erosion from the catchments. It has been stated that the type and concentration of suspended solids in a water body controls the turbidity of the water (Chapman, 1992). Over-cultivation along sections of the river banks and commercial vegetable production [Plates 4&9 (appendix)] along the stream leaves the soil bare and hence susceptible to erosion during the raining season. Hence, more soil particles, which constitute the major part of suspended matter contributing to turbidity in most natural waters, were discharged into, or displaced in, the water. The lower values recorded downstream may be attributable to self-remediation action of the river also observed by Larmie *et al.,* (2009). The excessive turbidity in water increases the cost of water purification processes such as flocculation and filtration costs (DWAF, 1998). Turbidity correlated negatively with pH upstream at p=0.01 level and positively with temperature at P=0.01 level.

Plate 4: Vegetable farms along the stream with which stream water is used for irrigation

5.1.5 Total Dissolved Solids

TDS is a common indicator of polluted waters. TDS values ranged from 0.86 to 0.94 mg/l. These values were well within the WHO guideline value of 1000 mg/l. According to the US Environmental Protection Agency (USEPA, 2000), the higher the mineral content in the water, the more total suspended solids will be formed. The level of suspended dissolved solid observed by the study could be due to discharge of waste coming from agricultural soil erosion and runoff into the stream (Plate 6). Palanivel and Rajaguru (1999) also observed and reported the same phenomenon.

5.1.6 Dissolved oxygen

Mean dissolved oxygen (DO) concentrations ranged from 5.89±2.01 to 7.87±0.41 mg/l in the dry season and 5.09±1.89 to 7.29±1.18 mg/l in the wet season (Table 2). The mean concentration of dissolved oxygen was relatively lower upstream with a value of 5.09±1.89 mg/l and high value of 7.87±0.41 mg/l downstream. The level of DO downstream can adequately sustain aquatic lives better than the upstream. According to the USDA (1992), the level of oxygen depletes primarily with the amount of waste added, the, reduced velocity and turbulence of the stream, the initial DO level in the stream, and the temperature of the water. The higher DO values downstream could be due to the increased velocity and turbulent nature of the water downstream. The minimum desirable dissolve oxygen concentration for maintaining aquatic life was found to about 5 mg/l (Lester and Birkett, 1992). Aquatic animals are most vulnerable to lowered DO levels in the early morning on hot summer days when stream flows are low, water temperatures are high and photosynthetic activities by aquatic plants is relatively lower (USEPA 2012).Consistently high levels of dissolved oxygen are best for a healthy ecosystem.

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5.2   ANALYSIS OF NUTRIENTS PARAMETERS

5.2.1 Phosphate (PO₄³⁻)

Phosphate may occur in surface water as a result of domestic sewage, detergents, agricultural effluents with fertilizers and industrial waste water. The phosphate levels identified within the study area was found in the range of 3.11 to 5.05 mg/l during the dry season and 3.11 to 4.86 mg/l in the wet season. These values were above the WHO (2003) limit of 0.5 mg/l to 2mg/l. This could be attributed to rainfall flushing phosphate rich pollutants or agricultural fertilizer (NP-K fertilizer) in the water body from the vegetable farming along the stream also reported by Cornish *et al.,* (1999). Phosphates like any other nutrient are harmless in lower concentrations but become harmful only in higher doses. Phosphates are primarily used in detergents to ensure efficient cleaning in hard water (EU business, 2010); these detergents are used by residents along the stream and may have contributed to the high level of phosphate. Residents have bathhouses situated outside their homes along the stream and wastewaters are discharge into the stream as shown in Plate 5, 12 and 13. There was no correlation between phosphate and the other nutrients analyzed.

Plate 5: Effluents from bath houses of residents along the stream discharged into the stream at midstream, Tetteh Quarshie

5.2.2 Sulphate (SO_4^{2-})

Sulphate occurs naturally in water as a result of leaching from gypsum and other common minerals (Manivaskam, 2005). According to WRC, 2003, discharge of domestic sewage tends to also increase its concentration. The variations of sulphate among the sampling points were statistically significant at the 5% level (Appendix 2a). The sulphate concentration varied between 58.4 and 76.40 mg/l during the dry season and from 47.00 to 75.20 mg/l during the wet season. This was within the prescribed WHO (2003) limit of 250 mg/l. Sulphates, when added to water, tend to accumulate progressively increasing concentration (WRC, 2003). This could account for the high levels recorded upstream in both the dry and wet season albeit within the WHO limit. The much lower sulphate values recorded could be because sulphate easily precipitates and settles to the bottom sediment of the river as mentioned by (Mathuthu *et al.,* 1997). Also, under anaerobic conditions, sulphur bacteria use sulphate as an oxygen source (Peirce *et al.,* 1998). Sulphate showed no correlation with the other nutrients analysed.

5.2.3 Nitrate – Nitrogen (NO_3-N)

Surface water can be contaminated by runoff of sewage and other wastes rich in nitrates such as fertilizers containing nitrates. Some nitrate enters waters from the atmosphere which carries nitrogen-containing compounds derived from combustion of fossil fuels such as gasoline (ga.water.usgs.gov/edu/nitrogen.htm). The nitrate content in the study area varied from 2.41 to 11.37 mg/l in the dry season and during the wet season varied from 2.01 to 10.14 mg/l. The highest values found for both seasons occurred upstream. Mid stream and downstream values were within

the WHO guideline limit of 3.00 mg/l. This could be attributed to farming activities along the stream with the heavy use of fertilizer which seep into the stream polluting it.

According to Adedokum *et al.,* (2008), significant nitrate contamination of surface water is found in areas of high population pressure and agricultural development. Also, many nitrogenous fertilizers are converted into mobile nitrates by natural processes which contaminate nearby water bodies more profusely (Freeze and Cherry, 1979). Nitrogen like any other nutrient is harmless in lower concentrations, but become harmful only in higher inter-convertible organic nitrogen. High nutrient levels can lead to algal blooms, loss of oxygen, and other problems that affect surface waters (Carpenter *et al.,*, 1998). Nitrate nitrogen showed a positive correlation with ammonia nitrate at p=0.05 level.

5.2.4 Ammonia-Nitrogen (NH_3-N)

The mean level of ammonia-nitrogen in the water samples for the dry period ranged from 10.60 ± 0.71 mg/l to 19.67 ± 1.49 mg/l (Table 6). In the wet season, mean concentrations varied from 10.09 ± 1.66 mg/l to 14.67 ± 1.91 mg/l. The highest values were recorded at downstream and midstream recorded lowest for both seasons. The exceptionally high loads observed upstream and downstream could be attributed to increased agricultural activities in the area.

There were seasonal variations between the dry and wet season with a relatively lower values observed for the wet season. In this study, the concentrations of NH_3-N were higher than the WHO limit. Higher NH_3-N values can be toxic to fish, but in small concentrations, it could serve as nutrients for excessive growth of algae (dumping of organic waste).

5.3   ANALYSIS OF HEAVY METALS

5.3.1 Aluminium

The mean Aluminium concentration of the surface water varied from 8.54±4.09 mg/l to 12.58±1.15mg/l during the dry season and the wet season recorded a mean of 10.79±4.23 mg/l to 16.55±1.86 mg/l with the highest level recorded downstream and the lowest recorded upstream. The sources of Aluminium in fresh water include domestic wastes, manufacturing processes involving metals, and the dumped sewage sludge (Bouraie *et al.,* 2010). The use of aluminium based pesticide (fungicide) such as Athelete 80WP for the control of mildew diseases of vegetables, fruits and tree crops. Aluminium is also the most abundant metal in the earth's crust and it is widely distributed. It is the third most abundant element it makes up some 8% of the earth's crust. Therefore, a potentially natural process far outweighs the contribution of anthropogenic sources, with regard to overall environmental exposure (National Environmental Health Monographs, 1998). Aluminium showed a positive correlation between manganese at p=0.05 level upstream, with iron at p=0.01 level midstream.

Plate 6a: Photograph showing dumping of electronic and household waste material along the banks of the stream at Dzorwulu

5.3.2 Manganese

Manganese concentration recorded in the water samples ranged from 0.34 ± 0.08 to 0.49 ± 0.20 mg/l during the dry season whilst in the wet season, levels of manganese ranged from 0.50 ± 0.09 to 0.89 ± 0.34 mg/l. Manganese levels in the samples exceeded the WHO limit of 0.40 mg/l probably as a result of the application of manganese based fertilizers by farmers, which enters soils. The high levels may also be the result of improper disposal of waste such as alkaline batteries, electrical coils and welding rods (Plates 6a, 6b & 13). These are washed into the stream during the wet season and could have attributed to the high values

(http://www.env.gov.bc.ca/wat/wq/BCguidelines/manganese/manganese.html).

Plate 6b: Close-up photograph of the miscellany of electronic and industrial solid waste dumped near the stream

5.3.3 Cadmium

Cadmium concentration in the samples were generally below detection limit except that levels detected upstream and downstream were 0.05±0.10 mg/l and 0.10±0.20 mg/l respectively during the dry season. These values were above the WHO general guideline value of 0.003 mg/l. Cadmium is the best known toxic metal and it is used in electroplating, battery, paints and plastic industry (Tyagi and Mehra, 1992). Cadmium may have entered the Onyasia stream from improper disposal of waste batteries and other cadmium containing-waste such as fertilizers into the stream through runoff (Plates 6a & b, 10 and 13). According to World Bank Group Handbook (1998), cadmium is mainly used as an anticorrosion coating in electroplating, as an alloying metal in solders, as a stabilizer in plastics (organic cadmium), as a pigment, and as a component of nickel-cadmium batteries.

The sources of cadmium in the aquatic environment are also from agricultural use of sludges, fertilizers and pesticides", burning of fossil fuels, and the deterioration of galvanized materials and cadmium-plated containers (Anon, 1996) such was observed during the field work in this project.

5.3.4 Iron

The mean concentrations of Fe in the water ranged from 0.81±0.78 to 1.04±0.91 mg/l during the dry season and 1.95±1.02 to 2.50±0.72 mg/l during the wet season. All the water points exceeded the background level and the WHO limit of 0.3 mg/l. The underlying soils in the Onyasia stream may basically be granite and analyses of rocks in Ghana (Kerbyson & Schandorf, 1966) have shown that $Fe_2 O_3$ composition in granite is about 2.8%. This could possibly be one of the

sources of Fe in surface waters. It has also been demonstrated by Langanegger (1987) and PeligBa (1989) that corrosive materials such as cans, tins and iron- based containers disposed into the stream may contribute significantly to the amount of Fe in the waters.

5.3.5 Copper

The results of this study revealed that, copper levels slightly decreased along the Onyasia stream. The concentrations of copper during dry season ranged from 1.26 ± 1.82 to 2.39 ± 3.03 mg/l and during the wet season, varied from 1.36 ± 1.93 to 2.80 ± 3.13 mg/l. Copper declined in concentration along the stream during both dry and wet seasons except upstream. Generally, the mean levels of copper in the stream were within the WHO guideline for Cu in domestic water supply (2.00 mg/l). The range obtained was within permissible value, hence, no adverse effects is anticipated from domestic use. Upstream recorded a relatively higher values which could probably be due to the use of pesticides especially copper based fungicide by the farmers along the stream. A report by National Agricultural Pesticide Impact Assessment Program (NAPIAP) briefing paper on Water Quality Standard and copper pesticides (1992) reiterated that copper compounds are used as fungicides and bactericides in agricultural production, for control of fungal rot, mildew, and decay of plant tissue materials. Strategies to meet the clean water standards could restrict the use of pesticides containing copper. The high contribution of copper from domestic activities is mainly a result of copper leaching from the piping used in household water systems (around 90% of the domestic contribution). The remaining 10% comes from human faeces, because some of the food we eat contains natural amounts of copper (Water UK, 2001). Plate 11a & b show human activity along the stream as excreta is released directly into the water as pollutant. Copper did not correlate with other heavy metals analyzed.

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5.4   Seasonal effect on concentration of metals

Generally, concentrations of trace metals were higher during the wet season than the dry season (Table 10). This can be attributed to the fact that, during the rainy season, metal-containing wastes such as empty containers of canned drinks and other food products are transported from nearby sites into the stream. This could be sources of additional metals which can increase the metal content in the stream.

5.5   Microbial load identified in the water samples under study

Mean log dry season values for total coliform which was 8.19 cfu/100ml was significantly higher than that recorded for the wet season (3.86 cfu/100ml). Total and faecal coliforms pollution was widespread, and the entire stream sampled was not suitable for domestic use without treatment. For agricultural purposes, there is a possibility of contamination from vegetables and other crops eaten in their raw state. The poor microbiological quality might be due to contamination caused by human activities and livestock. It is a common practice of people living along the stream to discharge their domestic waste as well as human excreta into the stream (Plate 7 & 14). Wild and domestic animals seeking drinking water also contaminate the water through direct defecation and urination (Plate 15). From the results, the total average of faecal coliforms for the entire study was high, an evident of the fact that people defecate directly into the water body. Thus, for water to be considered free from any human health-related risks, the faecal coliform count should be 0 cfu/100ml. Consequently, the water body under investigation is not safe for use that may impact on human and animal health such as washing, irrigation, and drinking water for ruminants. The present data from this study also emphasised the seasonal variation in the microbial count such that the counts in the wet season was found to be significantly lower than that recorded in the dry

season. This seasonal variation could be attributed to dilution factor of the streams water during the raining season. Also turbulence during the rainy season disturbs colonies of the coliforms and hence are dispersed reducing the load. The anthropogenic activities by human (and animals) have been clearly demonstrated in this work (plates 4-12) and these contribute immensely to the poor physico-chemical and microbiological quality of the Onyasia stream.

Plate 7: Photograph showing human defecating activity at Okponglo, East Legon

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1   Conclusion

It is concluded from the study that the Onyasia stream water at all the sampling points is not suitable for direct human consumption due to the high counts of faecal coliforms and total coliforms residual in the water.

All the heavy metals detected exceeded the WHO guideline except Cadmium where most of the values were below detection level.

With the exception of sulphate, all the elements exceeded the WHO limits. The Onyasia stream contained high phosphate coming mainly from the domestic and agricultural activities.

Generally all the physical parameters studied were within the WHO limits except for turbidity which far exceeded the WHO limits. The high turbidity observed in the stream is attributable to poor farming practices which result in large quantities of top soil ending up in the stream after heavy rains.

6.2   Recommendations

The results suggest that the effluents being discharged into the streams have considerable negative effects on the water quality in the receiving streams. Therefore, it is recommended that:

1. Public Awareness Forums should be created by the Environmental Protection Agency,

Ghana (EPA) and Accra Metropolitan Assembly (AMA) to educate the populace, the increased degradation of the Onyasia stream especially amongst people who live along the banks and surroundings of the stream and the effects it could have on their health and sustainance.

2. Farmers should be assisted in fertilizer and agro-chemicals application by agricultural extension officers of the Ministry of Food and Agriculture and EPA to avoid the incidence of high nutrient loads in surface waters.

3. A strict control of effluent volume and nutrient content as well as provision of sanitation facilities and piped water to the riparian communities by EPA and AMA.
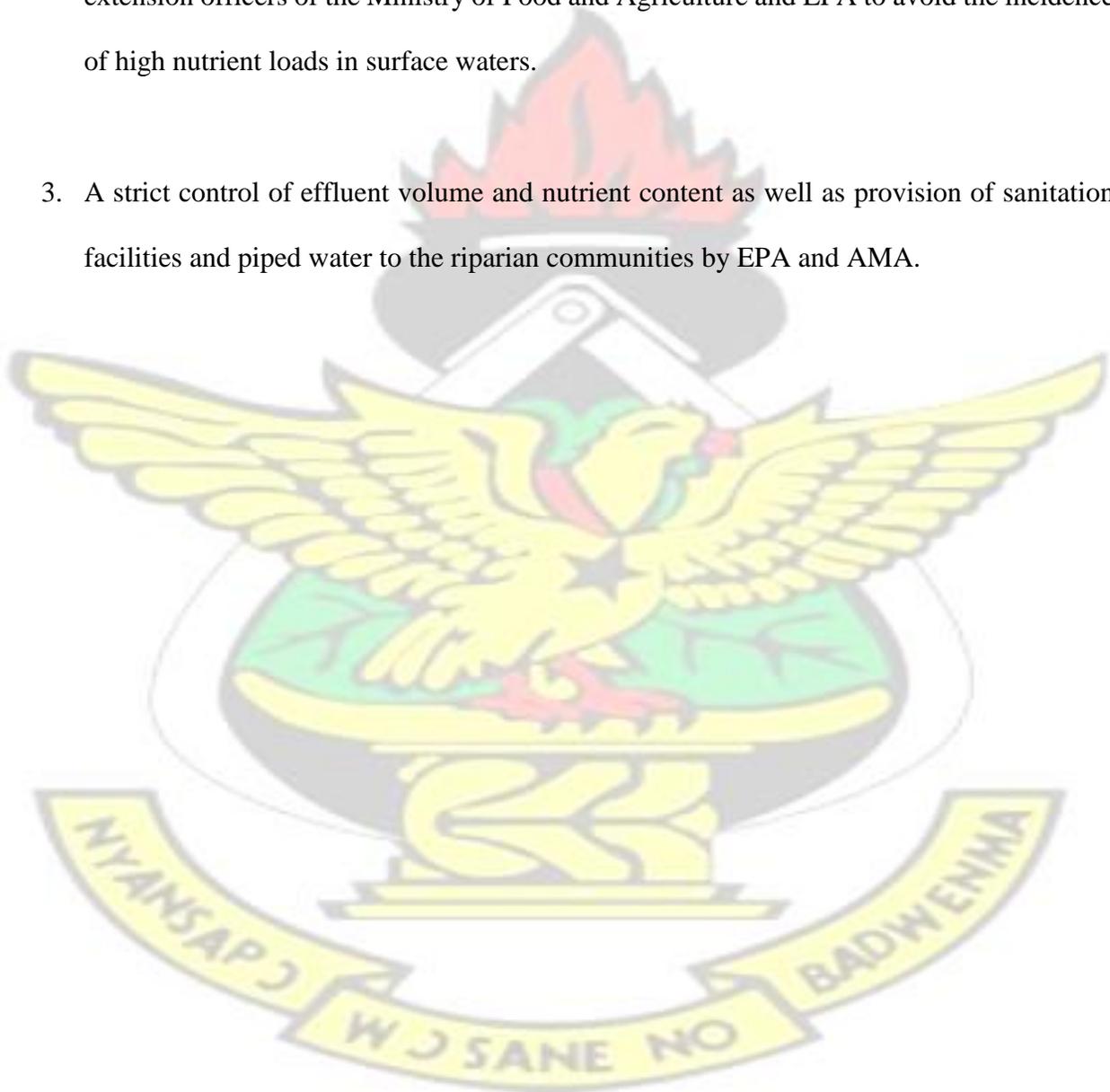
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APPENDICES

Appendix 1a- Mean data for Physico-chemical parameters of the Onyasia stream

SAMPLE CODES	pH (units)		TEMPERATURE (°C)		CONDUCTIVITY (µS/cm)		TURBIDITY (NTU)		TDS (mg/l)		DO (mg/l)	
	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON
A1	5.87	5.84	27.54	26.53	1.21	1.18	133.00	168.50	0.69	0.75	4.71	7.67
A2	5.99	5.76	29.68	26.85	1.77	1.37	126.00	204.50	1.01	0.78	6.43	3.94
A3	6.49	6.24	30.45	26.36	1.43	1.33	135.00	149.00	0.82	0.76	4.35	6.94
A4	6.69	6.51	30.01	26.35	1.50	1.28	98.10	69.30	0.86	0.71	4.78	7.85
A5	6.52	7.50	31.38	26.30	1.67	1.40	65.00	54.90	0.95	0.78	9.20	6.62
Mean	**6.31**	**6.37**	**29.81**	**26.48**	**1.52**	**1.31**	**111.42**	**129.24**	**0.86**	**0.76**	**5.89**	**6.60**
Stdev	**0.35**	**0.70**	**1.42**	**0.22**	**0.21**	**0.08**	**29.86**	**64.64**	**0.12**	**0.02**	**2.01**	**1.57**
B1	5.90	5.90	31.53	27.42	1.68	1.57	102.00	116.50	0.94	0.89	6.96	3.54
B2	5.96	5.92	30.67	27.66	1.62	1.51	70.90	102.50	0.92	0.87	6.12	3.16
B3	6.42	6.06	31.15	27.36	1.58	1.65	133.55	151.50	0.91	0.93	6.6	6.04
B4	6.71	6.67	31.30	27.56	1.67	1.60	106.00	120.50	0.97	0.90	7.66	7.79
B5	6.59	7.33	30.87	28.65	1.63	1.72	101.25	128.00	0.98	0.86	6.91	4.94
Mean	**6.31**	**6.37**	**31.10**	**27.73**	**1.63**	**1.61**	**102.74**	**123.80**	**0.94**	**0.89**	**6.85**	**5.09**
Stdev	**0.36**	**0.61**	**0.34**	**0.52**	**0.04**	**0.07**	**22.22**	**18.04**	**0.02**	**0.02**	**0.56**	**1.89**
C1	6.50	6.29	32.45	27.58	1.67	1.70	92.50	63.55	0.96	0.97	7.91	6.08
C2	6.77	7.36	32.23	27.89	1.66	1.68	120.25	68.10	0.94	0.96	7.91	7.96
C3	6.72	6.20	32.37	27.78	1.64	1.76	95.80	76.05	0.93	1.00	7.45	5.95
C4	6.77	6.77	31.55	27.90	1.61	1.69	103.00	57.45	0.92	0.96	7.56	8.48
C5	6.63	6.76	32.40	27.79	1.64	1.74	128.00	79.15	0.97	0.99	8.52	8.00
Mean	**6.68**	**6.67**	**32.20**	**27.78**	**1.64**	**1.71**	**107.91**	**68.86**	**0.94**	**0.97**	**7.87**	**7.295**

Stdev	0.11	0.46	0.37	0.12	0.02	0.03	15.52	8.89	0.02	0.01	0.41	1.18

Appendix 1b- Mean data for nutrient level in the Onyasia stream

SAMPLE CODES	PHOSPHATES (mg/l)		SULPHATES (mg/l)		NITRATE NITROGEN (mg/l)		AMMONIA NITROGEN (mg/l)	
	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON
A1	4.42	6.18	75.00	79.00	17.95	14.40	28.69	12.51
A2	6.08	5.64	79.00	78.00	17.00	13.40	18.69	17.28
A3	4.70	5.48	77.00	64.00	15.25	12.41	17.5	18.18
A4	5.20	3.26	81.00	80.00	3.75	4.81	11.87	10.74
A5	4.86	3.75	70.00	75.00	2.90	5.71	15.94	13.05
Mean	**5.05**	**4.86**	**76.40**	**75.20**	**11.37**	**10.14**	**18.53**	**14.35**
Stdev	**0.64**	**1.27**	**4.21**	**6.53**	**7.41**	**4.52**	**6.23**	**3.21**
B1	3.23	3.38	63.00	75.00	2.40	2.06	11.20	11.07
B2	2.71	2.97	72.00	77.00	3.15	1.85	10.77	11.27
B3	2.73	2.76	73.00	69.50	2.25	2.06	9.56	7.64
B4	3.16	2.94	67.00	60.00	2.05	1.34	10.23	9.08
B5	3.72	3.51	61.00	52.00	2.20	2.76	11.26	11.41
Mean	**3.11**	**3.11**	**67.20**	**66.70**	**2.41**	**2.01**	**10.60**	**10.09**
Stdev	**0.41**	**0.31**	**5.31**	**10.53**	**0.43**	**0.50**	**0.71**	**1.66**
C1	4.90	4.16	73.00	47.00	2.81	2.05	17.48	11.88
C2	5.32	5.06	64.00	43.00	2.80	2.11	20.70	16.34
C3	5.41	5.64	55.00	50.00	2.80	2.59	20.99	16.62
C4	5.36	4.93	47.00	44.00	3.15	3.60	18.80	14.37

C5	0.78	3.90	53.00	51.00	3.00	2.80	20.41	14.16
Mean	**4.35**	**4.73**	**58.40**	**47.00**	**2.91**	**2.63**	**19.67**	**14.67**
Stdev	**2.00**	**0.70**	**10.18**	**3.53**	**0.15**	**0.62**	**1.49**	**1.91**

Appendix 1c – Mean data heavy metals concentrations detected in the Onyasia stream

SAMPLE CODES	ALUMINIUM (mg/l)		MANGENESE (mg/l)		CADMIUM (mg/l)		IRON (mg/l)		COPPER (mg/l)	
	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON	DRY SEASON	WET SEASON
A1	7.87	6.65	0.37	0.26	0.24	0.00	2.18	3.43	0.01	0.16
A2	6.43	9.92	0.29	0.41	0.00	0.00	0.51	0.67	1.19	2.16
A3	3.51	7.36	0.23	0.27	0.04	0.00	0.69	2.13	7.42	7.97
A4	10.68	13.21	0.17	0.26	0.00	0.00	0.26	2.17	0.36	0.56
A5	14.23	16.81	0.88	1.27	0.00	0.00	0.41	1.37	2.98	3.17
Mean	**8.54**	**10.79**	**0.39**	**0.50**	**0.05**	**0.00**	**0.81**	**1.95**	**2.39**	**2.80**
Stdev	**4.09**	**4.23**	**0.28**	**0.43**	**0.10**	**0.00**	**0.78**	**1.02**	**3.03**	**3.13**
B1	9.99	14.72	0.48	0.83	0.00	0.00	1.44	2.70	3.13	5.12
B2	5.86	8.75	0.51	1.47	0.00	0.00	0.16	2.07	1.98	2.70
B3	17.27	21.13	0.23	0.54	0.00	0.00	2.33	3.66	2.60	4.16
B4	10.80	13.80	0.42	0.77	0.00	0.00	0.18	2.36	0.01	0.22
B5	12.31	12.10	0.79	0.83	0.00	0.00	1.10	1.77	0.01	0.02
Mean	**11.24**	**14.10**	**0.49**	**0.89**	**0.00**	**0.00**	**1.04**	**2.51**	**1.55**	**2.44**
Stdev	**4.13**	**4.53**	**0.20**	**0.34**	**0.00**	**0.00**	**0.91**	**0.72**	**1.45**	**2.29**

	13.99	17.72	0.46	0.65	0.00	0.00	2.11	2.81	2.27	2.34
C1	13.99	17.72	0.46	0.65	0.00	0.00	2.11	2.81	2.27	2.34
C2	11.45	15.94	0.36	0.48	0.03	0.00	0.62	2.48	4.02	4.32
C3	12.87	14.68	0.35	0.53	0.47	0.00	1.50	2.74	0.01	0.01
C4	11.35	19.18	0.28	0.43	0.00	0.00	0.44	1.56	0.01	0.11
C5	13.25	15.23	0.24	0.42	0.00	0.00	0.47	2.74	0.01	0.01
Mean	**12.58**	**16.55**	**0.34**	**0.50**	**0.10**	**0.00**	**1.03**	**2.46**	**1.26**	**1.36**
Stdev	**1.15**	**1.86**	**0.08**	**0.09**	**0.20**	**0.00**	**0.74**	**0.52**	**1.82**	**1.93**

Appendix 1d - Log of Total Coliform counts sampled from the indicated locations along the Onyasia stream

	MONTH	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
DRY SEASON	DEC	8.38	8.63	7.97	7.63	7.97	8.63	7.97	8.38	7.97	7.63	8.63	7.97	8.38	8.63	8.63
	JAN	8.36	8.60	7.95	7.60	7.95	8.60	7.95	8.36	7.95	8.60	8.60	7.95	8.36	8.60	8.60
	TOTAL MEAN	8.19														
	StDeV	8.22														
					Mean	StDev										
				Upstream	8.07	8.17										
				Midstream	8.15	8.20										
				Downstream	8.32	8.28										

		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
WET SEASON	MAY	5.18	3.40	3.26	4.18	4.20	3.40	3.18	3.26	4.23	3.34	3.30	3.40	3.36	4.18	3.18
	JUNE	3.04	4.08	4.23	3.18	3.11	4.18	3.15	4.15	3.11	4.04	4.00	3.18	3.20	3.18	3.18
	TOTAL MEAN	3.86														
	StDev	4.35														
					Mean	StDev										
					4.16	3.85										
				Ustream												
					3.65	3.80										
				Midstream												
					3.42	3.62										
				Downstream												

Appendix 1e - Log of Fecal Coliform counts sampled from the indicated locations along the Onyasia stream

	MONTH	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
DRY SEASON	DEC	6.63	6.97	6.97	6.38	5.63	6.38	5.97	5.97	6.63	6.97	6.38	5.97	6.97	6.63	6.38
	JAN	6.60	6.95	5.95	6.36	5.60	6.36	5.95	5.95	6.60	6.95	6.36	5.95	6.95	6.60	6.36
	TOTAL MEAN	6.41														
	StDeV	6.50														

					Mean	StDev									
				Ustream	6.45	6.59									
				Midstream	6.37	6.49									
				Downstream	6.40	6.48									
		A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	C5
WET SEASON	MAY	3.30	2.34	2.30	3.70	2.78	2.85	3.30	2.48	2.78	2.30	2.60	3.70	4.52	4.73	3.30
	JUNE	0.18	2.51	2.54	3.53	2.53	2.51	1.30	1.40	2.63	1.52	1.60	1.70	4.52	1.73	2.30
	TOTAL MEAN	3.51														
	StDev	4.01														
					Mean	StDev									
				Ustream	2.92	3.20									
				Midstream	2.49	2.72									
				Downstream	3.93	4.23									

Appendix 2a: ANOVA Tables for heavy metals parameters

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Aluminium	Equal variances assumed	0.476	0.496	-2.100	28	0.045	-3.02233	1.43899	-5.96998	-0.07469
Cadium	Equal variances assumed	9.591	0.004	1.676	28	0.105	0.05600	0.03342	-0.01246	0.12446
Manganese	Equal variances assumed	3.610	0.068	-2.129	28	0.042	-0.22523	0.10579	-0.44193	-0.00853
Iron	Equal variances assumed	0.163	0.689	-4.806	28	0.000	-1.35000	0.28088	-1.92536	-0.77464
Copper	Equal variances assumed	0.345	0.562	-0.567	28	0.575	-0.46833	0.82531	-2.15891	1.22224

Appendix 2b: ANOVA Tables for nutrient parameters

		Levene's Test for Equality of Variances		t-test for Equality of Means						95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2tailed)	Mean Difference	Std. Error Difference		Lower	Upper
Phosphates	Equal variances assumed	0.462	0.502	-0.139	28	0.891	-0.06533	0.47093		-1.02999	0.89932
Sulphates	Equal variances assumed	4.796	0.037	0.980	28	0.335	4.36667	4.45430		-4.75755	13.49089
Nitrate nitrogen	Equal variances assumed	0.708	0.407	0.331	28	0.743	0.63200	1.90707		-3.27447	4.53847
Ammonia nitrogen	Equal variances assumed	4.873	0.036	2.008	28	0.054	3.22967	1.60831		-0.06481	6.52414

Appendix 2c   ANOVA Tables for physico-chemical parameters

		Levene's Test for Equality of Variances		t-test for Equality of Means							
										95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2tailed)	Mean Difference	Std. Error Difference		Lower	Upper
pH	Equal variances assumed	5.281	0.029	-0.223	28	0.825	-0.03833	0.17200		-0.39065	0.31398
Temperature	Equal variances assumed	2.282	0.142	9.766	28	0.000	3.70700	0.37959		2.92944	4.48456
Conductivity	Equal variances assumed	4.351	0.046	0.926	28	0.363	0.05500	0.05942		-0.06672	0.17672
Turbidity	Equal variances assumed	9.492	0.005	0.004	28	0.997	0.05667	13.12729		-26.83337	26.94671
TDS	Equal variances assumed	2.245	0.145	1.342	28	0.190	0.04270	0.03181		-0.02247	0.10787

		0.993	0.328	0.932	28	0.359	0.54000	0.57957	-0.64719	1.72719
DO	Equal variances assumed									

Plate 8: Picture of water pumps used for irrigation by some farmers along the stream at Okponglo

Plate 9: Farmer fetching stream water to irrigate farm nearby downstream Dzorwulu

Plate 10: Improper disposal and burning of rubbish along the stream runoff during rainy season polluting it

Plate 11: Effluents from bath houses of residents along the stream discharged into the stream at midstream, Tetteh Quarshie

Plate 12: Effluents from residential homes at Dzorwulu discharged directly into the stream (Arrowed)

Plate 13: Inflow drain from industrial, commercial and residential homes discharging contents of drain into the Onyansia stream

Plate 14: Photograph showing human defecating activity inside a drain pipe emptying pollutant into the stream at Dzorwulu


Plate 15: Anthropogenic effect of human activity accentuated by the activity of rumen animals (cattle) defecating into the stream during search for water and food