CORRELATION BETWEEN LAND USE AND STREAM WATER QUALITY: A CASE STUDY OF KINAWATAKA STREAM CATCHMENT IN UGANDA

BY

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DECLARATION

I, **Ndugga Peter**, declare that this research report is my own work and I am submitting it for the Degree of Master of Science in Conservation and Natural Resource Management at Kyambogo University. This study has never been submitted before for examination for any degree at any other University.

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APPROVAL

This thesis is being submitted for examination with our approval as university appointed supervisors.

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DEDICATION

To my lovely parents, Mrs. and Mrs. Walugere.

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Firstly, l would like to thank God for giving me the strength to carry out this project. I would also like to extend my sincere gratitude to my family especially my parents and sister Ann for giving me both moral and financial assistance, as well as your patience and support. I am greatly indebted to my supervisors Dr. Santa Maria and Dr. Rosemary Nalwanga for their valuable guidance, encouragement and unwavering support during the course of this project.

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LIST OF ACRONYMS

APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
CL	Chloride
COD	Chemical Oxygen Demand
CV	Coefficient of Variation
DEM	Digital Elevation Model
DO	Dissolved Oxygen
E. coli	*Escherichia coli*
EC	Electro Conductivity
ERDAS	Earth Resource Data Analysis System
F. coliforms	Faecal Coliforms
GIS	Geographical Information System
GPS	Geographic Positioning System
HCL	Hydrochloric Acid
LULC	Land Use Land Cover
NEMA	National Environmental Management Authority
RS	Remote Sensing
SROS	Scientific Research Organisation of Samoa
T. coliforms	Total Coliforms
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UBOS	Uganda Bureau of Statistics
UV	Ultra Violet
WHO	World Health Organisation
WQI	Water Quality Index

ABSTRACT

Kinawataka wetland is an important ecosystem that plays a vital role in pollution and flood control as well as maintaining ground water supplies and quality in the Lake Victoria Basin. However, this wetland has undergone severe ecological degradation in the form of intensified industrial pollution, agriculture and climatic change. The main objective of this study was to determine the effect that land use activities in the Kinawataka stream catchment had on the stream water quality. The land use activities/cover in the stream catchment were determined by analysing 2018 Landsat images using supervised classification. To evaluate the stream water quality, *pH, EC, TDS, TSS,* Cl^-, SO_4^{2-}, *BOD, COD,* NO_2^-, NO_3^-, NH_3, *TN, TP, Total coliforms and faecal coliforms* were analysed using standard methods. The effect of land use activity on the stream water quality analysed by using *Spearman's Correlation* and *Principal Component Regression.*

The study revealed that the various land use (cover) activities were categorized into five (5) major land use characteristics which in order of coverage included; *Built-up Area (40.51%) as* the largest, *Grassland (18.89%), Plantations (Agric.) (18.76%), Bare Soil (15.61%),* and finally *Tree Cover (6.22%)* with the least area. The mean overall concentration of most the water quality parameters remained within their permissible NEMA effluent ranges except for *TSS (478.03±1271 mg/L), EC (418.70± 68.22 µS/cm) and faecal coliforms (306.6±214.76 cfu/ 100ml)* that exceeded the set guidelines. *Bare Soil* had a negative influence on the water quality as it increased with both the *TSS (rho = 0.357)* and *faecal coliforms (rho = 0.355)* at $p<0.05$. *Built-up Area* had a negative influence on the water quality as it increased with SO_4^{2-} *(rho = 0.506),* NH_3 *(rho = 0.410)* and *faecal coliforms (rh0 = 0.441)* at $p<0.05$. *Grassland* had a negative influence on the water quality as it increased with NH_3 *(rho = 0.370)* and NO_3^- *(rho = 0.389)* at $p<0.05$. *Plantations (Agric.)* had a negative influence on the water quality as it increased with NO_3^- *(rho = 0.370)* at $p<0.05$. *Tree Cover* had a positive increase influence on the water quality as it decreased with the increase in *pH (rho = -0.524), EC (rho = -0.572), BOD (rho = -0.386)* and Cl^- *(rho = -0.376)* at $p<0.05$. The principal component regression revealed that an increase in land cover with a combination of *Grassland, Plantations* and *Built-up area (PC1)* resulted in increased *pH, EC, COD* and NH_3 concentration in the stream. Areas with a *thin tree cover and large areas of exposed ground (PC2)* resulted in increased *TDS,* Cl^-, NH_3 and NO_2^- levels of the stream. Those areas covered by *bare soil, marram roads, garbage dump stations (PC3)* resulted in increased *TDS* concentrations of the stream. Therefore, it could

be concluded that with the exception of tree *cover*, the rest of the land use activities in the stream catchment deteriorated the stream’s water quality.

CHAPTER 1: INTRODUCTION

1.1 Background of study

Water quality ‘‘reflects the composition of water as affected by natural processes and by humans’ cultural activities, expressed in terms of measurable quantities and related to intended water use’’(Bahar et al., 2008a). According to Fourie (2005), humans rely on renewable freshwater for drinking, irrigation of crops, industrial use, production of fish and waterfowl, transportation, recreation and waste disposal yet it only amounts to 0.26% of the total global water quantity available for utilisation. Studies show that natural and human activities play a significant role in influencing the land use and land cover (LULC) changes of catchment areas (Matshakeni, 2016). Therefore, the land uses within watersheds have a great impact on the water quality of both streams and rivers (Huang et al., 2013a; Mwangi, 2014) because watersheds acts as a sink for accumulating materials, that severely degrade the environment (Fourie, 2005). Degradation of water quality can result from multiple land use activities that maybe either point or nonpoint sources pollution in nature. While point source pollution can easily be identified, e.g., wastewater from wastewater discharge outlet, nonpoint source pollution on the other hand is defined as a diffuse source of contamination from a wide area, and it is often difficult to attribute this contamination to a single location or source. Examples of nonpoint sources of pollution include urban land use, agricultural practices, and transportation infra- structures (Huang et al., 2013; Matshakeni, 2016; Seeboonruang, 2012; Xia et al., 2012).

Wetland resources have been identified as hot spot areas for increasing frequent conflicts over land use-land cover changes attributed to population growth (Seeboonruang, 2012). This can be dated back from 20th century where land-use change was a main cause for wetland loss and associated ecosystem services (Zorrilla *et al.*, 2014; Kassaye, 2014). It is approximated that 50% of the world’s population resides in cities. This percentage is predicted to rise to 60% by 2030 (Mackintosh & Davis, 2013).

In Uganda, the population has since increased from 4.8 million in 1948 to 30 million in 2008 and will likely reach 130 million by 2050 at a growth rate of 3.2% (Aryamanya, 2011); and with Kampala’s annual population growth rate at 5.61% (Byaruhanga & Ssozi, 2012), it is anticipated that the population needs will exert a lot of pressure on the existing wetland resources (Sica, *et al*., 2016; Shodimu, 2016; Busulwa *et al*., 2006). Studies have shown that population growth and related land use changes impede wetlands' ability to perform as a watershed "kidney" that removes nutrient loads from running waters within a catchment (Haidary *et al.*, 2013), hence affecting the water quality.

Kinawataka is an urban wetland located in Nakawa Municipality under the jurisdiction of Kampala Capital City Authority and covers an area of approximately 1.5 km^2. Its geographical co-ordinates are 32° 37' E and 0° 20' N. Its swamp and tributaries drain parts of Naguru Hill, Ntinda, Kyambogo, Banda, Mbuya, Mutungo and Butabika before it flows into Lake Victoria. The catchment area has also been noted for its approximated average population density of 3, 974 persons per km^2 that is responsible for degradation of the wetland (Busulwa et al., 2006; Lwasi, 2018; Nyakaana et al., 2014) in addition to its very dynamic changes in land use and land management practices; which according to Bahar et al. (2008) are some of the main factors that can alter the hydrological system as well as the quality of receiving water.

Prior studies attribute the deterioration in water quality of Kinawataka stream to several point sources of pollution like; 1) industrial activities like manufacture of plastics, polyvinylchloride (PVC) conduits, foam mattresses, pharmaceuticals, paints and soft- drinks, engineering works, garages and metal workshops; 2) effluents from the sewage stabilisation ponds in the Nakawa-Ntinda area that overflow into the stream then into Lake Victoria eventually (Banadda et al., 2009; LVEMP, 2005; Muwanga & Barifaijo, 2006; Nyakaana et al., 2014; Wanasolo et al., 2018). These point sources of pollution have in the past been associated with high nutrients loadings for nutrients like *Total Nitrogen*, *Total Phosphorus*, *BOD* and *COD* (Banadda et al., 2009; Busulwa et al., 2006; Wanasolo et al., 2018). It has been demonstrated by prior studies of stream and river health that water quality continues to be degraded by nonpoint pollutant sources (Mwangi, 2014; Nyakaana et al., 2014; Tumuheire, 2017b) despite national water quality standards and a very effective control agency put in place by the Uganda National Environmental Management Authority (NEMA).

Therefore, this study further explored the impacts of nonpoint sources of pollution from the surrounding land uses on the concentrations of selected water quality parameters within the wetland at sub basin level using advanced spatial tools such as Geographical Information Systems (GIS) to access land cover characteristics and extract topographical information for watershed scale analyses (Kang et al., 2010). Thus, regression analysis in combination with

GIS would reveal the relationships between land-use characteristics and various water quality parameters according to Kang et al. (2010). This would elucidate not only on the relationship between land use changes (i.e. and associated human activities) and the water quality, but also the entire wetland's efficiency in purifying the municipal waste water before it is discharged into the Murchison bay.

1.2 Problem Statement

Kinawataka wetland plays a vital role in the treatment of both municipal and peri-urban waste water. However, the wetland area has over the years declined from 9.4sq Km in the 1980s to 4.16 sq. Km in 2000 and significantly continues to deteriorate to date. This consequently impairs the wetland's regulatory function of water purification thereby rendering the stream water unfit for domestic use as well as incurring the government extra costs in water treatment. Like in any other stream, the waste water that finds its way into Kinawataka stream carries with it pollution that is both *point source* and *non-point source* in origin. A majority of the studies done on Kinawataka wetland have concentrated more on assessing the *point sources* of pollution (Banadda et al., 2009; Busulwa et al., 2006; Nabulo et al., 2006; Wanasolo et al., 2018) and scarce information is known about the other *non-point sources* of pollution. The particular origin of these *non-point* sources of pollution is very difficult to pin point and is often related to the various unregulated land use cover activities taking place within a catchment (LVEMP, 2005; Mwangi, 2014). Therefore, an understanding of how the land use and cover activities (forms) within the stream catchment affect water quality would give insights into better wetland management practices for monitoring *non-point source* pollution.

1.3 Aim of the study

The aim of this study was to investigate how the various land use-land cover activities in Kinawataka stream catchment affect the stream water, as a way of establishing the extent to which the wetland's ecosystem service of water purification has been impaired.

1.4 Objectives of the study

1.4.1 General objective

To determine the relationship between land use activities found in the Kinawataka stream catchment and the stream's water quality.

1.4.2 Specific objectives

1. To determine the variation in concentration of selected physicochemical parameters along Kinawataka stream.
2. To determine the variation in concentration of selected microbiological parameters along Kinawataka stream.
3. To determine the major land use land use/cover and how they relate to the concentrations of the water quality parameters of the stream.

1.5 Research Questions

1. What are the levels in physicochemical parameters of Kinawataka stream?
2. What are the levels in microbiological parameters of Kinawataka stream?
3. What are the major land use land use/cover forms and how do they relate to the quality of water of Kinawataka stream?

1.6 Significance

One intended outcome of this study is to paint a picture on the effectiveness of several policies and initiatives that had been enacted by government organs and authorities to mitigate any anthropogenic activities that maybe threatening Kinawataka. This study employed the use of a catchment approach where by the distribution of land use patterns within the stream catchment was explored using remote sensing and GIS.

1.7 Scope of the study

Land cover analysis and water sampling were limited to five (5) sub basins through which the stream crossed within the stream catchment of Kinawataka wetland.

This study limited the water quality analysis to the physicochemical, nutrient and microbiological water quality where sampling was done along five (5) stations from the areas of Ntinda-Buye (source) downstream to Butabika-Mayanja swamp (mouth) over a three-month period, March to May 2018.

CHAPTER 2: LITERATURE REVIEW

2.1 State of the water quality in the Kinawataka urban wetland catchment

UNEC (1995) defined water quality as the physical, chemical and biological characteristics of water that can be accepted for different purposes, it must not exceed permissible levels and standards set out by national governments and international organizations such as the WHO. Examples of such standards include faecal coliform and Total coliform must not be detected in a 100mL of water sample (i.e. number of colony counts/100mL for both drinking and aesthetic standards; less than 1/100mL for WHO drinking water standards; and less than 260/100mL for aesthetic standards). Water quality standards and guidelines are set for the sole purpose of protecting water quality for human use, contact recreation uses and the ecological health of freshwater ecosystems. Therefore, water quality can be defined as water that is suitable (given acceptable conditions) for a given use, such as, human drinking, stock water and recreational uses.

Poor water quality is one of the main problems facing the Kinawataka urban catchment, and the water has been reported to cause premature rotting of food crops grown within the area as well skin disorders (Kasozi & Tajuba, 2014). Water pollution problems associated with poor hygiene (Lwasi, 2018) and the illegal dumping of solid waste discharges from both municipal and cattle effluents, farm wastes and agricultural chemicals from farmlands, have been identified as the major problems among others. Furthermore, an increase in anthropogenic activities, such as agriculture, endangers the natural landscape and the biophysical environment of the catchment, thus causing sedimentation that escalates water quality impairment. For instance, given the steep slopes of the upper catchment topographical characteristics, in the course of heavy rains the landscape is susceptible to serious soil erosion and floods, because of vegetation clearing (Gumm, 2011). This consequently causes water pollution and deterioration of water quality through sedimentation.

2.1.1 Point source pollution

Point source pollution is referred to as pollution from a known point of discharge, or discharges of contaminants that originate from a fixed outlet and can be released into water bodies in pipes or drainage (Gyawali *et al.,* 2013). For instance, a mole pipe of known location, which drains waste discharge from the industrial area, may be responsible for increasing the nutrient levels in the wetland stream system hence eutrophication problems. While possible contaminants from a point source can be easily monitored by measuring discharge and pollutant levels

(Zhang & Wang, 2012) from an identified discharge point, its impact can be manageable, compared to non-point sources of discharge.

In the past, studies have assessed Kinawataka's water quality using a point source pollution approach that mainly involved quantifying heavy metals and physicochemical parameters water quality (Muwanga & Barifaijo, 2006; Busulwa *et al.,* 2006 and Nabulo, *et al.,* 2008) to convey the impact of point sources of pollution such as the industries within the wetland the wetland catchment. Implying that a lot more attention has been be put on regulating the effluent standards from these industries leaving out pollution from the other land use types. Thereby, neglecting the combined effect that the various mushrooming land use patterns have on the water quality. Kinawataka stream catchment's major point sources of pollution mainly comprise of surrounding industries, factories and slummy areas, which include Pepsi cola plant, Oxygas plant, Kireka-Mbuya road and Butabika hills draining surface runoffs with possible waste water contamination from around the city (i.e. covering household, industrial and agricultural discharge) (Nabulo *et al.*, 2006). Examples of possible main water pollutants from these point sources include detergents and faecal contamination, which originates from household, animal manure and agrochemicals.

2.1.2 Non-point source pollution

The problems associated with water quality contamination and pollution from a non-point source is that its origin cannot be guaranteed from a single source, but rather a combination of sources of different natures, which are often difficult to identify at a fixed locale (Agarwal S. K., 2005). These generally originate from urban and peri-urban runoffs, because of urban storm runoffs from agricultural and anthropogenic activities, which are often described as non-point discharges.

Nevertheless, the management of non-point sources of pollution has become a challenge, since it originates from different unknown sources of anthropogenic activities. The same problem was experienced in the United States (Bahar *et al.*, 2008), where non-point source pollution is an important environmental and water quality management problem. The limitedness of research-based information to identify possible sources and to understand the nature of land use impact and its relationship with stream water quality has lessened understanding on the control and management options to prevent nonpoint pollution within Kinawataka catchment.

Kibena *et al,*. (2014), emphasizes that the quality of receiving waters in any catchment is usually affected by the surrounding human activities in the vicinity as both point source pollution, such as wastewater treatment facilities and non-point source pollution, such as runoff from urban areas, mining and farmlands in order to give a complete picture of the effect land uses such that planning authorities can sustainably manage the use of urban wetland areas.

Therefore, the conservation of Kinawataka's natural resources requires key planning and regulatory authorities such as KCCA and NEMA to ensure the sustainable utilization and development of these resources for future generations as well as to limit/control the pollution from non-point sources.

2.2 Land Use Land Cover Activities

By definition, land use refers to how land is being used for any form of development (e.g. agriculture, industries, or for the purpose of building residential areas). Techato *et al*.,(2013) emphasizes that land use changes result from complex interactions such as policy, management, economics, culture, human behaviour, and environment. Which are exactly the major driving forces of land use change in Kinawataka wetland (Gumm, 2011).

Kinawataka is vulnerable due to pressure from the need of economic development (Kasozi & Tajuba, 2014) and subsistence farming of the local people, has raised concerns about the current pollution problems facing the wetland. Like other urban catchments, Kinawataka has identified multiple issues facing water quality, as a result of human and natural hazards.

The increasing land use activities such as agriculture, through mixed cropping and livestock/cattle farming and establishment of new residential areas within the borders of the wetland (Otage, 2012), threatens the wetland's ability to filter municipal waste water flowing through it. These developments are currently encroaching on the wetland's critical buffer zones that are important for safeguarding Lake Victoria from municipal wastes and contamination (Busulwa *et al.,* 2006). The effects of land-based developments in the wetland, by local residents and existing government infrastructures, have both exacerbated the pressures on the wetland: the catchment has often been reported as suffering severe degradation of critical catchment zones, which has led to the impairment of the water quality (Aryamanya, 2011).

The relative increase in the local population, together with commercial ventures utilizing the water supply from the wetland, has consequently decreased the water level which will negatively impact on aquatic plants and animals within the aquatic ecosystem. The adverse impact will increase with unsustainable land use practices that are detrimental to the environment.

2.3 Land use relationship with water quality

Land use and water resources are clearly linked (Gyawali *et al.,* 2013). This inter-relatedness could explain their potential relationship, the effects of land use developments affect the water quality of freshwater resources of rivers, lakes and streams. The realization of the risk involved and the detrimental effects of increasing concentrations of water pollutants, from both known and diffuse sources, marked an early attempt in the 1970s by the European Union to call for action to improve the quality of water resources. According to studies carried out in the United States in order to establish the relationship between non-point sources, land use and stream nutrients level of watersheds showed that streams draining from agricultural watersheds obtained higher nutrient concentrations than streams draining from forested watersheds. Some of these studies have found that the type and intensity of land use have a strong influence on the receiving water quality (Seeboonruang, 2012; Yong & Chen, 2002). Different land use types require a different intensity of land development, which could then determine how much it affects and influences the quality of water sources. Previous studies have positively concluded on the impact of agriculture, with high deforestation causing soil erosion and contamination to receiving water bodies (Bahar *et al*., 2008; Yong & Chen, 2002). Another study by Ngoye and Machiwa (2003) found that concentrations of nutrients (NO_3-N, NH_4-N, TP) were higher in urban and agricultural areas, as a result of higher inputs of waste into the river system.

Since its early development in 1970s, researchers are continuing to study land use on water quality in different geographical regions around the world. Osborne and Wiley (1988), in their study in the United States, have found that urbanization is a major factor controlling soluble reactive phosphorus, compared to agriculture. In regards to urbanization, the experience of (Li. *et al*, 2012), in their study of the Lia River basin in China, recorded high concentrations of TN, NH_4-N, NO_2-N and TP in urban land, which resulted in high nutrients discharge into the river, thus causing eutrophication problems.

These various experiences show how the effects of land use practices on water quality can be sometimes misleading, without conducting more research on station-specific locations in different countries and regions around the world. The results and outcomes of a study from a specific country are not necessarily applicable to other countries with their local watershed settings and catchment characteristics varied climatic conditions. Therefore, the varied results of previous studies may depend on local topographical characteristics of watershed and catchment areas, soil conditions, types of land use development, and local climatic factors, which could differentiate the experiences of one country and region from others. Thus, in order to have a clear understanding of such land use impact on water quality, several approaches have to be tested for better management options which hope to eventually assist restoring water quality in affected areas. Nonetheless, it can be concluded that changes in land use and land management practices are primarily responsible for the alteration of receiving water quality (Techato *et al.*, 2013).

2.4 Approaches to assessing land use and water quality relationship

The management of land-based pollution involves consideration of the two main sources of pollution: point and non-point sources. The nature underlying these two causes can be very complex with regards to their respective causes. Therefore, in order to address such complexities and their nature of pollution, it requires several approaches, rather than having a 'one size fits all' approach. This has been signalled by (Techato et al., 2013), who stated that the effects of land use on water quality are complicated, since such assessment involves complex biotic and abiotic interactions, especially in large drainage areas. This section provides a review of several approaches and methods that have been the land use composition of water catchment arears and other associated factors. The review would also assist with the identification of an appropriate and methodology for this study. Such an approach includes the use of a catchment scale, compared to only a part of the catchment/watershed; statistical analysis and modelling; and the wide use of technologies such as a geographical information system (GIS) and remote sensing (RS), as being well-advanced and useful management tools for water resources and land use management within catchment areas that engaged by previous and recent studies, to help understand the underlying factors affecting water quality, by considering

Catchment versus sub-catchment approach

Sliva & Williams, (2001) studied land use relationship with the river water quality of an Ontario watershed in Canada using two different scales of approach, where one is a 100m buffer zone and the other is a whole catchment approach. The results were compared between the two approaches over three seasons in which catchment landscape characteristics appeared to have a slightly greater influence on water quality than the buffer zone. This can be explained as follows: a large drainage area would have more space for draining more pollutants into water sources, compared to the lesser scale of a 100m buffer zone. However, a recent study in Zimbabwe by Kibena *et al.*, (2014), which focused on the upper catchment/upland area of the

Manyame River, found that both rural and urbanized parts of the catchment area. Their results indicate that an increase in settlements and agriculture activities had positive impacts on water quality, compared to forested lands. Following these results, a recommendation to consider a combined effort for point and non-point sources has been drawn up, as an outcome of their study. However, a holistic approach is needed for whole catchment areas, where low land areas, where low land areas could be considered to generate some interesting results, based on how much the lower reaches of the catchment could have impacted on the catchment river quality. This approach would see consideration of a ridge to reef approach that could help to identify problems facing all segments of the catchment, rather than just relying on the impacts on upper catchment areas.

CHAPTER 3: METHODS AND MATERIALS

3.1 Study Area

3.1.1 Delineation of Stream Catchment

A Digital Elevation Model satellite (DEM) image of the Kinawataka was downloaded from the United States Geological Survey website showing Kinawataka's elevation and flow direction. Once downloaded, the Kinawataka's DEM image was then used alongside the coordinates of the five (5) sampling points, to delineate a representative model of Kinawataka's basin and sub-catchments draining into each corresponding sampling stations. The sub catchment delineation process was run in ArcMap 10.3 software through the following step: first, the depressions of the DEM data were filled with the Fill tool in the hydrological module (Hydrology); second, the flow direction and accumulation were computed; third, different thresholds were set to extract the stream network, and determined a reasonable threshold of 1700 through comparison between the result and stream system map, which could generate the nearest approach to the actual stream system; fourth, Point Delineation, Batch Watershed Delineation and Batch Sub Watershed Delineation tools were used in the hydrological analysis expanding module (Arc Hydro Tools) to divide watershed into sub basins. (i.e. *DEM manipulation>Reconditioning the DEM>Flow direction> Flow accumulation*. Spatial analyst tools were used for this analysis. The sub-basins were named according to the areas that they drained and thus included; Ntinda-Kyambogo, upstream; Nakawa-Kireka, Mbuya and Mutungo, Mid-stream; and Butabika, downstream as shown below.

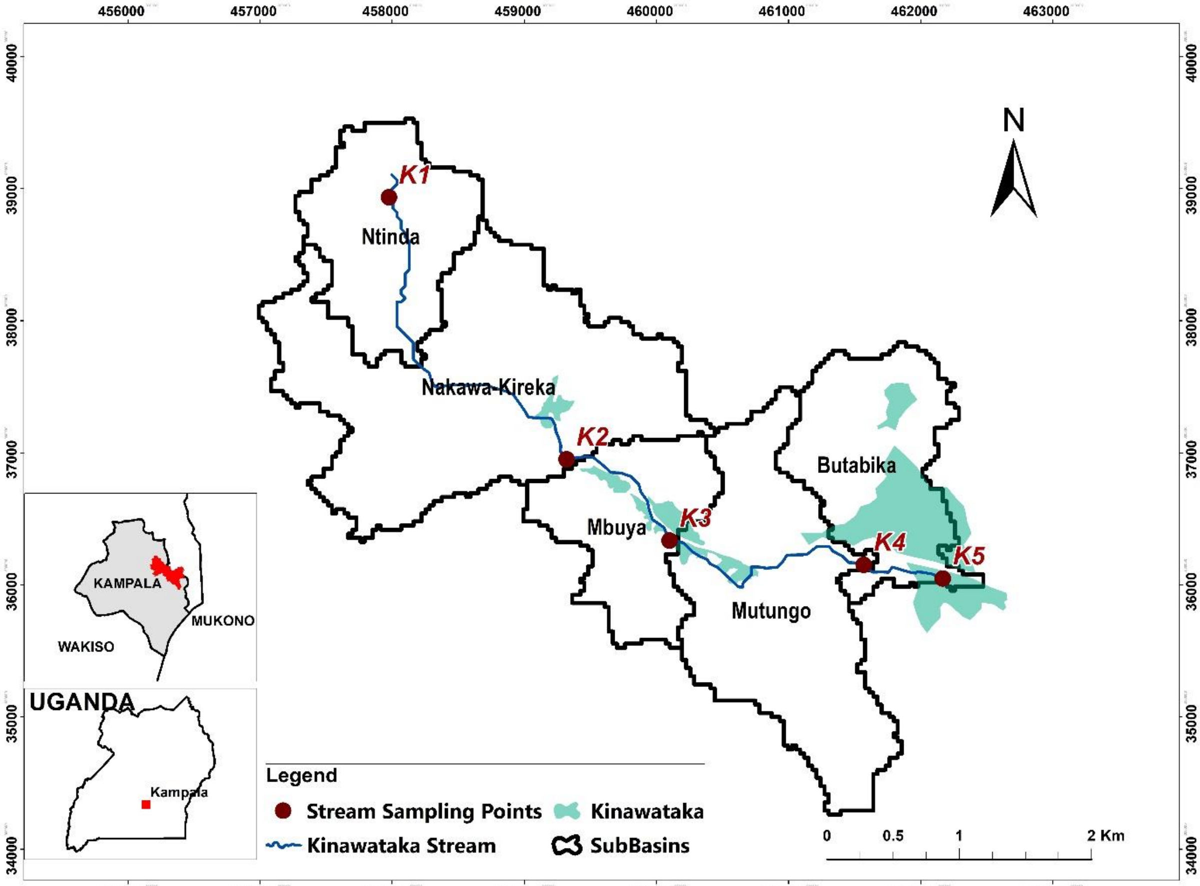

Figure 3.1: A Map Showing the Kinawataka Stream Catchment and the five(5) sampling points (K1, K2, K3, K4 and K5)

3.1.2 Kinawataka Wetland

Kinawataka wetland, also referred to as Kinawataka-Kawoya is an urban industrial and densely populated catchment (Busulwa et al., 2006), with an area coverage of 1.5 km^2 and is located in Nakawa sub-county, 6.5 km east of the city centre. Latitude: 0° 20' 0.4" (0.3334°) north; Longitude: 32° 37' 49.5" (32.6304°) east; Elevation: 1,159 meters. Kinawataka is part of a tributary system in which its waters flow south towards Lake Victoria from Kireka-Mbuya road and Butabika hills up to where it loops and joins Murchison Bay in the Kirombe-Port Bell area (Muwanga and Barifaijo, 2006). The wetland vegetation is dominated by *Papyrus sp* with patches of *Phragmites sp*., *Echnocloa sp*, and *Afromomum sp.*

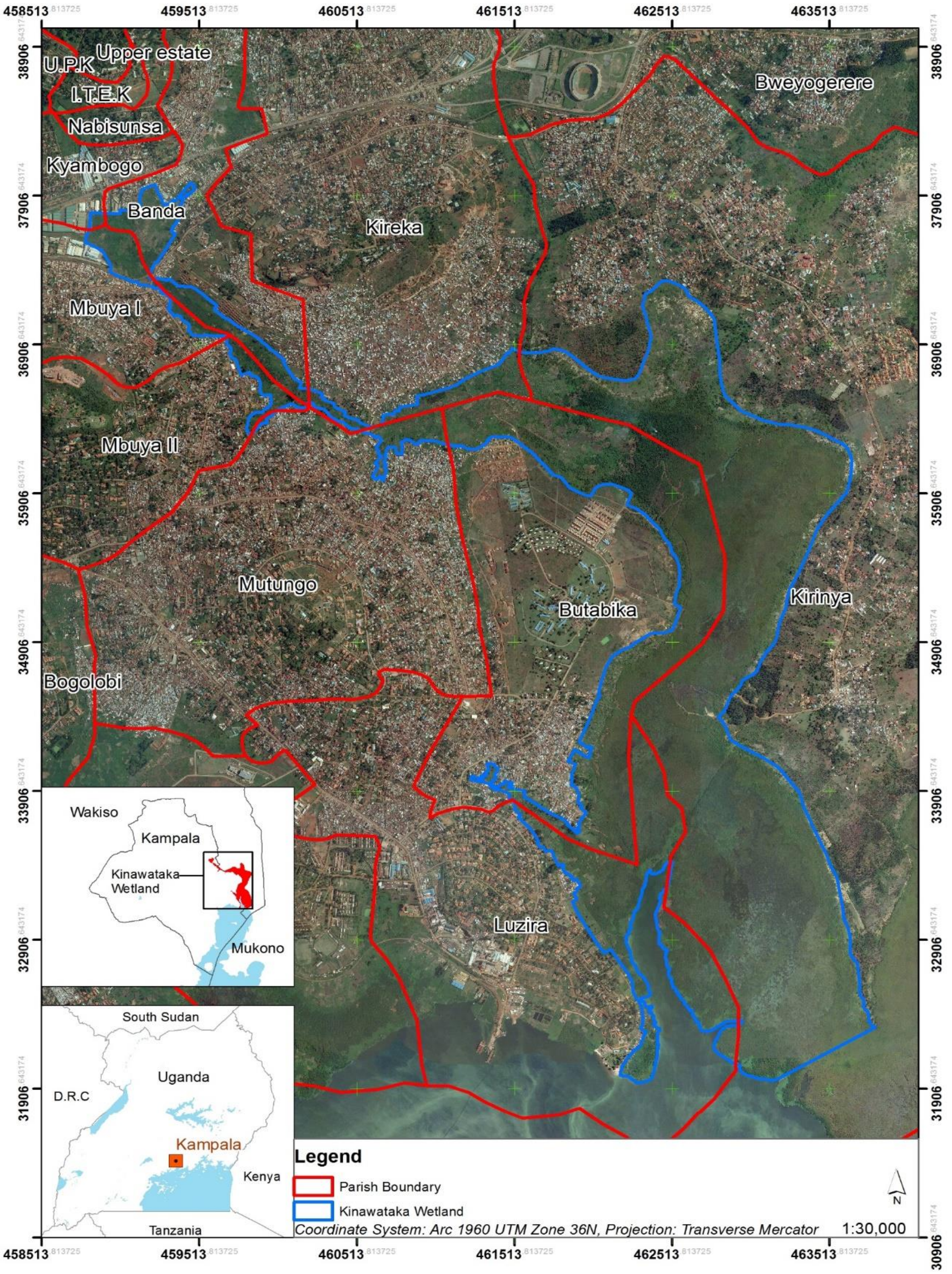

Figure 3.2:A Map Showing the Kinawataka Wetland Extent

3.2 Study Design

The study was carried out following the steps summarized in the flow diagram below.

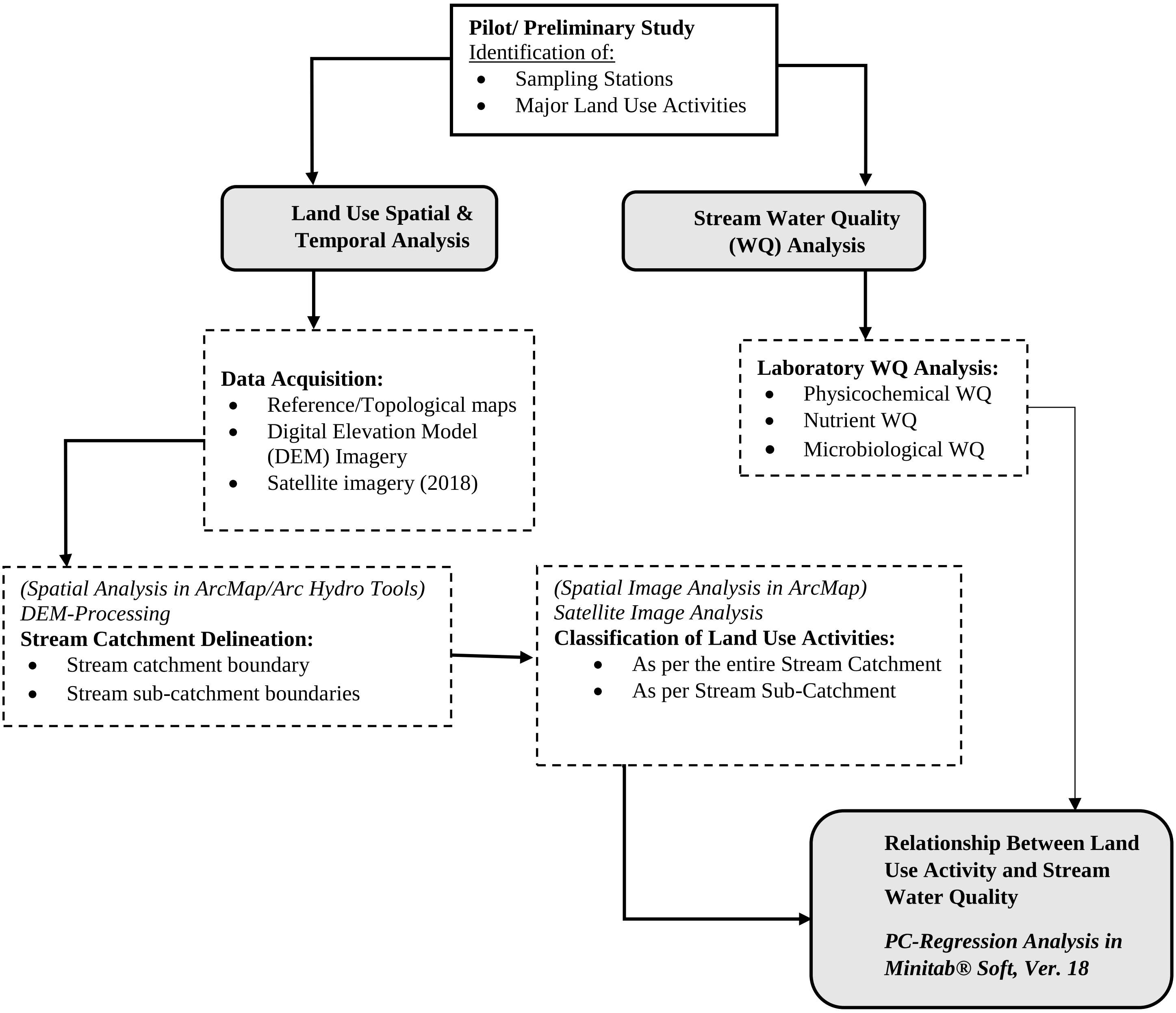

Figure 3.3: Flow Diagram of the Study Design

3.2.1 Preliminary Study

Prior to the actual water sampling and monitoring, preparation work was carried out for station appraisal to validate the sampling stations in the field. This involved meeting with the LCI chairpersons to inform them of intended research as well as to obtain any pertinent information regarding the land use activities within the stream catchment and the possible points of pollution into the stream thereof. Topography maps from the mapping section within the Ministry of Water, and Environment and Kampala City Council Authority were used.

3.2.2 Selection of Sampling Stations

The sampling stations were limited to five (5) due to limited research funds, simply because extra laboratory charges would have been incurred for multiple samples. Therefore, these five (5) sampling stations were spread out along the stream to best capture the most dominant land use activities along the stream flow (i.e. upstream, mid-stream and lower section of the stream) within the stream catchment. The selection process was further guided by the information obtained in the field preliminary studies, secondary data sources such as topographic maps and literature reviewed from previous studies. The criteria for the selection of sampling stations was as shown below:

Table 3.1: Showing the Selection Criteria for the Sampling Stations

On Ground Actual Land Use Land Cover Activities	**Location (Village area)**	**Assigned Sampling Station ID**	**Catchment Segment**	**GPS Coordinates**	
				Easting	*Northing*
• Marshes • Swamp • Tree Cover • Subsistence Farming/Agri. • Confined feeding operations. • Mixed Urban • Transportation, and Communication Utilities	Ntinda-Kyambogo	K1	Upper Catchment	457978	39499
• Industrial and commercial complexes • Commercial & Services *(i.e. Car bonds & washing bays)* • Residential *(i.e. Kinawataka slum)* • Transportation, and Communication Utilities	Nakawa-Kireka	K2	Mid Catchment	459325	37016
• Road construction • Settlements	Mbuya	K3		460423	36183

• Marram Backfills • Transitional Areas & Cleared land • Solid waste • Confined Feeding operations					
• Remaining extent of Kinawataka wetland/swamp • Tree Cover (Eucalyptus) • Residential	Mutungo	K4		460936	36141
• Kinawataka wetland (i.e. marshes and swamps) • Solid waste *(i.e. plastics and other forms of wastes)*	Butabika	K5	Lower Catchment	462680	36149

3.2.3 Selection of parameters

The following physicochemical and biological parameters were measured from the five sampling stations namely: pH, electro conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), chloride (Cl), Sulphate (SO_4^{-2}), ammonia (NH_3), nitrates (NO_3^-), nitrites (NO_2^-), total nitrogen (TN), total phosphorus (TP), biological oxygen demand (BOD), chemical oxygen demand (COD) and total coliforms, faecal coliforms. These parameters provide an overall view of the health of a water body (Fourie, 2005), since the characteristics of each parameter show either an indirect or direct type or occurrence of pollution (Kibena et al., 2014) which in turn may be a possible indicator of wetland degradation. Physical parameters often relate to chemical parameters: for instance, the variations in pH can be attributed to the presence of chemicals in water and would consequently affect the aquatic life. Aquatic species adapt to a specific range of pH and significant change in pH may threaten organism survival (Lei, 2013).

3.3 Determination of the Physicochemical Water Quality of Kinawataka Stream

Water samples were collected from five (5) sampling stations along the stream. These water samples were collected; one sample per station, twice a month in the morning for three months from March 2018 to May 2018. A total, 30 water samples were collected at each station. These were collected in sterile 1 L bottles and stored in a cooler box and later taken Directory of Water Resources Management Department laboratory, Entebbe for analysis.

3.3.1 PH, Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The readings for pH, EC and TDS were measured in situ using a Mettler Tolledo Seven Go portable meter. The probes of the meter were submerged 5-10 cm into the water at each of the sampling stations along the stream. Readings for the measured parameters were taken once the numbers appeared stable on the meter. This was repeated twice a month for three months from March 2018 to May 2018.

3.3.2 Total Suspended Solids (TSS)

The Total Suspended Solids (TSS) were analysed by gravimetric method. This method is based on Method 2540D of Standard Methods for the Examination of Water and Wastewater, 23rd Edition (Rice et al., 2017b). The samples were treated to a series of steps before analysis as follows: A glass-fibre filter was prepared by placing and cantering a filter disk onto the filter support screen of the filtration apparatus and attached the funnel. A low to moderate vacuum was then applied and later rinsed the filter with three successive volumes of ≥30 mL deionized or distilled water. The vacuum was left on until all traces of water had been removed from the filter. The vacuum was then turned off, and the filter was carefully removed from the filtration apparatus support screen by lifting and holding the filter only by the outer edge with forceps and transferred it to a filter pan. Both filter and pan were placed into a drying oven operated at a temperature of 103-105°C where the filter was dried at this temperature for no less than 60 minutes. The rinsed and dried filter was cooled to room temperature, and later removed the filter from the filter pan, weighed and recorded its weight - this is the tared weight of the filter. The pre-rinsed and pre-weighed filter was then replaced in the filter pan and stored it in a desiccator to used later on.

The sample's temperature was equilibrated to that of the room's temperature and a pipet or graduated cylinder was used to transfer a volume of well-mixed sample onto the filter with the vacuum applied. Using a graduated cylinder for samples having solids that clog the wide bore pipet tip, a sample volume that would result in a dried residue ranging from 2.5 to 200 mg was selected. The entire surface area of the exposed filter was rinsed with three successive volumes of ≥10 mL deionized or distilled water, allowing the water to completely drain between each rinsing and leave the vacuum on until all traces of water have been removed from the filter. The vacuum turned off and using forceps, the filter was carefully removed from the filtration apparatus support screen by lifting and holding the filter only by the clean outer edge without solids transferring it to a filter pan. The sample was dried in a convection oven at a temperature of 103-105°C for no less than 60 minutes. The filter pan containing the sample was removed from the oven, cooled to room temperature and then using the forceps carefully removed from the filter pan without touching the dried residue and weigh it. This was then recorded as the first 103°C weight. The drying cycle was repeated for no less than 60 minutes, and again cooled, weighed and recorded the second 103°C weight. The weight change between the first and second weights was calculated, and if the change was >0.5 mg, the drying cycle was repeated until the change in weight between the final weight and the previous weight was ≤0.5 mg. This was recorded and used as the final 103°C weight.

The concentration of total suspended solids then computed as follows:

Total Suspended Solids, as mg TSS/L = [(A – F) X 1,000] / S

Where A = final 103°C weight of the dried residue + the tared filter, mg,

F = tared filter weight, mg, and

S = mL of sample volume.

3.3.3 Sulphates

Preparation of Reagents

Conditioning reagent: 25ml of glycerol were measured and poured into a dry clean beaker. Then, 15 ml of concentrated hydrochloric acid were measured and added to the same beaker. To the same beaker, was added 50 ml of 95% isopropyl alcohol and mixed well. Then 37.5g of sodium chloride were weighed accurately and dissolved it in distilled water. The contents were all then mixed to make up the final volume to 250 ml using distilled water.

Standard Sulphate solution: 1.479g of anhydrous Sodium Sulphate were dissolved in distilled water. Using a funnel, the anhydrous Sodium Sulphate was transferred into a 1,000 ml standard flask making up to 1000ml using distilled water.

Blank, Standards and sample for testing: six 50 ml glass stoppered standard flasks (four for standards, one for the sample and one for the blank) were obtained. 10 ml of the standard Sulphate solution was added to the first standard flask, 20 ml to the second, 30 ml to the third and 40 ml to the fourth. To the fifth standard flask was added 20 ml of the water sample. The sixth standard flask was for the blank and to it was added distilled water alone. Then5 ml of conditioning reagent was added to all standard flasks. The volume in the flasks was made up to the volume to the 100 ml mark using distilled water.

3.3.4 Chemical Oxygen Demand (COD)

COD was determined using the closed flux method (Rice et al., 2017) following the procedure as follows. Culture tubes and caps were washed with 20% H_2SO_4 before using to prevent contamination. The samples were placed in the culture tubes or ampule and added digestion solution. Sulphuric acid reagent was carefully run down inside of vessel so an acid layer was formed under the sample-digestion solution layer and tubes tightly caped or ampules sealed, and each inverted several times to mix completely. Tubes or ampules were placed in block digester and preheated to 150°C and reflux for 2 hours behind a protective shield. The vessels were cooled to room temperature and placed in test tube rack. Then the culture tube caps were removed and added small TFE-covered magnetic stirring bars. 0.05 to 0.10 mL (1 to 2 drops) ferroin indicator was added and stirred rapidly on magnetic stirrer while titrating with standardized 0.10M FAS. The end point was a sharp colour change from blue-green to reddish brown. In the same manner a blank containing the reagents and a volume of distilled water equal to that of the sample was refluxed and titrated.

COD was given by:

COD as mg/L of O_2/L = $[(A\text{-}B) \times M \times 8000) / (V_{sample})$

Where: A = volume of FAS used for blank (mL); B= volume of FAS used for sample (mL);

M = molarity of FAS; 8000= miliquivalent weight of oxygen ×1000 mL/L

3.3.5 Biological Oxygen Demand (BOD)

The most widely used test indicating organic pollution of both wastewater and surface water is the 5-day BOD (BOD_5). This determination involved the measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. BOD_5 is the total amount of oxygen consumed by microorganisms during the first five days of biodegradation. Oxygen demand is associated with the biodegradation of the carbonaceous portion of wastes and oxidation of nitrogen compounds such as ammonia.

BOD dilutions were prepared using dilution water (it contains nutrients, the exact contents are described in APHA, (2005)) as follows: a blank (only dilution water); a 5 mL sample in a 300 mL BOD bottle, filled up with dilution water; a 15 mL sample in a 300 mL BOD bottle, filled up with dilution water; a 20 mL sample in a 300 mL BOD bottle, filled up with dilution water A 300 mL sample in BOD bottle was taken to prepare two sets of this sample. One set of the two sample was kept for Dissolved Oxygen (DO) analysis for day 0 (i.e., Sample0Day) and another sample in BOD incubator for 5 days at 20°C (Sample5Day).

The DO in different samples at t = 0 days was measured electrometrically using an Inolab Meter. The samples were incubated in 20°C for 5 days. The dissolved oxygen was later recorded after 5 days.

DO measurement was done as follows:

Dilution water was prepared by adding 2ml/L of the following reagents in distilled water: Phosphate buffer solution; Magnesium sulphate solution; Calcium chloride solution; Ferric chloride solution and Sodium Sulphite solution. For a given sample bottle, 1 ml of alkali azide was added followed by 1ml magnesium Sulphate solution. The bottled was well shaken and left open for5 minutes to settle the precipitate. 2ml of concentrated H_2SO_4 were added and a cap place on the bottle then well shaken until the precipitate dissolved. 203ml of sample in a conical flask were taken and titrated with standard sodium thiosulfate solution till the colour of sodium became either colourless or changed from dark yellow to light yellow. Few drops of starch indicator were added and titrated until the colour of the solution became either colourless or changed to its original sample colour and noted down the volume of 0.025N sodium thiosulfate consumed. Dissolved oxygen (DO) (in mg/L) = mL of sodium thiosulfate (0.025N) consumed. Then using a UV visible spectrometer, the Sulphate content in each water sample was measured.

3.3.6 Chloride (Cl^-)

The Chloride concentration was determined by pouring 50 ml of sample into a white porcelain container and then diluted the solution to 50 ml with reagent water. The pH was then adjusted to 8.3 using either H_2SO4 or NaOH solution.

Then, 1 ml of K_2CrO_4 indicator solution was added and mixed. Standard $AgNO_3$ solution was then added dropwise from a 25 ml burette until the orange colour persists throughout the sample.

3.3.7 Ammonia (NH_3)

Preparation of equipment: 500 ml of reagent water were added to an 800 ml Kjedahl flask. The distillation apparatus was steamed until the distillate showed no trace of ammonia.

Sample preparation: A de-chlorinating agent was added to the sample to remove any residual chlorine. To 400 ml of sample was added 1 N NaOH, until the pH was 9.5.

Distillation: The sample was then transferred to an 800 ml Kjedahl flask and added 25 ml of borate buffer. A volume of 300 ml was distilled at the rate of 6-10 ml/min. into 50 ml of 2% boric acid contained in a 500 ml Erlenmeyer flask. Since the intensity of the colour used to quantify the concentration was pH dependent, the acid concentration of the wash water and the standard ammonia solutions approximated that of the samples.

3.3.8 Nitrates (NO_3^-)

Nitrate was analysed in accordance to Standard Methods for the Analysis of Water and Wastewater (APHA, 1987). The water samples underwent a digestion process where 2 ml of raw water sample pipetted into 500 ml digested tubes. UV absorption of water samples was measured through a process of UV-screening using a Spectrophotometer set at 220nm to determine NO_3- under UV absorption. Water samples were subjected to a 0.45µ sample filtration to remove the effects of turbidity. A 0.2 ml of 1M Hydro Chloric Acid (HCL) was added into the filtrate and mixed thoroughly. Distilled water was then used to zero the spectrophotometer at 220nm, before taking the reading for the standards and water samples. This process repeated under a 275 nm spectrophotometer screening, followed by taking nitrate concentration readings.

Standards used for this analysis were prepared as follows: Nitrate stock, 1000 mg/l NO_3-N: dilute 10 ml of Nitrate standard (1000 mg/l NO_3^-) to 100 ml volumetric flask and make up with distilled water to the mark; Nitrate working solution: 10, 5, 2, 1, 0.5, 0 mg NO_3-/l were prepared by diluting 5, 2.5, 1, 0.5 and 0.25 ml of Nitrate intermediate standard (100 mg/l NO_3) to 50 ml volumetric flask and make up with distilled water to the mark.

3.3.9 Total Phosphorus (TP)

The analysis of total phosphorus was carried out using an Ascorbic acid reduction method in the standard methods for the examination of water and waste water (APHA, 2005)and the SROS Standard Operation Procedures. In this method, water samples undergo a digestion process to convert combined phosphate to orthophosphate which then reacts with ammonium molybdate and potassium antimonyl tartrate in acid medium to form a heteropolyic acid. This reaction can be reduced by ascorbic acid to form highly coloured molybdenum blue (APHA, 2005).

The reagents used for this method include sulphuric acid, $(H_2SO_4)_5N$: dissolve 1.3715g $K(SbO)C_4H_4O_6.1/2H_2O$ in 400 ml distilled water. This was stored in glass-stoppered bottle.

Ascorbic acid, 0.1M: dissolve 1.76g ascorbic acid in 100 ml distilled water. All the reagents in the following proportions for 100 ml of the combined reagent in a 100 ml volumetric flask: 50ml 5N H_2SO_4, 5 ml potassium tartratesolution,15 ml of ammonium molybdate solution, and 30 ml of ascorbic solution.

Once all reagents were prepared, they were left standing to reach room temperature before the analysis. The digestion of samples was prepared beforehand, according to APHA, 2005;DHV Consultants et. al., 2000.

Once the process was completed, samples were cooled at room temperature and ready for the analysis. The analysis involved the following procedures (APHA, 2005): 50 ml of sample was pipetted into a 125 ml conical flask. 1 drop (0.05 ml) of phenolphthalein indicator was then added. A discharge red colour appeared and another 5 N (Normality) of H_2SO_4 was added. 8.0 ml of combined reagent and mix thoroughly was then added. Sample time did not exceed 30 minutes. The samples were put inside the UV spectrophotometer, which was already set at 880 nm and the absorbance of each sample at 880 nm was measured. Blanks were also prepared by adding all reagents, except ascorbic acid and potassium antimonyl tartrate, to the samples. Therefore, blanks were recorded first before the samples. After reading absorbance from the samples, the absorbance of blanks was subtracted from the sample absorbance. Results of phosphorus concentration (mg/l) were recorded by checking the sample’s absorbance against the calibration curve.

3.3.10 Total Nitrogen (TN)

Total nitrogen (TN) was analysed using the process of digestion, distillation and titration of the Kjedahl method, in accordance to the method described by (Blakemore *et al.,* 1981), These procedures basically convert organic nitrogen to ammonia, which then distils the total ammonia into an acid absorbing solution (Boric Acid), determined by titration of 0.25M of sulphuric acid H_2SO_4.

The procedure involved pipetting 2 ml of raw samples into dry digestion tubes (500 ml calibrated glass test tubes), sorted out in an Aluminium heating block. The blanks and quality control samples were all prepared in triplicate. Two Kjeldahl copper catalyst tablets were then added to each digested tube. When all the samples were prepared (tubes), 20 ml of concentrated sulphuric acid (95%) (H_2SO_4) was carefully added into each mixture and gently swirled around. During preparation of samples, the Digester unit (BUCHI DIGESTAUTOMAT K-438) was turned on and pre-heated at 420^0C (~60mins), as it takes some time to heat up the unit to its required temperature. At 420^0C, the prepared samples in the rack were placed in the digested block (BUCHI DIGESTAUTOMAT K-438) and run for two hours. The sample's colour turned clear green as an aliquot sample solution, which completed the digestion process after a set time of 120 minutes.

The samples were allowed to cool down to room temperature before they were transferred to the distillation unit (Kjeldahl Unit K-370).

Each digested sample (tube) was placed in the Kjeldahl Distillation Unit (K-370) one at a time, in order to undergo distillation. The Kjeldahl Distillation Unit, with its build-in titrator, enables automatic calculation by the unit and readings were taken from the display on the titrator. The average of individual samples (with their triplicates) was taken, in order to determine total nitrogen concentration in mg/l.

3.4 Determination of the Microbiological Water Quality of Kinawataka Stream

3.4.1 Faecal coliform and Total coliform

Faecal coliform and Total coliforms were measured and determined in accordance with standard methods for the examination of water and wastewater (APHA, 2005). A filtration apparatus was assembled which included a vacuum pump, filtration manifold, glass funnels, clamps and 47 mm filter paper. Samples were labelled on petri dishes with sample codes and volume used. All pipette tips and small tubes were sterilized in an autoclave before use. All samples went through a dilution process, where three dilutions (i.e. 1 ml, 0.1 ml and 0.01ml) were prepared for each sample.

All dilutions were prepared and poured into fermentation tubes and labelled with sample codes and volume used. Approximately, 100 ml of buffered water was through, the funnels and vacuum. When all the water had run through, the vacuum was turned off and clamps and funnels were removed. Flamed tweezers were used to transfer a sterile 0.45 µm gridded membrane filter onto the receptacle (with the gridded side up), before carefully replacing the funnels back on and locking it with the clamps.

Prepared dilutions (1 ml,0.1 ml and 0.01 ml) were poured onto the filter. The vacuum was turned on, to allow the sample to draw completely through the filter. Once the water was filtered through the membrane, the vacuum pump was turned off. Using sterile tweezers, membrane filters were removed and placed carefully (to avoid tears) and placed onto m-Endo-ES agar in each receiving labelled petri dish. The filter funnels were then washed with buffered water and the filtration steps were repeated. Petri dishes were placed in the receiving tray in an inverted position, to allow visible growth of bacteria and these were then taken for incubation at 35 ±

0.5^0C for 22 to 24 hours. Interpretation of results included placing the petri dishes under the colony counter and counting for typical colonies for Total coliform. Coliform colonies were pink to dark red in colour with a green metallic surface sheen for ease of identification. Results of Total coliform were calculated as follows: [(No. of colonies)/ (volume filtered)] x 100 in cfu/100 ml. For F. coliform, the filters with coliform growth were transferred onto NA-Mug. These were then incubated at 35 ± 0.5^0C for four hours before readings were taken for the presence of F. coliform. When incubation was completed, the petri dishes were then placed under a UV light to view the blue fluorescence colonies for F. coliform counts.

3.5 Determination of the land use patterns in Kinawataka stream catchment for 2018

3.5.1 Obtaining Satellite Data

Satellite imagery for land use characterization was downloaded from Google Earth for the period 2018. Then for the purposes of sub catchment delineation Digital Elevation Model (DEM) satellite imagery was downloaded from the US Geological Survey (USGS) Earth Explorer website (http://www.earthexplorer.usgs.gov).

3.5.2 Ground Control Points for Accuracy Assessment

The hand-held Global Positioning System (GPS) was used to validate satellite data. Locations of points for accuracy assessment were determined through the device (Attua & Fisher, 2011, Jaafari & Nazarisamani, 2013). The advantage of a GPS is that it gives accuracy in real time or 1 to 3-meter post processing. At times, no consistent pattern between the various surfaces can be directly detected due to the complex nature of ground cover, hence the application of Hand held GPS (Matshakeni *et al*., 2009)

3.5.3 Land Use Land Cover (LULC) Classification

In order to identify and visualize the land use and land cover changes, the images were processed by running an unsupervised classification and supervised maximum likelihood classification algorithm of Kinawataka basin (area of interest). Maximum likelihood classification is a pixel-based statistical classification method which helps in the classification of overlapping signatures; pixels are assigned to the class of highest probability (Shodimu, 2016). The classification used in this study followed the classification proposed by Anderson *et al.,* (1976).

A geographic coordinate system of GCS_WGS_1984 was first checked and set up as a projection to WGS 1984, using the Spatial Reference Properties' function of ArcMap, before the data was used to create land use composition maps for the two years 2008 and 2018. The shape files were then added to the table of contents layers' window of ArcGIS. The land use layers of Kinawataka were first clipped using the "Clip Analysis' tool of the Geo-processing drop down menu on the ArcMap toolbar, in order to extract the area of interest defined by the boundary GIS layer of the catchment.

The 2018 existing GIS layers of dominant land use types of Kinawataka catchment were used to create an up to date land use map for the catchment with twelve dominant land use classes.

Table 3.2: Summarizes the land use land cover system as proposed by Anderson *et al.*, (1976).

Remote Sensed Land Use Land Cover Class (*Level I*)	**On Ground Actual Land Use Land Cover Activities** *(Level II)*
Tree cover	• Deciduous Forest Land • Evergreen Forest Land • Mixed Forest Land
Grassland	• Lawns • Pastures
Plantations (Agriculture)	• Crop land • Confined Feeding Operations • Other Agricultural land
Built-up Area	• Residential • Commercial and Services • Industrial • Transportation, Communications and Utilities. • Industrial and Commercial Complexes • Mixed Urban or Built-up Land
Bare soil	• Sandy Areas • Bare Exposed Rock • Strip Mines, Quarries and Grave pits • Transitional Areas, Cleared land • Marram backfills • Solid waste

3.6 Statistical Analysis Methods

The Spearman’s rho, also known as the Spearman’s Partial Rank Correlation is a nonparametric coefficient of rank correlation between two variables (X, Y) used to determine whether or not an association exists between the two variables (Ngwenya, 2006). The correlation was computed between two datasets namely land cover type & water quality parameters and land cover type & the synthetic pollution index (Xia *et al*., 2012).

The analysis for this study included descriptive statistics like; the mean, minimum, maximum, coefficient of variance (CV), standard deviation (stdev) and normality test of the physiochemical and microbiological water quality parameters analysed using *Minitab® version 18* statistical software.

Finally, a Principal Component Regression (PCR) model was used to cater for the multi-collinearity effects between the land use activities (Bahar et al., 2008a) and later regressed the principal component land use characterises with water quality parameters to determine the impact thereof (Dunn, 2017).This analysis was performed using *Minitab® version 18* statistical software.

CHAPTER 4: RESULTS

4.1 Physicochemical Stream Water Quality

4.1.1 Overall physicochemical parameter concentrations within the stream

Table 4.1 below summarizes the overall descriptive statistics of the physicochemical parameters. The values were analysed and presented as a total mean concentration for each of the select eight physicochemical water quality parameters assessed during the months of March, April and May 2018.

Table 4.1: Overall mean concentrations of the physicochemical parameters

Parameter		**Mean**	**Range**		**NEMA Effluent Standards**
			Min	**Max**	
pH		7.71±0.35	7	8.4	6.0-8.0
EC	[µS/cm]	418.70±68.22**	106	494	-
TDS	[mg/L]	243.23±42.77	74	309	1200
TSS	[mg/L]	478.03±1271*	1	4335	100
BOD	[mg/L]	6.08±5.453	0.056	27	50
COD	[mg/L]	30.14±75.96	0.29	105	100
Cl	[mg/L]	29.70±12.46	3.7	53.7	500
SO_4	[mg/L]	11.04±6.70	0	39	500
Ammonia	[mg/L]	2.99±2.41	0.942	9.870	10
Nitrates	[mg/L]	2.15±1.53	0.087	5.922	20
Nitrites	[mg/L]	0.94±2.18	0.678	12.255	2
Total N	[mg/L]	4.64±3.27	0.123	12.379	10
Total P	[mg/L]	1.11±2.40	1.017	12.260	10

*Exceeded the NEMA standards; **Exceeded the WHO Guideline of 400 µS/cm
-Missing value

Most of the parameters were within permissible NEMA effluent discharge standards apart from TSS whose mean overall concentration exceeded 100mg/L and EC whose mean overall concentration exceeded 400 µS/cm for WHO guidelines.

4.1.2 Variation in physicochemical parameters downstream

Figures 4.4 – 4.7 represent a summary of the variation in concentrations of physicochemical parameters per sampling station downstream. These measurements were taken as mean concentrations of the samples taken per sampling station during the study (May to March 2018).

4.1.2.1 pH

The pH of the collected water samples was determined using a Mettler Tolledo Seven Go portable meter. The pH of water determines the solubility (amount that can be dissolved in the water) and biological availability (amount that can be utilized by aquatic life) of chemical constituents such as nutrients (phosphorus, nitrogen, and carbon). The results in Figure 4.1 below show that pH had very little variation across the sampling stations, however it generally increased downstream.

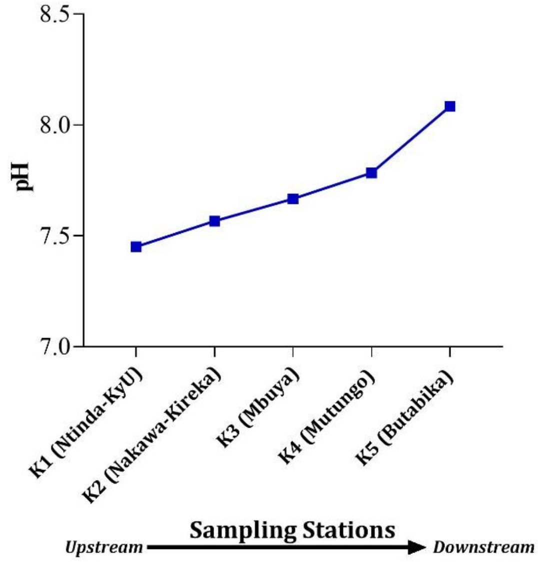

Figure 4.1: Variation in pH downstream

The highest pH recorded was 8.08±0.26 downstream at station K5 while the lowest was 7.45±0.34 upstream at K1.

4.1.2.2 TSS, TDS and EC

The concentration of Total Suspended Solids (TSS) of the collected water samples was determined using the gravimetric method 2540D while both TDS and EC were determined in-situ using a Mettler Tolledo Seven Go portable meter.

TSS can include a wide variety of material, such as silt, decaying plant and animal matter, industrial wastes, and sewage. High concentrations of suspended solids can cause many problems for stream health and aquatic life. High TSS in a water body can often mean higher concentrations of bacteria, nutrients, pesticides, and metals in the water. These pollutants may attach to sediment particles on the land and be carried into water bodies with storm water.

TDS is a measure of the amount of material dissolved in water. This material can include carbonate, bicarbonate, chloride, Sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, and other ions. A certain level of these ions in water is necessary for aquatic life. Changes in TDS concentrations can be harmful because the density of the water determines the flow of water into and out of an organism's cells. On the other hand, Electrical conductivity (EC) estimates the amount of total dissolved salts (TDS), or the total amount of dissolved ions in the water. The results are as shown in Figure 4.2 below.

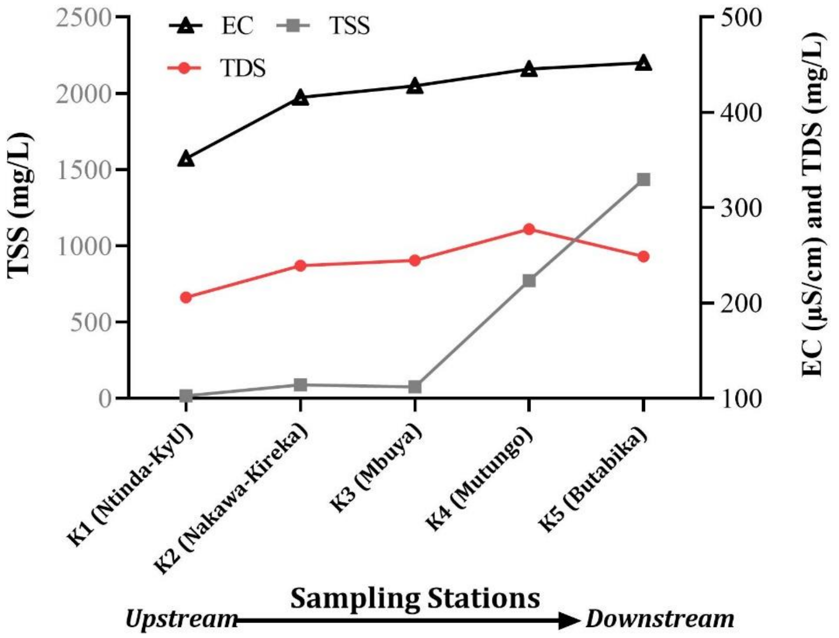

Figure 4.2: Variation in TSS, TDS and EC downstream

The concentration levels of TSS generally increased downstream, and ranged between 1±25.32 mg/L and 1437.50±2117 mg/L at stations K1 and K5 respectively.

The EC levels increased steadily downstream from 351.67 ± 125.11 µS/cm, K1 to 452.33 ± 36.11 µS/cm, K5. It ranged between 106 and 494 µS/cm, with a CV of 15.64% across each sampling station.

The TDS concentration levels increased steadily downstream from 205.53 ± 70.91 to 248.83 ± 20.30 mg/L from K1 to K5 and ranged between 74 and 309 mg/L with a CV of 17.5% across the sampling stations.

4.1.2.3 BOD and COD

BOD of wastewater effluents is used to indicate the short term impact on the oxygen levels of the receiving water. BOD analysis is similar in function to chemical oxygen demand (COD) analysis, in that both measure the amount of organic compounds in water. BOD was determined using the 5-day BOD (BOD_5) test while the COD was determined using the closed flux method. he results are as shown in Figure 4.3 below.

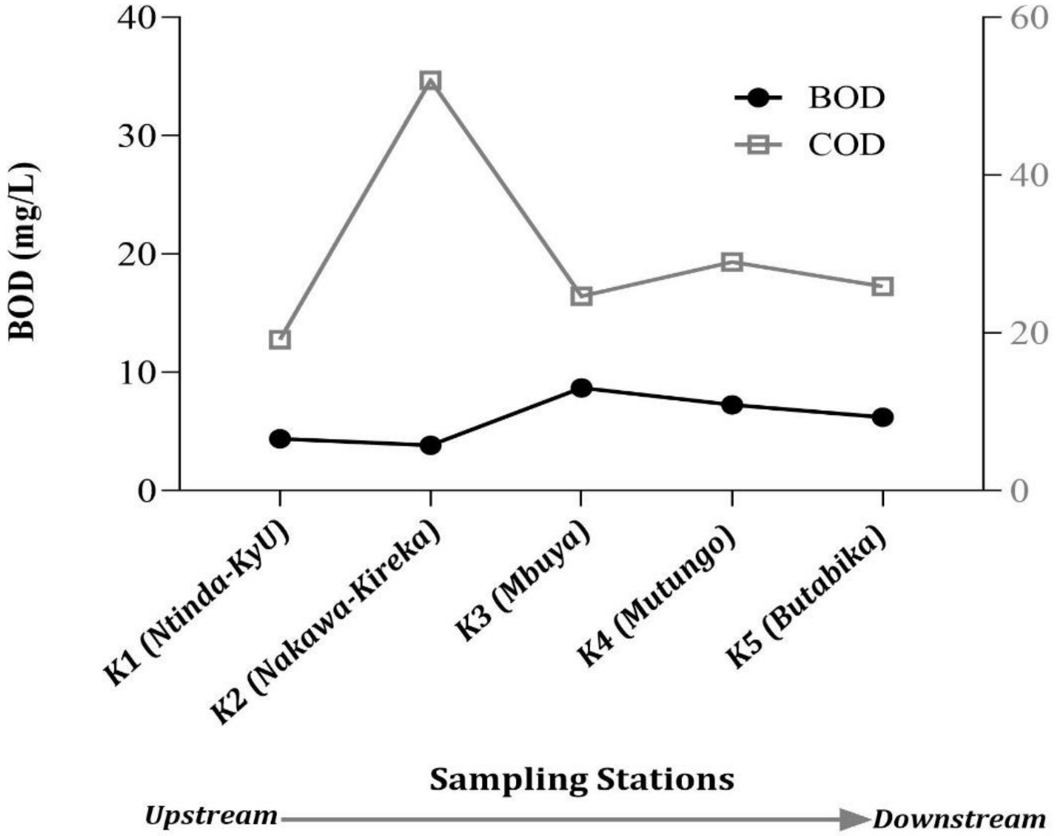

Figure 4.3: Variation of BOD and COD downstream

The BOD concentration generally increased downstream. The highest BOD concentration was 8.68±9.48 mg/L at K3 while the lowest was 3.83±3.43 mg/L at K2.

The COD concentration generally decreased downstream. The highest COD concentration was 52.00±38.37 mg/L at K2 while the lowest was 19.17±10.09 mg/L at K1.

4.1.3 Chlorides and Sulphates

Analysis for chlorides and Sulphates was done to investigate the potential effects of pollution from industrial processes, agricultural run-off and washing bays on the stream water quality.

The chlorides and Sulphates were determined by titration. The results were as shown Figure 4.4 below.

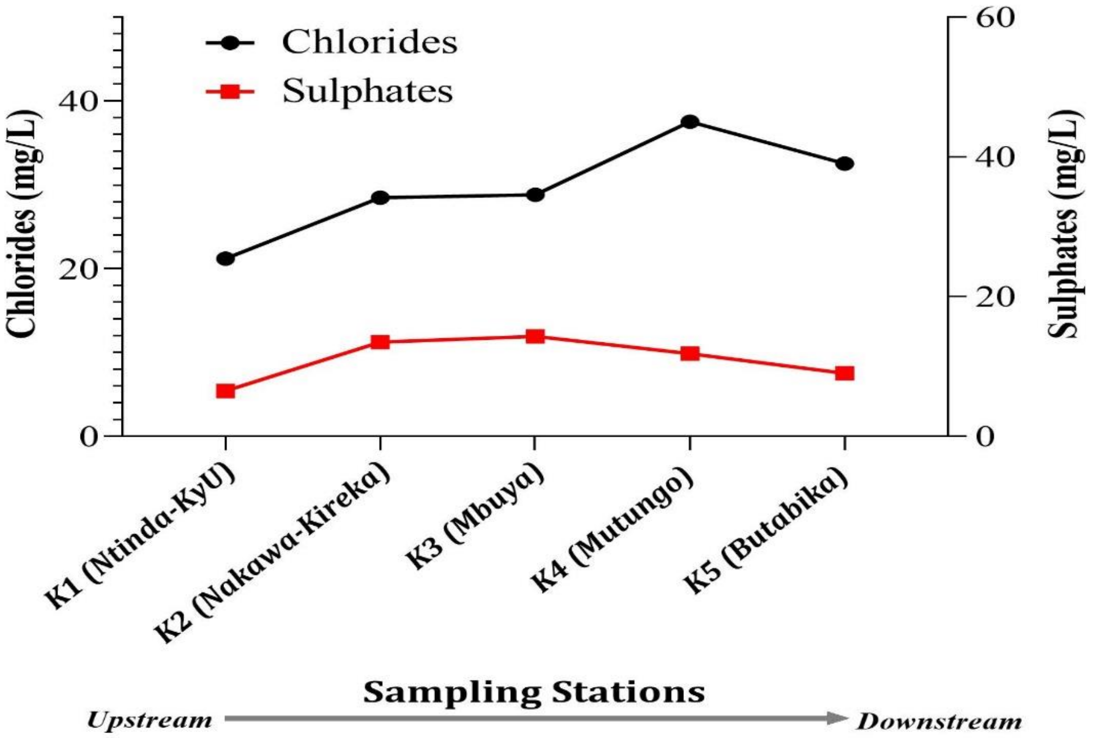

Figure 4.4:Variation of Chlorides and Sulphates downstream

The chloride concentration levels generally increased downstream from station K1 to K5 ranging between 3.7 and 53.7 mg/L with a CV of 39.20% across stations. The highest concentration was 37.53±17.03 mg/L at K4 while the lowest was 21.8 ± 6.78mg/L at station K1.

The concentration in Sulphates gradually increased between station K1 and K2 from 6.50 ± 3.27 mg/L to 13.50 ± 4.46 mg/L mid-stream and later dropped gradually 14.32 ± 12.23 mg/L to 9.03 ± 3.18 mg/L downstream through station K3 to K5, as shown in Figure 4.4.

4.1.4 Nitrites, Nitrates and Ammonia

The presence of nitrites in combination with ammonia and nitrates indicates possible environmental contamination (Saskatchewan Ministry of Health, 2008). Nitrites can enter water using corrosion inhibitors in industrial process water, or through the conversion from ammonia or nitrates. These were determined using digestion and the results are as shown in Figure 4.5 below.

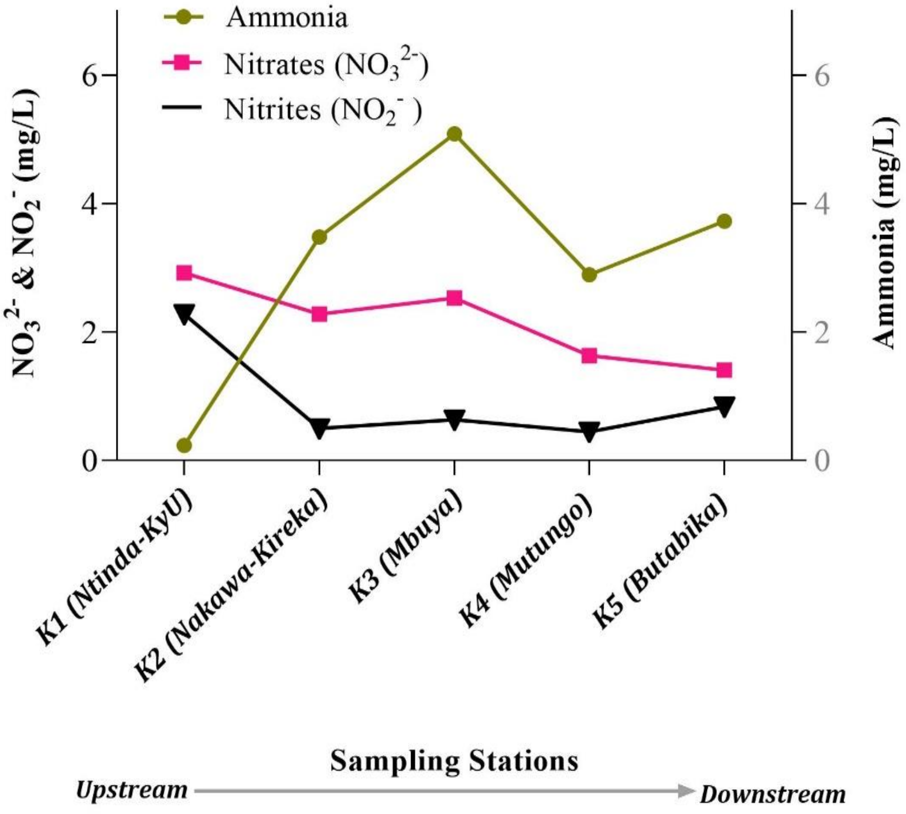

Figure 4.5: Variation of Nitrites, Nitrates and Ammonia downstream

The trend in nitrite concentration generally decreased downstream across stations K1 to K5, and averaged between 0.678 and 12.255 mg/L. The highest nitrite concentration recorded was 2.28 ± 4.89 mg/L upstream at K1 while its lowest concentration was 0.45 ± 3.65mg/L midstream at K4.

The trend in nitrate concentration also generally decreased downstream with a mean concentration that ranged between 0.087 and 5.922 mg/L downstream through stations K1 & K5. The highest nitrate concentration recorded was 2.92 ±2.62 mg/L upstream at K1 while its lowest concentration was 1.41 ± 1.12 mg/L downstream at K5.

The trend in ammonia concentration generally increased downstream with a mean concentration ranging between 0.9429 and 9.870 mg/L downstream through stations K1 and K5 respectively. The ammonia concentration recorded was 4.70 ± 3.05 mg/L midstream at K3 while its lowest concentration was 0.30 ± 0.21 Mg/L upstream at K1.

4.1.5 Total Nitrogen and Total Phosphorus

Possible sources of nitrogen and phosphorus in waterways include runoff from agricultural lands, where fertilizer is highly applied; possible leakage from septic systems; waste treatment plants; runoff from animal manure; and discharge from industrial zones (Gullat, 2013). The total nitrogen analysis was done using the Kjedahl method while analysis for total phosphorus was done using ascorbic acid reduction method and the results were as shown in Figure 4.6 below.

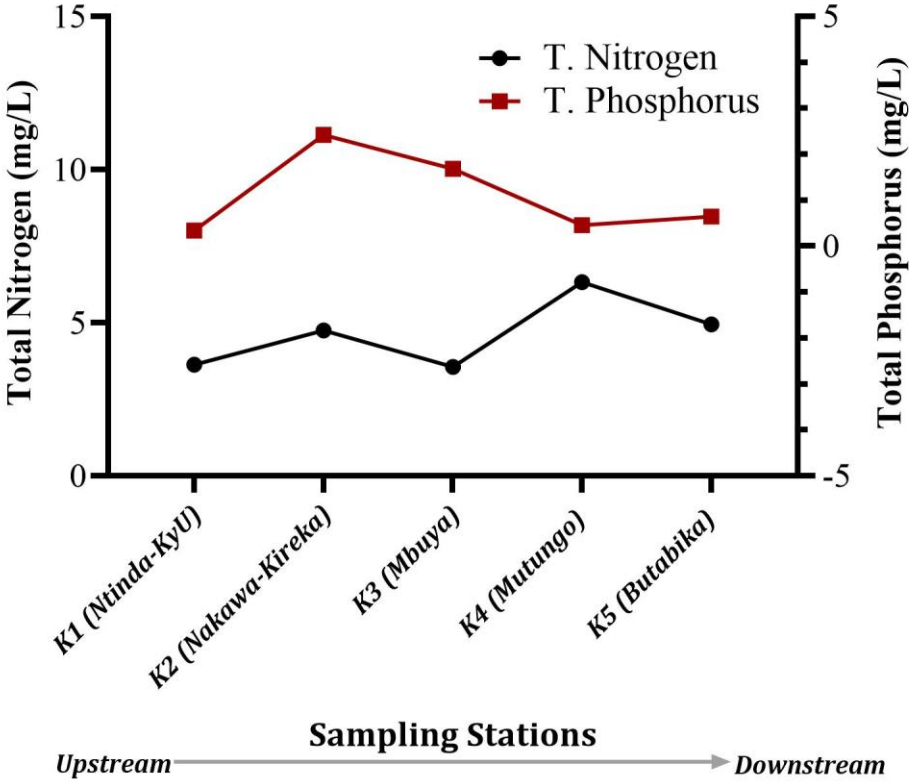

Figure 4.6:Variation of T. Nitrogen and T. Phosphorus downstream

The nitrogen concentration levels generally increased downstream between K1 and K5, with a mean concentration that ranged between 0.123 and 12.379 mg/L. The highest nitrogen concentration recorded was 6.32 ± 3.65 mg/L midstream at K4 while its lowest concentration was 3.63 ± 3.06 mg/L upstream at K1.

4.2 Microbiological Stream Water Quality

4.2.1 Overall microbiological count within the stream

Table 4.2 below, summarizes the overall stream bacterial count descriptive statistics. The values were analysed and presented as a total mean bacterial counts for each of the select five nutrient parameters assessed during the months of March, April and May 2018.

Table 4.2: Overall Microbiological Count in the stream

Parameter	Mean	Range		NEMA Effluent Standards
		Min	Max	
T.Coliforms [cfu/100ml]	1376.70±1873.43	201	7284	-
F. Coliforms [cfu/100ml]	306.60±214.76*	24.0	1235.0	300

*mean *F. Coliforms* count exceeded the national effluent permissible standards
-missing values

The faecal coliforms exceeded the permissible effluent standards with a mean of 306.60±214.76 cfu/100 ml while there was no recorded standard for the total coliforms. Total coliforms exhibited a higher CV of 136.08% compared to faecal coliforms. The highest mean concentration that exceeded the national effluent standard was an indication of a decline in stream water quality and a potential threat to public and ecosystem health of Kinawataka.

4.2.2 Variation of T. Coliforms and F. Coliforms downstream

Total coliforms include total bacteria associated with soil, in the water as well as animal and human waste. Early detection of total coliforms in a water system sends out a warning of possible contamination while faecal coliforms usually employed as an indicator of the presence of faecal matter in water. Their presence in high levels in water indicate not only the presence of faecal matter (e.g. sewage or from animal effluent), but also other disease-causing microorganisms (e.g. campylobacter). They were analysed using the serial dilution plate count method and the results are as shown in Figure 4.7 below.

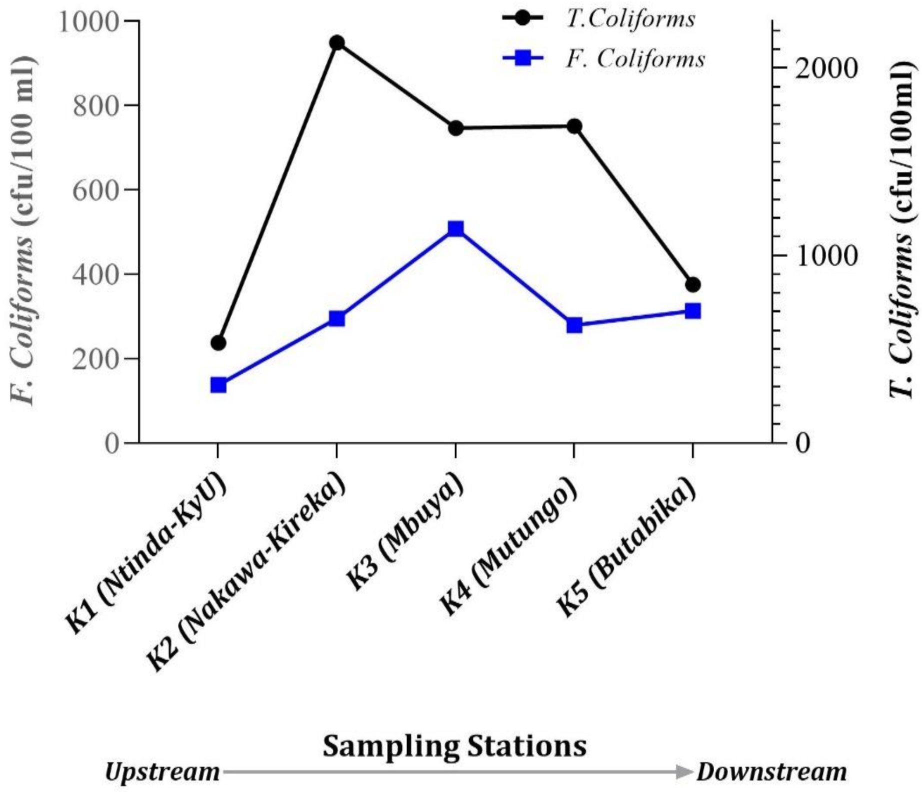

Figure 4.7: Variation of *T. Coliforms* and *F. Coliforms* downstream

The trend in T. Coliform levels was bell shaped (i.e. generally increased to a max mid-stream and later dropped towards lower stream,) ranging between 201 and 7284 cfu/100ml (K1 and K5). The highest total coliform count was 2135 ± 151 cfu/100ml midstream at K2 while the lowest count was 534 ± 266 upstream at K1.

The trend in F. Coliform levels generally increased downstream ranging between 24 and 1235 cfu/100ml (K1 and K5). The highest faecal coliform count recorded was 508 ± 359 cfu/100ml midstream at K3 while its lowest 138 ± 96 cfu/100ml upstream at K. The F. Coliform contamination exceeded Uganda’s National Effluent Standards of 300 cfu/100ml starting from K3 mid-stream to the lower parts towards K5.

4.3 Major Land Use Land Cover Activities and their Distribution within the Kinawataka Stream Catchment

The 2018 satellite image was processed, classified and analysed in ArcMap 10.3 and a land use map showing the five (5) major land uses, namely: Bare Soil, Built-up Area, Grassland, Plantations(Agric.) and Tree Cover was developed as shown below in Fig.4.1. below.

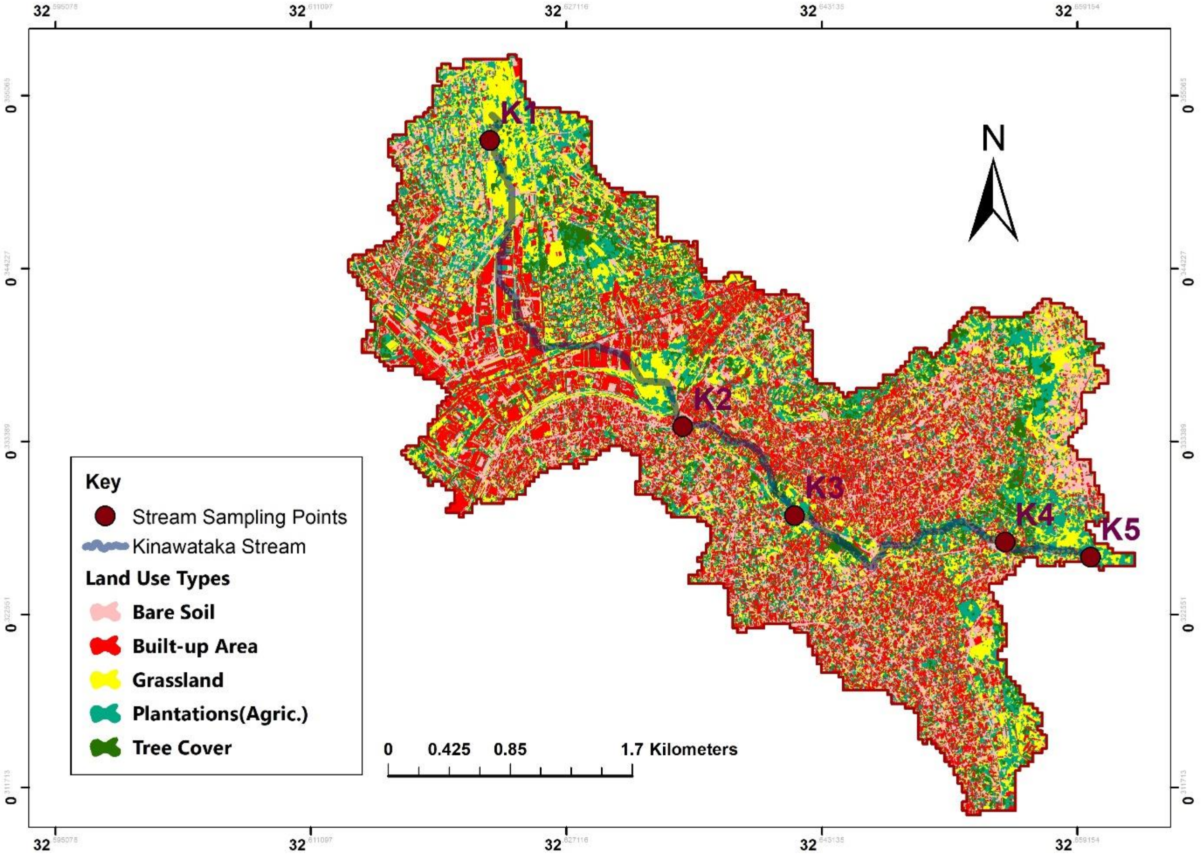

Figure 4.8: A Map Showing the Five (5) Major Land Use Activities of the Kinawataka Stream Catchment in 2018. (K1-K5=Sampling Points)

The observed land use activities throughout the Kinawataka stream catchment varied depending on the landscape's capabilities. The most dominant land use was Built-up Area which comprised of; industries, road network, human settlements coupled with subsistence farming dominated the mid-section of the catchment, while Tree Cover was the least dominant observed land use.

4.3.1 Distribution of the Land Use Activities within the Kinawataka Stream Catchment

To quantify the areal coverage for the different land use types, the pixel depth for each land use type were expressed as percentages. The results as shown in Figure 4.9 below showed that the Built-up Area was the most dominant at 40.51% while Tree Cover had the least coverage at 6.22%.

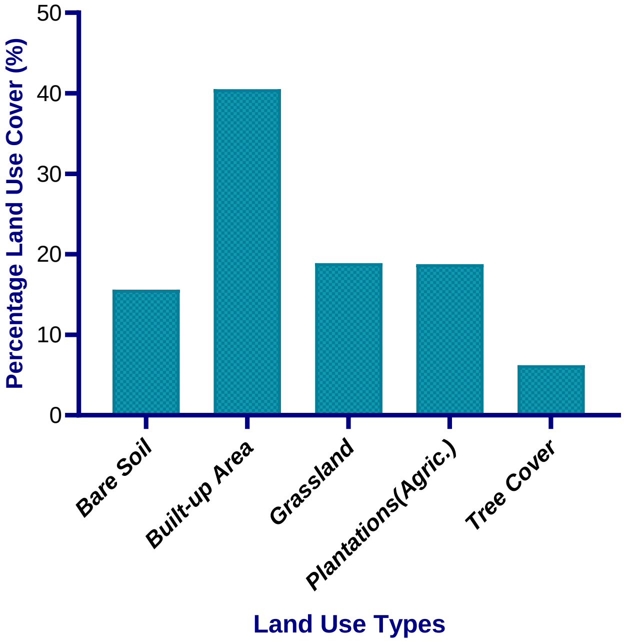

Figure 4.9: Stream Catchment Land Use Activity Distribution

4.3.2 *Sub-Basin Land Use Distribution*

The proportions (%) of each land use type within every sub-basin defined by each sampling station, were determined by dividing the area of each land use type by the area of the sub catchment, times 100%, in order to obtain the percentage of sub catchment covered by each land use type (Bahar *et al.*, 2008). The land use distribution pattern as per sub-basin was as shown below:

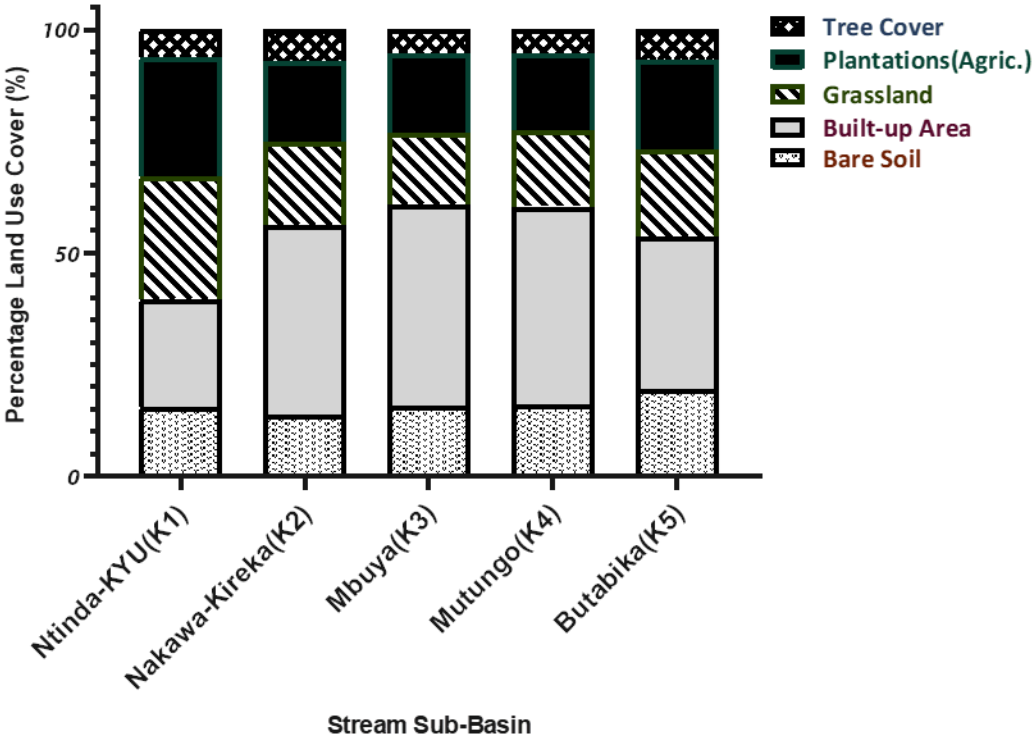

Figure 4.10: Sub-Basin Land Use Activity Distribution

In all the five sub-basins, Built-up area was the most dominant land use ranging from 24% (Ntinda-Kyambogo) to 45%(Mbuya). The Built-up area was highest midstream and lowest both upstream and downstream.

However, Tree Cover was the least dominant land use activity ranging from 4% in Mbuya to 7.1% in Nakawa-Kireka sub basin areas. The Tree Cover was highest both upstream and downstream and lowest midstream, (Ntinda-Kyambogo and Butabika sub basin areas respectively).

4.4 Relationship Between Land Use Form and Water Quality

4.4.1 Spearman's Correlation between Land Use Form and Water Quality

A Spearman's Rank correlation was initially performed so as to establish the correlation between the various land use classes and water quality parameters. The strength of the Spearman's *rho* correlation coefficient was determined according to its closeness to +1 or -1 whereby a closeness to zero showed no relation between land use and water quality.

4.4.1.1 Relationship between land use activity and physicochemical parameters

Table 4.3 below gives a summary of the physicochemical parameters that had a significant relationship with the land use activities within the stream catchment. The results are as shown below.

Table 4.3: Spearman's *rho* correlation coefficients for a relationship between land use type and stream water quality parameters.

	Land Use				
Variable	*Bare Soil*	*Built-up Area*	*Grassland*	*Plantations (Agric.)*	*Tree Cover*
pH	-0.107	-0.092	-0.193	-0.234	**-0.524****
	(0.574)	*(0.627)*	*(0.308)*	*(0.213)*	*(0.003)*
EC	0.289	-0.117	-0.133	-0.196	**-0.572****
	(0.122)	*(0.539)*	*(0.485)*	*(0.300)*	*(0.001)*
TDS	0.230	-0.030	-0.170	-0.147	-0.337
	(0.222)	*(0.874)*	*(0.369)*	*(0.437)*	*(0.069)*
TSS	**0.357***	-0.274	0.118	0.094	-0.227
	(0.040)	*(0.142)*	*(0.534)*	*(0.622)*	*(0.227)*
BOD	0.223	-0.063	-0.041	-0.019	**-0.386***
	(0.235)	*(0.742)*	*(0.829)*	*(0.922)*	*(0.035)*
COD	0.026	0.163	0.248	0.192	-0.008
	(0.891)	*(0.391)*	*(0.187)*	*(0.309)*	*(0.968)*
Cl^-	0.262	0.127	0.107	0.073	**-0.376***
	(0.163)	*(0.505)*	*(0.572)*	*(0.700)*	*(0.040)*
SO_4^{2-}	0.263	**0.506****	0.342	0.259	0.060
	(0.161)	*(0.004)*	*(0.064)*	*(0.166)*	*(0.752)*
NH_3	0.308	**0.410***	**0.370***	0.278	-0.183
	(0.098)	*(0.025)*	*(0.044)*	*(0.136)*	*(0.333)*
NO_3^-	0.351	0.276	**0.389***	**0.370***	**0.386***
	(0.057)	*(0.139)*	*(0.034)*	*(0.044)*	*(0.035)*
TN	0.178	-0.073	-0.102	-0.028	-0.088
	(0.348)	*(0.702)*	*(0.591)*	*(0.882)*	*(0.645)*
TP	0.081	0.069	-0.054	-0.093	-0.194

	(0.669)	*(0.717)*	*(0.778)*	*(0.627)*	*(0.304)*
Total Coliforms	0.156	0.238	0.306	0.347	0.265
	(0.410)	*(0.205)*	*(0.100)*	*(0.060)*	*(0.156)*
Faecal Coliforms	**0.355***	**0.441***	0.346	0.295	-0.222
	(0.050)	*(0.015)*	*(0.061)*	*(0.114)*	*(0.239)*

**rho* value was significant at a p < 0.05 level
***rho* value was significant at a p < 0.01 level

Generally, the land use type within the stream catchment showed a significant correlation with the various concentrations in physicochemical parameters.

Bare Soil vs. Water Quality

Bare Soil had a positive significant relationship with both TSS (*rho* = 0.357, *p*=0.040, *N=30)* and Faecal coliforms (*rho*=0.441, *p*=0.015). Implying therefore, that an increase in the Bare Soil within the stream catchment area would consequently result in an increase in concentration of TSS and Faecal Coliform contamination and impaired the quality of the water as a result.

Built-up Area vs. Water Quality

Built-up Area had a positive significant relationship with Sulphates (*rho*=0.506, *p=0.004, N=30),* Ammonia (*rho*=0.410, *p*=0.025, *N=30)* and Faecal coliforms (*rho*=0.355, *p*=0.054). Thus an increase in Built-up Area within the stream catchment would result in an increase in the concentration of Sulphates, Ammonia and Faecal contamination

Grassland vs. Water Quality

Grassland had a positive significant relationship with both the Ammonia (*rho*=0.370, *p=0.044, N=30)* and Nitrate concentration (*rho*=0.389, *p*=0.034, *N=30).* Thus an increase in Grassland within the stream catchment would result in an increase in the concentration of both Ammonia and Nitrates.

Plantations(Agri.) vs. Water Quality

Plantations(Agri.) had a positive significant relationship with Nitrite concentration (*rho* = 0.370, *p*=0.044, *N=30).* Implying therefore, that an increase in the Plantations(Agri.) within the stream catchment area would consequently result in an increase in concentration of Nitrites.

Tree Cover vs. Water Quality

Tree Cover had a negative significant relationship with pH (*rho*=-0.524, *p*=0.003), EC (*rho*=-0.572, *p*=0.001), BOD (*rho*=-0.386, *p*=0.035) and Chlorides (*rho*=-0.376, *p*=0.040). This would imply that the reduction in Tree Cover in the stream catchment consequently resulted in the increase in pH, EC, BOD and Chloride concentration.

Conversely, there was a positive significant relationship between Tree Cover and Nitrate concentration (*rho*=0.386, *p*=0.035). This inferred that an increase in Tree Cover within the stream catchment increased the Nitrate concentration of the water.

4.4.2 A Principal Component of the Land Use Land Cover Classes

In order to resolve the multi-collinearity effect among the explanatory land use land cover variables, a principal component analysis was performed on the land use land cover classes grouping them into distinct principal components that had no linear correlation to each other. The results of the principal component analysis were as shown in Table 4.4 below.

Table 4.4: Results of the Land Use Principal Component Analysis (PCA)

Land Use Types	**Principal Components**		
	PC1	**PC2**	**PC3**
Bare Soil	0.3444	0.5595	**0.7507**
Built-up Area	**0.5179**	0.0893	-0.2313
Grassland	**0.5202**	0.0063	-0.2604
Plantations(Agric.)	**0.5185**	-0.0358	-0.2655
Tree Cover	0.2716	**-0.8282**	0.4946
Cum. Proportion of Var. (%)	69.5	87.5	98.4

[in bold] land use factor loadings ≥ 0.5 or ≤ -0.5

According to the PCA results in Table 4.4 above, the land use land cover explanatory variables were categorized into three(3) principal components basing on strength in linear correlation and their respective factor loading contributions of each land use land cover class to a its corresponding principal component. Thus grouping the land use land cover activities most associated together into a single group based on association as follows:

First Principal Component (PC1)

PC1 explained 69.5% of the variance within the land use land cover class dataset and was characterized by high positive loadings for Grassland, Plantations(Agric.) and Built-up Area (i.e. 0.5202, 0.5185 and 0.5179 respectively). Based on the positive correlation amongst each of the land use land cover class characteristics, PC1 therefore represented those areas within the stream catchment with human settlement with a high population density and infrastructure of built environment.

Second Principal Component (PC2)

PC2 explained 87.5% of the variance within the dataset and was characterized by high negative loadings for Tree Cover (i.e. -0.8282). Based on the inverse correlation, PC2 therefore represented those areas within the stream catchment whose trees and shrubs were being cut down to provide wood fuel for cooking and brick making.

Third Principal Component (PC3)

PC3 explained 98.4% of the variance within the dataset and was characterized by only high positive loadings for Bare Soil (i.e. 0.7507). Therefore, PC3 only represented those areas within the stream catchment that mainly represented areas of open fields (such as play grounds and compounds), marram roads, car washing bays, and garbage dump sites.

4.4.2.1 Regression analysis between the Land Use Principal Component and the stream Water Quality Parameters

Table 4.5 below summarizes the four land use pattern regression models that were significant with the water quality parameters.

Table 4.5: Regression Results for Land Use Principal Components and Water Quality Parameters

Variable	**Principal Components**								
	PC1			**PC2**			**PC3**		
	R^2	F	Pr > F	R^2	F	Pr > F	R^2	F	Pr > F
pH	0.500	33.52	**0.003***	0.087	0.288	0.629	0.208	0.790	0.440
EC	0.650	14.59	**0.022***	0.593	4.361	0.128	0.534	0.169	0.708
TDS	0.316	1.255	0.918	0.804	12.27	**0.039***	0.969	31.82	**0.030***
TSS	0.498	0.157	0.718	0.020	0.061	0.821	0.473	2.689	0.297
BOD	0.618	4.856	0.114	0.376	1.806	0.272	0.005	0.018	0.903
COD	0.784	10.92	**0.046***	0.125	0.427	0.560	0.059	0.190	0.693
Chloride	0.002	0.008	0.931	0.824	14.02	**0.033***	0.928	13.05	0.071
Sulphates	0.024	0.075	0.803	0.710	7.338	0.803	0.264	1.074	0.376
Ammonia	0.588	12.59	**0.024***	0.550	3.663	**0.016***	0.148	0.519	0.523
Nitrates	0.480	2.941	0.987	0.230	0.898	0.413	0.410	2.085	0.244
Nitrites	0.029	0.090	0.783	0.834	15.123	**0.030***	0.003	0.008	0.931
Total N	0.080	0.262	0.644	0.326	1.454	0.314	0.589	4.292	0.130
Total P	0.268	1.098	0.372	0.119	0.404	0.570	0.575	4.060	0.137
T.Coliforms	0.996	98.72	0.074	0.065	5.583	0.099	0.123	0.422	0.562
F.Coliforms	0.155	0.549	0.513	0.423	2.198	0.234	0.326	1.451	0.315

*significant at 0.05 level

PC1 vs. Water Quality

A principal component regression was used to test whether the areas in the stream catchment undergoing both urbanisation and infrastructure development (according to PC1) significantly predicted the quality of stream water. It was found that PC1 significantly predicted the levels in pH ($R^2 = 0.500$, $F = 33.52$, $p=0.003$), EC ($R^2 = 0.650$, $F = 14.59$, $p=0.022$), COD ($R^2 =0.784$, $F = 10.92$, $p=0.046$) and Ammonia ($R^2 = 0.588$, $F = 12.59$, $p=0.024$).

PC2 vs. Water Quality

A principal component regression was used to test if areas with a sparse tree cover (PC2) significantly predicted the quality of stream water. It was found that a decline in tree cover significantly predicted TDS concentration ($R^2 = 0.804$, $F = 12.27$, $p=0.039$), Chloride ($R^2 = 0.824$, $F = 14.02$, $p=0.033$) and Ammonia ($R^2 = 0.550$, $F = 3.663$, $p=0.016$).

PC3 vs. Water Quality

A principal component regression was used to test if areas with exposed and bare soil (PC2) significantly predicted the quality of stream water. It was found that an increase in exposed and bare soil significantly predicted TDS concentration ($R^2 = 0.969$, $F = 31.82$, $p=0.030$).

CHAPTER 5: DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Variation in the Downstream Concentrations of Selected Physicochemical Parameters

pH

The observed low upstream pH level around K1(Ntinda-Kyambogo) compared to the proceeding sampling stations downstream was because K1 was a more pristine section of the stream with a less developed sub-basin characterized by land use land cover activities like marshes, tree cover which had enough vegetation cover that filters urban pollutants thereby maintaining good pH levels.

The observed gradual increase in mid-stream pH levels between K2(Nakawa-Kireka) and K4(Mutungo) could be attributed to land use activities associated with the use and discharge of soaps and detergents such as surrounding slums, residential areas and car washing bays located within the mid-section the catchment. This is essentially because some of the residents in these locations have resorted to the collecting, washing and packing of plastics (i.e. polythene bags & plastic bottles) from the stream for resale to earn income. Furthermore, the locals that dwell in the communities within the mid-catchment area usually use and pour their domestic waste water after washing into the stream for lack of a proper drainage system, which was also seen in a similar study conducted by Kasozi & Tajuba, (2014).

The spike in pH downstream between K4(Mutungo) and K5(Butabika) could be attributed to the accumulation effect or the fact that this part of the watershed is situated on limestone($CaCO_3$) containing high concentrations of bicarbonate ions such when water percolates through the soil and flows through the ground water system it carries some of these bicarbonate ions into the stream towards K5(Butabika). Otherwise, level in pH would have been expected to drop to normal downstream due to the presence of marshes, swamps and trees that contain humic acids that are produced by decaying vegetation and the self-purification process of the stream.

An article by Fondriest Environment (2013) mentions detergents and soap-based products in wastewater as a potential cause of high pH levels in stream waters and further stipulates that further increment pH levels beyond 9.0 consequently damage the gills and skins of aquatic life if ammonia is present in water. On the other hand a study by Wanasolo *et al.*(2018) found established the rise in pH within Kinawataka to be due the effluent produced from the soft drinks making factories within.

Total Suspended Solids (TSS)

The observed elevated levels in the overall average concentration in TSS above NEMA permissible standards in Kinawataka stream is due to effluent inflows discharged from the city and surrounding suburbs. This municipal effluent within the Kinawataka stream catchment could be attributed to land use activity related pollution like: soil erosion usually associated to construction and agricultural site runoff; industrial and domestic wastewater discharge; urban runoff from roads and parking lots; flooding from chronically increased flow rates; algae growth from nutrient enrichment; dredging operations in the stream itself or feeder tributaries or ditches; and channelization.

The upstream concentration in TSS around K1 (Ntinda-KyU) was lower compared to the concentrations at other sampling stations because K1 was more pristine section of the stream with a less developed sub-basin characterized by land use land cover activities like marshes, tree cover, agricultural confined feeding operations and mixed urban areas. In a similar study by Seumaloisalafai (2015), lower upstream TSS concentrations were observed as well.

The observed gradual increase in downstream TSS concentration from around station K2(Nakawa-Kireka) to K5(Butabika) could be attributed to soil erosion associated to marram back fills, construction site runoff, industrial and domestic wastewater discharge, urban runoff from roads and parking lots, flooding from chronically increased flow rates, algae growth from nutrient enrichment, dredging operations in the stream itself or feeder tributaries or ditches; and channelization.

The presence of suspended solids in water is usually an indication of possible pollution from a wide variety of pollutants like pathogens (bacteria, protozoa, helminths), microbeads (from exfoliating soaps), silt, decaying plant & animal matter, industrial wastes, and sewage (Fondriest Environmental, 2014). Suspended solids can clog fish gills, either killing them or reducing their growth rate (Matshakeni et al., 2009). They also reduce light penetration. This reduces the ability of algae to produce food and oxygen. When the water slows down, as when it enters a reservoir, the suspended sediment settles out and drops to the bottom, a process called siltation. This causes the water to clear, but as the silt or sediment settles it may change the bottom. The silt may smother bottom-dwelling organisms, cover breeding areas, and smother eggs (Natural Resources and Environment Protection Cabinet (NREPC), 2020).

Total Dissolved Solids (TDS)

The upstream concentration in TDS around K1 (Ntinda-KyU) was lower compared to the concentrations at other sampling stations because K1 was a more pristine section of the stream with a less developed sub-basin characterized land use land cover activities like marshes, tree cover, agricultural confined feeding operations and mixed urban areas and thus the available TDS concentrations could be attributed to the natural accumulation of alkalinity and calcium concentrations resulting from processes like weathering.

The observed gradual increase in mid-stream TDS concentration from around station K2(Nakawa-Kireka) to K4(Mutungo) could be attributed to a number of factors such as: 1) the efficient delivery and accelerated dissolution of calcium carbonate associated with impervious surfaces and drainage systems in urban or built-up watersheds; 2) increased sulphate concentrations most likely resulting from more efficient delivery of deposited or spilled sulphur from impervious areas and wastewater leaks or illicit discharges most especially between K2 (Nakawa-Kireka) and K3(Mbuya); and 3) elevated chloride concentrations resulting from varied sources as wastewater leakages, runoff of lawn fertilizers and spills or discharges of varied substances containing chlorides associated with land uses like washing bays as well as car mechanic workshops which are the major especially between K2(Nakawa-Kireka) and K4(Mutungo).

The eventual drop in TDS concentration downstream around K5(Butabika) could be attributed to two factors namely: 1) the dilution effect due increased water volumes towards the end of the stream; and 2) the presence of pristine wetland vegetation such as swamps and marshes that filter the water from the inlets and tributaries around sub-basin K5(Butabika).

There in the long run elevated concentrations of TDS in the stream would pose caution and indicate the possible presence of harmful contaminants such as iron, manganese, sulphate bromide and arsenic.

Electro Conductivity (EC)

The upstream *EC* levels around K1 (Ntinda-KyU) were lower compared to the concentrations at other preceding sampling stations because K1 was a more pristine section of the stream with a less developed sub-basin characterized land use land cover activities like marshes and tree cover. Areas around K1 had land use activities that had a more intact vegetation cover therefore there's limited discharge of dissolved ions and inorganic dissolved solids (i.e. phosphates and nitrates) compared to the preceding land use activities mid-stream between K2(Nakawa-Kireka) and K5(Butabika) with significant urban and agricultural land use that have been shown to increase conductivity levels (Edwards et al., 2000).

Therefore, leap in EC levels mid-stream could be attributed to land use activities such as industrial complexes, commercial services, residential areas and confined feeding operations that are associated with urban runoff from roads, wastewater from septic systems and on-station wastewater treatment and runoff from agricultural fields that are non-point source in origin.

On the other hand, a high rate of degradation of organic matter by biological processes can also increase the conductivity of water (Dallas & Day, 2004). In a similar study on Kinawataka by Muwanga & Barifaijo (2006), the EC concentrations also exceeded the WHO guidelines and was attributed to grazing.

Biological Oxygen Demand (BOD)

The very low BOD concentrations upstream could be attributed to K1(Ntinda-KyU) having a more pristine environment with balanced land use land cover activities such as marshes, mixed urban and subsistence agriculture normally associated with low levels of organic waste discharge into the stream as opposed to K2(Nakawa-Kireka). BOD is a measure of the amount of oxygen consumed by microorganisms in decomposing organic matter in stream water and its sources usually include leaves and woody debris; dead plants and animals; animal manure; effluents from pulp and paper mills, wastewater treatment plants, feedlots, and food-processing plants; failing septic systems; and urban storm water runoff (US EPA, 2006). Therefore, a very high BOD concentration is indicative of presence of very low oxygen content in the water due rapidly decomposing organic matter.

This supports the spike in BOD concentration around K2(Nakawa-Kireka) that could be attributed to the discharge of high volumes of organic waste, usually associated to land use activities like residential areas (i.e. particularly Kinawataka slum) characterized by unplanned human settlements on either side of the stream due to uncontrolled urbanization. Therefore, due to the poor housing infrastructure and drainage systems in place, most of their solid waste and waste water (organic matter) are loaded into the stream at these stations. A study by Hua, (2017) showed the BOD of stream water to increase with residential areas due contamination from sewage discharge.

However, the subsequent drop in BOD downstream from K3(Mbuya) to K5(Butabika) could be attributed to decline in human settlements combined with marsh and swamp vegetation (wetland area) and a few communities carrying out animal husbandry.

Chemical Oxygen (COD)

The spike in COD concentration around K2(Nakawa-Kireka) could be attributed to the presence of industrial activity related land such as Oxy Gas, Pepsi Cola, Car Bonds and Washing Bays within the vicinity that discharge effluent containing organic matter into the stream. The COD later dropped downstream between K3(Mbuya) and K5(Butabika) as the industrial activity related land use forms declined in the subsequent lower parts of the catchments, as they were dominated more by human settlements, marsh and swamp vegetation (wetland area) and a few communities carrying out animal husbandry. A study by (Hua, 2017) associated elevated COD concentrations to increase in built-up area and particularly to particularly industrial activity related land uses.

COD is a measure of the amount of oxygen required to oxidize all organic matter (Matshakeni, 2016b). A high concentration in COD is usually as a result of the presence of high concentrations of organic matter and nutrients in water in the presence of a strong oxidizing agent. It is generally used to indirectly determine the amount of organic compounds in aquatic systems. High COD indicates presence of all forms of organic matter, both biodegradable and no biodegradable and hence the degree of pollution in waters (Islum et al., 2019). Therefore, effluent containing organic materials that would release nutrients directly (LVEMP, 2005) into the stream is being heavily loaded from the mentioned point sources of pollution located between stations K1 and K2. Therefore, the estimation of high COD along with BOD was indicative of toxic conditions and the high loadings of non-biodegradable substances (Islum et al., 2019).

Chlorides

The initial low Chloride concentration upstream could be mainly attributed to leaching from minerals, rocks and saline deposits in the natural setting due to the upper catchment's more pristine condition compared to preceding catchment sections downstream. Chloride is a salt compound resulting from the combination of the gas chlorine and a metal. Some common chlorides include sodium chloride ($NaCl$) and magnesium chloride ($MgCl_2$) (Natural Resources and Environment Protection Cabinet (NREPC), 2010).

However, for the case of K2(Nakawa-Kireka) and K4(Mutungo), the rise in chloride concentration could be attributed to industrial and municipal wastes associated with K2(Nakawa-Kireka) and irrigated agricultural activities associated with land use around K4(Mutungo). On the other hand, Chlorides may also be derived from domestic effluents, roads and industries (Bahar et al., 2008a) which were also evident within the stream catchment.

Sulphates

Sulphates can be naturally occurring which could explain the upstream low concentrations around K1(Ntinda-KyU) due to natural sources like mineral weathering and the decomposition of organic matter. Another natural contributor to sulphate concentration, would be the breakdown of leaves that fall into a stream, of water passing through rock or soil containing gypsum and other common minerals, or of atmospheric deposition (Hamid et al., 2020; KY NREPC, 2010).

However, the observed slight increment in suphate concentration mid-stream between K2(Nakawa-Kireka) and K4(Mutungo) could be attributed to; 1) urbanization and industrial related land uses such as the burning of fossil fuels resulting in the bulk precipitation and dry deposition of sulphate ions as well as runoff containing agricultural fertilizers and herbicides on a small scale respectively; and 2) the growth of algal blooms especially around K2(Nakawa-Kireka) from effluent containing large nutrient concentrations leading to eutrophication.

Ammonia

The spike in Ammonia concentration around the mid-stream sampling stations K2(Nakawa-Kireka) and K3(Mbuya) could be attributed to sewage discharge from both the commercial structures and residential areas related land use forms located on either side of the stream as well as slums. This in turn is supported by prior studies by Wanasolo et al., (2018) and

Matshakeni, (2016b) that found elevated concentrations of Ammonia to associated with organic pollution resulting from domestic sewage, industrial waste in built-up areas.

Ammonia is a decomposition product from urea and protein usually found in domestic wastewater (Natural Resources and Environmental Protection Cabinet (NREPC), 2010a). The average overall ammonia concentration of the stream exceeded 0.53mg/L which according to the Kentucky Natural Resources and Environmental Protection Cabinet (NREPC) (2010) is toxic to fresh water organisms. This greatly endangers the Lake Victoria as a reservoir.

Nitrates

The initial elevated Nitrate concentration both upstream and mid-stream (from K1 to K3) could be attributed to land use activities that yield NO_3-rich municipal waste water that comes from residential wastes, septic systems and garbage dump which is very characteristic of Kampala city. The Nitrate concentration later dropped downstream in the preceding lower catchments attributed to: 1) the small scale infrastructural developments in the vicinity of the lower stream catchments, hence a decline in the volume of municipal waste generated; 2) stream self-purification related factors like increased volume flow and dilution factor considering that it was the wet season; and 3) absorption and conversion of NO_3 to ammonia. A similar study by Hamid et al., (2020) found the increase in Nitrate concentration to be associated with municipal waste in urban streams.

Total Phosphorus (TP)

As observed, the lower initial upstream TP concentration around K1(Ntinda-KyU) compared to its preceding mid-stream concentrations around K2(Nakawa-Kireka) and K3(Mbuya) could attributed to the presence of a more pristine environment in sub-basin areas within the vicinity to K1. These were characterized with land use land cover activities such as fairly undisturbed vegetation cover comprising of both marshes, swamps and tree cover coupled with mixed urban built-up areas, whose yield of TP containing effluent was rather low compared to the land use activities midstream section of the stream catchment. Simply because, some of the phosphorus is used by vegetation and soil microbes for normal growth when in appropriate quantities.

However, the spike in TP concentration around sampling station K2(Nakawa-Kireka) could be attributed to effluent discharged from land use activities related to uncontrolled urbanisation. Areas around K2(Nakawa-Kireka) were dominated by: 1) industrial, commercial complexes and residential areas such as the Kinawataka slum that discharge sewage and a lot of waste water containing high TP loadings; and 2) detergents used by car washing bays along the stream between stations K2 and K3. In a study by Tumuheire (2017), the concentration levels of Total phosphorus flowing out of the stream of upper Kinawataka wetland exceeded the maximum permissible levels set by NEMA which was similar to the high levels observed around station K2 in Fig.4.9. In excess quantities, phosphorus can lead to water quality problems linked to eutrophication and harmful algal growth which has been found to be an indication of pollution due to erosion carrying domestic sewage, industrial, and agricultural effluents with fertilizers (Seumaloisalafai, 2015). The ideal range known to prevent long term eutrophication for a water body is 0.5 mg/L to 0.005mg/L according to the National Aquatic Resource Surveys (2017). However, Kinawataka's average overall phosphorus concentration exceeded this range putting the waters at risk of eutrophication.

On the other hand, the observed drop in TP concentration downstream from K3(Mbuya) through K4(Mutungo) to K5(Butabika) could be attributed to the decline in built-up area and increase in wetland vegetation in form of marshes and swamps within the lower catchment areas. This is because wetlands naturally serve as sinks for phosphorus found in sediments or dissolved in water or other particulates that are transported with these particles during erosion (Matshakeni, 2016b).

Total Nitrogen

The observed spike in nitrogen concentration around sampling station K4(Mutungo) could be attributed to: 1) nutrient and fertilizer runoff from extensive land use agricultural activities as some communities utilize these the wetland fertile soils to grow crops like bananas, sugarcanes, yams and maize: and 2) the downstream garbage accumulation as the water flows towards K5(Butabika). Similar to what was found by Peterson & Risberg, (2008) that fertilized agricultural field and lawns, sanitary landfills and garbage damps contribute to nitrogen related pollution. A study by Kibena et al., (2014) showed strong positive relationships for both built-up urban areas and agricultural activities unlike this study that only found the relationship in catchment areas with agricultural activities.

In principle the major routes of entry of nitrogen into bodies of water are municipal and industrial wastewater, septic tanks, feed lot discharges, animal wastes (including birds and fish), according to Peterson & Risberg, (2008), but wasn't the case for the areas midstream around K2(Nakawa-Kireka) and K3(Mbuya) that showed low nitrogen loadings. Excess nitrogen concentrations can cause over-production of plankton and as they die and decompose they use up the oxygen which causes other oxygen-dependent organism to die (Bergstrom & Ritter, 2000).

5.2 Variation in the Downstream Concentrations of a Select Microbiological Parameters

Total Coliforms

The observed spike in levels of total coliforms around K2(Nakawa-Kireka) could be attributed to the stream increasingly receiving inflow of sewage and waste effluents from the surrounding areas due to municipal and peri-urban related land use activities. A prior study by (Islam et al., 2019) showed there to be a strong link between total coliforms and municipal effluents. DOH (2007) attributes total coliforms to environmental non-point sources of pollution associated with soil and vegetation. A study by Hua, (2017) showed that were built-up areas were significant polluters of water quality through total coliforms.

However, the observed downstream decline in the level of total coliforms around K3(Mbuya) towards K5(Butabika) could be attributed to: 1) the reduced inflow of sewage and waste effluents from the surrounding areas associated with low residential cover and built-up area; 2) increase in stream volume flow; and 3) dilution of the stream water. Compared to K5(Butabika), K4(Mutungo) had relatively higher levels of total coliforms due to inflows of waste effluents containing animal manure from areas with animal husbandry (feed lots). Simply because, total coliforms are a group of bacteria that are widespread in nature. All members of the total coliform group can occur in human faeces, but some can also be present in animal manure, soil, and submerged wood and in other places outside the human body (USEPA, 2012).

Faecal Coliforms

The observed gradual increase in level of faecal coliforms between K1(Ntinda-KyU) and K3(Mbuya) could be attributed to increasing inflows of raw and municipal sewage from domestic and animal husbandry activities like poultry farming taking place in both the urban and peri-urban areas within the catchment. This is because faecal coliform bacteria in aquatic environments are a sub group of total coliforms that indicate water contamination with the faecal material of man or other animals (Natural Resources and Environmental Protection Cabinet (NREPC), 2010b). A study by, Matshakeni, (2016) also found faecal coliform contamination to be due to sewage contamination of in built-up areas. Faecal coliform contamination poses a potential health risk for the communities utilizing to waterborne pathogenic diseases include typhoid fever, viral and bacterial gastroenteritis and hepatitis A.

However, the downstream drop in faecal coliforms could be attributed to 1) the reduced inflow of sewage and waste effluents from the surrounding areas associated with low residential cover and built-up area; 2) increase in stream volume flow; and 3) dilution of the stream water.

5.3 The Major Land Use Activities and their Distribution within the Kinawataka Stream Catchment

5.3.1 The Major Land Use Activities in Kinawataka Stream Catchment

According to the results from satellite image classification analysis in Fig. 4.1, the Kinawataka stream catchment comprised of *Bare Soil, Built-up Area, Grassland, Plantations (Agric.)* and *Tree Covers* as the major land use activities which were similar to those found in a study by Tumuheire (2017b). The five (5) mentioned land use activities each represent a combination of several human (land cover) activities as observed on ground, for instance:

Bare Soil represented those areas within the catchment that were: undergoing extensive clearing of vegetation; areas that were being back filled with marram for both road & industrial construction; as well as damping of solid waste which were similar to the activities mentioned in Otage's, (2012) newspaper article in the Daily Monitor at the time.

Built-up Area was representative of the urban areas which were heavily development with concrete and impervious surfaces such as buildings, slabs, pavers and tarmac roads. This is congruent with the fact that part of Ntinda and Nakawa areas had been gazette by the government for industrial development (Wanasolo *et al.,* 2018), it also represented mushrooming (up-coming) human settlements often located in slummy areas of Kinawataka village and surrounding areas.

Grassland mainly represented the grass contained with compounds, lawns as well as thin vegetation located along roads and walk ways.

Plantations (Agric.) represented those areas within the catchment that were covered by papyrus plantations and other agricultural plantations such as; sugarcanes, bananas and yams located within sections of the Kinawataka swamp. This is indicative of the encroachment on the swamps by the local residents for subsistence farming by the local residents living within the Kinawataka slums as result of the lack of demarcated wetland boundaries (Tenywa, 2007).

Tree Cover was representative of the very dense vegetation cover that included hard wood indigenous trees, thick shrubs, as well eucalyptus plantations.

5.3.2 Distribution of Land Use Activities within the Kinawataka Stream Catchment

On the other hand, the observed variation in the distribution of the land use activities within the stream catchment is dependent on the landscape capabilities and the institutional planning & regulatory framework within the stream catchment area. Therefore, the overall dominance in Built-up Area can be attributed to the fact that the catchment lies within the area (*Ntinda-Nakawa)* that had been gazette by the government for industrialization which consequently became a conflicting interest as far as the trade-off between wetland degradation and sustainable development was concerned (Musoke, 2014). It is understood that the observed increment in coverage of Built-up Area is due to the rapid conversions of the then other land uses *(i.e. Tree Cover, Plantations (Agric.) & Grassland to Bare Soil)* to Built-up Area at the expense of the wetland vegetation to allow for the construction of more human settlements, road networks, commercial buildings and schools.

5.4 Relationship Between Land Use Patterns and Kinawataka Stream Water Quality

5.4.1 Spearman's Rank Correlation

Bare Soil and Water Quality:

The observed significant increase in cover in *Bare Soil* with concentration in *TSS* and *Faecal Coliforms* could be attributed to soil erosion that is usually associated to *Bare Soil* related land use land cover activities in transitional areas such as cleared land for construction or agriculture, quarries, open fields, marram back filled sites and garbage dump sites especially during the wet season. The sediments and dust particles found in the soil carried with the water contain a wide variety of pollutants like pathogens (bacteria, protozoa, helminths) (Fondriest Environmental, 2014). Another prior study by Zeb *et al.* (2011) also observed soil erosion to have been a significant contributor towards increasing the concentration of TSS in water.

Built-up Area and Water Quality:

The observed positive correlation between Built-up Area, SO_4^{2-} , NH_3 and faecal coliforms concentrations could be attributed to effluent generated in areas that were heavily development due to rapid urbanization. Commercial buildings and services, industries, usually characterize built-up areas, residential areas made of concrete and impervious surfaces such as buildings, slabs, pavers, and tarmac roads from which large quantities of municipal waste as domestic sewage and industrial waste containing SO_4^{2-} and NH_3 are discharged. A similar studies by Bahar et al., (2008b) and Haidary & Amiri, (2013) showed the sulphate concentration to increase built-up areas while Wanasolo et al., (2018) and Matshakeni, (2016b) found elevated concentrations of Ammonia to associated with organic pollution resulting from domestic sewage, industrial waste in built-up areas in similar studies.

Grassland and Water Quality:

The observed positive correlation between Grassland, NH_3 and NO_3^- concentrations could be attributed to organic waste produced because of livestock grazing. Grazing has been found to yield NH_3 and NO_3^- through leaching of urea from animals' urine into the soil (Webb et al., 2005). Other studies have however found grassland to have a positive influence on water quality (Huang et al., 2013b), particularly $NH_{3.}$ This was because the grass played a key role in reducing surface run off and absorbed the pollutants.

Plantations (Agric.) and Water Quality:

Plantations (Agric.) and the NO_3^- concentration could be attributed to run off from agricultural fields containing significant amounts of $NO_{3.}^-$ Plenty of soil nutrients are carried by run off from agricultural fields especially those with poor agricultural practices in addition to fertilizer run off (Namugize et al., 2018). In a prior study by Hamid et al., (2020) found feed lots as an agricultural point source of pollution for NO_3 simply because animal manure is a source of $NO_{3.}$

Tree Cover and Water Quality:

The observed significant increase in *Tree Cover* with a decline in *pH* level, could be attributed to mainly: 1) the filtration of the water as it percolates through the soil and the ions are taken up by the plant roots; and 2) stream inflowing water picking up acidity due to humic soils that usually occur in forest-floors and marshes as a result of decaying vegetation causing the water to be slightly acidic. Thus the close proximity of tree cover close enough to stream banks has been seen to contribute towards a low water pH(Roswell, 2005).

The observed significant inverse relationship between *Tree Cover EC, BOD* and *Chloride* concentration could be attributed to trees being excellent filters for urban pollutants often characterized by organic and inorganic compounds, nutrients and fine particulates responsible for raising the *EC, BOD* and *Chloride* concentrations. Trees serve as natural sponges, collecting and filtering rainfall and releasing it slowly into streams and rivers, and are the most effective land cover for maintenance of water quality. They achieve this by filtering sediments and other pollutants from the water in the soil before it reaches a water source, such as a stream, lake or river (Somvichian-Clausen, 2016). A previous study by Bahar et al. (2008), observed similar effects of trees on the *EC* and *Chlorides*.

5.4.2 Principal Component Regression

PC1 vs. Water Quality:

The observed increase in the levels in *pH* with *PC1* (areas experiencing rapid infrastructure development in form residential areas, communication, education, health, power, market, commerce and leisure facilities) areas could be attributed to those land use activities associated with the discharge and use of large volumes of soaps and detergents such as residential areas and car washing bays. On the other hand, this could also be attributed to presence of exposed large deposits limestone during road construction which are easily eroded into the stream.

The observed increase in the levels in *EC* in the stream with *PC1* could be attributed to effluent containing inorganic wastes such as the ions, compounds and salts that find their way into the water through run off from urban, mixed urban and agricultural land use land cover activities that are characterized by concrete and impervious built surfaces and drainage systems. In a similar study by Edwards et al., (2000), also confirmed a strong relationship between stream conductivity and urban and agricultural land use activities.

The observed increase in the levels in both NH_3 and *COD* could be associated with contamination that was organic in nature having its source from sewage discharge, untreated wastewater and septic systems predominantly in urban areas as well as congested residential areas with poor sanitation facilities and industries. Similar results were documented by (Matshakeni, 2016b; Wanasolo et al., 2018). On the other hand, this could also be attributed to farm input chemicals such as herbicides and pesticides off from areas practising agriculture within the catchment. Bahar's et al., (2008) observations in a study on the '*Relationship* *between river water quality and land use in a small river basin running through the urbanizing area of Central Japan'*, were in support of agriculture being a significant contributor to the increase in COD concentration.

PC2 vs. Water Quality:

The observed decline in the concentration in both *TDS*, NH_3 and Nitrites in catchment areas with land use activities that promote *tree cover (PC2)* such as ever green forests like eucalyptus plantations and swamps could be attributed to these physicochemical parameters being associated with key plant nutrients which when taken up by plants play an important role in adding nitrogen, promoting photosynthesis and plant growth. This was also similar to what was seen in sub-basins K1(Ntinda-Kyambogo) located upstream and K5(Butabika) located downstream that had a significantly larger tree cover and thus the water samples taken at these stations had lower concentrations in *TDS* and NH_3 while on the other hand sub-basins with less tree cover and more urban or built-up area and bare soil mid-stream had elevated *TDS* and NH_3 levels.

On the other hand, elevated chloride concentrations were associated with areas along the stream that had very little or no tree cover and often discharge varied substances containing chlorides such as car washing bays, car mechanic workshops and wastewater leakages. This was similar as well to the elevated *chloride* concentrations observed mid-stream between K2(Nakawa-Kireka) and K4(Mutungo) populated by slums, car washing bays and mechanic workshops.

This emphasizes the importance of conserving or planning for urban green spaces(trees) in urban planning as trees are excellent filters for urban pollutants and fine particulates which without would allow the direct flow of pollution from various land use activities into Murchison bay area unfiltered.

PC3 vs. Water Quality:

Particulary in this study, the oberseved positive correlation between PC3 and the levels in TDS could be attributed to the soil erosion from then on-going road construction that was taking place within the stream catchment at that time. This was because PC3 areas were mainly characterized with bare soil and thus experienced a lot of soil eroison.

5.5 CONCLUSIONS

By analysing the relationship between the land use distribution patterns and water quality within the Kinawataka stream catchment, this thesis has shown how various human activities directly or indirectly influenced the stream water quality.

5.5.1 To determine the major land uses and their distribution within the stream catchment

The area mid-section of the stream catchment was densely populated and thus a hot spot for infrastructure development such as roads, shelters, schools, sewers and commercial structures. This part of the wetland has undergone intense encroachment due human activities.

5.5.2 To determine the variation in concentration of selected physicochemical parameters (i.e. pH, EC, TDS, TSS, BOD, COD, Cl- and SO_4^{2-}) downstream

- The high levels for both *TSS* and *EC*, raises concern of the presence of certain human activities that generate and discharge effluent that isn't in line the national effluent requirements. These human activities may fall under either one or both of the point and non-point sources of pollution within the stream catchment.
- The $SO_4{}^{2-}$ loadings were already high enough above 0.5mg/L to promote the growth of algal blooms, hence deteriorating the quality of water.

5.5.3 To determine the variation in concentration levels of selected nutrient parameters downstream

- The NH_3 loadings were already high enough above 0.53mg/L to cause toxic conditions for fresh water organisms. The loss in the diversity of fresh water organisms such as fish causes food insecurity to the surrounding communities.
- The *TP* loadings exceeded the range of 0.005mg/L to 0.5 mg/L, beyond which caused eutrophication. Therefore, in the invent that the discharge of these pollutants into the stream goes on unchecked, their accumulation will further deteriorate the stream's water quality.

5.5.4 To determine the variation in concentration of selected microbiological parameters downstream

The presence faecal coliform contamination was indicative of poor sanitary conditions that are normally associated with densely populated areas that lack proper sanitary facilities. As a result, the stream water is very unfit for domestic use as well as human consumption, which poses a risk of the spread of water-borne diseases among the communities within the stream catchment.

5.5.5 To determine the effect of the land use patterns on the water quality parameters of the stream

The areas within the stream catchment with significant *Tree Cover* had better water quality, as these represented the pristine sections of the wetland than those that were heavily transformed such as the Built-*up, Bare Soil, Grassland* and *Plantations(Agric.) areas* due to human activities.

5.6 RECOMMENDATIONS

5.6.1 Recommendations for Further Research

- A more detailed study focusing on both seasons i.e. wet and dry should be carried out. This will give a fair representation of how land use could affect stream water quality, in regards to pollution prevention and proper management within the catchment level. Comparison analysis between the two seasons would make it possible and ideal to generate more interesting information in this regard to help with future management and pollution control at the source level.
- For further research, an epidemiological study could be done to assess a spatial distribution and correlation analysis between the water-borne disease cases or illness reported, and faecal-indicator bacteria concentrations from those who reside within Kinawataka catchment or those whose households are serviced by the water supply system sourced from Kinawataka stream.

5.6.2 Recommendations to Policy Makers and Government

- The levels of contaminants will change again according to future changes in the land use patterns. Hence future land developments and management should consider with sustainable development for the future generations. With better land–use planning within the stream catchment, we may be able to curtail some of the current water quality problems. Since water quality is maintained or improved by increasing the tree cover and swamp vegetation in the catchment, the protection of wetland vegetation should be encouraged.

- The results of microbiological analysis in this study revealed a great risk of Kinawataka stream from microbial contamination from the surrounding settlements that dump their faecal wastes into the stream. The government is encouraged to promote proper sanitary pit latrines or toilets for the surrounding slum communities especially mid-stream (mid catchment).

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APPENDICES

Appendix 1: Water Quality Raw Data

Sampling Station	Month	Sample	pH	EC *µS/cm*	TDS *mg/L*	TSS *mg/L*	BOD *mg/L*	COD *mg/L*	Cl *mg/L*	Sulphates *mg/L*	Ammonia *mg/L*	Nitrates *mg/L*	Nitrites *mg/L*	Total N. *mg/L*	Total P. *mg/L*	T.Coliform *cfu/100ml*	F.Coliform *cfu/100ml*
K1	March	1	7.2	106	74	13	4.6	30	22	9	0.397	0.302	0.12	0.123	0.473	305	24
		2	7.5	396	277	1	2	12	29.3	7	0.285	0.197	12.255	3.935	0.461	770	306
	April	1	7.6	414	228	9	7.3	12	18	8	0.294	5.922	0.194	7.337	0.343	920	130
		2	7.4	424	233	4	2.4	24	9.8	0	0.124	1.367	0.678	3.113	0.422	240	72
	May	1	7	337	185	7	0.564	7	22	7	0.06	5.62	0.194	0.446	0.173	435	142
		2	8	433	238	68	9.5	30	26	8	0.643	4.106	0.23	6.834	0.135	535	152
K2	March	1	7.7	417	292	148	2	30	33	22	3.198	2.042	0.234	5.02	0.397	1400	240
		2	7	380	209	54	5	97	33.8	12	4.7	2.104	0.864	4.17	12.26	2100	155
	April	1	7.9	421	232	154	2.9	20	24	9	5.95	3.71	0.178	11.932	0.257	5040	244
		2	7.6	417	229	40	2.6	35	4	14	0.099	0.365	0.631	4.067	0.992	2944	577
	May	1	7.2	435	239	35	0.9	105	38	12	3.433	1.99	0.57	2.657	0.406	654	211
		2	8	425	234	96	9.6	25	38	12	3.393	3.453	0.52	0.628	0.21	673	345
K3	March	1	7.8	380	266	90	4.2	15	31	6	9.87	2.306	0.864	4.694	0.53	600	432
		2	7.8	380	209	90	4	20	31.1	11	4.57	2.469	0.864	4.694	0.154	458	344
	April	1	7.7	449	247	56	3.6	19	25	9	5.87	3.433	0.29	0.75	0.227	510	355
		2	7.2	436	240	32	2.3	32	3.7	39	0.876	1.406	0.094	3.046	0.53	6960	1235
	May	1	7.5	476	262	77	27	34	40	9.9	4.226	1.991	0.96	2.886	2.18	675	291
		2	8	447	245	105	11	28	42	11	2.799	3.567	0.72	5.254	6.48	873	391
K4	March	1	7.8	421	295	116	1.5	11	26	19	2.865	1.944	0.171	2.542	0.654	405	335
		2	7.9	436	305	4335	4.2	22	53.7	15	0.807	0.657	0.081	11.866	0.781	445	333
	April	1	7.8	448	246	66	9	27	53.7	9	6.206	3.445	0.304	9.29	0.189	377	209
		2	7.7	442	309	48	11	20	9.8	7	0.054	0.0875	0.564	5.742	0.071	7284	253
	May	1	7.9	477	262	56	5.8	68	40	11	4.52	1.399	0.82	2.866	0.484	865	322
		2	7.6	450	248	16	12	26	42	10	2.86	2.272	0.73	5.634	0.576	765	222
K5	March	1	7.9	395	217	116	3.3	33	34	9	3.19	1.965	0.127	0.362	0.867	306	230
		2	8.4	436	240	4335	5	27	30.2	11.6	4.69	0.453	1.783	3.984	0.651	338	277
	April	1	7.8	494	272	66	14	35	29.7	9	5.118	3.375	0.28	12.379	0.517	375	260
		2	8	474	260	50	0.05	0.286	28	3	0.942	1.311	0.476	4.242	1.017	2944	580
	May	1	8.4	436	240	58	5	17	30.2	11.6	4.69	0.453	1.783	3.984	0.651	201	201
		2	8	479	264	4000	10	43	43	10	3.094	0.889	0.56	4.749	0.148	904	330