

**ANTHROPOGENIC POINT SOURCES AND LEVELS OF NUTRIENTS TO
WINAM GULF OF LAKE VICTORIA, RIVER KISAT AND NYALENDA
WIGWA STREAM IN KISUMU CITY**

BY

CHAMULA PATRICK MUSUNGU

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MASENO UNIVERSITY

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ABSTRACT

Liquid waste materials discharged at industries and Wastewater Treatment Plants (WWTP) are usually swept off through surface runoff into River Kisat (RK) and Nyalenda Wigwa stream (NWS) and finally into the Winam Gulf of Lake Victoria leading to eutrophication. The waste material consists of chemical nutrients especially compounds of nitrogen and phosphorus. There is lack of information on the efficiency of the Lagoons in reducing the levels of nutrients and the contribution of industries towards pollution, therefore the current study was carried out in order to acquire knowledge that will be useful for management of water quality and related functions. The objective of the study was to determine efficiency of nutrient removal from municipal waste disposals by Kisat Wastewater Treatment Plant (KWWTP) and Nyalenda Waste Stabilization Ponds (NWSP) and the contribution of nutrient concentrations by some industries (Fish Processing Factory-FPF, Flourmill and Matchbox Factory) and Landfill to River Kisat. Samples of wastewater were collected along RK and NWS and also at the inlet, within and outlet of the suspected point sources preserved and analyzed in the laboratory. Visible spectrophotometry with Cadmium reduction and Griess Ilosva methods were used for analyzing nitrates (NO_3^- -N). Visible spectrophotometry and Griess Ilosva methods were used for analyzing nitrites (NO_2^- -N). Digestion and Vanadomolybdophosphoric acid colorimetric methods were used for analyzing total phosphorus (T-P). Ammonia nitrogen (NH_3 -N) was analyzed by Kjeldahl distillation followed by back titration method while organic nitrogen (N_{Org}) by kjeldahl digestion followed by distillation and then back titration. The MSTAT-C programme of analysis of variance was carried out on the recorded raw data. The concentration of nutrient parameters varied significantly ($P \leq 0.05$) with sites (inlet, within and outlet) at KWWTP and NWSP except for NH_3 -N which had no significant difference. Concentrations of nutrient removal in mg/l at KWWTP are 0.019 (NO_2^- -N), 0.235 (NO_3^- -N), -0.116 (NH_3 -N), 0.720 (N_{Org}) and 0.142 (T-P); while at NWSP are 0.073, 0.188, 0.000, 0.441 and 0.475, respectively. Generally KWWTP and NWSP only slightly reduced the concentration of incoming nutrients, as most of the nutrients were discharged into RK and NWS, respectively. Percentages concentration removal at KWWTP are 41.304 (NO_2^- -N), 13.710 (NO_3^- -N), -4.866 (NH_3 -N), 27.047 (N_{Org}) and 10.350 (T-P); while at NWSP are 50.000,

10.410, 0.000, 16.604 and 30.784, respectively. Concentration of nutrient parameters varied significantly with sites (inlet, within and outlet) and also with industries and Landfill. There was significant interaction effect ($P \leq 0.05$) for all the parameters determined, meaning the responses did not occur in a uniform pattern. Concentrations contribution in mg/l at FPF are 0.007 (NO_2^- -N), 0.299 (NO_3^- -N), -0.140 (NH_3 -N), 0.297 (N_{Org}) and 0.082 (T-P); while at Flourmill, Matchbox Factory and Landfill are 0.020, 0.432, 0.222, 0.579 and 0.089; 0.011, 0.080, 0.228, 0.156 and 0.248; 0.115, 0.337, 0.633, 0.559 and 0.160, respectively. The nutrient concentration increased significantly from inlet to outlet of the industries and Landfill. The highest concentration of NO_2^- -N and NH_3 -N were contributed by Landfill while NO_3^- -N and N_{Org} by Flourmill and T-P by Matchbox Factory. The lowest concentration of NO_2^- -N, NH_3 -N and T-P were contributed by FPF while NO_3^- -N and N_{Org} by Matchbox Factory. The concentrations of nutrient parameters contributed by most industries were below the guideline allowable limits except for NH_3 -N that was contributed by Landfill, was above the limit. The concentration of nutrient parameters varied significantly ($P \leq 0.05$) with the sites (main source, pre-junction FPF, post-junction FPF and post-junction KWWTP; Pre-junction Lagoons and Post-junction Lagoons) along RK and NWS. Concentrations variation in mg/l from the main source of RK to downstream are 0.011-0.177 (NO_2^- -N), 1.391-2.102 (NO_3^- -N), 1.309-2.783 (NH_3 -N), 1.493-2.949 (N_{Org}) and 0.856-1.171 (T-P); while at NWS are 0.017-0.118, 1.352-1.822, 2.325-2.480, 2.074-2.608 and 0.530-0.967, respectively. There was an increase in the concentration of nutrient parameters from the main source to downstream of RK and NWS. The point sources of nutrients to Winam Gulf of Lake Victoria include FPF, Flourmill, Matchbox Factory and Landfill. The KWWTP and NWSP are not efficient in removing nutrients from wastewater as the percentage concentrations removed were below guideline allowable limits except for NO_2^- -N that was above. Upgrading of KWWTP and NWSP is required so as to be more efficient because low concentrations of nutrient pollutants are removed from wastewater. Establishment of more efficient WWTP along rivers within the Lake Basin is required in order to capture the waste emanating from various industries before it reaches the rivers and the lake. More research is required on how to design a more efficient WWTP. More research is needed on other suspected point sources within Lake Victoria Basin.

CHAPTER 1

1 INTRODUCTION

1.1 Background information

River Kisat and Nyalenda Wigwa Stream drain their water into Winam Gulf of Lake Victoria. Eutrophication at the Gulf is due to high nutrient loads from rivers feeding it (Cowi, 2002; Lvemp, 2003; Nzomo, 2005). Suspected point sources include Fish Processing Factory, Flourmill, Matchbox Factory and Landfill. The raw materials available at the point sources are suspected to be highly nutritious and these include food materials, minerals, chemicals, human and plant nutrients and therefore there is need for waste treatment before discharge from point sources (Bean, 1992; Salha *et al.*, 2009; Gumisiriza *et al.*, 2009). Past studies show ineffective or lack of proper effluent treatment, therefore the concentrations of chemical nutrients are suspected to be great (Nzomo, 2005). Kisat Wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds are located along River Kisat and Nyalenda Wigwa Stream, respectively. Odada *et al.* (2004) note that Wastewater Treatment Plants are malfunctioned; therefore there is inefficiency in removing nutrients (compounds of nitrogen and phosphorus) by the Plants. Efficient measures are necessary in ensuring that chemical nutrients are removed. The UN report of 2009 indicates that high nutrients in municipal wastes are in these areas. Low lying areas of Nyalenda and Usoma are prone to increased pollution and this is due to use of pit latrines occupying the ground water table (UN, 2009). Flush floods and surface runoffs aid in transportation of the wastes to the Wastewater Treatment Plants (UN, 2009). To understand the eutrophication problem in Winam Gulf, it is necessary to identify potential sources and to determine the concentration of the compounds of nitrogen and phosphorus in various regions.

1.2 Problem statement

Water hyacinth has impeded water transport and eutrophication cause massive death of aquatic animals (Nzomo, 2005; Agak, 2000; Mwita and Nkwengulila, 2008; Kayombo and Jorgensen, 2006). Nitrogen and phosphorus nutrients lead to flourishing of these

plants in the Gulf. Previous studies have not shown the contribution of Landfill and inefficiency of Wastewater Treatment Plants to the pollution arising from nitrogen and phosphorus nutrients. Lack of this information impedes appropriate planning in solving the problems arising from pollution caused by nutrients. Due to inefficiency of Wastewater Treatment Plants it is most probable that high nutrients from Plants and surface runoffs reach Winam Gulf leading to eutrophication. The current study was therefore designed to avail this information.

1.3 Objectives

Broad objective

To determine efficiency of nutrient removal from municipal waste disposals by Kisat Wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds and the contribution of nutrient concentrations by some industries and Landfill to river Kisat.

Specific objectives

- a) To identify the point sources of nutrients to Winam Gulf of Lake Victoria.
- b) To determine efficiency of removal of species of nitrogen (NO_2^- -N, NO_3^- -N, NH_3 -N and organic nitrogen) and T-P by Kisat Wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds from municipal wastewater.
- c) To determine the concentration of species of nitrogen (NO_2^- -N, NO_3^- -N, NH_3 -N and organic nitrogen) and T-P contributed by Fish Processing Factory, Flourmill, Matchbox Factory and Landfill at car wash into the aquatic system.
- d) To determine the concentration levels of species of nitrogen (NO_2^- -N, NO_3^- -N, NH_3 -N and organic nitrogen) and T-P along River Kisat and Nyalenda Wigwa Stream.

1.4 Hypotheses

- a) Kisat wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds are not efficient in removing chemical nutrients from municipal wastewater.
- b) Fish Processing Factory, Flourmill, Matchbox Factory and Landfill do not release nutrients into aquatic systems.

1.5 Justification

There is possible organic pollution of drinking and domestic water (Kayombo and Jorgensen, 2006). The high nutrients cause eutrophication and reduction of Lake Victoria Water quality (Kayombo and Jorgensen, 2006). There is impeded Lake Victoria Transport including no access to Kisumu Port. This is due to existence of the sheet of water hyacinth. This further hampers fishing in the Gulf and landing of the fishing boats. This leads to increased cost of fishing because water hyacinth tears nets (Kayombo and Jorgensen, 2006; Oguttu *et al.*, 2008). The condition also hampers local and international tourists who ride boats to see the lake scenery like watching hippos and islands. According to UN (2009) municipal wastes contain high levels of nutrients and due to malfunction of major Wastewater Treatment Plants in Kisumu City; there is low nutrient removal efficiency (Odada *et al.*, 2004). Some of the raw materials used in major industries within Kisumu City contain high levels of nutrients carried by wastewater entering the rivers and Winam Gulf leading to high nutrient loads and poor water quality (Bean, 1992; Salha *et al.*, 2009; Gumisiriza, 2009). The study would provide data to identify the sources of the compounds and thus facilitate a management strategy to stop their entry into the lake and as a result ensure long term environmental sustainability of the lake ecosystem. The data generated can be used in developing policies for environmental management of the lake and the Lake Basin catchment.

CHAPTER 2

2 LITERATURE REVIEW

2.1 Lake Victoria Basin Wastewater Treatment Plants and their functions

Kisat Wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds are located near River Kisat and Nyalenda Wigwa Stream, respectively. It is reported that the Wastewater Treatment Plants at Lake Victoria Basin are malfunctioned (Odada *et al.*, 2004). Wastewater from the Wastewater Treatment Plants drained into River Kisat and Nyalenda Wigwa Stream and is suspected to be untreated before discharge hence causing eutrophication at Winam Gulf of Lake Victoria (Nzomo, 2005; Cowi, 2002; Lvemp, 2003). Effective removal of chemical nutrients is therefore required in order to take necessary mitigation measures towards environmental pollution. Determination of the concentration of nutrients that is removed by the Wastewater Treatment Plants is necessary.

Research done by Kalibbala (2005) indicates that effluent from Wastewater Treatment Plants flow into Lake Victoria without pre-treatment. He further notes that there are malfunctioned Wastewater Treatment Plants at Lake Victoria Basin. Municipal untreated sewage runoff, storm water and animal waste are sources of microbiological pollution (Odada *et al.*, 2004). They further note that the root causes for microbiological pollution is due to the treatment works in municipalities as they are either inadequate, using old and obsolete technology, have ageing components or have simply ground to a halt. Poor planning, lack of maintenance and inadequate investment in municipality wastewater treatment systems have contributed to the increased untreated effluent discharge (Odada *et al.*, 2004). Nzomo (2005) reports that major towns like Kisumu have malfunctioned Sewage Plants which released effluents of poor quality. River Kisat is heavily loaded with liquid waste from Kisat Wastewater Treatment Plant (Nzomo, 2005). Research done by Gumisiriza *et al.* (2009) indicates that the nature of fish processing wastewater have inorganic compounds from detergents and disinfectants used in the factories that lead to eutrophication.

In low lying areas of Nyalenda and Usoma, construction of pit latrines is further inhibited by the ground water table and the flush floods are inherent in these areas (UN, 2009). Similarly there is encroachment of informal trading into recreational space and street verges, blocked sewers, clogged drainage from illegal dumping of solid waste, lack of effluent pre-treatment facilities in industry, and discharge of inadequately treated wastewater into the natural streams from both Municipal Plants and industries (UN, 2009). Abnormal high levels of T-N of sewage discharge in Marimba River in Zimbabwe confirm that Sewage Treatment Plant effluents can be major source of pollution in rivers (Nhapi and Tirivarambo, 2004). Studies have shown that the concentration of T-P in wastewater fluctuates from upstream to downstream. A study carried out found that increased discharge results into increased T-P concentration due to increased hydrological energy and its effects on the physical mechanisms of phosphorus release (Hanrahan *et al.*, 2003; Zaimes and Schultz, 2002). Neal *et al.* (2000b) note that the variation in phosphorus concentration associated with Wastewater Treatment Plants inputs to River Kennet relates to variation in several factors. They include volumetric discharge from the Treatment Plant, volumetric dilution associated with changing river flow upstream of the effluent input, volumetric dilution downstream as the contributing drainage area increased, confounding influences of diffuse sources including agricultural runoff and other within-river processes such as absorption by plants and adsorption by bottom/suspended sediments as well as phosphorus cycling between sediments and the water column (Neal *et al.*, 2000b).

In another study, most nutrients are removed through incorporation into the tissues of wetland sediments and incase of nitrogen losses to the atmosphere through denitrification in root zone of the aquatic plants (Kayombo and Jorgensen, 2006). Oguttu *et al.* (2008) note that the Kirinya Maturation Pond, part of the National Water and Sewerage Corporation (NSWC) public sewer and linked with the urban drainage system, contributes high loads of nutrient that leads to the eutrophication of Lake Victoria. The final effluent discharged from the NSWC contributed 8t/y of nitrogen into Kirinya west urban wetland during an annual cycle (Oguttu *et al.*, 2008).

2.2 Lake Victoria Basin Industrial activities

Fish Processing Factory, Flourmill, Matchbox Factory and Landfill are some of the suspected point sources of pollution within Lake Victoria Basin. The raw materials available at point sources are highly nutritious (Bean, 1992; Salha *et al.*, 2009; Gumisiriza *et al.*, 2009). It is suspected that the effluents from some other point sources contain nutrients that require removal before the wastewater is drained into aquatic systems to avoid causing eutrophication (Gumisiriza *et al.*, 2009). Before the mitigation measures are taken, it is necessary to determine the concentration of nutrients discharged by the Industries and Landfill into the aquatic systems.

Odada *et al.* (2004) found that Fish Processing Factories, Agro-Processing Factories and abattoirs discharge raw/untreated waste to feeder rivers and lakes. They further note that outdated and banned soaps and detergents are being used and contribute to eutrophication. Agro based industries (Fish Tanneries) discharge semi-treated effluents to rivers (Nzomo, 2005). Fish processing located in the major urban centres of the Lake Victoria Basin generate a lot of fish waste and large volume of processing wastewater (Gumisiriza *et al.*, 2009). Oguttu *et al.* (2008) note that the continuing proliferation of the water hyacinth (*Eichhornia Crassipes*) has been linked to the increasing nutrient loads to the lake from the urban and industrial centres. Agro-industrial activities on water quality of River Nyando contribute to high levels of nutrients that increase downstream (Raburu and Okeyo-Owuor, 2002). They note that water quality is poorer below than above the factories and this imply that industries discharge chemical nutrients into rivers. In Uganda there are increased discharges of municipal effluents and Agro-Marine, Gomba, leather discharge industrial wastewater into Lake Victoria (Oguttu *et al.*, 2008). Discharge into the lake of excess compounds of nitrogen and phosphorus originate from various industries within Kisumu City (FAO, 1994).

Use of raw materials, chemical reagents for cleaning and preservatives in the industries contribute to nutrients when wastewater is discharged into the surrounding (Bean, 1992; Odada *et al.*, 2004). Fish as a raw material at Fish Processing Factory is protein in nature hence contain compounds of nitrogen (Oguttu *et al.*, 2008). Phosphine being used as

fumigant in flourmill is a compound of phosphorus (Salha *et al.*, 2009). Raw materials for the manufacture of matchboxes include matchsticks, ammonium phosphate, phosphorus sesquisulphide, red phosphorus, potassium chloride, powdered glass, animal glue, zinc oxide, sulphur, rosin, antimony trisulphide and urea formaldehyde (Bean, 1992). Materials dumped at Landfill are foodstuff remains and household used products made up of compounds of nitrogen and phosphorus (UN, 2009). Madadi *et al.* (2007) note that municipal and industrial wastewater treatment plants are known to be the major point sources of phosphorus in urban areas.

2.3 Compounds of nitrogen

Total oxidized nitrogen (TON) exists in two forms; nitrite nitrogen and nitrate nitrogen (Ellis *et al.*, 1989). Organic nitrogen and ammonia can be determined together and have been referred to as 'Kjeldahl nitrogen' (Eaton *et al.*, 1995). Organic nitrogen is referred to as organic N, nitrate nitrogen as NO_3^- -N, nitrite nitrogen as NO_2^- -N and ammonia nitrogen as NH_3 -N (Greenberg *et al.*, 1985).

2.4 Sources of compounds of nitrogen

Organic nitrogen is either an integral part of protein molecules or partial breakdown products of these molecules including peptides, amino acids and urea (Greenberg *et al.*, 1985). Ammoniacal nitrogen is as a result of the biological decomposition and stabilization of organic nitrogen (Greenberg *et al.*, 1985). It is the end product of the metabolic activity of heterotrophic micro-organisms (Barber, 1995). Ammonia is oxidized by autotrophic bacteria to nitrite and then to nitrate (Zhang *et al.*, 2010). The following reactions take place in the presence of respective nitrosomonas and nitrobacter bacteria (Zhang *et al.*, 2010),



During rainy season the water quality conditions of a lake highly deteriorates (Sawyer, 2003). Runoff from agricultural activities and wet atmospheric deposition contribute compounds of nitrogen into a lake (Scholes, 2007). These agricultural activities include application of artificial fertilizers such as NH_4NO_3 (Scholes, 2007). During lightning

and thunderstorm the atmospheric nitrogen is converted into nitrates in the presence of nitrogen fixing bacteria (Sawyer, 2003). Most consumable manufactured products are made up of compounds of nitrogen (Galloway *et al.*, 2008). Nitrite nitrogen can also enter a water supply system through its use as a corrosion inhibitor in industrial process (Eaton *et al.*, 1995). The human activities that take place at industries therefore could be contributing to an increase in the concentration of nitrite nitrogen.

2.5 Nitrogen cycle

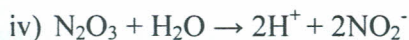
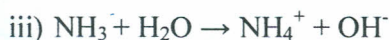
Nitrogen can exist in seven oxidation states (Sawyer, 2003), and essentially all are of environmental interest. Table 2.4.1 illustrates oxidation states of nitrogen.

Table 2.5.1. Oxidation states of nitrogen

Oxidation state	-3	0	1	2	3	4	5
Nitrogen compound	NH ₃	N ₂	N ₂ O	NO	N ₂ O ₃	NO ₂	N ₂ O ₅

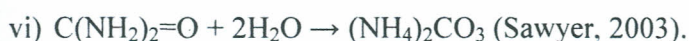
Source: (Sawyer, 2003)

These forms combine with water to form inorganic ionized species that can reach high concentrations, as illustrated in equations (iii) to (v),



According to Sawyer (2003) and Reinert and Hroncinch (1990), the atmosphere is a large reservoir from which nitrogen is constantly removed by the action of electrical discharge, nitrogen fixing bacteria and algae, and combustion processes. During electrical thunderstorms nitrogen is oxidized to NO, which is oxidized by ozone in the atmosphere to form NO₂ which in turn is reduced back to NO by photolysis (Galloway *et al.*, 2008). This forward and backward reaction establishes a steady state concentration between NO and NO₂, with NO generally being by far the dominant species (Seinfeld, 1986). Combustion processes such as in the internal combustion engine of automobiles, also lead to conversion of N₂ to NO and NO₂ (Sawyer, 2003). Other oxidative reactions with NO₂ in the atmosphere lead to the conversion of NO₂ to N₂O₅, which according to N₂ being converted by bacteria to form protein, can combine with water in the atmosphere to

produce the nitrate of nitric acid, which reaches the surface of the earth with falling rain (Galloway *et al.*, 2008). Nitrate is also produced by direct oxidation of nitrogen or of ammonia in the production of commercial fertilizers and therefore the nitrate serves to fertilize plant life and is converted to proteins (organic nitrogen); according to Seinfeld (1986). It is noted that major means by which atmospheric nitrogen enters the nitrogen cycle is through conversion to protein by nitrogen fixing bacteria and this includes the photosynthetic cyano bacteria, which have many similarities to algae (Seinfeld, 1986). Compounds of Nitrogen are released in the waste products from the body during life and at death the protein stored in the body becomes waste matter for disposal (Fassbender, 1993). The urine contains the nitrogen resulting from the metabolic breakdown of proteins and therefore nitrogen exists in urine principally as urea which is hydrolyzed rather rapidly by the enzyme urease to ammonium carbonate, as presented in the following equation,



Faeces of animals contain protein matter (organic nitrogen) and the protein matter in dead animals and plants are converted to ammonia by action of heterotrophic bacteria, under aerobic or anaerobic conditions (Seinfeld, 1986; Noophan *et al.*, 2009). Some nitrogen always remains in non digestible residue sink and as such it becomes part of the detritus in water or sediments, or the humus in soil (Sawyer, 2003). The ammonia released after the action of the bacteria on matter is oxidized by the autotrophic nitrifying bacteria, therefore one group (nitrosomonas) converts ammonia under aerobic conditions to nitrite and derive energy from the oxidation,



The nitrite formed in this reaction is oxidized by another group of nitrifying bacteria (nitrobacter) to nitrate,



The nitrate formed may serve as fertilizer for plants, however, some is carried away in water percolating through the soil which does not have the ability to hold nitrate (Sawyer, 2003). This frequently results in relatively high concentrations of nitrate in ground waters (Seinfeld, 1986). Nitrification also can result in some production of N₂O (Falkowski,

1997; Noophan *et al.*, 2009). Under anaerobic conditions nitrate and nitrite are both reduced by a process called denitrification and hence nitrate ion is reduced to nitrite ion, and then reduction of nitrite occurs (Fassbender, 1993; Noophan *et al.*, 2009). Through reduction of nitrite it is converted to ammonia then to protein by bacteria and mostly nitrate is reduced to N_2O and nitrogen gas which escapes to the atmosphere (Eaton *et al.*, 1995; Noophan *et al.*, 2009). It is a serious loss of fertilizing matter in soils when anaerobic conditions develop (Eaton *et al.*, 1995). N_2O can be reduced through photolysis to produce N_2 and an excited state of oxygen which oxidizes another portion of the N_2O to NO (Galloway *et al.*, 2008; Noophan *et al.*, 2009). These are transformations of nitrogen occurring in water, soil and the atmosphere through chemical, photochemical and biological processes as indicated in Figure 2.4.1 (Sawyer, 2003).

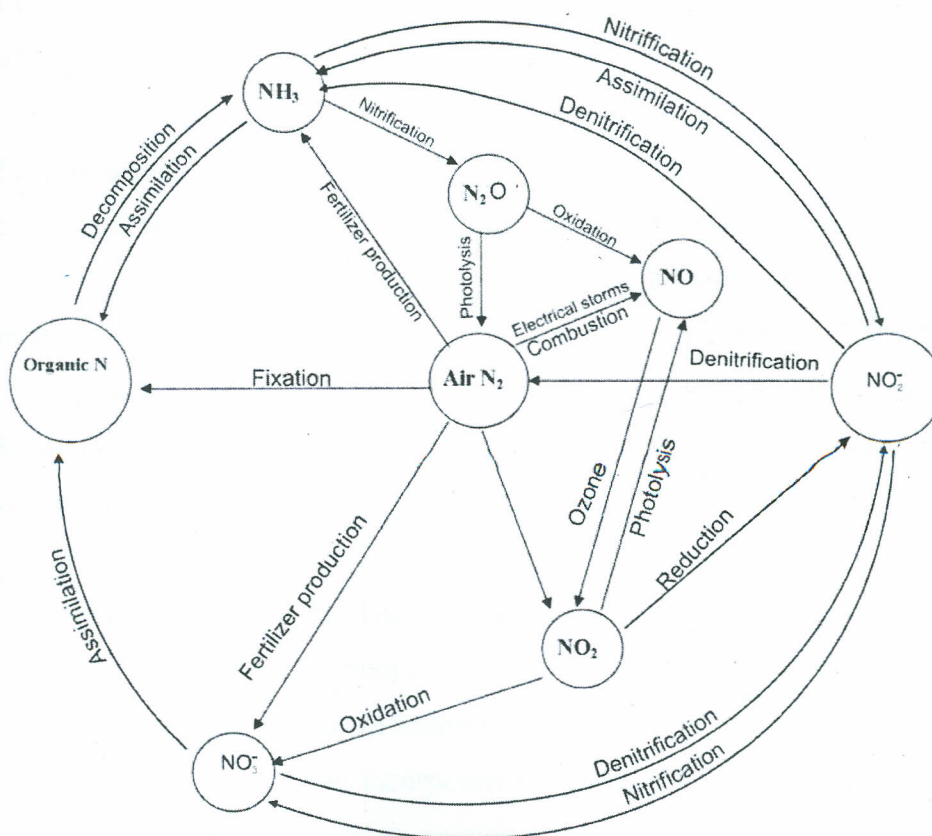


Figure 2.4.1 Transformations of nitrogen occurring in water, soil and atmosphere through chemical, photochemical and biological processes (Source: Sawyer, 2003)

2.6 Compounds of phosphorus

Mineral compounds of phosphorus include orthophosphates, polyphosphates and organic phosphates (Greenberg *et al.*, 1985). Orthophosphates include tri-sodium phosphate (Na_3PO_4), di-sodium phosphate (Na_2HPO_4), mono-sodium phosphate (NaH_2PO_4) and di-ammonium phosphate ($(\text{NH}_4)_2\text{HPO}_4$) (Eaton *et al.*, 1995). Polyphosphates include sodium hexametaphosphate $\text{Na}_3(\text{PO}_3)_6$, sodium tri-polyphosphate ($\text{Na}_5\text{PO}_{10}$) and tetra-sodium pyrophosphate ($\text{Na}_4\text{P}_2\text{O}_7$) (Greenberg *et al.*, 1985). Organic phosphates are formed primarily by biological processes (Ellis *et al.*, 1989; Neal *et al.*, 2000a). Inorganic monomeric phosphorus is usually termed as soluble reactive phosphorus (SRP) or orthophosphate while total dissolved phosphorus (TDP), represents SRP plus dissolved hydrolysable polymeric inorganic and organic phosphorus (DHP) (Neal *et al.*, 2000a). Total phosphorus (T-P), represents TDP plus particulate phosphorus (PP) (Ellis *et al.*, 1989; Neal *et al.*, 2000a).

2.7 Sources of compounds of phosphorus

Phosphorus occurs in several organic, inorganic and particulate forms in natural waters and therefore these forms of phosphorus mentioned in section 2.6 occur in solution and particles (Eaton *et al.*, 1995; Porter, 1975; Hanrahan *et al.*, 2003; Jarvie *et al.*, 2000; Neal *et al.*, 2000a). Larger quantities of the same compounds may be added when the water is used for laundering or other cleaning processes (Greenberg *et al.*, 1985). Phosphates are used extensively in the treatment of boiler waters and also orthophosphates applied to agricultural or residential cultivated land as fertilizers are carried into surface waters with storm runoff (Greenberg *et al.*, 1985). They are also contributed to sewage by body wastes and food residues and formed orthophosphates in biological treatment processes (Madadi *et al.*, 2007). Phosphates occur in bottom sediments and in biological sludges, both as precipitated inorganic forms and incorporated into organic compounds (Eaton *et al.*, 1995; Neal *et al.*, 2000b). Polyphosphates are present as builders of some commercial cleaning preparations for the public health sector and organic phosphates enter sewage water through body wastes and food residues (Greenberg *et al.*, 1985). Organic phosphates may result from the breakdown of organic pesticides that contain phosphates.

They may exist in solution, as particles, loose fragments, or in the bodies of aquatic organisms (Madadi *et al.*, 2007).

2.8 Guideline allowable limits

The World Health Organization (WHO) guidelines provide interim targets for countries that still have very high levels of pollution to encourage the gradual cutting down of emissions. The WHO quality guidelines are designed to offer global guidance on reducing the health impacts of pollution. Interim targets are aimed at promoting a gradual shift from high to lower concentrations. If these targets are to be achieved, significant reductions in risks for acute and chronic health effects from pollution can be expected. Progress towards guideline values, however, should be the ultimate objective of achieving the lowest concentrations possible (Helmer and Hespanhol, 1997). The guideline allowable limits for NO_2^- -N, NO_3^- -N, NH_3 -N, organic nitrogen and T-P are 3 mg/l (WHO, 2004), 10 mg/l (WHO, 2004), 0.5 mg/l (GOK, 2006), 10 mg/l (WHO, 2004) and 1 mg/l (Jiang *et al.*, 2004), respectively. The guideline values mentioned here could help in evaluating the quality of water entering Winam Gulf as far as nutrients are concerned in the present study.

2.9 Contribution of compounds of nitrogen and phosphorus to pollution in water and soil systems

When sewage and agricultural run off containing phosphates and other nutrients enter natural water bodies, they cause increase in the concentration of the chemical nutrients leading to eutrophication (Kayombo and Jorgensen, 2006); the process of providing water body with excess nutrients for the aquatic life it supports (Palmer, 2001). A lake starts as oligotrophic (clear water) and due to activities in its catchment, it collects substances leading to algal bloom, marshy- eutrophic stage; then the aquatic environment perishes since it turns into dry land (Palmer, 2001). This can be prevented by treating the inflow to the river (Ellis *et al.*, 1989; Moss, 1969). Highly affected by eutrophication are those parts of the lake shore, for example Winam, Napoleon and Mwanza gulfs and Murchison Bay (Kayombo and Jorgensen, 2006). Various activities take place at the point sources (industrial areas, urban settlements and various institutions) around Winam Gulf and rivers flowing into Winam gulf (Kayombo and Jorgensen, 2006). Such activities include

farming, livestock rearing, poultry keeping and deforestation (Kayombo and Jorgensen, 2006). Application of fertilizers to the farms around the water catchment areas causes some compounds of nitrogen and phosphorus to leach into adjacent water bodies (Neal *et al.*, 2000b; Raburu and Okeyo-Owuor, 2002). The rivers fed with water from the farms could be carrying the agrochemical residues into Lake Victoria and this is what the current study was to unravel.

Other important sources of compounds of nitrogen and phosphorus into Lake Victoria include industrial, domestic and municipal effluents (Kayombo and Jorgensen, 2006). In the lake there exist living things that include flora and fauna; including phytoplanktons and zooplanktons (Raburu and Okeyo-Owuor, 2002). These include microorganisms, algae, and aquatic weeds such as water hyacinth (a ferocious water weed), fish, snakes and crabs (Nzomo, 2005). The nutrients in question enable the organisms to grow rapidly but due to some biological reaction they may result into poisoning of aquatic animals (Mwita and Nkwengulila, 2008; Nzomo, 2005). There are various nutrients which once deposited into the lake that may cause the menace (Moss, 1969; Ochumba, 1986). The rapid growth of water hyacinth negatively affects regional trade, employment and revenue collection as it impedes transport (Agak, 2000). The problem is that ferries and boats may not sail smoothly as the water hyacinths act as barriers and fishing exercise is negatively affected and therefore resulting into decreased employment (Agak, 2000).

Levels of nitrate ion in drinking water do increase with time (Porter, 1975). Intensive cultivation of land facilitates the oxidation of reduced nitrogen to nitrate in decomposed organic matter in the soil provided with aeration and moisture (Kayombo and Jorgensen, 2006). Composition of inorganic fertilizers can be determined by analyzing ash contents and the use of fertilizers made of compounds of nitrogen accumulates nitrates in the soil which contaminates the ground water (Ellis *et al.*, 1989). Nitrogen existence in high amounts in water may lead to a disease known as Methemoglobinemia in infants (Eaton *et al.*, 1995). In the presence of bacteria in the stomach, reduction of nitrate to nitrite occurs (Eaton *et al.*, 1995),



The nitrite ion combines with and oxidizes the haemoglobin in the blood to form methemoglobin preventing the proper absorption and transport of oxygen to the cells (Eaton *et al.*, 1995). The infant turns blue and suffers respiratory failure (Porter, 1975). Most of the nutrients are removed through incorporation into the tissues of wetlands sediments while nitrogen is lost to the atmosphere and through denitrification in root zone of the aquatic plants (Whitehead, 1995). Algal growth causes deoxygenation of the water that threatens the survival of deep water fish species (Nzomo, 2005). Nitrate and phosphate ions levels in fresh water cause excessive aquatic plants growth (Downing and Rath, 1988).

Urban wastewater and runoff in Kenya contain the highest T-N and T-P pollution loading to Lake Victoria amounting to 2,019t/y and 848t/y, respectively (Kayombo and Jorgensen, 2006). Urban wastewater and runoff in Uganda contain 767t/y T-N and 484t/y T-P, respectively; while for Tanzania amount to 719t/y T-N and 292t/y T-P, respectively (Emmanuel *et al.*, 2000; Kayombo and Jorgensen, 2006). The industrial nutrient loading to Lake Victoria are 324t/y T-N and 208t/y T-P for Tanzania, 57t/y T-N and 46t/y T-P for Kenya and 33t/y T-N and 88t/y T-P for Uganda (Kayombo and Jorgensen, 2006). The total industrial nutrient to Lake Victoria is 414t/y for T-N and 342t/y for T-P (Kayombo and Jorgensen, 2006). Concerning pollutant loading collected by rivers to the lake, River Kagera transport the highest load of T-N (29,303t/y) and T-P (1,892t/y); followed by River Nzoia T-N (3,340t/y) and T-P (946t/y), according to Kayombo and Jorgensen (2006). This therefore strengthens the current study on nutrients loads in the suspected point sources into Lake Victoria. The present study was to investigate into the possible contribution of these nutrients into Winam Gulf water through possible point sources. The results could help in creating mitigation measures that may assist Winam Gulf and the bigger Lake Victoria region in surmounting the current eutrophication and water hyacinth problem.

CHAPTER 3

3 METHODOLOGY

3.1 Area of study

The regions where sampling was done are Kisat Wastewater Treatment Plant (KWWTP), Nyalenda Waste Stabilization Ponds (Lagoons)-NWSP, Industries {Fish Processing Factory (FPF) located next to KWWTP and is known as Capital Fish, Flourmill (United Millers) and Matchbox Factory located near Otongilo trading centre and is known as Kenya Matches}, Landfill located at 'car wash' near shores of Winam Gulf of Lake Victoria, Nyalenda Wigwa Stream located near Nyalenda Waste Stabilization Ponds and River Kisat located in Kisumu city, Kenya as illustrated in Figures 3.1.2, 3.1.3(a), 3.1.3(b) and 3.1.3(c). Figure 3.1.2 also indicates the location of Kisumu City and surrounding features while Figure 3.1.1 is map of Lake Victoria Basin.

30°E 31°E 32°E 33°E 34°E 35°E 36°E 37°E

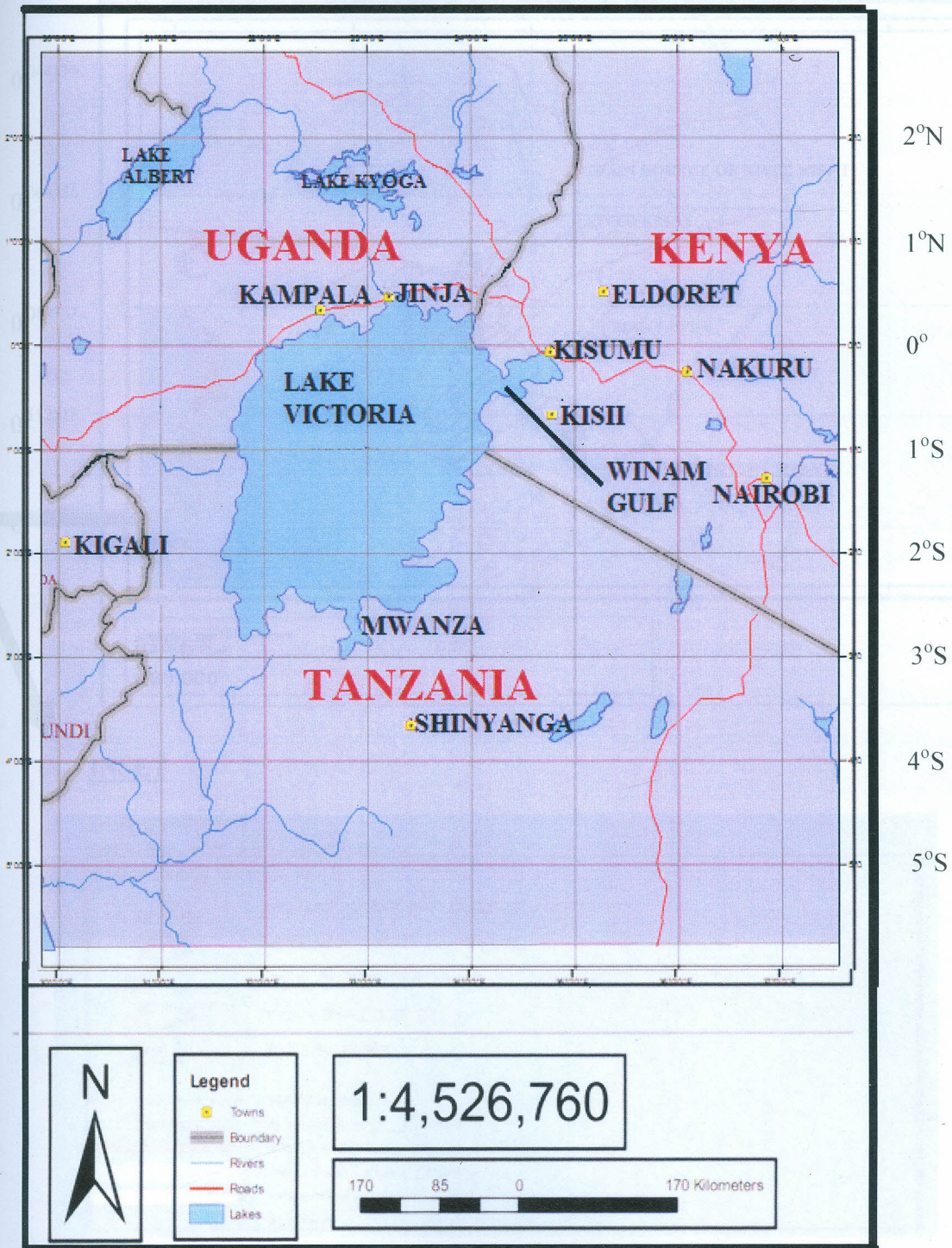
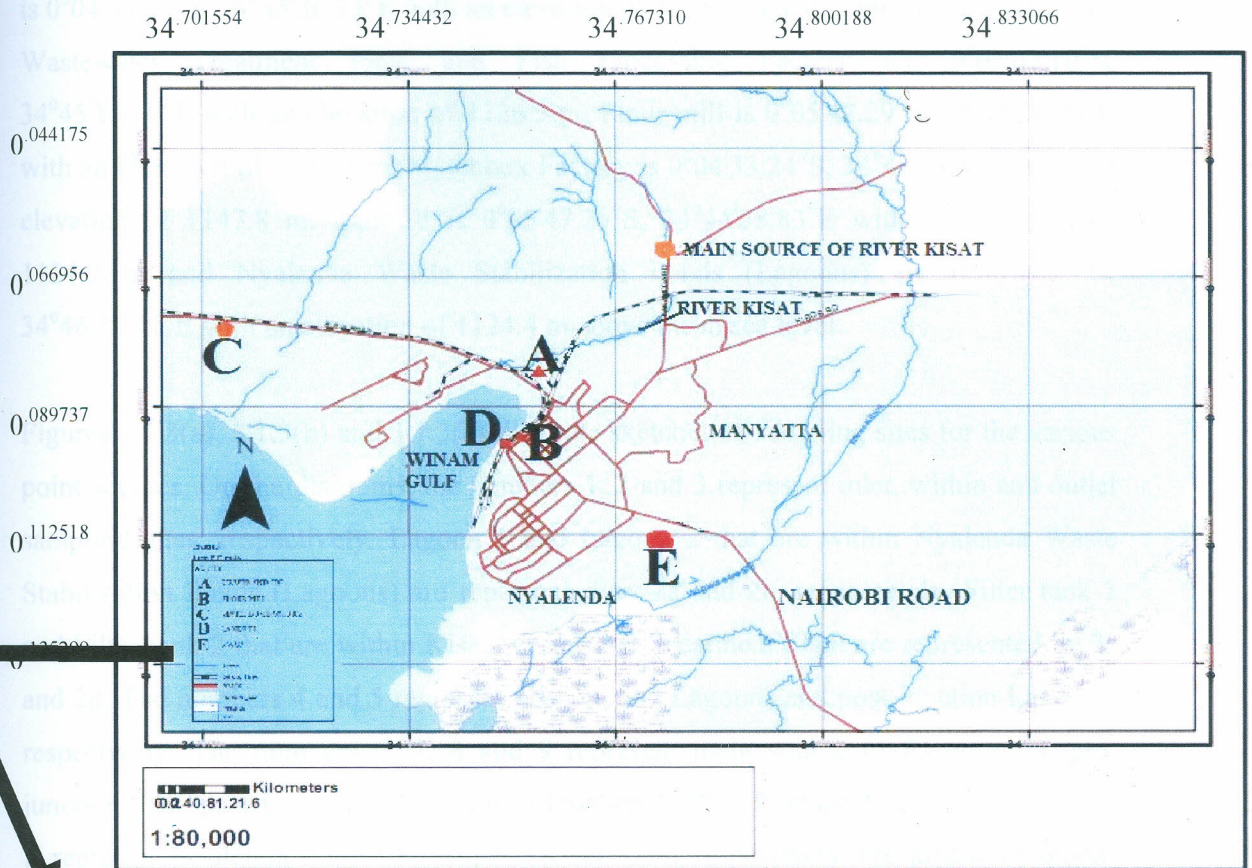


Figure 3.1.1 Map of Lake Victoria Basin (adopted from Bartholomew, 1989) surrounding features and the sampling sites of various point sources (Modified from Butler, 1959; GIS Section, Municipal Council of Kisumu, 2003)



INSET

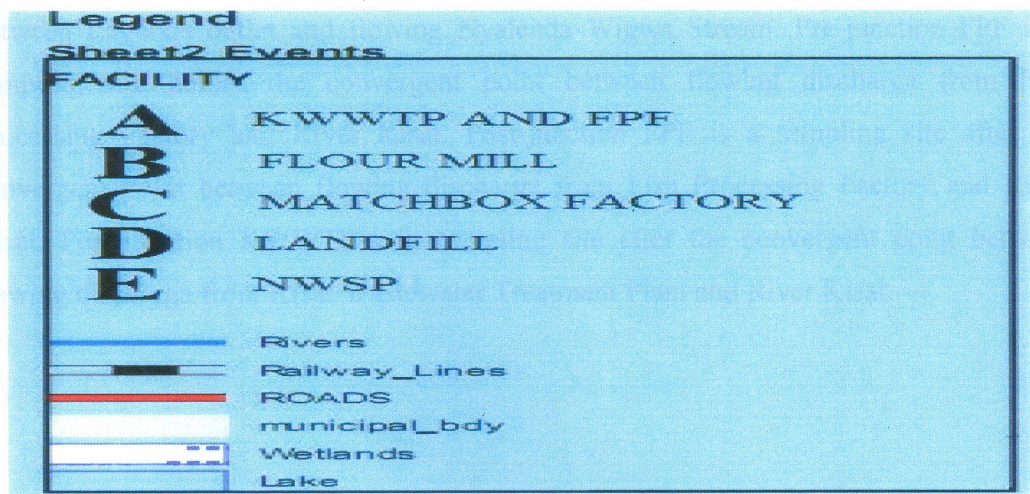
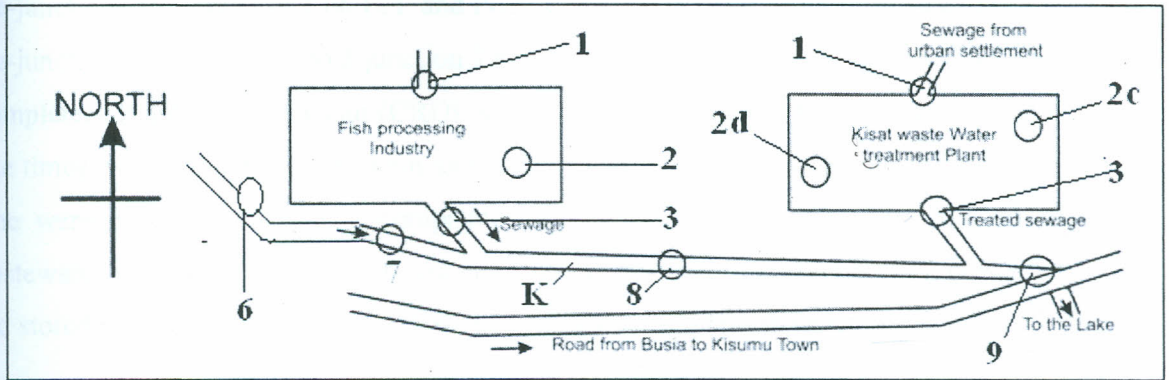


Figure 3.1.2 Map of the Winam Gulf showing the location of Kisumu City, surrounding features and the sampling sites of various point sources (Modified from Butler, 1959; GIS Section, Municipal Council of Kisumu, 2003)

The grid positions of the sampling regions were recorded. The main source of River Kizat is $0^{\circ}04'49.21''\text{S}$, $34^{\circ}45'36.33''\text{E}$ with an elevation of 1131.9 m above mean sea level, Kizat Wastewater Treatment Plant and Fish Processing Factory are $0^{\circ}05'02.10''\text{S}$, $34^{\circ}45'15.10''\text{E}$ with an elevation of 1126.5 m, Flour mill is $0^{\circ}05'42.29''\text{S}$, $34^{\circ}45'08.09''\text{E}$ with an elevation of 1132.5 m, Matchbox Factory is $0^{\circ}04'33.24''\text{S}$, $34^{\circ}42'18.56''\text{E}$ with an elevation of 1147.8 m, Landfill is $0^{\circ}05'47.25''\text{S}$, $34^{\circ}44'58.83''\text{E}$ with an elevation of 1124.7 m and Nyalenda Waste Stabilization Ponds (Lagoons) are $0^{\circ}06'49.25''\text{S}$, $34^{\circ}46'25.41''\text{E}$ with an elevation of 1124.4 m above mean sea level.

Figures 3.1.3(a), 3.1.3(b) and 3.1.3(c) illustrate sketches of sampling sites for the various point sources. On the diagrams, the numbers 1, 2 and 3 represent inlet, within and outlet sampling sites, respectively. Lagoon 1 and Lagoon 2 that are within Nyalenda Waste Stabilization Ponds (Lagoons) are represented by 2a and 2b, respectively. Filter tank 1 and Filter tank 2 that are within Kizat Wastewater Treatment Plant are represented by 2c and 2d. The numbers 4 and 5 represent pre-junction Lagoons and post-junction Lagoons, respectively. The numbers 6, 7, 8 and 9 represent main source of River Kizat, pre-junction FPF, post-junction FPF and post-junction KWWTP, respectively. Letters N and K represent Nyalenda Wigwa Stream and River Kizat, respectively. Pre-junction Lagoons is a sampling site before the convergent point between runoffs from Nyalenda settlement and Lagoons outlet. Post-junction Lagoons is a sampling site after the convergent point between Lagoons outlet and flowing Nyalenda Wigwa Stream. Pre-junction FPF is a sampling site before the convergent point between flowing discharge from Fish Processing Factory and River Kizat. Post-junction FPF is a sampling site after the convergent point between flowing discharge from Fish Processing Factory and River Kizat. Post-junction KWWTP is a sampling site after the convergent point between flowing discharge from Kizat Wastewater Treatment Plant and River Kizat.



KEY

○ Sampling site

Figure 3.1.3(a) Sketch of sampling sites at KWWTP, FPF and RK.

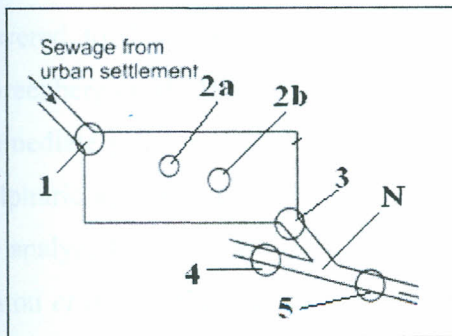


Figure 3.1.3(b) Sketch of sampling sites at NWSP.

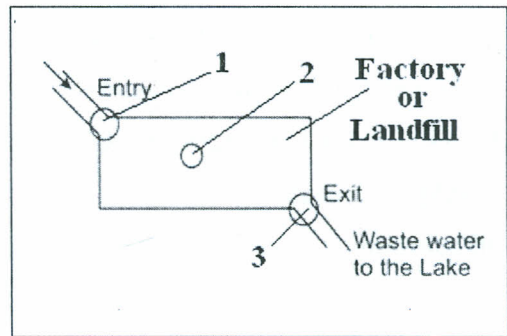


Figure 3.1.3(c) Sketch of sampling sites at Flourmill, Matchbox Factory and Landfill.

3.2 Sampling, preservation and storage

Sampling was done at Kisat Wastewater Treatment Plant (KWWTP), Nyalenda Waste Stabilization Ponds (NWSP), industries (Fish Processing Factory-FPF, Flourmill and Matchbox Factory), and Landfill and along River Kisat (RK) and Nyalenda Wigwa Stream (NWS). Samples were taken from the inlet, within and outlet sampling sites of the KWWTP, NWSP, industries and Landfill. They were taken along RK at the main source,

Pre-junction FPF, Post-junction FPF and Post-junction KWWTP. They were also taken at Pre-junction Lagoons and Post-junction Lagoons along NWS. Sampling was done in a Completely Randomized Design (CRD) at three different times of the day in three days. The times were 8.00 am, 12.00 noon and 6.00 pm. The samples taken at each respective time were made up to form a composite sample. Each time of the day, 500 ml of wastewater sample was collected using improvised container into glass bottles, preserved and stored until after the third day when the composite sample was formed.

Preservation of samples to be analyzed for ammonia nitrogen was done by adding sodium thiosulphate in order to destroy residual chlorine immediately after collection to prevent its reaction with ammonia; 0.8 ml of 18.6 M sulphuric acid was added, stoppered and stored in an icebox at 4°C as recommended by Eaton *et al.* (1995). That was done in order to maintain the states of the constituents, retard hydrolysis of chemical compounds, biological changes that inevitably continue after sample collection and reduce volatility of constituents (Greenberg *et al.*, 1985). The addition of the acid enabled the pH to be lowered to 2 in order to minimize precipitation and adsorption on container walls (Greenberg *et al.*, 1985). Storage of samples to be analyzed for nitrite nitrogen was done immediately by freezing at -20°C while those for nitrate nitrogen, 0.8 ml of 18.6 M sulphuric acid was added and frozen at -20°C (Eaton *et al.*, 1995). Storage of samples to be analyzed for T-P was done by freezing immediately below -10°C as recommended by Eaton *et al.* (1995). The stored samples were transported to the refrigeration for further storage prior to the analysis. The frozen samples were allowed to thaw to room temperature prior analysis. The Kisat Wastewater Treatment Plant for example had 4 sampling sites as illustrated in Table 3.2.1. A total of 12 samples were taken from the sampling sites. Total number of samples taken from Nyalenda Waste Stabilization Ponds (Lagoons), Fish Processing Factory, Flour mill, Matchbox Factory, Landfill and river Kisat were 18, 9, 9, 9, 9 and 12, respectively. A total of 78 samples from 26 sampling sites in 7 regions within Kisumu city were collected.

Table 3.2.1 sampling method used

Regions	Number of sampling sites	Number of samples
Kisat Wastewater Treatment Plant	4	4x3
Nyalenda Waste Stabilization Ponds (Lagoons) and Nyalenda Wigwa Stream	6	6x3
Fish Processing Factory	3	3x3
Flour mill Factory	3	3x3
Matchbox Factory	3	3x3
Landfill	3	3x3
River Kisat	4	4x3
Total	26	78

3.3 Materials, chemicals and reagents

Materials used were available at Maseno University Chemistry laboratory while those not present were purchased from Nyanza and Cross laboratories in Kisumu City. Solvents, reagents and standards used were of analytical grade (AR).

3.4 Experimental procedure and chemical analysis

3.4.1 Nitrite nitrogen (NO_2^- -N)

Greiss-Ilosva diazotization with UV-VIS spectrophotometric method was used in the analysis of nitrite nitrogen. The experimental procedure by Greenberg *et al.* (1985) was adopted. In this procedure, suspended solids were removed from 20 ml of each sample using a 0.45 μm -diam-membrane filter and a syringe. One millilitre of sulphanilamide was added to 2ml of each standard (sodium nitrite solution), left to stand for 5 minutes and then added 1 ml NED dihydrochloride. The solution was mixed and left to stand for 5 minutes. The above procedure was repeated but using filtered samples instead of standards. The pH of each filtered sample was adjusted to the range of between 5 and 9 with 1 M HCl or NaOH as appropriate. Fifteen minutes after adding colour reagents (sulphanilamide and NED dihydrochloride) to the samples and standards, absorbance was taken at 543 nm using Shimadzu UV-VIS spectrophotometer 1650 PC, purchased from Kyoto Japan. A standard curve was prepared by plotting absorbance of standards against NO_2^- -N concentration. The concentrations of samples were computed directly from the curve as proposed by Greenberg *et al.* (1985). The MSTAT-C programme of analysis of

variance was carried out on the recorded raw data as outlined in APPENDIX I where Factorial ANOVA for the factors is given.

3.4.2 Nitrate nitrogen (NO_3^- -N)

Cadmium reduction method followed by Greiss-Ilosva diazotization with UV-VIS spectrophotometric method was used in the analysis of nitrate nitrogen. The experimental procedure by Greenberg *et al.* (1985) was adopted. In the procedure, the reduction column was prepared first by inserting a glass wool into the bottom and then filled with water to prevent entrapment of air. Sufficient Cu-Cd granules treated with CuSO_4 were added to produce a column of 18.5 cm long. The column was washed with 200 ml dilute NH_4Cl -EDTA solution to eliminate interferences which would have lowered reduction efficiency and was thereafter activated by adding 100ml of a solution composed of dilute sodium nitrate standard and NH_4Cl -EDTA at the rate of 10 ml/min. Suspended solids were removed from 50 ml of each sample using a 0.45 μm -diam-membrane filter and a syringe. The pH of each filtered sample was adjusted to the range of between 5 and 9 with 1 M HCl or NaOH as appropriate. To 25 ml of each sample, 75 ml of NH_4Cl -EDTA solution was added and mixed. Each mixed sample was poured into the column and collected at a rate of 10ml/min. In this process, nitrate was reduced almost quantitatively to nitrite. After discarding the first 25 ml, the rest was collected in original sample flask. Ethanol was poured into the column between the samples, for pre-extracting oil and grease. That prevented them from coating the Cd surface. NH_4Cl -EDTA solution was poured onto the top of the column and was let to pass through the system. Cu-Cd column was stored in the solution and was never let to dry. This was done because the columns were used severally. One millilitre of sulphanilamide was added to 2 ml of each standard (sodium nitrite solution), left to stand for 5 minutes and then added 1 ml of NED-dihydrochloride. The solution was mixed and left to stand for 5 minutes. The above procedure was repeated but using samples collected from the column instead of standards. A correction was made for NO_2^- -N that was present in the sample by analyzing without the reduction step and then subtracting. One hour after adding colour reagents (sulphanilamide and NED-dehydrochloride) to the samples and standards, absorbance readings were measured at 543 nm using the Shimadzu UV-VIS 1650

spectrophotometer. A standard curve was prepared by plotting absorbance of standards against NO_2^- -N concentration. Samples concentrations were computed directly from the curve (Greenberg *et al.*, 1985).

3.4.3 Ammonia nitrogen ($\text{NH}_3\text{-N}$) and organic nitrogen (N_{Org})

Kjeldahl distillation followed by back titration method was used in the analysis of ammonia nitrogen while Kjeldahl digestion followed by distillation and then back titration method was used in the analysis of organic nitrogen. The experimental procedure by Greenberg *et al.* (1985) and Day and Underwood, 1991 was adopted. In the experimental procedure, a mixture of 500 ml water and 20 ml borate buffer was added to distillation flask and pH was adjusted to 9.5 with 6 M NaOH solution. A few glass beads were added and the mixture was used to steam out the distillation apparatus. To minimize contamination, distillation apparatus was left assembled after steaming out and until just before starting sample distillation. Steaming out flask was disconnected and immediately sample flask was transferred to distillation apparatus. Fifty milliliters of sample was distilled and 40 ml of distillate collected in a 100 ml Erlenmeyer flask containing 10 ml indicator (indicating boric acid solution) for titrametric method. Distillation receiver was lowered for the end of the delivery tube to be free of contact with the liquid and distillation continued during the last minute for cleansing condenser and delivery tube. The distillate was titrated with standard 0.01 M H_2SO_4 titrant until boric acid indicator turned to pink. The residue in the distillation flask was used for organic nitrogen determination. Fifty milliliters of digestion reagent (mixture of K_2SO_4 , CuSO_4 , water and concentrated H_2SO_4) was added carefully to the distillation flask. A few beads were added and after mixing, heated to remove acid fumes. The mixture was boiled briskly until the volume was greatly reduced. Digestion continued for an additional 30 minutes until the mixture became transparent and pale green. After digestion, it was left to cool and then diluted to 300 ml with water and mixed. Fifty millilitres of sodium hydroxide-thiosulphate reagent was added carefully to form an alkaline layer at the bottom of the flask. The flask was connected to a steamed distillation apparatus and swirled to ensure complete mixing. A similar distillation procedure was used for determining ammonia and organic nitrogen by difference as adopted from Greenberg *et al.* (1985).

3.4.4 Total phosphorus (T-P)

Digestion followed by vanadomolybdophosphoric acid colorimetric measurement method was used in the analysis of total phosphorus. The experimental procedure by Greenberg *et al.* (1985) was adopted. In the procedure, each of the 50 ml of the filtered samples was measured and put into digestion tubes. To each digestion tube, 1 ml of 18.6 M concentrated $\text{H}_2\text{SO}_{4(\text{aq})}$ and 5 ml of 1.54 M concentrated $\text{HNO}_{3(\text{aq})}$ were added. The mixtures were heated at a temperature of 110°C . This enabled the process of digestion to take place. The process took place until the solutions became colourless as the volumes reduced to about 1ml. The solutions were cooled and in each digestion tube, 20 ml of distilled water, 1 drop of phenolphthalein indicator and 1 M NaOH solution were added that led to production of a faint pink colour. The neutralized solutions were filtered for the removal of turbidity and each transferred into 100ml volumetric flask. The sample volume was adjusted to 100 ml with distilled water, ready for vanadomolybdophosphoric acid colorimetric measurement. One drop of phenolphthalein was added to each of the 50 ml digested sample that had more than 10 value of pH. The red colour was discharged with hydrochloric acid before diluting to 100 ml. Excessive colour was removed from each sample by shaking with 200 mg activated carbon for 5 minutes and filtered to remove carbon. Thirty five millilitres of each sample was placed in 50 ml volumetric flask. Ten millilitres of Vanadate-molybdate reagent was added and diluted to the mark with distilled water. A blank was prepared in which 35 ml of distilled water was substituted for the sample. After 10 minutes absorbance of a sample versus a blank at a wavelength of 470 nm was measured. Calibration curves were prepared using volumes of standard phosphate solutions. Standards with each set of samples were also analyzed using the method of Greenberg *et al.* (1985). The concentrations of samples were computed directly from the curve.

4 RESULTS AND DISCUSSION

4.1 Effects of Kisat Waste Water Treatment Plant on concentration of nutrient parameters

The concentrations of nutrient parameters at Kisat Wastewater Treatment Plant are presented in table 4.1.1.

Table 4.1.1 Concentration variation for nutrient parameters at Kisat Wastewater Treatment Plant

Sampling sites	Concentration				
	NO ₂ ⁻ -N (mg/l)	NO ₃ ⁻ -N (mg/l)	NH ₃ -N (mg/l)	N _{Org} (mg/l)	T-P (mg/l)
Inlet	0.046	1.714	2.384	2.662	1.372
Filter 1	0.035	1.572	2.310	2.558	1.307
Filter 2	0.030	1.526	2.313	2.402	2.267
Outlet	0.027	1.479	2.500	1.942	1.230
CV%	5.660	0.770	0.130	0.040	1.550
LSD (P ≤ 0.05)	0.005	0.032	0.008	0.003	0.052
Concentration of nutrient removed	0.019	0.235	-0.116	0.720	0.142
Concentration of nutrient removed %	41.304	13.711	-4.866	27.047	10.350
Guideline allowable limits	3.000	10.000	0.500	10	1.000

The difference in concentration of each nutrient parameter between inlet and outlet was significant (P ≤ 0.05). Apart from NH₃-N and T-P the concentration of other parameters reduced significantly, hence was attributed to biodegradation of the effluent or in case of species of nitrogen denitrification process took place (Sawyer, 2003). The concentration of NH₃-N decreased due to ammonia volatilization (Nhapi and Tirivarombo, 2004) and

autotrophic nitrifying bacteria oxidizing NH_3 -N to NO_2^- -N then to NO_3^- -N (Zhang *et al.*, 2010),



The concentration of NH_3 -N increased due to N_{Org} , NO_2^- -N and NO_3^- -N reduced by process called denitrification under anaerobic conditions in presence of heterotrophic bacteria (Sawyer, 2003). The concentration of T-P increased due to increased hydrological energy and its effects on the physical mechanisms of phosphorus release (Hanrahan *et al.*, 2003) while decreased due to uptake or adsorption by bottom/suspended sediments (Neal *et al.*, 2000b).

The concentrations of NH_3 -N and T-P discharged at KWWTP were 2.500 mg/l and 1.230 mg/l, respectively. The values were above guideline allowable limits of 0.500 mg/l (GOK, 2006) and 1.000 mg/l (Jiang *et al.*, 2004), respectively. Those of NO_2^- -N, NO_3^- -N and N_{Org} were 0.027 mg/l, 1.479 mg/l and 1.942 mg/l, respectively. The values were below guideline allowable limits of 3.000 mg/l, 10.000 mg/l and 10.000 mg/l (WHO, 2004), respectively. Nutrient parameters in the urban wastewater were drained through KWWTP into River Kisat, even though the amounts of the parameters were reduced by the wastewater treatment process.

Percentage concentration of nutrient removed for NO_2^- -N was 41.304% and therefore it was above guideline allowable limit of 1% (Gloyna, 1971; Awuah and Abrokwa, 2008). Percentages concentration of nutrient removed for NO_3^- -N, NH_3 -N, organic nitrogen and T-P were 13.710%, -4.866%, 27.047% and 10.350%, respectively and were therefore below guideline allowable limit of 23.800%, 39.500%, 57.300% and 40.000%, respectively (Gloyna, 1971; Awuah and Abrokwa, 2008).

4.2 Effects of Nyalenda Waste Stabilization Ponds (Lagoons) on concentration of nutrient parameters

The concentrations of nutrient parameters at Nyalenda Waste Stabilization Ponds (Lagoons) are presented in table 4.2.1.

Table 4.2.1 Concentration variation for nutrient parameters at Nyalenda Waste Stabilization Ponds (Lagoons)

Sampling sites	Mean concentration				
	NO ₂ ⁻ - N (mg/l)	NO ₃ ⁻ - N (mg/l)	NH ₃ -N (mg/l)	N _{Org} (mg/l)	T-P (mg/l)
Inlet	0.146	1.806	2.153	2.656	1.543
Lagoon 1	0.119	1.724	2.334	2.524	1.536
Lagoon 2	0.118	1.653	2.401	2.274	1.490
Outlet	0.073	1.618	2.326	2.215	1.068
Pre-junction Lagoons	0.017	1.352	2.325	2.074	0.530
Post-junction Lagoons	0.118	1.822	2.480	2.608	0.967
CV%	15.040	0.790	19.790	0.030	2.110
LSV (P ≤ 0.05)	0.031	0.028	NS	0.001	0.053
Concentration of nutrient removed	0.073	0.188	0.000	0.441	0.475
Concentration of nutrient removed %	50.000	10.410	-	16.604	30.784
Guideline allowable limit	3.000	10.000	0.500	10.000	1.000
Concentration increment along NWS	0.101	0.470	0.155	0.534	0.437

There was significant decrease in the concentration of nutrient parameters as from the inlet to outlet except for NH₃ -N. That was due to efficient utilization of nutrients by macrophytic vegetation in the Lagoons. There was no significant difference in the concentration of NH₃ -N from inlet to outlet. That might have been attributed to by nitrification and denitrification processes that were taking place simultaneously. There

was significant increase in the concentration of nutrient parameters downstream Nyalenda Wigwa Stream due to volumetric discharge from the Lagoons.

The concentrations of NH_3 -N and T-P discharged at NWSP were 2.326 mg/l and 1.068 mg/l, respectively. The values were above guideline allowable limits of 0.500 mg/l (GOK, 2006) and 1.000 mg/l (Jiang *et al.*, 2004), respectively. Those of NO_2^- -N, NO_3^- -N and N_{Org} were 0.073 mg/l, 1.618 mg/l and 2.215 mg/l, respectively. The values were below guideline allowable limits of 3.000 mg/l, 10.000 mg/l and 10.000 mg/l (WHO, 2004), respectively. Nutrient parameters in the urban wastewater were drained through NWSP into Nyalenda Wigwa Stream, even though the amounts of these parameters were reduced by the wastewater treatment process.

Percentage concentration of nutrient removed for NO_2^- -N was 50.000% and therefore was above guideline allowable limit of 1.000% (Gloyna, 1971; Awuah and Abrokwa, 2008). Percentages concentration of nutrient removed for NO_3^- -N, NH_3 -N, N_{Org} and T-P were 10.410%, 0.000%, 16.604% and 30.784%, respectively and were therefore below guideline allowable limit of 23.800%, 39.500%, 57.300% and 40.000%, respectively (Gloyna, 1971; Awuah and Abrokwa, 2008).

The concentrations increment for NO_2^- -N, NO_3^- -N, NH_3 -N, N_{Org} and T-P along Nyalenda Wigwa Stream were 0.101 mg/l, 0.470 mg/l, 0.155 mg/l, 0.534 mg/l and 0.437 mg/l, respectively and were therefore below guideline allowable limit of 3.000 mg/l, 10.000 mg/l, 0.500 mg/l, 10.000 mg/l and 1.000 mg/l, respectively (GOK, 2006; WHO, 2004; Jiang *et al.*, 2004).

4.3 Effects of industries (Fish Processing Factory, Flour mill and Matchbox Factory) and Landfill on concentration of nutrient parameters

The concentration of nutrient parameters at industries (Fish Processing Factory, Flourmill and Matchbox Factory) and Landfill are presented in tables 4.3.1 (a), 4.3.1 (b), 4.3.1 (c), 4.3.1 (d) and 4.3.1 (e).

Table 4.3.1 (a) Concentration variation for nitrite nitrogen at industries (Fish Processing Factory, Flour mill and Matchbox Factory) and Landfill

Nutrient parameter		Concentration for nitrite nitrate in mg/l at Industries				
		Fish Processing Factory	Flour mill	Match box	Land fill	Mean sites
NO ₂ ⁻ -N	Inlet	0.010	0.010	0.114	0.117	0.063
	Within	0.013	0.014	0.119	0.219	0.091
	Outlet	0.017	0.030	0.125	0.232	0.101
	Mean industry	0.013	0.018	0.119	0.189	
	CV%		5.110			
	LSD (P ≤ 0.05)		0.006			0.008
	Interaction		0.009			
	Concentration contribution	0.007	0.020	0.011	0.115	0.038
	Guideline allowable limit		3.000			

Table 4.3.1 (b) Concentration variation for nitrate nitrogen at industries (Fish Processing Factory, Flour mill and Matchbox Factory) and Landfill

Nutrient parameter		Concentration for nitrate nitrogen in mg/l at Industries				
		Fish Processing Factory	Flour mill	Match box	Land fill	Mean sites
NO ₃ ⁻ -N	Inlet	1.233	0.993	1.359	1.793	1.344
	Within	1.456	1.243	1.389	2.019	1.527
	Outlet	1.532	1.425	1.439	2.130	1.632
	Mean industry	1.407	1.220	1.396	1.981	
	CV%		0.850			
	LSD (P ≤ 0.05)		0.019			0.023
	Interaction	0.297	0.026			
	Concentration contribution	0.299	0.432	0.080	0.337	0.288
	Guideline allowable limit		10.000			

Table 4.3.1 (c) Concentration variation for ammonia nitrogen at industries (Fish Processing Factory, Flour mill and Matchbox Factory) and Landfill

Nutrient parameter		Concentration for ammonia nitrogen in mg/l at Industries				
		Fish Processing Factory	Flour mill	Match box	Land fill	Mean sites
NH ₃ -N	Inlet	2.479	1.498	1.512	2.345	1.958
	Within	2.074	1.615	1.690	2.708	2.022
	Outlet	2.339	1.720	1.740	2.978	2.194
	Mean industry	2.297	1.611	1.647	2.677	
	CV%		0.120			
	LSD (P ≤ 0.05)		0.004			0.004
	Interaction		0.005			
	Concentration contribution	-0.140	0.222	0.228	0.633	0.236
	Guideline allowable limit			0.500		

Table 4.3.1 (d) Concentration variation for organic nitrogen at industries (Fish Processing Factory, Flour mill and Matchbox Factory) and Landfill

Nutrient parameter		Concentration for organic nitrogen in mg/l at Industries				
		Fish Processing Factory	Flour mill	Matchbox	Landfill	Mean sites
N _{Org}	Inlet	1.970	1.033	1.680	2.479	1.791
	Within	1.950	1.328	1.751	2.853	1.970
	Outlet	2.267	1.612	1.836	3.038	2.188
	Mean industry	2.063	1.324	1.756	2.790	
	CV%			0.220		
	LSD (P ≤ 0.05)			0.007		0.008
	Interaction			0.009		
	Concentration contribution	0.297	0.579	0.156	0.559	0.397
	Guideline allowable limit			10.000		

Table 4.3.1 (e) Concentration variation for total phosphorus at industries (Fish Processing Factory, Flour mill and Matchbox Factory) and Landfill

Nutrient parameter		Concentration for total phosphorus in mg/l at Industries				
		Fish Processing Factory	Flour mill	Matchbox	Landfill	Mean sites
T-P	Inlet	0.846	0.495	0.491	1.392	0.806
	Within	0.849	0.669	0.488	1.499	0.876
	Outlet	0.928	0.584	0.739	1.552	0.951
	Mean industry	0.874	0.583	0.573	1.481	
	CV%			11.360		
	LSD ($P \leq 0.05$)			0.149		NS
	Interaction			0.199		
	Concentration contribution	0.082	0.089	0.248	0.160	0.145
	Guideline allowable limit			1.000		

There was significant difference in the concentration of nutrient parameters from factory to factory. Values for NO_2^- -N were similar at FPF and Flourmill while for T-P were at Flourmill and Matchbox. There was significant increase in the concentration of nutrient parameters from the inlet to the outlet except for T-P. Concentration of NH_3 -N at FPF decreased due to ammonia volatilization (Nhapi & Tirivarombo, 2004) and autotrophic nitrifying bacteria oxidizing NH_3 -N to NO_2^- -N then to NO_3^- -N (Zhang *et al.*, 2010) while increased due to heterotrophic bacteria reducing NO_3^- -N to NO_2^- -N then to NH_3 -N under anaerobic condition (Sawyer, 2003) and usage of raw materials during manufacturing processes (Bean, 1992; Salha *et al.*, 2009; Gumisiriza *et al.*, 2009). Concentration of Organic nitrogen at FPF decreased due to conversion of N_{Org} to NH_3 -N by action of heterotrophic bacteria under anaerobic conditions (Sawyer, 2003) while increased due to raw materials used containing high concentration of N_{Org} (Bean, 1992; Salha *et al.*, 2009; Gumisiriza *et al.*, 2009). There was no significant different of T-P from inlet to the outlet, that's the inlet did not change levels of T-P. Concentration of T-P increased at Flourmill and Matchbox Factory, due to detergents and disinfectants used during cleaning (Gumisiriza *et al.*, 2009) and raw materials used were containing T-P (Bean, 1992; Salha *et al.*, 2009; Gumisiriza *et al.*, 2009). The concentrations of T-P decreased due to uptake by bottom/suspended sediments (Neal *et al.*, 2000b). There was

significant interaction among the individual parameters, implying that the response was not similar or happened differently (Li *et al.*, 2010). Industries and Landfill discharged nutrient parameters due to usage of detergents and disinfectants made up of inorganic compounds (Gumisiriza *et al.*, 2009) and the raw materials during the manufacturing processes (Bean, 1992; Salha *et al.*, 2009; Gumisiriza *et al.*, 2009).

Fish Processing Factory had the lowest concentration output of nitrite nitrogen while landfill the highest. The outlet sampling sites had the highest concentration of the nitrite nitrogen; therefore the industries contributed nitrite nitrogen to the pollution. The concentrations of NO_2^- -N contributed by Fish Processing Factory, Flourmill, Matchbox Factory and Landfill were 0.007 mg/l, 0.020 mg/l, 0.011 mg/l, 0.115 mg/l and 0.038 mg/l, respectively and were below the guideline allowable limit of 3.000 mg/l (WHO, 2004); therefore they were not posing a pollution risk. Matchbox Factory had the lowest concentration output of nitrate nitrogen while Flourmill the highest. The outlet sampling sites had the highest concentrations of nitrate nitrogen; therefore the industries contributed to the pollution. The concentration values for NO_3^- -N contributed by Fish Processing Factory, Flourmill, Matchbox Factory and Landfill were 0.299 mg/l, 0.432 mg/l, 0.080 mg/l, 0.337 mg/l and 0.288 mg/l, respectively and were below the guideline allowable limit of 10.000 mg/l (WHO, 2004), therefore they never posed a pollution risk. FPF had the lowest concentration output of ammonia nitrogen while Landfill the highest. Apart from the Fish Processing Factory the rest of the industries' outlets had higher concentrations of ammonia nitrogen than the inlets and thus it was an indication that there was a contribution towards pollution. The concentrations of ammonia nitrogen contributed by Fish Processing Factory, Flourmill, Matchbox Factory and Landfill were 0.140 mg/l, 0.222 mg/l, 0.228 mg/l, 0.633 mg/l and 0.236 mg/l, respectively. Apart from FPF the rest of the industries discharged NH_3 -N that was above the guideline allowable limit of 0.500 mg/l (GOK, 2006) and therefore did not pose a pollution risk.

Matchbox Factory had the lowest concentration output of organic nitrogen while Flourmill the highest. Generally the outlet sites had the highest concentrations of organic nitrogen; therefore the industries contributed to the pollution. The concentrations of

organic nitrogen contributed by Fish Processing Factory, Flourmill, Matchbox Factory and Landfill include 0.297 mg/l, 0.579 mg/l, 0.156 mg/l, 0.559 mg/l and 0.397 mg/l, respectively. These values were below the guideline allowable limit of 10.000 mg/l (WHO, 2004); therefore they were not posing a pollution risk. FPF had the lowest concentration output of T-P while Matchbox the highest. The outlet points of industries had higher concentration of total phosphorus than the inlet showing that they contributed to the pollution. The concentrations contributed by Fish Processing Factory, Flourmill, Matchbox Factory and Landfill include 0.082 mg/l, 0.089 mg/l, 0.248 mg/l, 0.160 mg/l and 0.145 mg/l, respectively. The concentration values for T-P obtained at the point sources were below the guideline allowable limit of 1.000 mg/l (Jiang *et al.*, 2004), therefore never posed a pollution risk.

4.4 Effects of river Kisat on concentration of nutrient parameters

The concentrations of nutrient parameters along River Kisat are presented in table 4.4.1.

Table 4.4.1 Concentration variation for nutrient parameters at river Kisat

	NO ₂ ⁻ -N (mg/l)	NO ₃ ⁻ -N (mg/l)	NH ₃ -N (mg/l)	N _{Org} (mg/l)	T-P (mg/l)
Main source	0.011	1.391	1.309	1.493	0.856
Pre-junction FPF	0.020	1.688	2.371	2.544	0.651
Post-junction FPF	0.078	1.851	2.640	2.779	0.968
Post-junction KWWTP	0.177	2.102	2.783	2.949	1.171
CV%	4.050	0.380	0.250	0.100	0.860
LSD(P≤0.05)	0.008	0.017	0.015	0.006	0.020
Guideline allowable limit	3.000	10.000	0.500	10.000	1.000
Concentration increment along RK	0.166	0.711	1.474	1.456	0.315

There was significant increase in the concentration of nutrient parameters from main source to downstream of River Kisat due to volumetric discharge from FPF and KWWTP (Neal *et al.*, 2000b) and confounding influences of diffuse sources including agricultural runoff. There was an increase in the concentration of T-P due to increased hydrological energy and its effects on the physical mechanisms of phosphorus release (Hanrahan *et al.*, 2003; Zaimes and Schultz, 2002). The concentration of T-P decreased from the main source due to uptake by bottom/sediments or volumetric dilution downstream as the contributing drainage area increased or within river processes such as absorption by plants (Neal *et al.*, 2000b).

The concentrations of NH_3 -N and T-P at post-junction KWWTP were 2.783 mg/l and 1.171 mg/l, respectively. The values were above guideline allowable limits of 0.500 mg/l (GOK, 2006) and 1.000 mg/l (Jiang *et al.*, 2004), respectively. Those for NO_2^- -N, NO_3^- -N and N_{Org} were 0.177 mg/l, 2.102 mg/l and 2.949 mg/l, respectively. The values were below guideline allowable limits of 3.000 mg/l, 10.000 mg/l and 10.000 mg/l (WHO, 2004), respectively. Therefore the deposition of nutrient parameters into river Kisat made Lake Victoria more contaminated.

The concentration increment for NH_3 -N along River Kisat was 1.474 mg/l and was above guideline allowable limit of 0.500 mg/l (GOK, 2006). The concentrations increment for NO_2^- -N, NO_3^- -N, N_{Org} and T-P were 0.166 mg/l, 0.711 mg/l, 1.456 mg/l and 0.315 mg/l, respectively and were below guideline allowable limit of 3.000 mg/l, 10.000 mg/l, 10.000 mg/l and 1.000 mg/l, respectively (WHO, 2004; Jiang *et al.*, 2004).

CHAPTER 5

5 SUMMARY, CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE STUDIES

5.1 Summary

1) Concentrations of nutrient parameters removed by Wastewater Treatment Plants are illustrated in Table 5.1.1. The concentrations of NO_3^- -N, NH_3 -N, N_{Org} and T-P removed by KWWTP and NWSP are below guideline allowable limits while that of NO_2^- -N was above.

Table 5.1.1 Concentration and percentage of nutrient removed

	NO_2^- - N	NO_3^- - N	NH_3 - N	N_{Org}	T-P
Concentration removed at KWWTP (mg/l)	0.019	0.235	-0.116	0.720	0.142
Percentage concentration removed at KWWTP (%)	41.304	13.710	-4.866	27.047	10.350
Concentration removed at NWSP (mg/l)	0.073	0.188	0.000	0.441	0.475
Percentage concentration removed at NWSP (%)	50.000	10.410	0.000	16.604	30.784
Percentage guideline allowable limit (%) (Gloyna, 1971; Awuah and Abrokwa, 2008)	1.000	23.800	39.500	57.300	40.000

2) Concentrations of nutrient parameters contributed by industries are illustrated in Table 5.1.2. The highest concentration of NO_2^- -N and NH_3 -N were contributed by Landfill while NO_3^- -N and N_{Org} by Flourmill and T-P by Matchbox Factory. The lowest concentration of NO_2^- -N, NH_3 -N and T-P were contributed by FPF while NO_3^- -N and N_{Org} by Matchbox Factory. The concentration of NH_3 -N contributed by Landfill was above guideline allowable limit while those contributed by FPF, Flourmill and Matchbox Factory were below the guideline allowable limit. The concentrations of NO_2^- -N, NO_3^- -N, N_{Org} and T-P contributed by FPF, Flourmill, Matchbox Factory and Landfill were below the guideline allowable limits.

Table 5.1.2 Concentrations of nutrient parameters contributed by industries and Landfill

	Concentration of nutrient parameter in mg/l				
	NO ₂ ⁻ -N	NO ₃ ⁻ -N	NH ₃ -N	N _{Org}	T-P
FPF	0.007	0.299	-0.140	0.297	0.082
Flourmill	0.020	0.432	0.222	0.579	0.089
Matchbox Factory	0.011	0.080	0.228	0.156	0.248
Landfill	0.115	0.337	0.633	0.559	0.160
Guideline allowable limit (GOK, 2006; WHO, 2004; Jiang <i>et al.</i> , 2004)	3.000	10.000	0.500	10.000	1.000

3) The concentrations of nutrient parameters from the main source to downstream of River Kisat (RK) and Nyalenda Wigwa Stream (NWS) increased as illustrated in Table 5.1.3.

Table 5.1.3 Concentrations of nutrient parameters along RK and NWS

	Concentration of nutrient parameters in mg/l				
	NO ₂ ⁻ -N	NO ₃ ⁻ -N	NH ₃ -N	N _{Org}	T-P
RK	0.011-0.117	1.391-2.102	1.309-2.783	1.493-2.949	0.856-1.171
Increment RK	0.106	0.711	1.474	1.456	0.315
NWS	0.017-0.118	1.352-1.822	2.325-2.480	2.074-2.608	0.530-0.967
Increment NWS	0.101	0.470	0.155	0.534	0.437
Guideline allowable limit (GOK, 2006; WHO, 2004; Jiang <i>et al.</i> , 2004)	3.000	10.000	0.500	10.000	1.000

5.2 Conclusions

- The point sources of nutrients to Winam Gulf of Lake Victoria include FPF, Flourmill, Matchbox Factory and Landfill.
- Kisat Wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds are not efficient in removing most nutrients from wastewater as the percentage concentrations removed are below guideline allowable limits
- Industries (Fish Processing Factory, Four mill and Matchbox Factory) and landfill contribute to concentrations of nutrients (NO₂⁻ -N, NO₃⁻ -N, NH₃ -N, organic

nitrogen and T-P) into aquatic systems which were below guideline allowable limits. The concentration contribution for NH_3 -N was above the guideline allowable limit.

- d) Concentrations of nutrient parameters increase from upstream to downstream of River Kisat and Nyalenda Wigwa Stream.

5.3 Recommendations

- a) Upgrading of Kisat Wastewater Treatment Plant and Nyalenda Waste Stabilization Ponds (Lagoons) so as to be more efficient because low concentrations of nutrient pollutants are removed from wastewater.
- b) Establishment of more efficient Wastewater Treatment Plants along rivers within the Lake basin to capture the waste emanating from various industries before it reaches the rivers and the lake.

5.4 Suggestions for future studies

- a) More research on how to design a more efficient Waste Treatment Plant.
- b) More research should be done on other suspected point sources within the Lake Victoria Basin.

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