ASSESSING SOURCES, LEVELS AND DISCHARGE LOADS OF NITROGEN AND PHOSPHORUS OF RIVER KISAT INTO LAKE VICTORIA - KISUMU MUNICIPALTY, KENYA

BY

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ABSTRACT

River Kisat is a perennial river draining the Mamboleo – Kisumu basin between Latitude $0^0$04'12.42" S and Longitude $34^0$46'33.86" E to the North and Latitude $0^0$05'13.52" S and $34^0$45'00.15" E to the South. It drains a distance of about 10 Kms through Industrial, Slums and Sewerage Treatment Plant (STP) areas into Winam Gulf. The river is polluted from various sources of pollutants ranging from non-point to point sources. This has resulted in changes in the trophic status of the lake at Winam Gulf from mesotrophic to hypertrophic. Pollution in the lake has reduced biotic abundance and diversity. A study was therefore designed on River Kisat, which is believed by many researchers as one of the major source of pollution into Lake Victoria, to generate data and results that will aid in the management of Lake Victoria water pollution and its probable source River Kisat. The specific objectives of this study were ; to identify main point and non-point sources of pollution to River Kisat, to determine the pollution status of River Kisat through measurement of Nitrogen and Phosphorus nutrient concentration levels, and to establish the amount of Nitrogen and Phosphorus discharge loads into Winam gulf from River Kisat. The study was conducted during wet and dry seasons for a period of one year (2009) in order to capture the seasonality and was confined to 8 stations (STN 1, 2, 3, 4, 5, 6, 7 & 8) within the course of River Kisat, located at probable sources of pollution. The samples were collected from the middle of the channel through scoop method while sediments were collected using grab method. Samples from selected run-offs causes, during rainy season, were also collected. Sampling containers were first cleaned and samples pretreated using 0.02N HCl. The samples were then stored under refrigeration at temperatures of 4^0C before analyses. The data obtained from the analyses were then subjected to statistical analyses using Excel spreadsheet by comparing variations between stations and between months through line graphs, bar charts, and descriptive statistics and ANOVA. The DO concentration levels between stations ranged between 1.33 (STN 6) and 4.11 mg/l (STN 8). The pH levels ranged between 7.00 (STN 6) and 7.41 (STN 3). In terms of nutrient (N & P) concentrations at STN 6 exhibited low concentrations but probably one of the main pollutant of the river. The NH_4^+ concentrations within the river course between stations ranged between 0.15 (STN 7) and 1.89 mg/l (STN 4) with a maximum in STN 4. The NH_4^+ concentration is high during dry season but low during wet season. The NO_2^- concentrations between stations ranged between 0.04 (STN 7 & 8) and 0.23 mg/l (STN 5). NO_3^- ranged between 0.35 (STN 8) and 0.96 mg/l (STN 5). The NO_3^- concentrations increases with increase in discharge. SRP and TP concentrations ranged from 0.16 to 1.04 mg/l and 0.21to 1.39 mg/l respectively. STN 4 is the main contributor of SRP. The total discharge load in a year during the study period is estimated at 140.5 tons/year. The TN concentrations shoot with increasing discharge rates. TP load per year is estimated at 155.8 tons/year. The TP also increases with discharge rates but at a lower scale compared to TN. The DO concentrations are low compared to standard guidelines for drinking and aquatic life. The nitrogen species concentration levels for both fisheries and domestic use falls within recommendable levels except for NH_4^+. The concentration levels of nitrogen species tend to increase with decreasing discharges except for NO_3^- and to some extent NO_2^-. The phosphorus levels are very high compared to water quality standard for fisheries but within recommendable levels for drinking. The major pollution sources, both point and non-point, lies between STN's 1-6. STN 7 and 8 are near the river source devoid of major developments and are therefore less polluted. The government should therefore introduce a policy of Polluter Pays Principle (PPP) with the revenue collected plowed back into cleaning the river. These data would be important to policy makers like Municipal Council of Kisumu (MCK), National Environmental Management Authority (NEMA), Kenya Marine and Ministry of Public Health, Lake Basin Development Authority (LBDA).

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the study

Aquatic pollution is a global problem that varies in the type of pollutants and in trophic scale. Water pollution occurs when a water body is overloaded with nutrients or materials (Kifferstein and Krantz, 1994). Aquatic nutrient pollution range in scale from oligotrophic (nutrient poor) to hypertrophic (nutrient enriched) (Straskraba and Tundisi, 1999). Myriad of world water bodies have shifted from oligotrophic to meso or hypertrophic status due to elevated nutrient loading as a result of land-use changes within the basins. Major land-use changes that have been noted to lead to exacerbated nutrient loading are namely: Deforestation, Agriculture, Urbanization, Industrialization and Overpopulation. Excessive nutrient levels have been noted to lead to the following problems: Excessive algal blooms; Economic loss due to fish kills and other biotic losses; Replacement of desirable fish by less desirable fishes; Increased cost of water treatment for domestic uses especially during periods of excessive algal blooms; production of toxins by certain algal species which may affect the fish and the nervous system of human beings; Human respiratory distress and death in infants due to high level of nitrates (Straskraba and Tundisi, 1999). Even though no pollution- related human deaths have been reported in Kenya, experts shiver at the possibility of very serious long term implications of unchecked poisoning of rivers (Opalla, 2001).

Lake Victoria, the second largest fresh water lake in the world, occupies an area of 68,800Km^2 and has one of the richest biological diversity. Fishes from the lake forms a major source of protein to the riparian communities and a major foreign exchange earner to the riparian countries. The lake water is also used for domestic purposes and should therefore be of excellent quality. Over the past half a decade, the trophic sequence of the lake has changed from mesotrophic (low nutrient) to hypertrophic (nutrient laden) conditions occasioned by changes in land-use (Hecky, 1993). A comparison of historic data to recent measurement at offshore sites (Odada and Olago, 2002) reports a rapid eutrophication of Lake Victoria between 1960's to mid 1990's: sedimentation rates changed from 57 to 90 gm^{-2}yr^{-1} (dry weight), dissolved silica decreased from 80 to 10μM, the mixed layer thickness changed from about 40 – 50 to 30 – 40 m, and there has been a 5-fold decrease in transparency and 2- to 10-fold increase in chlorophyll. Higher photosynthesis and oxygen saturation occur in surface waters, where the biomass is now 3 – 5 times greater than observed in the 1960's. The dominant phytoplankton group has changed from predominantly Silica based diatoms to nitrogen fixing blue green cyanobacteria perhaps as a result of a change in N:P ratio's within the lake. The Phytoplankton productivity doubled compared to measurements three decades ago. These changes are believed to be as a result of high nutrient influx.

Winam gulf is the most impacted water mass from nutrient loads from point and non-point sources due to numerous rivers, urban towns, industries and agricultural activities within the basin; and also because of its semi encloser resulting into minimal mixing. One of the major urban towns greatly impacting the gulf is Kisumu Municipality due to its size, population and industrialization. Effluents from urban centres, industries, agricultural activities are mainly transported into the lake basins via rivers. River Kisat has been noted by many investigators as the principle transporter of pollutants. Effluents from Kisumu industries as well as partially treated sewage are discharged into Lake Victoria via Kisat stream (Obudho, 1995). According to Butunyi and Menya, (2008) sewage discharge into River Kisat that drains into the lake is not fully treated, this is because only half of the Kisat sewerage plant is operational and though it reduces the biological oxygen demand (BOD) to a reasonable level, it does not meet the set standards. A study of water quality using diatoms as bio- indicator in catchments of Lake Victoria gave results showing that there were high values of temperature, ionic content, nutrients and organic loads in Kisat than Nyando and Kibos (Lungaiya, 2002). By–products of the thriving fish business in Obunga are discharged directly into River Kisat (Butunyi and Menya, 2008). Lungaiya, (2002) reported that indicator values for saprobity, oxygen requirements, and nitrogen uptake metabolism were higher in Kisat than in Nyando and Kibos. The emptying of wastes into Lake Victoria by River Kisat, Auji and run-offs could have contributed significantly to hyacinth weed invasion; hence changing of the aquatic ecosystem (Obera and Oyier, 2002).

This study would like to establish the point sources of pollution, concentration levels of nitrogen and phosphorus within River Kisat and the discharge loads into Winam gulf of Lake

Victoria. This information will help in the management planning of the Municipal, Industrial and Agricultural effluents discharged into the river.

1.2 Statement of the Problem

Lake Victoria water resource is the lifeline of the riparian communities and the Nation of Kenya at large. It supports one of the richest biological diversity in the world including its domestic use by the riparian urban towns. Within the past 5 decades, the trophic status of the lake has drastically shifted from mesotrophic to hypertrophic due to anthropogenic influx of effluents from the urban centres, industries and agricultural activities within the basin. This has prompted a shift of the algal community structure from a predominantly diatom community to a toxin producing and N_2- fixing blue green cyanobacteria. Pollution in the lake has also reduced biotic abundance and diversity in the lake, besides making the water treatment too expensive to the town councils. The water borne diseases due to eutrophication has been noted to result into deaths in some countries. In Kenya, due to exacerbated pollution levels due to land-use changes, Lake Victoria water resource is a time bomb waiting to be reported.

Lake Victoria eutrophication in the past 5 decades, through River Kisat as a point source, is believed by the investigator to be driven by demographic changes, industrialization and social set-up. Kisumu town has greatly expanded and is inhabited by a larger population than 50 years ago. Kisumu, also being trading centre for the East African Community, has seen an increased number of industries with a majority draining their effluents into River Kisat. Kisumu sewarage plant at Kisat with a design capacity of 9,000 cubic meters had over-stretched its capacity and was receiving 15,000 cubic meters, much of which flows into lake Victoria without treatment (Nzomo , 2005). This is due to demographic change within the town. Butunyi and Menya, (2008) reported that as River Kisat trickles along through Obunga slum, the river receives volumes of discharge of an assortment of wastes. The slum lacks proper sanitation facilities and both solid and liquid wastes find their way into the river through point and non-point areas. Residues from makeshift distillers of "chang'aa", an illicit local spirit brewed within the slum, also enters the river. According to Nzomo, (2005), tons of raw effluents from Kisumu town's sewer system, drains into Winam gulf via River Kisat and is the major source of lake pollution. In Lake Victoria, accelerated growth of water hyacinth (*Eichornia crassipes*) is partly attributed to illegal disposal of solid and liquid wastes in rivers, for example Kisat, which drains into the lake (Rotich *et al,* 2005). River Kisat receives pollutants from industrial effluents and discharges from a municipal sewage treatment plant (Lungaiya, 2002). Large amount of sewage waste in water generates a high Biological oxygen demand (BOD), which robs the water of dissolved oxygen (Raven and Berg, 2005).

The results of these effluent discharges have increased the nutrient levels, especially Nitrogen and Phosphorus, within River Kisat. According to Obera and Oyier, (2002) the presence of NH_4^+ and PO_4^- in River Kisat and Auji in Kisumu municipality was as a result of pollution from proximal wastes and latrines/sewage; hence the presence of blood worm and cut fish in the two rivers. Elevated NO_3^- concentrations greater than 10 ppm is known to cause respiratory problems in humans through a fatal disease called Methaemoglobinemia

It is therefore pertinent for this study to try and elucidate the sources of nutrient pollution, concentration levels, and nutrient loads into Winam gulf from River Kisat. The concentration levels will be compared to the WHO set standards to establish the levels of pollution. These data would help stakeholder departments like NEMA, Kisumu Municipality (Local government), Ministry of Public Health, Ministry of water, Institutes of higher learning and the Industries to come up with policies for mitigation and for proper waste management from the urban centre.

1.3 Objective of the Study

General Objective

To identify source of pollution, pollution status of river Kisat and the loads of nitrogen and phosphorus discharged into Winam Gulf of Lake Victoria.

Specific Objectives

1. To identify main point and non-point sources of pollution to River Kisat.
2. To determine the pollution status of River Kisat through measurement of Nitrogen and Phosphorus nutrient concentration levels and other Physico-Chemical variables.
3. To establish the amount of Nitrogen and Phosphorus discharge loads into Winam gulf from River Kisat.

1.4 Hypothesis

1) Pollution of River Kisat is mainly from point and non-point organic pollutants.
2) The concentration levels of Nitrogen and Phosphorus within River Kisat are above recommendable levels both for domestic and fisheries purposes.
3) Nitrogen and phosphorus are discharged into Lake Victoria through River Kisat.

1.5 Justification

The waters of Lake Victoria are drastically becoming highly eutrophicated, triggering an algal bloom. With the increased levels of nutrients, there has been a shift in the algal community structure from siliceous diatom to more obnoxious blue green cyanobacteria that produces toxins called mycrosystis. These changes have caused great problems to the lake including: fish kills, loss of certain indigenous fish species, loss of biodiversity, high cost of water treatment, dangers to public health due to toxins and elevated nutrients, Loss of aesthetic values of the lake water etc (Butunyi and Menya, 2008). These problems are envisaged to increase in magnitude and scale if no proper management policies are put in place.

A number of studies have been conducted in the lake and along River Kisat to assess the water quality status, but non of the studies conducted established the source of the nutrients, concentration levels and discharge loads especially of Nitrogen and Phosphorus into Winam gulf from River Kisat. Nitrogen and Phosphorus are the macronutrients needed for effective primary productivity and its study is paramount to the establishment of high productivity of the lake, especially of the obnoxious cyanobacteria. N: P ratios has been implicated by some researchers as the major cause of algal shift. The study of nitrogen and phosphorus is therefore pertinent to the problems facing the lake basin.

It is therefore necessary to determine the source, concentration levels and discharge loads of nitrogen and phosphorus into Winam gulf from River Kisat and compare the result with the WHO water quality standards so as to develop a data bank of River Kisat to aid in the development of management policies. With the cost of living escalating each day, proper management of River Kisat would help people who live in the slums of Obunga and Nyawita have access to clean water and make some savings from their income.

1.6 Scope of the Study

The scope of this study was the entire course of River Kisat with reference to nitrogen and phosphorus pollutants; both dissolved and particulate. R. Kisat drains from the environs of Mamboleo; Latitude 0°04'12.42"S and Longitude 34°46'33.86"E (Altitude 1176m) to Latitude 0°05'13.52"S and Longitude 34°45'00.15"E (Altitude 1140m) at the river mouth. It flows over a distance of 10 km and discharges its waters into Lake Victoria, which is the second largest fresh water Lake in the world.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Lake Victoria, the world's second largest fresh water body in terms of surface area (area = 68,800 Km^2); supports one of the highest biodiversity in the world, especially the fisheries yielding approximately one million tones of fish per annum (Herdendorf, 1990; Sitoki et al, 2010; LVFO, 2009). The lake has had extraordinary ecological changes that have occurred in the past 5 decades attributable to anthropogenic effect, nutrient recycling and climatic changes due to global warming (Hecky, 1993; Johnson et al., 1992; Johnson, 1996 and Mugidde, 1993). There has been a rapid eutrophication of the Lake waters that has increased the chlorophyll levels by more than 10 – folds within the past 5 decades (Adams and Ochola, 2002). Mugidde, (1993) reported a doubling of the phytoplankton biomass compared to 3 – decades ago. This is caused by the abundance in nutrients. The dorminant phytoplankton group also changed from diatoms to N_2 – fixing blue green algae attributed to a reduction in silicon and a change of N:P ratio from 16:1 to less than 8:1 (Hecky, 1993). This implies that nitrogen is becoming more limiting and hence the shift in algal species. The greater portions of these nutrients are washed from Terrestrial ecosystems through rivers or non-point sources into the lake.

2.2 Sources of Pollution

There are two sources of pollution, namely point and non-point sources. A Point source of pollution discharges to the environment from an identifiable location, whereas a non point source of pollution enters the environment from a widespread area (Keith and Corwin, 2005). Point sources are easier to control, more readily identifiable and measurable and generally more toxic. Non point sources are normally of agricultural activities, urban and industrial runoff, and fertilizer application. Lake Victoria is the final destination of factory effluents, sewage from urban centers and oil spillage from transport activities (UNEP, 2005). The most common non point source pollutants include eroded sediment, fertilizer, pesticides, organic manure, salts and sewage sludge (Banadda et. al, 2010). The quality of Lake Victoria is affected by large discharge of untreated sewer and nutrient run off from agricultural land, forest and municipal slums and could be contributing to the loss of biodiversity (Getenga et.

al; 2004; Henry and Kishimba, 2000). Most detergent and fertilizer are phosphate based, thus washing of clothes and cars and fertilizer application in farms within the Lake basin are direct source of phosphorus pollution in the Lake (Alweny, 2007).

2.3 Nutrient levels in water bodies

The two primary nutrients of concern for water quality are nitrogen (N) and phosphorus (P). Enrichment of lake or river waters with nutrients mainly phosphorus and nitrogen is called Eutrophication (Alweny, 2007). Eutrophication decreases the value of rivers, lakes and estuaries for recreational, fishing, hunting and aesthetic enjoyment. Banadda, (2011) reported that runoffs into Lake Victoria during wet season increase the levels of ammonia, phosphorus, nitrates and nitrite. Ammonia varied from 0.1 - 0.19 mg/L; Phosphorus from 0.01 - 0.18 mg/L; nitrites from 0.01 - 0.05 mg/L, and nitrates from 0.02 - 0.36 mg/L. DO in the Lake was 6.2 and 3.6 mg/L at Gaba landing site during wet and dry season respectively. The high levels were attributed to high levels of organic wastes emanating from human activities. The study compares well with the study under review because levels of the nutrients were determined at the discharge point during wet and dry months. According to Alweny, (2007) the appearance of a massive algal bloom in Kitulubu bay along the shores of Lake Victoria was attributed to high levels of nutrients that resulted into fish kills due to reduced oxygen levels.

This study compared well with the study under review although it did not consider nutrient levels in sediment. Seasonality in concentration of nutrients, particularly in agricultural areas is common with peaks being recorded during high flow periods (Prost, 1985, Sundlad *et al.*, 1994, Markantonales *et al.,* 1995). Seasonality in nutrient levels can be attributed to the deposition in the sediment during low flow periods and resuspension and transportation during high flow periods. During the start of heavy rains in November 1997 high total Phosphorus quantities flowed into Lake Naivasha from its catchment rivers, originating from the middle where human settlement is highest and agriculture is intense. During dry seasons the inflows were considerably reduced (UNESCO, 1999). The study could have established whether the levels fall within the recommended water quality standards. A study conducted along Nairobi River revealed that nitrogen and phosphorus levels were highest during dry seasons (UNEP, 2003). This study compares well with the study under review except that it did not consider the nutrient levels in the sediment. A study conducted along River Njoro revealed that levels of ammonium, nitrite, total nitrogen and phosphates recorded the highest means during dry seasons. The pattern was not the same for total phosphorus which recorded the highest mean during wet seasons (Makoba *et al*., 2008). The study did not establish the sources of these nutrients since this would have made it possible to develop recommendations on how to control and manage pollution in the river.

Eutrophication of water bodies caused by over enrichment with nitrogen and phosphorus has been found to cause toxic algal bloom, loss of oxygen, fish deaths, loss of biodiversity and other degradation of aquatic environment. High nutrient content such as nitrates pollution in drinking water is harmful to human and other animals (Carpenter, 1998). High concentration of nitrates (NO_3^-) can interfere with oxygen transport in the blood of infants younger than one year, causing blue baby syndrome (Di and Cameron, 2002). High concentration is also toxic to cattle and can cause abortion in animals. According to Otieno, (2008); pH levels were found to be within the national watercourses standards by WHO recreation for since it recorded 7.04 while the recommended levels is 6.5 -8.5. The DO levels during the study under review recorded 4.32 mg/L, this was less than that set by the natural water courses standards. The study compares well with the study under review. It could have determined levels of nitrogen and phosphorus and compared with the set water quality standards.

2.4 Nutrients levels against set water quality standards

Nitrates and Nitrites

Nitrate is a colorless, tasteless, and odorless compound that is not easy to detect unless water is chemically analyzed. It is due to this characteristic of nitrogen that it's important analyze the amount of nitrates from water sources that are used for drinking annually. Nitrates dissolves easily but does not degrade quickly, nitrates can be flushed down to ground water or carried long distances , it therefore means that the amount of nitrates discharged into the lake stays for longer period .In rivers and streams from urban areas ammonia and phosphate concentration are higher downstream due to accumulated nutrients in the sewage effluents, about 10% samples taken from urban rivers have ammonia levels greater than chronic exposure for aquatic life. It is therefore necessary to determine levels of ammonia in the river to establish whether it is within the recommended levels. Natural levels of nitrogen seldom exceed 0.1 mg/l (UNEP, 2002)

According to a report by UNEP,(2002) ammonia gives an indication of the amount of nitrogen present in the form of raw sewage and the levels of nitrites and nitrates in waste water indicates the decrease of ammonia through oxidation which is a measure of biological degradation. High levels of nitrates in the water can cause a condition known as methemoglobinemia (blue baby syndrome), a condition found especially in infants less than six months of age, the condition is known to cause brain damage. Children should not therefore be allowed to drink water that exceeds 10mg/L NO_3-N. Pregnant women, adults with reduced acidity, and people deficient in enzyme that changes methemoglobin back to hemoglobin are also susceptible to nitrite – induced methemoglobinemia. Symptoms of the disease include a bluish color on and around the eyes and mouth, headaches, dizziness, and difficulty in breathing (Self and Waskom, 2008).If recognized in time, methemoglobinemia can be treated with an injection of methelene blue. In adult's prolonged intake of high levels of nitrates are linked to gastric problems due to the formation of nitrosamine compounds that have been shown to cause cancer in test animals. It is therefore important to determine the levels of nitrate in the river to determine the nitrate levels.

According to Self and Waskom, (2008) young livestock are also affected by nitrates the same way human babies are affected, but the MCL in this case is 100mg/L NO_3-N. Ruminant animals (cattle , sheep) are susceptible to nitrate poisoning because bacteria present in the rumen convert nitrate to nitrite, horses are monogastric, but their large cecum acts much like a rumen, this makes them to be more susceptible to nitrate poisoning than other monogastric animals. Common symptoms include abdominal pain, diarrhea, muscular weakness or poor coordination, blood that is chocolate brown, in calf animals may abort within a few days.
A report on nitrates and nitrites in drinking water by Wilkes University recommended that nursing mothers use water that has NO_3-N concentration below 10 mg/L since nitrates may be passed to infants in breast milk. Ammonia usually originates from specific industrial discharges and human wastes such as urine or from organic matter. Ammonia is highly toxic

to fish at concentration greater than 5mg/l (UNEP, 2002).Environmental Management Act, (1981) recommended that nitrate standards are 200mg/l, 100mg/l , 100mg/l, 10mg/l for fresh water aquatic life ,livestock watering , wildlife and recreation respectively. Recommended Water quality standards for nitrite are 1 mg/l,0.06mg/l-0.02mg/l , 10mg/l,10mg/land 1mg/l for drinking, livestock ,wildlife and recreation respectively (EMA,1981).

Ammonia

Two factors are important to toxicity of ammonia to aquatic organisms are pH and temperature of water environment. The Ph and temperature affect the amount of un- ionized ammonia which is the most toxic to aquatic life (Nordin and Pommen, 1986). Ammonia is extremely toxic and even at relatively low levels poses a threat to fish health. At low levels (less than 0.1mg/L), NH_3 acts as a strong irritant, especially to gills and prolonged exposure lead to gill hyperplasia, a condition where gill lamella swell and thicken , restricting the water flow over the gill filaments resulting into respiratory problems. At higher levels (greater than 0.1mg/L) even short exposure can lead to skin, eye and gill damage. It can also lead to ammonia poisoning by suppressing normal ammonia excrement from the gills, this will lead to damage to internal organs due to high concentration in the body. Concentrations of ammonia species depend on both pH and water temperature, but in normal circumstances any reading above 0.1mg/l should be considered as unacceptable and steps taken to reduce it. As external concentration of free ammonia rises, a fish will accordingly have a harder time releasing ammonia this will cause its internal blood level of free ammonia to rise (Alleman, 1998).

During wet weather, nutrient levels in rivers reduces due to dilution from surface run off, major sources are domestic sewage and industrial discharge (UNEP, 2002). According to Nordin and Pommen, (1986) water with excessive amounts of ammonia may affect agricultural use such as irrigation or water supplied to livestock. It is important to establish levels of ammonia in the river since it is used by livestock farmers to water animals .Since the river discharge its water into the lake, it would also be important to determine the levels that are discharged into the lake. Ammonia is highly toxic to fish at concentration greater than 5mg/l (UNEP, 2002), the results will help in determining whether ammonia levels are safe for fish life. Nitrates dissolves easily but does not degrade quickly, nitrates can be flushed down to ground water or carried long distances, it therefore means that the amount of nitrates discharged into the lake stays for longer period . According to Alleman, (1998) the presence of NH_3 and NH4+ in water is viewed as indicators that a given water has been contaminated, usually in relation to the direct discharge of an ammonia bearing waste (e.g. wastewater effluents, storm water, etc).The recommended range by FAO for ammonium-Nitrogen is 0-5mg/l in irrigation water.

Phosphorus

Sewage from wastewater treatment plants and septic tanks is one source of phosphorus in rivers. Sewage effluent should not contain more than 1 mg/l phosphorus according to U.S. Environmental Protection Agency (Mitchell and Stapp, 1992).

Physico-chemical parameters

Biological respiration, including that related to decomposition processes reduces DO concentrations. Water discharge high in organic matter and nutrients can lead to decreases in DO concentration as a result of increased microbial activity (respiration) occurring during the degradation of organic matter. Concentrations of DO in unpolluted waters are usually close to, but less than, 10mg /l (Chapman and Kimstach, 1992). According to (Chapman and Kimstach, 1992) DO levels below 5mg/l may adversely affect the functioning and survival of biological communities and below 2 mg/l may lead to the death of most fish.

Recreation and Aesthetics

This is a water use for which high concentration of nitrites, nitrates or ammonia is not likely to cause any different problems in terms of body deterioration. The more likely problem would be eutrophication related problems when high concentration of nitrogen and accompanying phosphorus cause heavy accumulations of algae. However to protect recreational users who may ingest water, it is recommended that the drinking water criteria should apply to water users for recreation contact or visual (EMA, 1981).Water quality criteria indicates that maximum recommended levels for nitrates and nitrites are a maximum of 40mg/l for fresh aquatic life,100mg/l for livestock, wildlife and 10mg/ for recreation.

While for the nitrites the recommendation a maximum levels are10mg/l ,for livestock watering and wildlife 1 mg/l for recreation,0.06 mg/l for fresh water aquatic life and 1 mg/ for drinking water (EMA, 1981).

2.5 Nutrient loads into the Lake

Due to excess phosphate and nitrogen that results into eutrophication, nearly all bottom of Lake Victoria experience prolonged anoxia for several months (Madadi *et al.*, 2006). According to studies conducted by Lake Victoria Environmental and Management Programme, (2002) to establish levels of nutrient in the lake gave critical values with nutrient loading from the urban areas amounting to 3,028 t/y and 2,686 t/y of total nitrogen and phosphorus respectively and this only included pollution loading from urban areas close to lakeshore. Water hyacinth which comes as a result of nutrient enrichment to water bodies is not only a flourishing breeding habitat for the alternative host for biomphalaria snail causing schistomiasis, but also a home for the vector mosquito , a heaven for snakes, at the expense of commercial fish species (Madadi *et al.*, 2007). According to Madadi *et al.*, (2007) eutrophication process is likely accelerate production of toxins in the Lake and toxins produced dinoflagilates such as pfiesteria in marine environment are widely known to cause massive fish kills, human memory loss, paralysis and even death. The bloom- forming species of cyanobacteria can also produce potent hepato-(liver) toxins termed microcystins known for poisoning domestic livestock. Nitrogen and phosphorus discharged into the lake through River Kisat contributes towards eutrophication which causes prolonged anoxia for several months, a condition which has a negative effect towards fish production (Madadi *et al.*, 2006).

2.7 Conceptual Framework

The aquatic ecosystems exist within basins and draw their pollution from anthropogenic activities within the terrestrial environment. The sources of pollution to the basins are either through point or non-point (diffuse) sources. The major pollutants are the macro-nutrients of Nitrogen and Phosphorus that is believed to have lead to the deleterious eutrophication of River Kisat and its recipient Lake Victoria .Algae only needs a small amount of phosphorus to live, excess phosphorus causes extensive algal growth called ʺ blooms "which are classic symptoms of cultural (Mitchell and Stapp,1992).The first symptom of eutrophication is algal bloom , followed by vegetative growth , the end result is negative impact on water for domestic use, recreation and economic use . The NH_4^+, NO_2^-, NO_3^- and TN concentrations of Nitrogen and SRP and TP concentrations of Phosphorus were therefore studied in order to understand the trophic status, the pollution sources and the loads discharged into the lake.

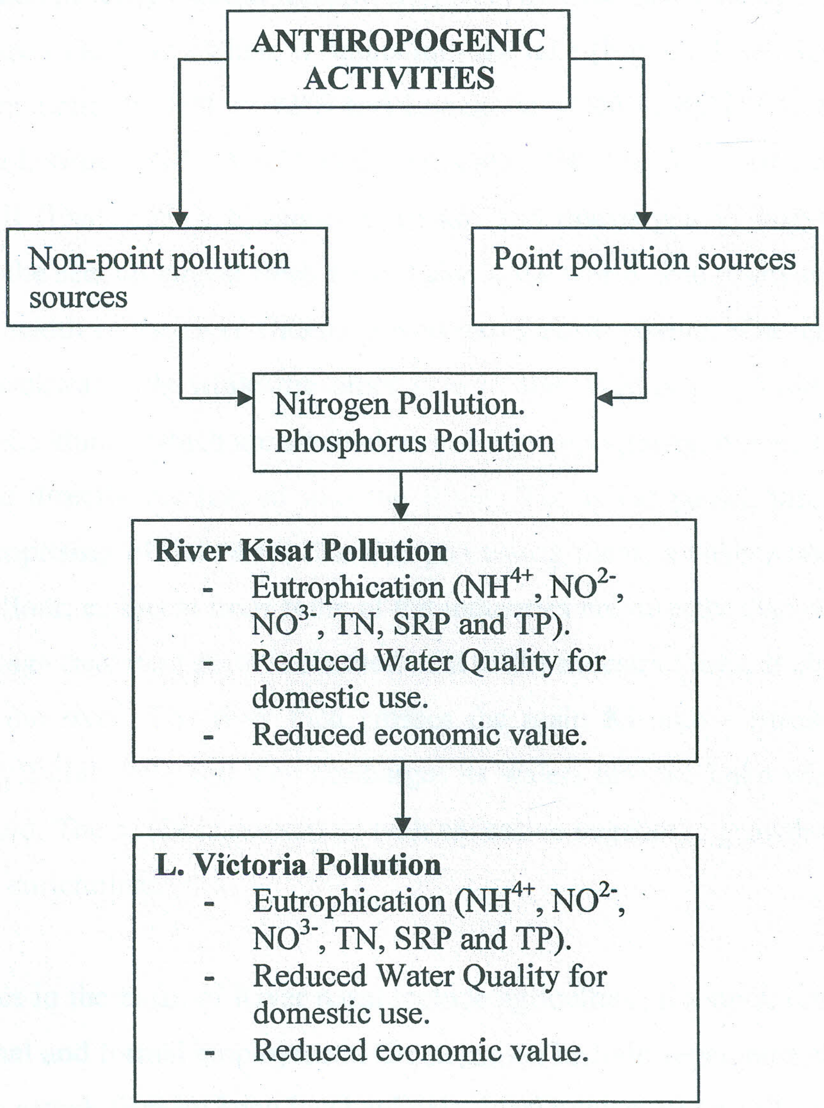


Figure 2.1 Conceptual frameworks.

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

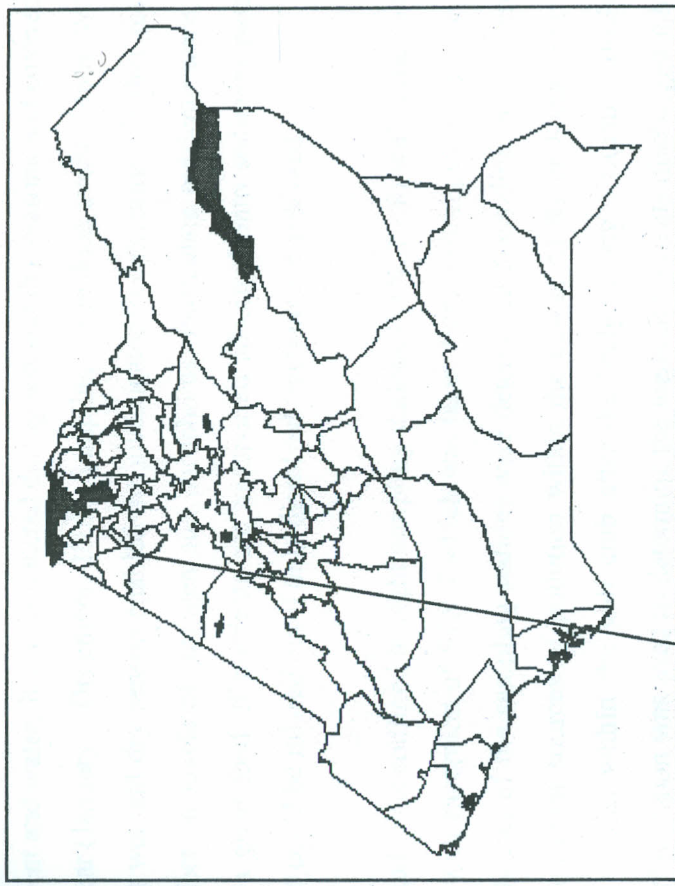
3.1 Study Area

River Kisat is located in Kenya within Kisumu city, Kisumu East District draining areas from Mamboleo to Nyanza Golf club where it drains into the lake (Fig: 1). River Kisat drainage basin runs between Latitude 0°04'12.42"S and Longitude 34°46'33.86"E (Altitude 1176m) near Mamboleo to Latitude 0°05'13.52"S and Longitude 34°45'00.15"E (Altitude 1140m) at the river mouth. It flows over a distance of 10 km and discharges its waters into Lake Victoria, which is the second largest fresh water Lake in the world. The upstream of the river is narrow and the width of the river widens as you move down stream. On one side of the river are the Kanyakwar hills while the other side of the river is the densely populated Obunga and Nyawita slums, which are situated on a sloppy topography, domestic waste from the two slums are directly discharged into the River. The River passes through Kisumu industrial area comprising of industries like fish processing plant, a bakery and factory for processing maize flour, effluents from some of the industries are directly discharged into the river. Kisat sewerage treatment plant is situated next to the industrial area; it also discharges its effluents into the river. The river then crosses the main Kisumu - Busia road, flows through Nyanza golf club field and then discharges its waters into the Lake without passing through any wetland. The River is associated with excessive vegetative growth this being an indication of river enrichment.

Economic activities in the basin of River Kisat include agriculture, livestock production, and petty trade, informal and formal employment. Crops grown include vegetables, maize, beans, and root crops. Livestock farmers keep local animals, local poultry and small ruminants. The crop and livestock farmers use the water from the river to water their crops and livestock respectively. Use of farm input like fertilizer and pesticides by farmers along the river basin is limited. The farm produce is used as source of food and income.

Kisumu town has had a gradual increase in the urban population; ranging from 365,000 people in 1999 to around 600,000 people (MCK, 2005). The population density is 828 persons per square kilometer while the growth rate is 2.8 % per year. The city experiences high population densities, especially in the peri urban and low –income area of Nyawita and Obunga (KMC, 2005).

Map of Kenya



Study Area (River Kisat Area)

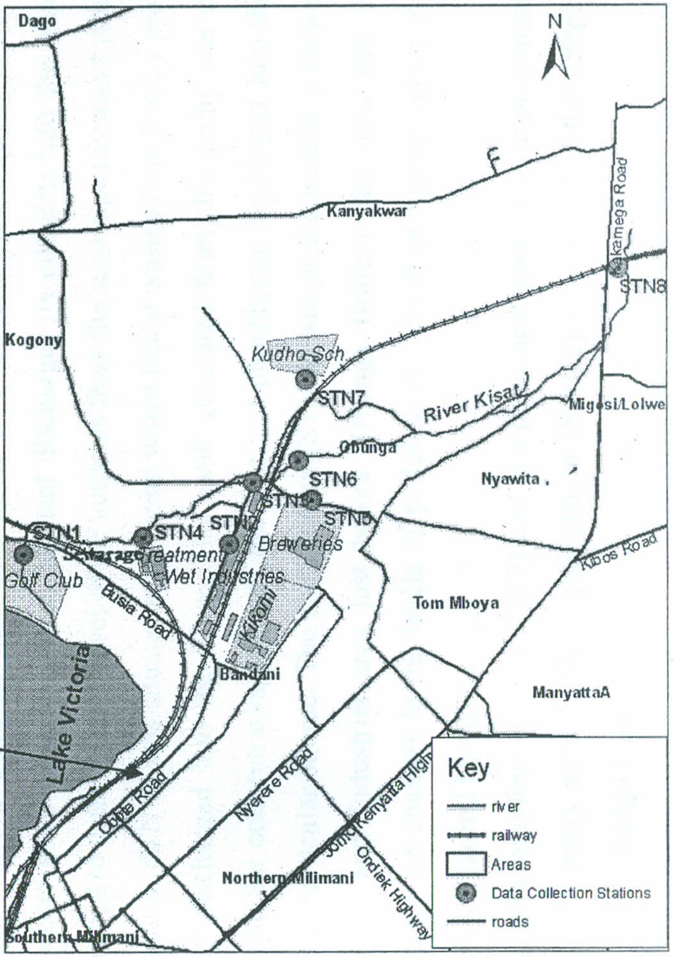


Figure 3.1: Map of study area-source (Field Map)

3.2 Study Design

This was an experimental design that focused on assessing levels and discharge loads of nitrogen and phosphorus of River Kisat into Lake Victoria, the unit of measurement were sediment and water. It was conducted during wet and dry seasons and covered a period of one year (January – December, 2009). Samplings were done every month. Water analyses during wet and dry season enabled the investigator to determine whether seasonality has an effect on levels of nitrogen and phosphorus. Particulate nutrients were investigated since a great load of nutrients are transported adsorbed onto sediment particles whose impact could be missed out if only dissolved fractions are analyzed.

The study was confined to eight sampling stations (STN. 1 - 8) within the course of River Kisat with exception of STN 7 which was taken from a spring draining into River Kisat. The choices of the sampling stations were determined depending on the perceived point and non-point sources of pollution within the course of River Kisat. The first station (STN 1) was within the golf club after the bridge along Kisumu - Busia road. This particular station was used to determine the loads of nutrients discharged into the lake; it was at this same point where river discharge rate was also determined. The point at which the effluent from a fish processing factory discharges its effluent into the river was the second station (STN 2). The third station (STN 3) was situated just before the Kisat sewerage treatment plant discharge into the river. The fourth station (STN 4) was at the point where Kisat sewerage treatment plant discharges its effluents into the waterway. This helped to determine the level of the nutrients from the sewerage treatment plant. The fifth station (STN 5) was situated at the point where liquid wastes from locally processed fish are discharged into the River. The result generated from this point was used to determine the concentration level of nitrogen and phosphorus discharged into the river from this particular source. The sixth station (STN 6) was at the boundary between the two slums and Industrial area just before (Obunga Bridge), the data was to give information on changes in the levels of pollution as a result of human activities in the slums (Obunga and Nyawita).

The seventh sampling station (STN 7) was at a permanent spring (Ayanga) situated next to Kudho primary school. The eighth station (STN 8) was just after the bridge along Kisumu - Kakamega road.

Station seven and eight were treated as control since, they are the main water source for the river. The nutrient discharge load into the Lake by the River was determined per year. Run off was also collected at various points, RUN-OFF 1 was situated at a point next to the bridge along Kisumu – Busia road, RUN-OFF 3 was situated next to STN 3, RUN-OFF 6 was next to STN 6.

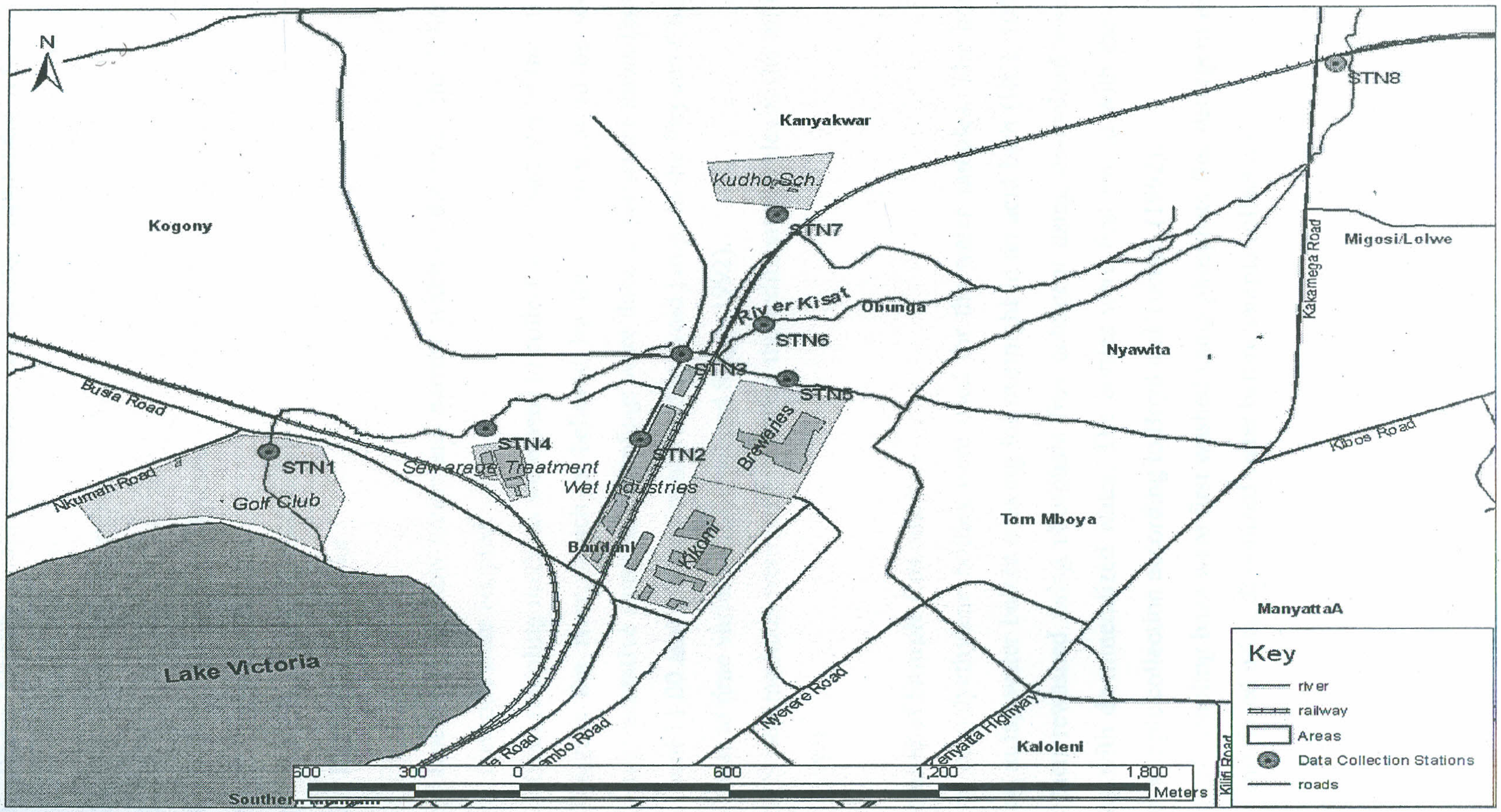


Figure 3.2: Map of River Kisat showing sampling stations along the river-source (Field Map).

3.3 Sample Collection

The following sampling equipment were used during the study:

1. Water Quality multi parameter monitoring equipment (YSI Yellow Spring Instrument 650)
2. Cooler box with ice cubes
3. GPS
4. 500 ml Polyethylene Bottles.
5. Polyethylene Bags.
6. Vehicle.
7. Ekman Grab sampler

Due to the shallow nature and narrow width of the river, the following sampling methods were adopted:

1. Grab sampling methods were used to collect water samples at the mid point section across the river, which is believed by the investigator to be well mixed and representative samples. Samplings were done at particular times (between 9.00 am and 11.00 am) for consistency and to avoid jumps in the Physico-Chemical readings due to time variation (Mitchel and Stapp, 1992).
2. Scoop methods were used to collect the sediment samples at the mid section of the river.

Treatment of Sample Containers:-

500 ml of polyethylene bottles were used for the water samples. The bottles were first washed in tap water before soaking for overnight in an acid bath (HCl. 10%). The bottles were then rewashed using phosphate free detergent using de-ionized water before final rinsing with de-mineralized water. The bottles were first rinsed with the sampling water before sample collection according to Boyd and Tucker, (1992).

Sediment sampling bags were first washed using phosphate free detergent using de-ionized water and rinsed using de-ionized water before sample collection.

3.4 Sample Handling

Storage and Preservation of Samples:-

The maximum permissible time which may elapse between collection and analysis of a sample will vary with the variable being measured (Boyd and Tucker, 1992). It is advisable for samples to be preserved immediately after collection in order to prevent the following setbacks to the samples while in transit:

1. Adsorption of substances onto the sides of the bottles.
2. pH alteration through metabolic activity of micro-organisms.
3. Release of metabolites by micro-organisms

Preservation would therefore extend the permissible time of storage. The preservation methods were the addition of acid to dissolve metals, prevent precipitation, and inhibit bacteria; and refrigeration to decrease bacterial growth and retard certain chemical reactions.

For the study case, though the samples were analyzed in less than 24 hrs, the samples were preserved immediately after collection using HCl (0.02N concentration). This was done for all the water samples except for the Total Nitrogen (TN) and Total Phosphorus (TP). After sample collection, the samples were cooled under $4^{0}C$ in a cooler box during transit to the Lab. On reaching the Lab, the samples were analyzed immediately (Less than 24 hrs after sampling).

Sediment samples were cooled below $4^{0}C$ using cooler boxes while on transit to the Lab where they were refrigerated before analyses.

3.5 Rainfall Data Collation:-

Rainfall data was obtained from Kenya Metrological Department. The station is situated at the Kisumu airport. The rainfall data was a daily collection throughout the year 2009. The daily data were summed in order to obtain monthly rainfall data. A total of twelve months was covered during the period of January –December 2009.

3.6 Sample Analyses

3.6.1 Water Samples:-

The following equipments were used during the analyses and the analyses methods described below have been taken from Standard Methods for The Examination of Water and Wastewater (APHA 2005; 21st Edition). For detailed analytical procedures, therefore, refer to this citation.

Equipment:-

1. Spectrophotometer at 880 nm (Shimanzu – UV).
2. Cadmium Reduction Column.
3. H_2O De-ionizer.
4. Distillation unit.
5. Filter Papers
6. Filtration unit
7. Analytical Weighing Balance.
8. Micro-Pipettes.
9. Autoclave
10. Beakers
11. Pipette
12. Magnetic stirrer.

3.6.2 Phosphorus

Soluble Reactive Phosphorus (SRP)

100 ml of the sample was filtered using 0.45 µm membrane filters. The filters were first soaked for 24 hrs in distilled water and dried before use. 25 ml of the filtrate was poured into a 125 ml beaker and Ascorbic acid method used to analyze the sample. This method involves the formation of phosphomolybdic acid and the subsequent reduction of this acid by ascorbic acid to intensely colored molybdenum blue. The intensity of the blue color increases in proportion to the amount of phosphorus present and is measurable photometrically (APHA, 2005).

Total Phosphorus (TP)

The various forms of phosphorus were first hydrolyzed to orthophosphate by treatment with acid, potassium persulfate, heat and pressure. 50 ml of the sample was measured into a 125-ml beaker. One drop of phenolphthalein solution was added. If the colour turns pink, enough sulfuric acid solution was added with a dropper to cause the colour to disappear. Next, a quantified sulfuric acid and potassium persulfate solution was added. The beaker was covered with Aluminium foil and autoclaved at 15 to 20 psi (778 mm to 1,038 mm Hg) for 30 minutes. The resultant orthophosphate was then measured using the ascorbic acid method as described above (APHA, 2005).

3.6.3 Nitrogen.

Nitrite (NO_2^-).

100 ml of the water sample was filtered using 0.45 μm membrane filter. 50 ml of the filtrate was placed in a 125 ml beaker and analysed for the Nitrite. Colorimetric methods generally used for nitrite employ diazotizing reagents. Nitrite reacts with these reagents in acidic solution to form diazonium salts. The diazonium salts are coupled with amino or hydroxyl groups of aromatic compounds to form colored azo compounds. The method used here uses Sulfanilamide as the diazotizing reagent and N-(1-naphthyl)-ethylenediamine as the coupling reagent. The azo compound is bright pink and measured photometrically. This method is called Sulfanilamide method (APHA, 2005).

Nitrate (NO_3^-).

Nitrate is analysed using the Cadmium Reduction Technique. In the cadmium reduction method, nitrate is reduced almost quantitavely to nitrite when a water sample is passed over cadmium filings that have been treated with copper sulfate. The resultant nitrite is measured as above through reacting with sulfanilamide and N-(Naphthyl)-ethylenediamine to form a highly colored (pink) azo-compound so its concentration may be measured photometrically (APHA, 2005).

Ammonium (NH_4^+).

50 ml of the water sample was filtered through a 0.45 μm membrane filter. Vacuum fiter was avoided since some ammonia would be lost from solution under reduced pressure. 10 ml of the filtered solution was pipetted into a 50 ml beaker and stirred using a magnetic stirrer. The stirred sample was then subjected to Phenate method of ammonia analyses. In the phenate method, phenol and hypochlorite react in an alkaline solution to form phenylquinone-monoimine which, in turn, reacts with ammonia to form indophenol. Indophenol gives the solution a blue colour, the intensity of which is proportional to the concentration of ammonia present (APHA, 2005).

Total Nitrogen (TN)

All forms of nitrogen were hydrolysed to Nitrate using Potassium persulfate before adopting the cadmium reduction method as outlined above (APHA, 2005). Samples for TN analysis were not filtred, 10 ml of sample was added to 5ml of potassium persulfate this is to help break down nitrogen compound into nitrates, inorder to hasten the process the mixture was then autoclaved at high temperature and pressure. After autoclaving the mixture was then allowed to pass through the cadmium reduction column to break the nitrates into nitrites. The nitrites were then analysed using sulfanilamide method as shown above.

3.6.4 Sediment samples:-

20g of the sediment sample was dried in an oven at near room temperature in order to retain the volatile fractions of the nutrients. After drying 0.2g of the sediment was weighed and then digested with 20ml of concentrated HCl. The digestate was then diluted using de-ionized water and the factor of dilution recorded. The diluted digestate was then analysed for the specific nutrients using the methods outlined above.

3.6.5 Nutrient Discharge Loads:-

Nutrient discharge loads were measured by first measuring the flow velocity of the river. The measurements were taken at STN 1 after the Kisat Bridge within Nyanza Golf club. A distance of 20 m was marked and a floater placed at the center of the river at the elevated mark point and the time to reach the lower mark recorded. The cross-sectional area of the river channel was taken at the lower mark. This was taken by measuring the river's width from water mark to water mark and mean depth taken from four equidistant points across the river. Cross-sectional area was found by multiplying the mean depth and the width of the river. Units of measurements were in meters (m).

River discharge velocity (ms^{-1}) multiplied by the cross-sectional area (m^2) gives us the volume of water discharged through the lower mark per second (m^3s^{-1}). 0.001 m^3 contains 1 litre. Therefore, (Volume of discharge per second/0.001) gives us litres discharged per second through STN 1. Litres discharged per second (ls^{-1}) multiplied by the nutrient concentrations (mgl^{-1}) gives us weight discharged load per second (mgs^{-1}). This can then be transformed to load per day, week or year; taking note of seasonal fluctuations.

3.7 Data Analysis

Data analysis commenced as soon as the data collection was completed .Data was entered in excel spread sheet .Replicate sample data were cleaned using excel spreadsheet and subjected to descriptive statistics to establish Means, Std. Error bars and Standard Deviations (S.D.). Means were plotted for X-Y error bars. Means were also subjected to two-way ANOVA with replication to establish the F-test values and the *P*-values for significance (Miguel et al, 2002). The data was then presented through line graphs, bar charts so as to compare variations of nutrients between stations and months .Tables were used to determine p values within water and sediment samples.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Temporal distribution of Rainfall and discharges.

Nutrient levels within river channels are normally influenced by seasonal changes. The levels may vary per season depending on the source of pollution. In drainages where point sources are the main courses of pollutions; pollution levels are high during dry season and low during wet season due to dilution factor (Bannada, 2011). In drainages with non-point sources as the main courses of pollution; pollution levels are higher during wet season and low during dry season because they are washed by run-offs (Mitchell and Stapp, 1992). It was, therefore, found pertinent by the investigator to include rainfall data for the period of study. Rainfall data was obtained from Kenya Metrological Department. The station is situated at the Kisumu airport. The rainfall data were collected on daily basis throughout the year 2009. The daily data were then summed to obtain the monthly rainfall (mm). A total of twelve months were covered during the period of January – December, 2009.

The Western Kenya rainfall pattern can be divided into two, namely: Long rains and Short rains. The long rains are between March – June while short rains are between September – November. In this study, dry months are considered to have rainfall of less than 50mm. During the study period, the rainfall received ranged between 11.2 (Jan.) to 279.3 mm (Sept.) while the discharge ranged between 0.08 (Feb.) to 0.925 m^3s^{-1} (Sept.). During the months of January, February, June, July and October, according to fig. 4.1, the mean rainfall figures were less than 50mm while in the months of March, April, May, August, September, November and December the rainfall averages were above 50mm. The rainfall peak was obtained in the months of March and September. The discharge rates were less than 0.15 m^3s^{-1} in the months of February, March, June, July, August and October. The rest of the months had discharges above 0.15 m^3s^{-1}. The discharge peak was in the month of September.

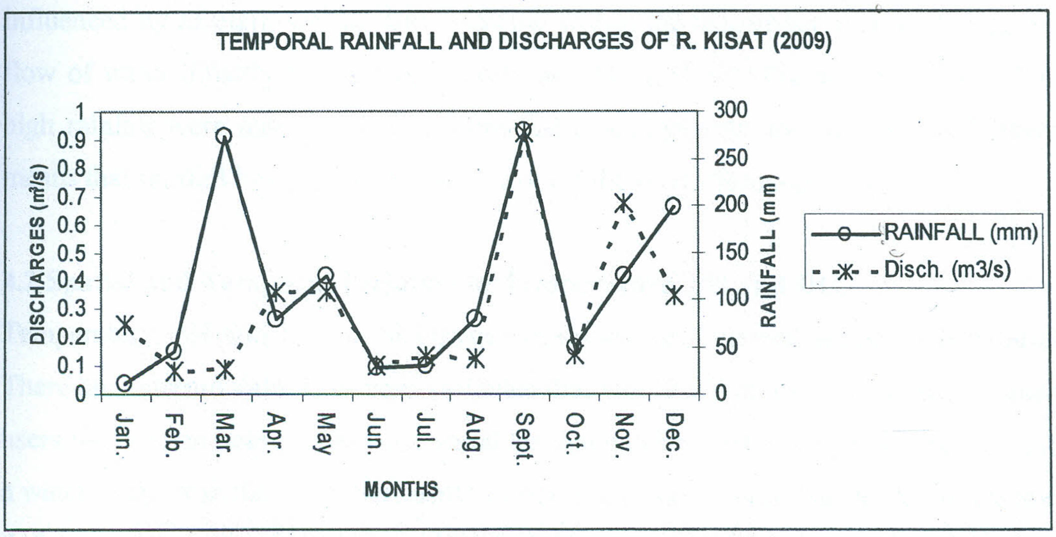


Figure 4.1 Temporal distribution of rainfall and discharge rates - 2009 (Source: Kenya metrological department (rainfall) and discharge rates (Field Data)).

Because of changes in climatic patterns due to Global Warming, the weather patterns have become difficult to predict and short rainy seasons sometimes receive more rain than the long rainy season. Because some data were collected just before the onset of the rains; which later came torrentially within the months (e.g. March), it was thought wise by the investigator to augment the rainfall data with the discharge rates as measured during the study; which is believed to better explain the nutrient dynamics than rainfall data. From fig.4.1, the peak rainy month of March is unconformable with the discharge rate for the same month. In the month of March, sampling was done before the onset of rains as can be seen from the pattern between rainfall and discharges. It is clear from the two patterns that there exist some conformity and that the discharge data can therefore be used to explain nutrient dynamics and the effect of seasonality.

The rainfall pattern during the study period exhibited a sharp rise during the last month of the first quarter and the last month of the third quarter of the year under review. The last month of the fourth quarter also received high rainfall but was below the rainfall amounts received in the last months of the first and third quarter .The last month of the second quarter received low rainfall .The first month of every quarter was associated with dry spell (low rainfall). The findings concur with Ministry of Agriculture annual report for Kisumu East District, (2009) which exhibited the same rainfall patterns. Discharge rates also followed the same pattern as that of the rainfall .River discharge rate is normally influenced by rainfall, springs and overflow within the catchment area, and underground flow of water directly to the river (Raven and Berg, (2005).Fig 4.2 above revealed that high rainfall were associated with increased discharge rate and vice versa, it therefore means that rainfall has got a direct influence on the river discharge rate.

4.2 Spatial and Temporal variation of Temperature, pH and DO.

Temperature, pH and Dissolved Oxygen (DO) are very critical water quality variables. There are extreme values of these variables that would affect the aquatic life or other end users like human beings. They are variables that can be used to gauge the health status of a water body. It is therefore pertinent to understand these variables and factors leading to their spatial or temporal change. The variables are mainly influenced by the Time of sampling, Algal biomass, Organic waste, Altitude, Seasons, Respiration rates etc. (Straskraba and Tundisi, 1999).According to EU water quality standards the recommended pH levels for natural water bodies lies between 6.5 to 8.5 as indicated in appendix 111.

4.2.1 Temperature

The temperature and temperature range of rivers have a large impact on the type of fish and macroinvertebrates that are present , during the study temperatures between months were found to range between 20.77 (Apr.) to 26.91 ^{0}C (Jun.) with marked peaks in the months of February and June. This was found to correlate with low discharge periods (dry periods) (Fig. 4.2).This results concurs with a report issued by Marborough District Council, (2005) which stated that dry river beds absorbs more heat than water and will also retain the heat for longer periods .When these areas are subsequently wetted again the temperature of the water can be artificially raised. Generally, temperatures of the river during the study were found to inversely correlate to the discharge rates.

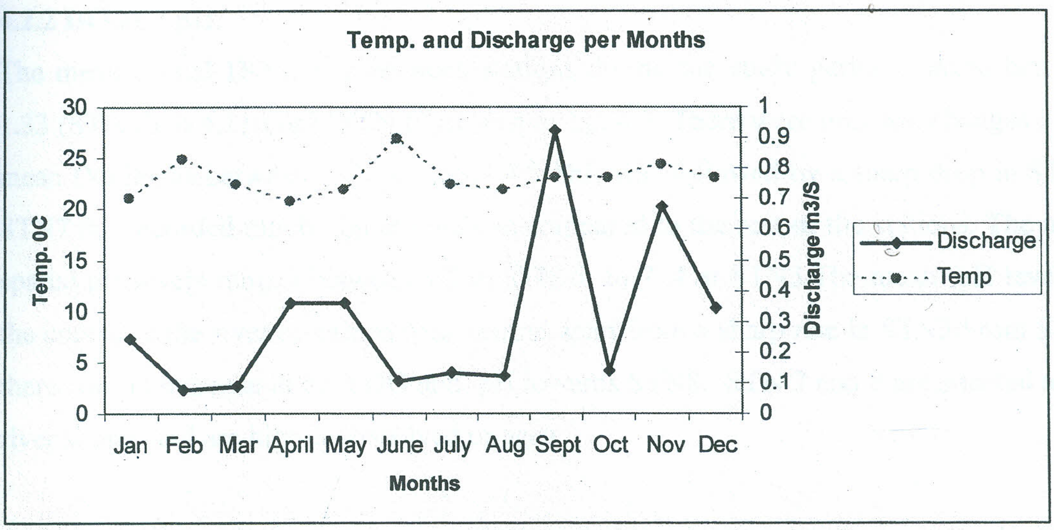


Figure 4.2 Temperature and discharge rates of River Kisat per given months of sampling.

During high discharge rates, the temperatures were generally low while during low discharges the temperatures were relatively high as can be seen in fig 4.2. The temperatures could also have been affected by the time of sampling. Samplings done in the wee hours of the day are bound to have lower temperatures (Itome *et al.*, 2008). The mean temperature recorded during the year under review is believed by the investigator not to be conducive for fish yields but was very conducive for vegetative growth. This result is supported by Mitchell and Stapp, (1992) which stated that temperatures above 20°C allow for high vegetative growth and high incidences of fish diseases due to stress arising from thermal pollution or decrease in oxygen since cool water can hold more oxygen than warm water. The temperature of the river therefore is not conducive for fish production, but is quite conducive for vegetative (plant) growth. Fig 4.2 indicates that increase in discharge rate had some minimal effect on temperature as can be seen in the month of September. This observation concurs with that of Mitchell and Stapp, (1992) which stated that thermal pollution can also result from storm water running off warmed urban surfaces like streets, sidewalks, and parking lot. Run –off therefore slightly elevates temperature of the river.

4.2.2 DO and pH.

The mean spatial DO levels between stations during the study period, ranged between 1.33 (STN 6) to 4.11 mg/l (STN 8) as seen in fig. 4.3. There were minimal changes in the mean DO levels between STS, s 1,2,3,4 &5.This was followed by a sharp drop in STN6. STN7 &8 recorded much higher levels as compared to the rest of the stations. The mean spatial pH levels ranged between 7.0 at STN 6 to 7 .4 at STN3.The mean pH levels in the course of the river remained near neutral apart from a sharp rise in STN3.From STN6 there was an increase in both DO and pH towards STN8. STN 7 and 8 are situated at the river source and are high in dissolved oxygen.

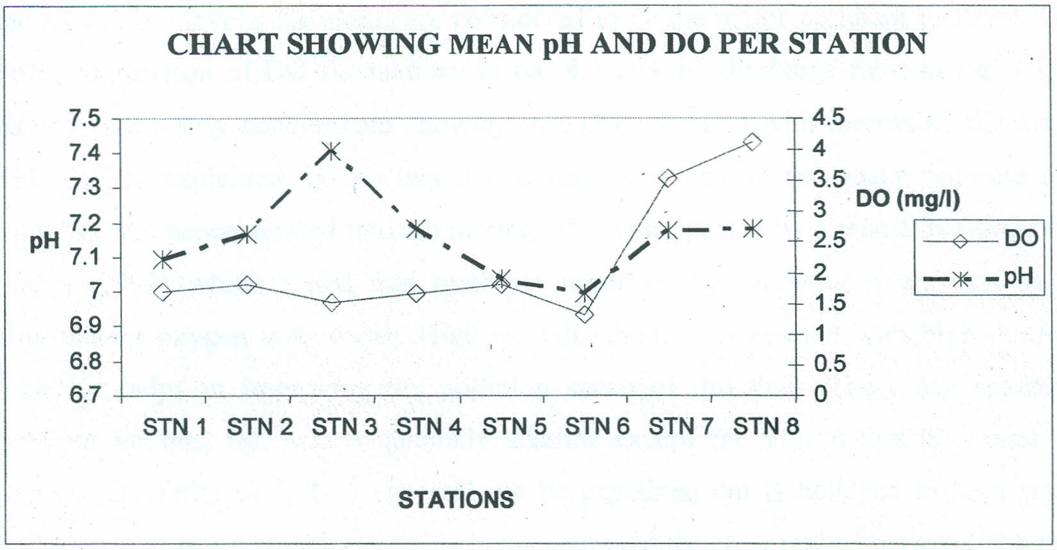


Figure 4.3 Spatial Variation of Mean pH and DO per stations along River Kisat (2009).

The lower stations are low in dissolved oxygen with an extreme low at STN 6. It is situated in an area influenced by influxes from the neighboring slums of Obunga and Nyawita. It is herein believed by the investigator that the DO levels within River Kisat are mainly influenced by the decomposition of organic wastes from the slums, industries and sewerage treatment plant. This report concurs with that of Itome *et al.*, (2008) which stated that reduced oxygen levels in River Kiu in Githurai occurred probably due to increasing quantities of oxygen demanding organic waste in water. From fig. 4.3, a lot of organic waste is probably contributed into River Kisat from the two slums; hence the low DO levels at STN 6, this is a sign of pollution. There was a sharp rise in DO levels at STN 7 and 8, indicating that the level of pollution at these two stations was much lower than the rest of the stations. According to WHO standards for drinking water resources, the minimum level of DO should be 5 mg/l. It therefore means that in terms of DO levels water at STN8 is slightly below the recommended standards for drinking.

At STN 4 where raw sewerage from the treatment plant is disposed into the river and the subsequent station lower in the river channel (STN1); the dissolved oxygen are low. This is attributed to the Biochemical Oxygen Demand (BOD) from the organic decomposition (Boyd, 1998). The minimum recommended oxygen level for fish life is 5 mg/l (Banadda, 2011). This means that oxygen levels within the entire course of the river and the STN7 (Spring) falls below the set DO standards, and this is a sign of pollution. Therefore, from the spatial DO levels, the slums are considered to be the major pollutant to River Kisat. From comparison of DO fluctuations in fig. 4.3 and the discharge rates in fig. 4.1, the patterns are nearly concomitant showing that DO increases with increasing discharges. This can be explained by the fact that during rainy season the water becomes more turbulent and hence aerated through mixing. This is supported by a report by Mitchel and Stapp, (1992) which stated that tumbling water on fast moving rivers acts to mix atmospheric oxygen with water. High rainfall which is associated with high discharge therefore helps in improving the pollution status of the river. The mean spatial pH between stations, fig. 4.3, is generally alkaline except for STN 6 that is neutral. The extreme alkalinity of STN 3 can still not be explained but is believed to be a sign of pollution .The mean spatial pH levels in the course of the river ranged between 7.0 to7.4; this means that the mean pH changes in the river course were minimal. Therefore discharge from point and non point sources of pollution did not influence pH levels, or the buffering capacity of the river was efficient. The result concurs with that of UNEP, (2003) which stated that discharge rate into Nairobi River resulted into minimal pH levels in the river course.

The mean temporal DO levels ranged between 1.4 (Aug.) to 3.15 mgl^{-1} (May) (Fig. 4.4). The DO levels between months were generally low but with peaks during the months of April, May, September and November. These are the months of high discharges as observed in fig. 4.2. The mean temporal pH ranged between 6.9 in the month of August to 7.3 in the month of July (Fig. 4.4).

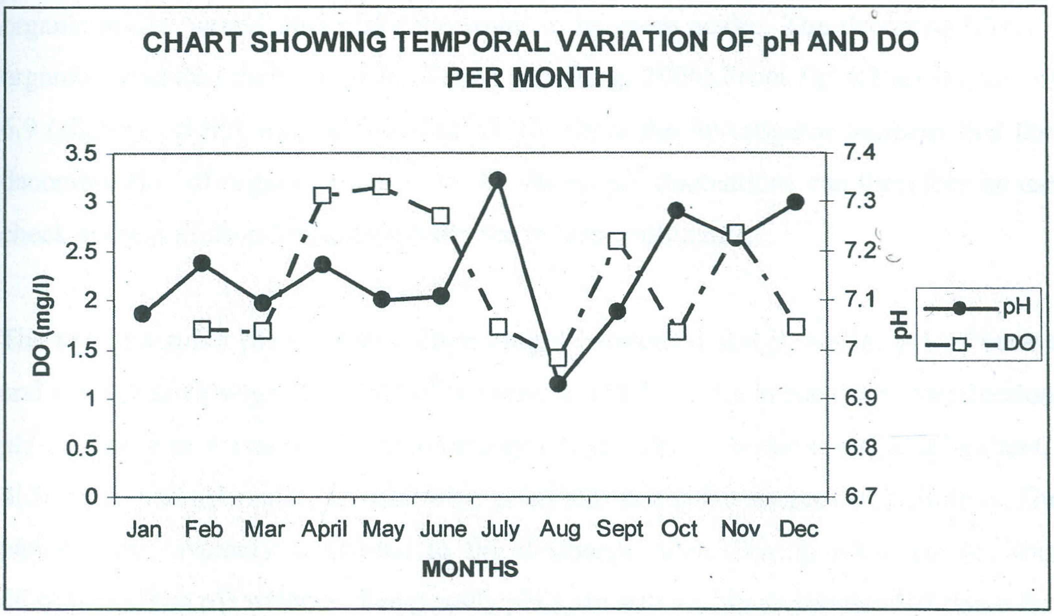


Figure 4.4 Temporal variation of Mean pH and DO per months of River Kisat (2009).

The mean temporal DO levels are always below 3.5 mg/l (Fig. 4.4) meaning that long exposure of organisms, especially fish, to these levels would impede their growth. In months with less than 2 mg/l, an exposure of only a few hours would be lethal to the organisms (Boyd, 1998). This implies that during dry season, River Kisat is lethal for fish life. Throughout the entire period the mean DO levels remained below the recommended levels as indicated section 4.2.2 above.

pH is the measure of acidity or alkalinity of a water mass. Water with pH below 7 is considered acidic while pH of more than 7 is alkaline. The pH levels may be influenced by time of sampling through plant respiration. Marborough District council, (2009) reported that large fluctuation in pH outside a river natural pH range can lead to stress on aquatic life and low pH also mobilizes otherwise bound heavy metals , an increase in which can be toxic to aquatic life.EU recommendation for pH in stream water ranges between 6.5 -8.5.The study under review revealed that mean temporal pH levels were within the EU recommended levels this was due to the fact mean pH levels ranged between 6.9 (Aug.) to 7.35 in (July.) , and therefore in terms of pH the river is safe for aquatic life. At night when plants give out carbon-dioxide, the waters becomes more acidic while during the day when they give out oxygen and take in carbon-dioxide from the waters, the water becomes more basic (Itome *et al.*,2008). Decomposition of the organic matter would also make the water to be more acidic. The decomposition of the organics produces carbonic acid (Raven and Berg, 2005).From fig 4.3 above low pH of 6.9 (slightly acidic) was exhibited at STN6 where the investigator believes that there is decomposition of organic waste from the slums. pH fluctuations can therefore be used to check at the pollution levels especially the organic pollutants.

The recommended pH for fish culture ranges between 6 and 9, while pH of between 5 and 6 leads to slow growth , pH of between 4 and 5 results in retarded reproduction and pH of less than 4 results in fish mortality (Boyd, 1998). Without extreme outliers, it is difficult to use pH results to determine point and non-point sources of pollution. The pH patterns are inversely correlated to the discharge rates. During rainy period, there is dilution and the pH reduces. Temporally pH,s are still within recommended range for fish production. It is herein believed that because of the rapid flow and turbulent mixing of the River Kisat water mass, the pH has remained near neutral.

4.3 Nutrient dynamics

4.3.1 Nitrogen

The three species of nitrogen, namely ammonium (NH_4^+), nitrite (NO_2^-) and nitrate (NO_3^-) are important components of the dissolved inorganic nitrogen (DIN) reservoir, as they represent the principle sources of nitrogen available for primary vegetative production (Boyd, 1998). It therefore, herein analyzed to show the spatial and temporal variation during the study.

4.3.1.1 Spatial

Spatial distribution of nutrients would help us understand the pollution levels and point and non-point sources of pollution within River Kisat.

Ammonium - NH_4^+

At the temperature and pH range typical of most rivers ammonia exists predominantly in the ionized form ($NH4^+$) (Marborough District Council, 2009) .The spatial concentration of ammonium in water within River Kisat ranged between 0.01 mg/L within Run-Off 1, to 1.89 mg/L at STN 4 (fig. 4.5). The mean ammonium concentration observed at STN 7 was 0.15 mg/L. This station recorded the lowest ammonium levels.STN1 and STN4 exhibited the highest ammonium levels. Mean ammonium levels generally increase towards the discharge point.

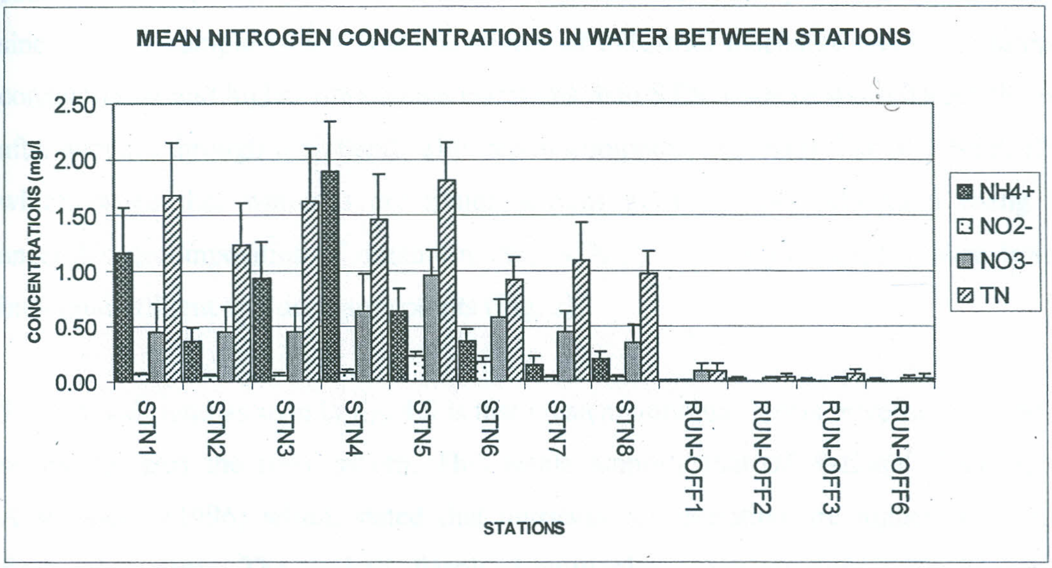


Figure 4.5 Mean nitrogen concentrations in water between stations.

Run-offs recorded negligible nutrient levels; this is believed by the investigator to be due to dilution effect since the sampling was normally done a day or two days after heavy down pour. The high ammonium concentration is a sign of an anoxic environment reminiscent with STN 4 due to sewerage discharge from wastewater treatment plant at Kisat. The high levels at this particular station is mainly due to human waste which is major source of ammonium .The results confirms that of a report by UNEP, (2003) which stated that high levels of ammonium in Nairobi River was due to discharge of human waste from informal settlement. STN 7 and 8 are near the river source and are therefore low in ammonia due to less effluent. STN 6 exhibits low concentration of ammonia and other nitrogen nutrients than STN 1, 3, 4 and 5 but is believed by the investigator to have the greatest pollution impact to River Kisat than any other station. STN 6 is considered to be a non-point pollution source having the greatest impact during rainy seasons when the discharge rates are high as shall be discussed below. It is only at STN 1, 3 and 4 whereby the ammonia concentrations are higher than the nitrate concentrations. Ammonia being the reduced form of nitrate and STN 1 being at the extreme end near the River mouth just after STN 4, therefore the higher concentration shows the impact of the sewerage treatment plant which is partially treated and anoxic. This concurs with a report by

UNEP, (2003) on Nairobi River basin programme phase 11 which stated that water leaving sewerage plants showed high amounts of ammonia an indication of anoxic condition .The anoxic condition at STN 3 may be occasioned by the wetland at this point since STN 2 sample which is at the source of industrial discharge has lower ammonia concentration and higher nitrate concentrations than STN 3 where it discharges the waste after passing through a wetland. This report compares well with that of UNEP, (2003) which stated that wetlands are major sources of ammonia pollution a rising from anaerobic decomposition of organic matter. STN 2, 3 and 5 are samples taken from the industrial effluent and discharge points (Fig. 2).

The general trend as seen in fig. 4.5 is that mean ammonium levels increase from the river source towards the river mouth. This result supports that of National Water Quality Assessment, (1996) which stated that nutrients concentration are highest downstream from urban areas. The desired dissolved ammonium concentrations for a healthy fish yield are between 0.2 to 2 mg/L (Boyd, 1998). Therefore, the mean ammonium spatial concentration ranges obtained during the study, 0.01 to 1.89 mg/L, fell within the desired range. Other set standards which vary from one body to another and from country to country are as attached in appendices III and IV. All the stations exhibited NH_4^+ levels of more than 0.02mg/l which is above AZECC recommended levels for protection of ecosystem health .Water that is determined to be safe for one use may be unacceptable for another purpose, therefore many water quality experts refer to their measurement in terms of specific use (Mitchel and Staff, 1992)

The same nitrogen patterns are also seen in the sediments as discussed for water samples (fig. 4.5). This is a clear sign that the industries and sewerage treatment plant are point sources of pollution to River Kisat and that they mainly discharge organic pollutants which increases the ammonia levels and reduces DO concentrations through decomposition as observed above (fig. 4.3).

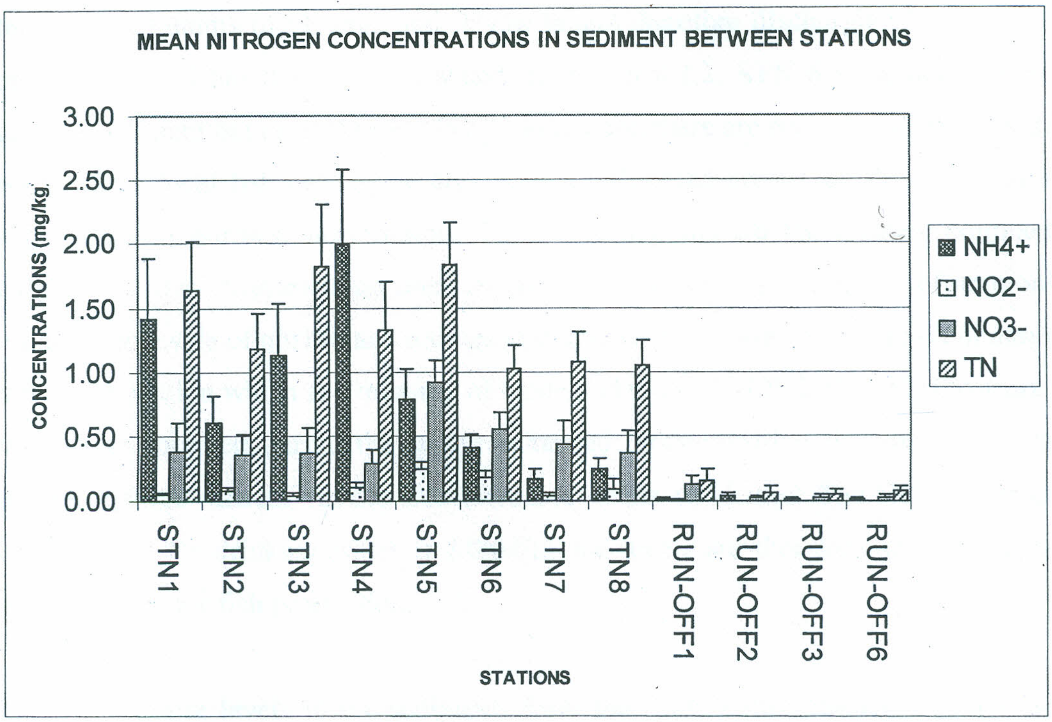


Figure 4.6 Mean nitrogen concentrations in sediments between stations (2009).

Nitrite - NO_2^-

The nitrite which is an intermediary reduced form of nitrate can also be used as an indicator of the degree of bacterial action on organic pollutants. The mean nitrite spatial concentrations in water ranged between 0 to 0.23 mg/L. The concentrations within the river course ranged between 0.04 (STN 7 and 8) to 0.23 mg/L (STN 5). It is still clear, from the nitrite results that the major sources of pollution emanate between STN 1 to 6 which entails the slums, industries and sewerage treatment plant.

The acceptable concentration ranges for nitrite in water for fisheries is less than 0.3 mg/L (Boyd, 1998). The spatial mean nitrite concentration ranges in water obtained during the study was therefore within the recommended levels for fisheries. In STN 5 in the months of April, May, June, July September and November (2009), the concentrations were 0.38, 0.4, 0.33, 0.33, 0.36 and 0.34 mg/L respectively. These are higher than the acceptable levels as stated above. In STN 6, the levels were higher than the acceptable range during the months of April, May, September and November when the investigator recorded levels of 0.45, 0.46, 0.44 and 0.39 mg/L respectively. During these months, (April, May, September and November), there were increased discharge rates and the more than normal ranges are therefore attributed to the run-offs especially for STN 6 which drains from the two slums of Obunga and Nyawita and therefore discharging high amount of organic matter from the slums as stated in section 4.2.2. STN 6 is coming out as the greatest pollutant but only during rainy periods when there are run-offs. STN 5 that drains wastes from local fish processing area is also influenced greatly by the discharge rates and high with nitrite concentrations. These two stations are the greatest pollutants in terms of nitrites. Nitrites is an intermediate stage in bacterial oxidation of ammonia to nitrates, the levels of nitrites and nitrates in wastewater indicates the decrease of ammonia through oxidation which is a measure of biodegradation (UNEP, 2003). This concurs with the results obtained during the study; enhanced biodegradation due increased organic wastes at these stations results into increased levels of nitrites. The EU recommended nitrite levels for drinking water is 3.0mg/l, the levels are therefore safe for drinking water but not for fish production.

The mean nitrite levels in the sediments from the study within the river course ranged between 0.1 to 0.25 mg/L. The patterns between stations here still exhibits the results found under water. STN 5 and 6 are still implicated to bear the greatest responsibilities they to River Kisat pollution.

Nitrate - NO_3^-

Nitrate which is the most oxidized form of nitrogen, during the study ranged between 0.023 to 0.96 mg/L in the water. Within the river course, nitrate ranged between 0.35 (STN 8) to 0.96 mg/L (STN 5) (fig. 4.5). STN 4, 5 and 6 shows high concentration of nitrates than the other stations and are believed to be the sources of pollution. STN 4 and 5 are point sources while STN 6 is believed to be a non-point source of nitrates. The acceptable nitrate concentration ranges for a better fish yield is 0.2 to 10 mg/L (Boyd, 1998). Therefore in terms of nitrate, concentration ranges along River Kisat are therefore well within the acceptable range. The 10 mg/L recommended for drinking water by Environmental Management Act, (2006) is also not exceeded during this study. STN 7 and 8 are still consistent with low nutrient levels compared to the rest of the stations along the river being at the river source. Individual samplings showed many stations having nitrate concentrations lower than the recommended ranges for drinking and fish production. However the nitrate levels are above recommended levels for aquatic plant growth in all the stations apart from STN8. This report concurs with ANZECC guidelines which identified 0.444 mg/l as nitrate levels above which nuisance aquatic plant growth will occur. The nitrate levels in STN8,7,6,5 & 2 were higher than ammonium levels , apart from STN6 the rest of the stations exhibited much higher DO levels as shown in fig.4.3 meaning that oxidation rates were higher at these STN,s. This results concurs with that of Marborough District Council,(2009) which stated that due to oxidation nitrate become more dominant due to enhanced level of oxygen levels in a water body.

The reason why STN6 exhibited high levels of $NO3^+$ irrespective of the fact that the oxygen levels at this point was low cannot be explained by the investigator.

It is important to note that NH_4^+ concentration in the water was highest in STN 4 while NO_2^- and NO_3^- concentrations are low compared to many other stations along the river channel (STN 1-8) (fig. 4.5). Ammonium, a constituent of urea and organic decomposition is expected to be high at STN 4 due to sewerage effluents from the municipal. This report supports Mitchell and Stapp, (1992) which stated that sewage is the main source of ammonia added by humans to rivers. With proper treatment of the sewerage, the NH_4^+ is oxidized to NO_2^- and NO_3^- (the most oxidized form of nitrogen). The high NH_4^+ and low NO_2^- and NO_3^- concentrations, therefore, point to the fact that Kisat sewerage treatment plant is not efficient. The speciation of nitrates in the sediments takes the form as in the water, implying that the explanations given above for water holds for sediments as well.

Total Nitrogen - TN

Nitrogen was considered during the study because its one of the nutrients that limit vegetative productivity. Total nitrogen indicates the amount of nitrogen present in both organic and inorganic form within a water sample (Mitchell and Stapp, 1992) .The study revealed that Total Nitrogen levels were higher than that of $NH4^+$, $NO3^-$ $NO2^-$ in all the stations apart from STN4 whereby mean ammonia levels were higher than mean Total Nitrogen. Higher levels of Total nitrogen within the stations as compared to NH4+, NO3- and NO2-, according to the investigator is as a result of availability of other forms of nitrogen other than nitrite, nitrates and ammonia. The investigator is not able to explain the reason why NH4+ levels in STN4 is higher than mean Total nitrogen.

From the results above (fig. 4.5), STN 5 had the most discharge of Total Nitrogen (TN) than any other station. The reason why this station had the highest Total Nitrogen is because it is a point source generating high volume of organic wastes from fish by filleting. This is supported by Ogutu et al., (1998) reported that a fish –filleting factory in Uganda that discharges it's effluents into Lake Victoria recorded very high annual loads that amounted to 0.1t NH4+ and from food processing industries, the highest annual loads of organic matter discharged to the lake amounted to 36.8 t. STN 6 has the least of total nitrogen (TN) concentration and yet the investigator believes that it contributes the greatest load of nutrient pollutants. STN 6 is influenced by run-offs from the two slums mainly during the rainy season. Because of the myriad structures, the run-off discharges are great and the nutrient load is heavily diluted as a resultant of the heavy discharges. Looking at the Standard Errors (SE), (fig. 4.5), it is evident that SE increases downstream suggesting that nutrient pollution from point and non-point sources increases from the river source. During dry season, pollution from point sources elevates the nutrient concentration levels downstream while during wet season the levels plummets due to dilution hence the high SE downstream (Kifferstein and Kanz,2002).

4.3.1.2 Temporal

Rainfall influences nutrients differently. The more oxidized form of nitrogen is expected to increase with increasing rainfall because it is during this period that the waters are more oxygenated (fig. 4.4 and 4.7).The months of April, May, June, July September and November (2009), had mean nitrite concentrations were 0.38, 0.4, 0.33, 0.33, 0.36 and 0.34 mg/L respectively. In the months of February and March (2009), the concentration levels of NO_3^- are exceptionally high and yet they have the lowest discharges.

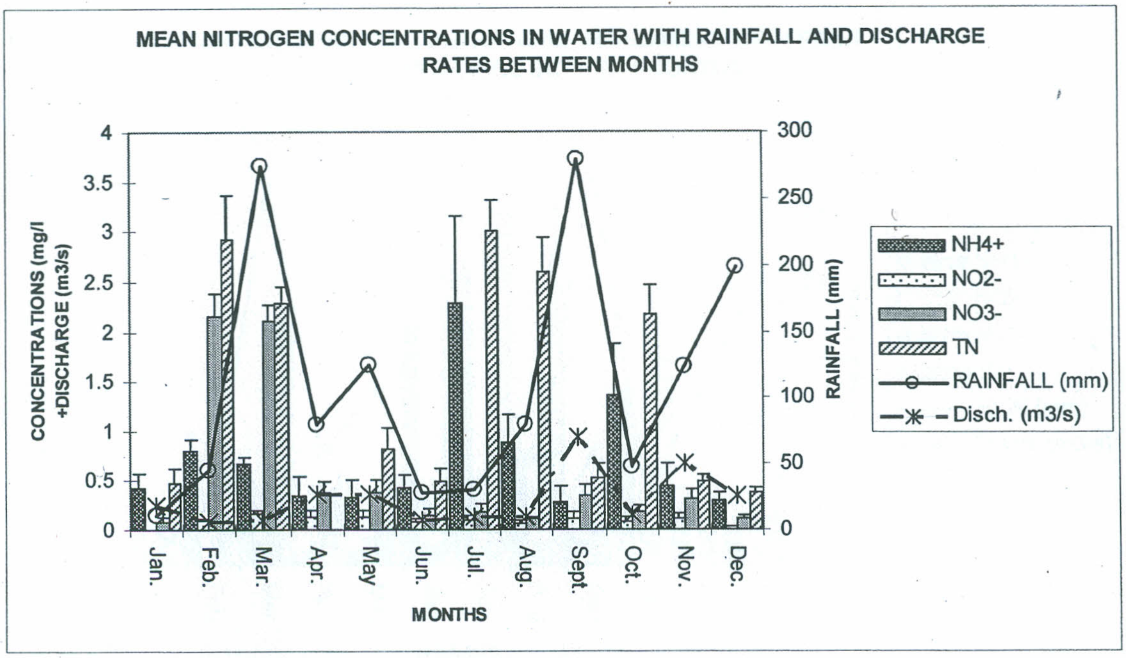


Figure 4.7. Temporal distribution of nitrogen concentrations in water with rainfall and discharges between months.

The explanation for this disparity is less understood by the investigator. The NH_4^+ concentrations are high during dry season when the water is less oxygenated and poorly mixed (fig. 4.7) , the levels reduce during wet weather. Generally, during dry season the concentration levels especially the reduced form of nitrogen is high hence the TN concentrations are also high during dry season but low during wet season. This shows that the river course is mainly influenced by organic point and non-point pollutants and is supported by Loague and Corwin, (2002) report that point and non point sources of pollution both contributes towards river pollution through discharge of organic wastes. The fact that NH_4^+ levels reduces during wet season and rises during dry season concurs with the UNEP, (2003) report which revealed that the cause of reduced ammonium during wet season along Nairobi River is was as a result of dilution effect.

The temporal distributions of the Standard Error (SE) bars are nearly uniform indicating that the effect of dilution across the river channel is uniform and there is not much deviation of concentrations from the means during the sampling seasons.
The nitrogen concentration in the sediments exhibits the same patterns and the same explanations above will apply (fig. 4.8).

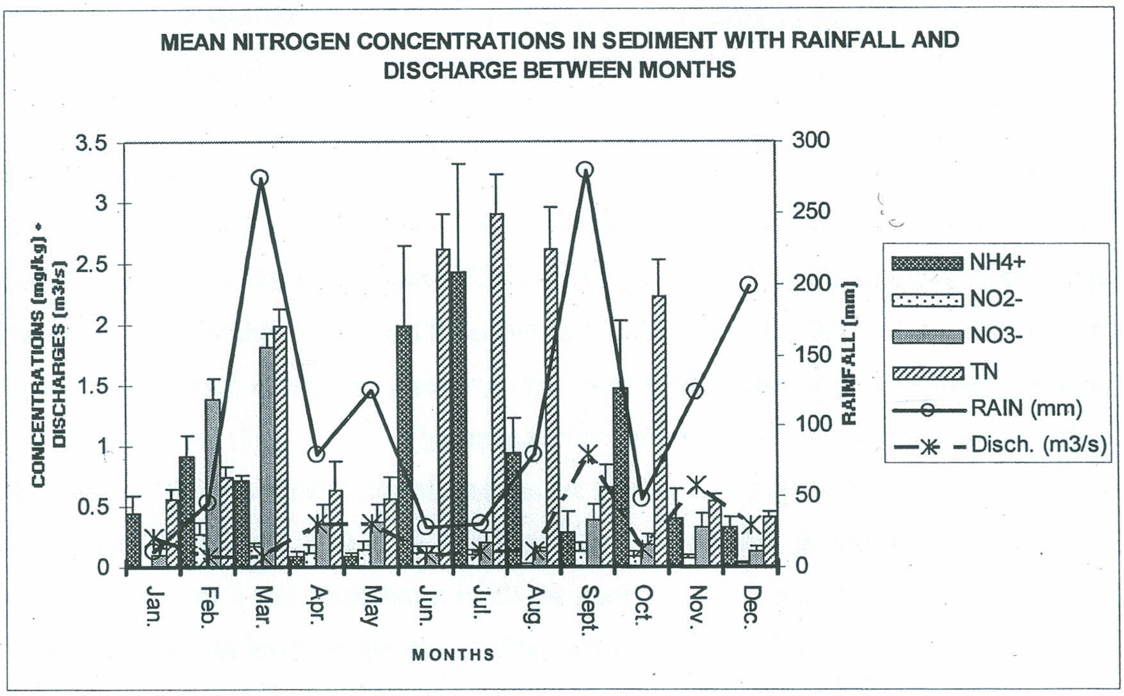


Figure 4.8 Mean nitrogen concentrations in sediments with rainfall and discharges between months.

The mean nitrogen levels in water and sediment exhibited the same behavior, this means that the there exists an equilibrium between the rate of adsorption and resuspension of nutrients from the sediments. This study concurs with that conducted by Deng *et al.,* (2005) on Xiangxi River which stated that the rate of nutrients adsorption and release was constant along the course of the river. Seasonality therefore does not influence internal nutrient adsorption by the soil particles or release into the river.

4.3.2 Phosphorus

Phosphorus is essential to the growth of organisms and can be the nutrient that limits primary productivity. It occurs in natural waters and in wastewaters almost solely as phosphates. They are classified as orthophosphates, condensed phosphates and organically bound phosphates. They occur in solutions, as detritus and in the bodies of aquatic organisms. Small amounts of orthophosphates and certain condensed forms of phosphorus arise from water treatment while a bulk of it is from laundering or other cleaning detergents.

Orthophosphates applied to agricultural or residential cultivated land as fertilizers are carried into surface waters with storm runoffs. Organic phosphates are formed primarily by biological processes. Organic phosphates are contributed to the sewerage by body wastes and food residues (Mitchell and Stapp, 1992).

4.3.2.1 Spatial

The levels of Total Phosphorus and Soluble Reactive phosphate increased from the river source towards the discharge point. There was a sharp decline on levels of both Total Phosphate and Soluble Reactive Phosphate at STN2. Generally, STN 4 &1 showed the highest contribution of Soluble Reactive Phosphorus (SRP) than any other station within the river course (Fig. 4.9). The mean concentration ranges of Soluble Reactive Phosphorus (SRP) in water between stations are 0.16 to 1.04 mg/l while Total Phosphorus ranged between 0.21 to 1.39 mg/l. The mean levels of Soluble Reactive Phosphate were lower than that of Total Phosphates in all the stations. The Total phosphate and Soluble Reactive phosphate levels in the Run –off remained extremely low.

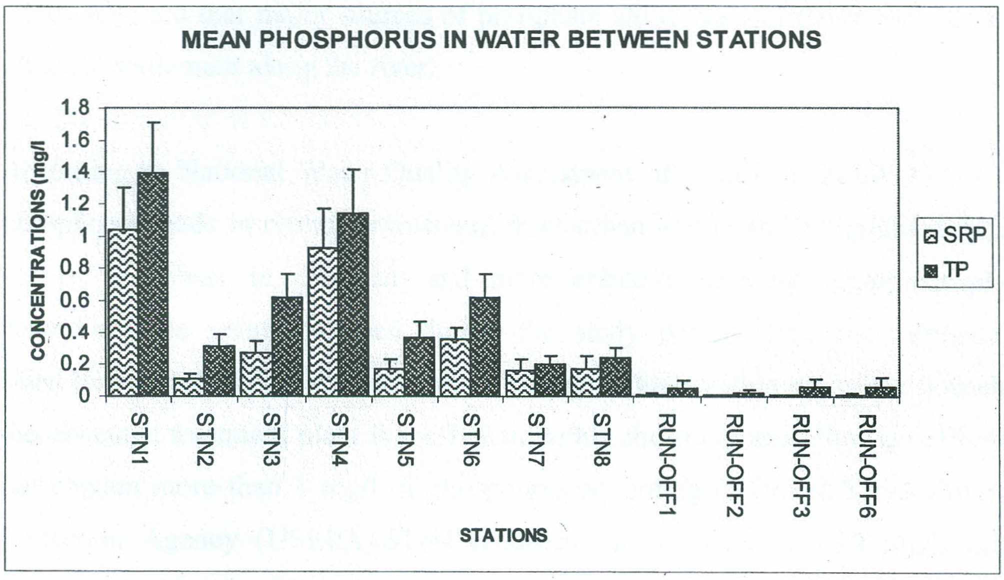


Figure 4.9 Spatial distribution of phosphorus in water within the river course.

From the nutrient loads as is discussed below (Subsection 4.4) and captured in fig 4.13, the highest loads occur during wet seasons meaning that other sources of pollution apart from point sources contributes to the pollution of River Kisat through runoffs probably from agricultural activities and slums along the river channel (Fig. 4.13).The increase in phosphorus levels down steam is due to cumulative effect from the source towards the discharge point, the major contributor being the Kisat sewerage treatment plant . This study compares well with a study conducted by Khorshed and Ghazali, (2004) which stated that phosphorus levels in River Al-Khair increased significantly downstream with a sharp rise where domestic sewage effluents are discharged. STN 7 and 8 which are the river source stations are low in phosphorus concentrations due to less pollution. They also show little difference between SRP and TP indicating that the lower stations are also polluted by other forms of phosphorus besides orthophosphates. This finding concurs with that of a report generated by UNEP, (2003) which stated that phosphate levels at the upstream of Nairobi River were very low. The condensed phosphates and the organic phosphates are also contributed a lot by the point sources of pollution. The Standard Error (SE) bars increases from the source downstream. This point to the main sources of pollution being downstream, as point sources gives greater deviation from the means due to season variations. A sharp rise in phosphorus levels at STN6 from the river source is believed by the investigator to be as a result of informal settlement contributing towards phosphorus pollution from domestic wastes. The result is supported by UNEP, (2003) which reported that major sources of phosphate along Nairobi River were as a result of informal settlement along the river.

According to National Water Quality Assessment of Nutrient (NAWQA), a declining phosphorus loads in rivers downstream from urban areas can be explained by restricted use of phosphate in detergent and more effective sewerage treatment plant. This contradicts the result obtained during the study period since the opposite is true. Therefore use of phosphate detergent is still quite high within the urban households and the sewerage treatment plant is inefficient within the study area .Sewage effluent should not contain more than 1 mg/l of phosphorus according to Unites States Environmental Protection Agency (USEPA).STN4 recorded mean levels of 1.39 mg/l, this further confirms the fact that the sewerage treatment is not effective since it has failed to meet this standards.The desired concentration range of Soluble Reactive Phosphate for fish life is between 0.005 to 0.2 mg/l (Boyd, 1998). This means that the Soluble Reactive Phosphate levels along the river are too high for fish life and would encourage high productivity of aquatic plants. Other set standards which vary from one body to another and from country to country are as attached in appendices III and IV.

The pattern is the same in the sediments and the above explanation applies (Fig. 4.9),

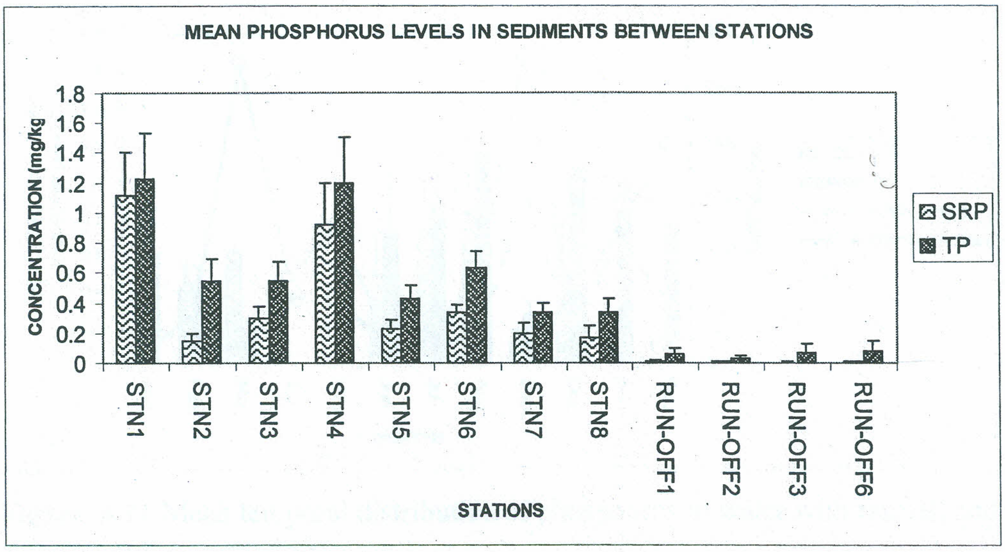


Figure 4.10 Spatial distribution of phosphorus in sediments along the river channel.

The study revealed same pattern of behavior of phosphorus levels in water samples between stations. This is believed by the investigator to be due to the fact that, the release and adsorption rates of phosphorus within sediments is at equilibrium. This is supported by Deng *et al,* (2005) report which indicated that the equilibrium concentration of phosphorus adsorption and release from the sediment of River Xiangxi was 0.1mg/l.

4.3.2.2 Temporal

During the study period the mean temporal Soluble Reactive Phosphorus (SRP) in water ranged between 0.12 (Sept.) to 0.82 mg/l (Aug.) while the Total Phosphorus (TP) ranged between 0.19 (Mar.) to 1.14 mg/l (Aug.) (Fig. 4.11). This implies that the concentration ranges are way above the recommended levels of fish life SRP as given above (subsection 4.3.2.1), except for the month of September which had very high discharge rates with mean Soluble reactive Phosphate of less than 0.2mg/l. Mean levels of Total Phosphorus remained high as compared to Soluble Reactive Phosphate throughout the year under study apart from the months of Feb, Mar and Apr.

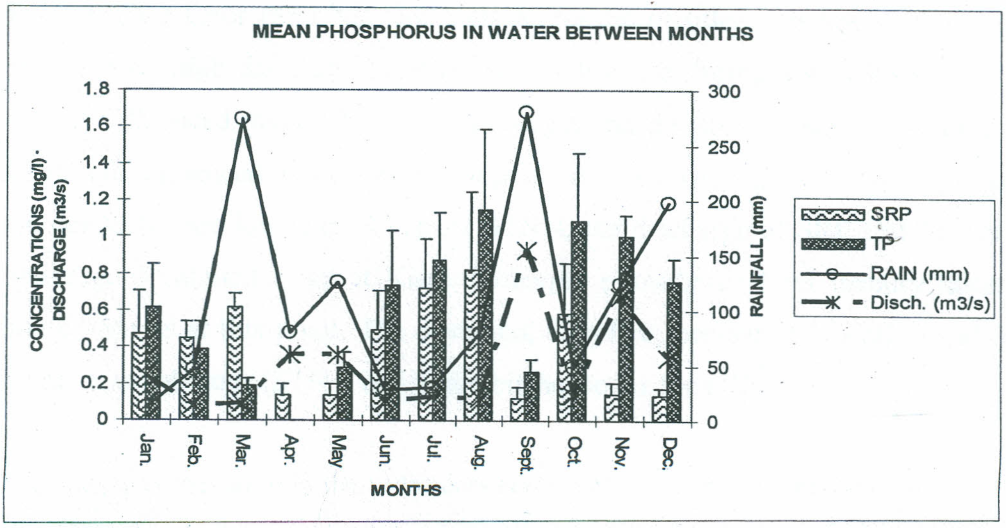


Figure 4.11 Mean temporal distribution of phosphorus in water with rainfall and discharges.

The mean levels of Soluble Reactive Phosphate ranges were way above the recommended levels of fish life SRP as given above (subsection 4.3.2.1) except for the month of September which had very high discharge rates with mean Soluble reactive Phosphate of less than 0.2mg/l. Dilutions therefore reduced the concentration levels during the month of September .Rainfall and the discharge rates influence the phosphorus concentrations in the same way. During the months of low rainfall implying low discharges, the soluble reactive phosphorus (SRP) and total phosphorus concentrations are high and during months of high discharges and high rainfall the concentrations are low. This is due to dilution factor. This does not imply that the loads are high during low discharge periods as shall be seen under the discharge loads below, fig 4.13.The results is supported by a report generated by UNEP, (2003) which indicated that phosphorus levels along Nairobi River were much higher in the dry weather than wet weather. The mean Total phosphorus was higher than the mean Soluble Reactive Phosphorus throughout the year under study apart from the months of Feb, Mar and Mar .According to Water Quality Monitoring Technical Hand Book, (1999), Total Phosphorus includes all forms of phosphorus (dissolved and particulate, organic and inorganic form) thus exhibits higher levels than other phosphorus species in water bodies. The reason why the months of Feb, Mar and Apr recorded higher levels of Soluble Reactive Phosphate than Total Phosphorus can't be explained by the investigator.

The Standard Error (SE) bars are high during the months with low discharge than the months with high discharge periods. This is because during low discharge periods the river is influenced mainly by point discharges and the concentration deviation from the means are influenced by the degrees of point influxes. During periods of high discharges, the deviations are low (Fig. 4.11). At STN 4, the discharge of SRP and TP are highest. Sewerage Treatment Plant at Kisat discharges phosphorus from laundry materials and human wastes at this point. The deviation, therefore, between this station and the River Kisat source stations (STN 7 and 8) are big hence the high SE.

The pattern is the same in the sediments and the above explanation applies (Fig. 4.12).

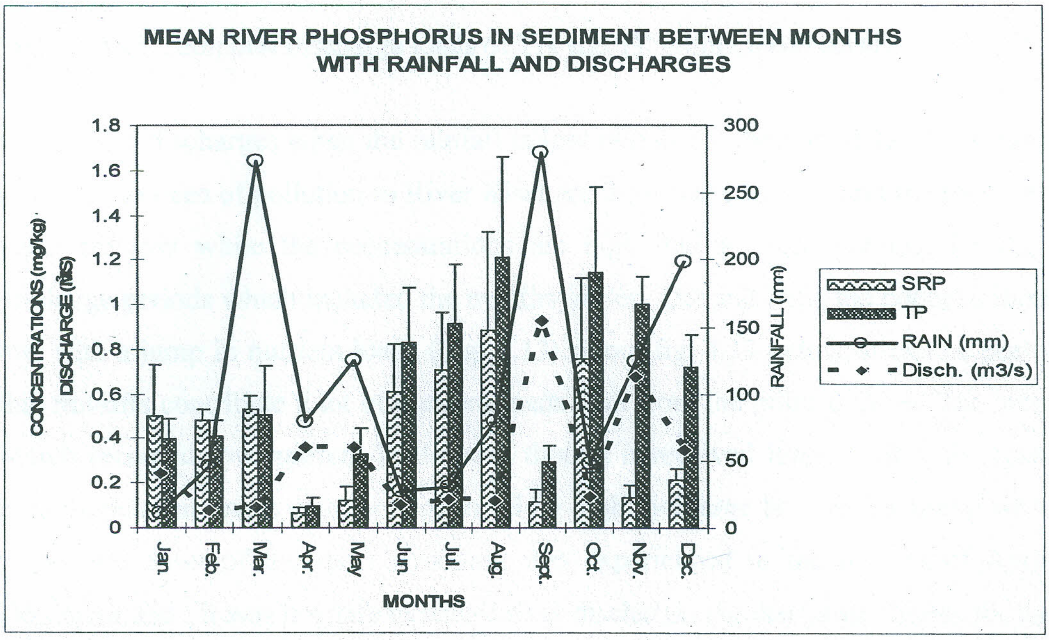


Figure 4.12 Mean temporal distribution of phosphorus in sediment with rainfall and discharges.

4.4 Nutrient loads

4.4.1 Total Nitrogen (TN)

The temporal load of TN ranged between 9.17 (Jun.) to 570.43 (Nov.) Tons/yr (Fig. 4.13). Fig.4.13 exhibited an increase in discharge of nitrogen loads towards the last months of the year, with a sharp rise from the month of August. The month of June had one of the lowest discharges of nutrient loads while the month of November had the highest. The months of April and December recorded no figures. The total discharge load in a year during the study period is estimated at **140.5 Tons N/yr.**

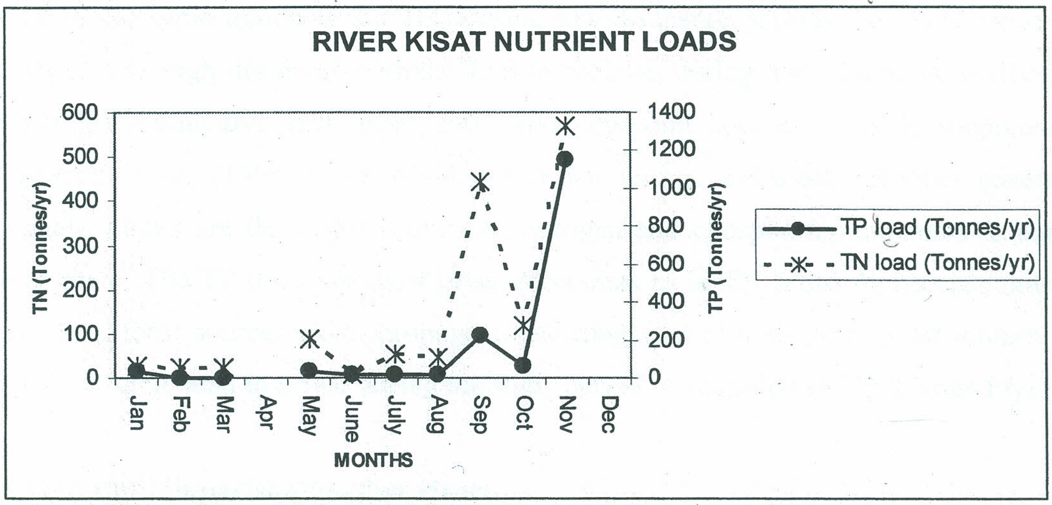


Figure 4.13 Temporal discharge loads of TN and TP within River Kisat.

During low discharges when the rainfall is low like in the months of Jan, Feb, Jun, July and Aug, sources of pollution to River Kisat are from point sources and the total nitrogen loads are low while the concentrations are high during these periods. During high discharge periods which included the months of Sep, Oct and Nov, the concentrations are low with a jump in nutrient loads (Fig. 4.13). From fig. 4.13 below, it can be postulated that run-offs contribute a lot of nutrient loads than from the point sources. The month of March recorded low nutrient loads even though it received high rainfall, the reason is because nutrient levels were not enhanced by high discharge because sampling was done before the onset of the rains .Flooding was experienced in the months of April and December and it was not safe to record river discharge, the discharge figures for the two months were therefore not available. The mean annual Total nitrogen loads of 140.5t/y is believed by the investigator to have been contributed by nonpoint and point sources of nitrogen pollutants which discharges sewage, other organic waste households and farms from the river catchment area. This is supported by Carpenter *et al,* (1998) report which stated that sewage and urban activities generating organic wastes are the major sources of nitrogen and phosphorus pollutants to aquatic ecosystem.

4.4.2 Total Phosphorus (TP)

The temporal load of TP ranged between 1.93 (Mar.) to 1152.36 (Nov.) Tons/yr (Fig. 4.13). The month of March had one of the lowest Total Phosphorus discharges while the month of November had the second highest discharges. The Total Phosphorus load follows the same trends as the TN. During low discharge periods the loads are low as compared to high discharge periods. This is because, during high discharge periods, the loads are cumulative both from point and non-point sources. This is supported by Carpenter *et al.,* (1998) report which stated that sewage and urban activities generating organic wastes are the major sources of nitrogen and phosphorus pollutants to aquatic ecosystem. The TP does not show great excursions as in TN probably because much of the phosphorus sources are anthropogenic meaning a lot of it are from point sources. The total discharge load in a year during the study period is estimated at **155.8 Tons P/yr.**

4.4.3 Data Comparison to other rivers

River Kisat, though a tiny river, has a significant impact to Lake Victoria's pollution than any other river from the Kenyan side of the lake (Table 1).With only 0.29 m^3/s, the river discharges TN loads more than R. North Awach with a discharge rate of 3.8 m^3/s (Kayombo & Jorgensen, 2006). At an equivalent discharge rate with R. Nzoia, R. Kisat would discharge a TN load of **57,372 Tons/yr** which is way above any of the rivers in Table 1.This makes River Kisat the major pollutant, especially to the Nyanza gulf.

The TP is equally significant to Lake Victoria's pollution than any other river on the Kenyan portion of the lake (Table 1). The TP in River Kisat exceeds many of the Kenyan rivers (e.g. R. Yala, North Awach, South Awach and Sio). This implies that River Kisat has a major source of phosphorus which is here believed to be the sewerage from the municipal waste. Kisumu being the third largest city in Kenya contributes a lot of phosphorus through the municipal waste. At an equivalent discharge rate with R. Nzoia, R. Kisat would discharge a TP load of **63,476 Tons/yr** which is way above any of the rivers in Table 1. River Kisat is herein believed to be a major source of pollution to the gulf and the entire Lake Victoria.

The study under review revealed that the loads of TP discharged into the lake through River Kisat is higher than that of TN by **15.3 Tons /yr** .If all the rivers within the catchment of Winam gulf were to follow the same pattern then the TP loads within Winam gulf would the higher than that of TN. The finding does not concur with that of Kayombo and Jorgensen, (2008) that revealed that input of nutrients from the rivers located in the catchment of Winam gulf is **49,505 Tons /yr** of TN and **5,693 Tons/yr** of

TP. It therefore means that most rivers discharge very lower loads of TP into the gulf as compared to TN apart from River Kisat.

Table 1. Comparison between discharge rates and the total nutrient discharge loads between rivers draining into the Kenyan portion of Lake Victoria (Source: R. Kisat (Field data); Other rivers (Kayombo & Jorgensen, 2006).

	R. Kisat	R. Nyando	R. Yala	R. Sondu	R. Nzoia	R. Gucha	R. North Awach	R. South Awach	R. Sio
DISCHARGE (m^3/s)	**0.29**	**14.7**	**27.4**	**40.3**	**118**	**62.7**	**3.8**	**6.0**	**12.1**
TN (T/yr)	**141**	**520**	**999**	**1,374**	**3,340**	**2,849**	**112**	**322**	**248**
TP (T/yr)	**156**	**175**	**102**	**318**	**946**	**283**	**15**	**39**	**47**

4.5 Statistical ANOVA analyses for water and sediment samples.

From the statistical findings in Table 2 and 3 below from the ANOVA test for $\alpha = 0.05$; the P values are all less than 0.05 except for NO_2^- within months. There are therefore significant differences in all the data between stations and months except for NO_2^- within months. This is a clear indication that the pollution of River Kisat is mainly influenced by anthropogenic effluent influx from the municipal waste water, riparian slums and industries along the basin which are not consistent temporally and are spatially different. The no significant difference for NO_2^- within months is believed by the investigator to be as a result of its intermediary oxidation nature. Its presence in the waters of River Kisat is believed by the investigator to originate either from the oxidation of ammonium or the reduction of the nitrates through the bacterial action and minimally from anthropogenic influx. This result in very low concentrations which when coupled with dilutions would yield minimal difference within samples. The main pollution source for River Kisat is therefore believed to be mainly through point sources.

Table 2. Statistical ANOVA for Water (α = 0.05)

	NH_4^+			NO_2^-			NO_3^-			TN			SRP			TP		
	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P
Stations	7.58	2.13	6.23E-07	5.23	2.13	6.51E-05	5.91	2.13	1.63E-05	4.24	2.13	0	8.68	2.13	8.09E-08	9.92	2.13	9.2E-09
Months	5.00	1.92	7.91E-06	1.42	1.92	0.18	60.31	1.92	3.12E-33	31.32	1.92	5.48E-24	2.81	1.92	0	5.01	1.92	7.66E-06

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Table 3. Statistical ANOVA for Sediment (α = 0.05)

	NH_4^+			NO_2^-			NO_3^-			TN			SRP			TP		
	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P	F	F Crit.	P
Stations	5.76	2.13	2.2E-05	3.57	2.13	0	7.99	2.13	2.86E-07	4.95	2.13	0	7.63	2.13	5.6E-07	5.10	2.13	8.49E-05
Months	5.54	1.92	1.87E-06	2.35	1.92	0.01	40.59	1.92	1.58E-27	27.62	1.92	2.47E-22	2.97	1.92	0	3.56	1.92	0

CHAPTER FIVE

5.0 CONCLUSIONS

Pollution of River Kisat emanates from point and non-point sources of industries, municipal wastes from Kisumu, farming activities and slums within the basin. The major pollution sources, both point and non-point, lies between STN's 1 – 6. STN 7 and 8 are near the river source devoid of major developments and are therefore less polluted. The study revealed that STN 3 and 4 are the major point sources of the most reduced form of nitrogen (e.g. NH_4^+). At STN 3, this is due to a wetland upstream while in STN 4 it emanates from human wastes through the Sewerage Treatment Plant (STP). The STP is therefore ineffective since effective STP ought to have oxidized NH_4^+ to the more oxidized form NO_3^-. STN 1 concentrations are as a result of the cascading effect from STN 4 with adjustments from run-offs during rainy season. At STN 5 where local traders process their fish also showed high levels of point pollution due to fish wastes (e.g. fish guts) that increases NH_4^+ levels. At STN 2, this is a discharge from the cereal industry before emptying into River Kisat, has minimal pollution compared to STN's 1, 2, 3, 4 and 5. STN 6 is a non-point pollution point from the slums which is believed by the investigator to be low in nutrient concentrations but high in nutrient loads during wet season when the domestic and human wastes are flushed through run-offs into the river. The discharge loads of TN shoots during wet seasons and this is believed by the investigator to result from organic matter that originates from the non-point sources of slums and the entire river basin. The concentration levels of nitrogen components for fisheries falls within the recommendable ranges. The nitrogen components also fall within recommendable levels for domestic use except for NH_4^+ which is attributed to high human wastes into the river system. The concentration levels of nitrogen components increases with decreased discharges except for NO_3^- and most likely NO_2^-. The NO_3^- concentrations are therefore mainly from non-point sources and discharged into the river system during wet season. The NH_4^+ is mainly from point source and hence high during dry season.

Phosphorus replicates the same results as in Nitrogen. The major pollution sources are between STN 1 – 6 as compared to STN 7 and 8 which are near the river source devoid of developments. STN 4 is the major point source of phosphorus pollution from laundry detergents through municipal wastes. In STN 1, the concentration is high due to cumulative effect from STN 4 and run-offs in between. The discharge loads of TP increases during wet seasons and this is believed by the investigator to result from non-point sources of slums and the entire river basin. The phosphorus levels are very high compared to water quality standard for fisheries. This is likely to be due to the use of laundry detergents within the municipality. According to the EU standards for drinking water, the river quality in terms of nutrient levels falls within recommendable levels for drinking.

River Kisat is one of the most polluted river sources into Lake Victoria discharging the greatest loads of TN and TP per year considering the river discharge rates. The loads greatly increase during wet seasons due to discharges through non-point sources through run-offs.

The pH of the river falls within acceptable ranges both for drinking and aquatic life in comparison to many standard guides. The DO concentrations are low compared to standard guidelines for drinking and aquatic life and this could be attributed to increased organic pollutant within the river channel.

5.2 Recommendation

1) Spreading $AlSO_4$ within the STP can be used to precipitate phosphorus in order to seal the bottom against phosphorus release. Alum form gelatinous flocks that sorb dissolved phosphorus. Flocks accumulate on the bottom and sorb phosphorus that leaches out of sediments. Experience has shown that chemical coagulation of phosphorus is highly effective in lakes and reservoirs for at least several years (usually 4 – 5, sometimes up to 14 years) (Cooke et al. 1993, 1993a).
2) STP can be aerated and oxidized. The goal of this method is to decrease phosphorus release from the sediments. Ferric Chloride is applied to the sediment that is low in iron to decrease phosphorus release. Simultaneously lime is added to create a pH level that is optimum for denitrification ($7.0 < pH < 7.5$). Consequently, calcium nitrate is injected into the top 30 cm of sediments to oxidize and break down organic matter and denitrify the sediments. This method is called the RIPLOX method, (Ripl, 1994).

3) Along the river channel, a constructed wetland needs to be created. The constructed wetland is able to filter the pollutants and trap the elements and denitrify the reduced forms of Nitrogen into Nitrogen gas.
4) The dilapidated Kisumu STP needs rehabilitation in order to be able to accommodate present population and the population in a few decadal years to come.
5) The results showed that the sewerage treatment plant, wastes from fish processing and domestic discharge from non-point sources results into varying pollution levels in the river. There is need for the municipal council of Kisumu to control and manage pollution from such point and non-point sources through provision of proper sanitation.
6) Because of the pollution emanating from the industries, the government should introduce a policy of Polluter Pays Principle (PPP). The revenue collected could be injected back into cleaning the river and the policy may control impunity.
7) The riparian community needs to be sensitized on the environmental awareness and the need to conserve the river. Regular monitoring of the water quality needs to be undertaken to identify changes within the river channel.

5.3 Areas for further Research.

This study only undertook measurement of nutrient concentration levels, sources and loads discharged into Lake Victoria. The effects of organic pollutants are many and not limited to DO and pH only. Organic pollutants affect also the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) of the water. These parameters were not looked at in this study and any future study should encompass these parameters. When looking at the loads, this study only looked at the Dissolved loads of nitrogen and phosphorus into the lake, traction loads of nutrients are difficult to analyze but should be estimated for River Kisat in order to get the overall impact of the river. The Heavy metal loads should also be checked.

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