IMPACTS OF ANTHROPOGENIC ACTIVITIES ON WATER QUALITY AND BIOTIC ECOSYSTEM IN PAGER RIVER, KITGUM MUNICIPALITY, NORTHERN UGANDA

BY

AMONO HOPE
BEM, KIU
20/U/2326/MES/PS

A RESEARCH REPORT SUBMITTED TO THE FACULTY OF AGRICULTURE AND ENVIRONMENT IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER'S OF SCIENCE IN ENVIRONMENTAL SCIENCE AND NATURAL RESOURCE MANAGEMENT OF GULU UNIVERSITY

OCTOBER, 2023

DECLARATION

I, **Amono Hope** declare that this research report is my original work which has never been submitted for any award in any institution.

Signature: ……..... Date: ……16th/10/2023……

AMONO HOPE

20/U/2326/MES/PS

APPROVAL

I hereby sign to approve that this research report has been prepared under my supervision.

Supervisors:

Name: **Dr. Denis Nono (PhD)** Date: 24/10/2023

Sign: ……...

Name: **Dr. Richard Louis Labeja (PhD)** Date: 24/10/2023

Sign: …….

DEDICATION

I dedicate this research to my parents Lamakio Celest Odonga and Ayoo Alice Odonga, my uncle Anywar Tonny, my aunty Ayoo Santine. To my siblings; Omona Alfonse Degozone, Lamunu Agnes, Laker Jacqueline, Acala Paska, Atimango Benna, Auma Fiona Abur, Aciro Joyce, Apoto Jilda Joan, Akello Catherine,Oringa Vincent Zamasky not forgetting my friends Ojok Raymond and Aber Brenda

May almighty god bless you all.

ACKNOWLEDGMENT

I would like to acknowledge and give my warmest thanks to my supervisors Dr. Denis Nono and Dr. Richard Louis Labeja who made this work possible. Their guidance and advice carried me through all the stages of writing my project. I would also like to thank my sponsor, Mastercard Foundation (RUFORUM) for giving me the great opportunity to pursue this education level and fully supporting my research project.

I would also like to give special thanks to my parents, siblings, friends and my entire family for their continuous support and understanding when undertaking my research. Your support and prayers for me were what sustained me this far.

Finally, I would like to thank God, for letting me through all the difficulties. I have experienced your guidance day by day.

TABLE OF CONTENTS

DECLARATION ..... **i**
APPROVAL ..... **ii**
DEDICATION ..... **iii**
ACKNOWLEDGMENT ..... **iv**
TABLE OF CONTENTS ..... **v**
LIST OF FIGURES ..... **viii**
LIST OF TABLES ..... **ix**
ABBREVIATIONS AND ACRONYMS ..... **x**
ABSTRACT ..... **xii**
CHAPTER ONE: INTRODUCTION **1**
1.2 Statement of the Problem 3
1.3 Study Objectives 4
1.3.1 General objective 4
1.3.2 Specific objectives 4
1.4 Research Questions 5
1.5 Significance of the Study 5
1.6 Ethical Considerations 5
1.7 Limitations of the study and possible way forward 6
1.8 Theoretical Framework 7
CHAPTER TWO: LITERATURE REVIEW **8**
2.0 Introduction 8
2.1 The Anthropogenic Activities with Potential Negative Impact on Water Quality 8
2.2 The Potential Influences of the Anthropogenic Activities on Water Quality of Rivers 10
2.3 The Potential Influences of the Anthropogenic Activities to Biotic Ecosystem of Rivers 14
2.4 River protection/buffer 17

2.4 Conclusion 17

CHAPTER THREE: RESEARCH MATERIALS AND METHODS 18

3.0 Introduction 18

3.1 Study Area 18

3.2 Data Collection 19

3.2.1 Assessing anthropogenic activities along Pager River 19

3.2.2 Determining influences of anthropogenic activities on the water quality 20

3.3 Selection of study sites 20

3.3.1 Water quality parameters and samples collection 21

3.3.2 Testing selected water quality parameters 21

3.4 Data Analysis 26

3. 4.1. Analysis of anthropogenic activities along Pager River 26

3.4.2 Analysis of Water Quality Data 26

3.4.3 Analysis of Macroinvertebrate Diversity Metrics data 29

3.6 Research Dissemination Plan 30

CHAPTER FOUR: PRESENTATION OF RESULTS 31

4.1 Introduction 31

4.2 Anthropogenic Activities identified along Pager River 31

4.3 Variation of Water Quality at different locations along Pager River 33

4.3.1 ANOVA and t-test results of selected water quality parameters 33

4.3.2 Water quality indicators for irrigation and domestic use 34

4.4 Variations of Benthic Macroinvertebrate metrics at different locations along Pager River 37

4.4.1 ANOVA and t-test results for selected Benthic Macroinvertebrate metrices 37

CHAPTER FIVE: DISCUSSION OF RESULTS 40

5.1 Introduction 40

5.2 Anthropogenic Activities along the Pager River with potential influence on Pager River water quality 40

5.3 Influence of Anthropogenic Activities on River Pager water quality 42

5.3.2 Suitability of water for irrigation 45

5.3.3 Suitability of water for domestic use 45

5. 4 Influence of Anthropogenic Activities on River Pager Biotic Ecosystem 46

CHAPTER SIX: CONCLUSION AND RECOMMENDATION 48

6.1 Conclusions 48

6.2 Recommendations 49

REFERENCES 50

APPENDICES 64

Appendix 1: Proposed Survey Checklist 64

Appendix 2: The GPS locations of anthropogenic activities along River Pager with potential negative impacts on water quality and biotic ecosystem 66

Appendix 3: Actual Values for Physicochemical and Bacteriological Water Quality Parameters ... 69

Appendix 4: Daily rainfall record from March to July 2022 70

Appendix 5: Benthic macroinvertebrates field/sites counts 72

Appendix 6: Introductory Letter 78

Appendix 7: Gulu University Research Ethics Approval 79

LIST OF FIGURES

Figure 1 Map of Kitgum Municipality showing the study area and water sampling sites 18

Figure 2: Percentage of Anthropogenic activities identified during survey along Pager River 31

Figure 3: Locations of the anthropogenic activities along the river Pager with potential negative impacts on water quality and biotic ecosystem.....32

Figure 4: Monthly SAR, MAR and EC at the study sites.....35

Figure 5: Monthly WQI at the study sites.....36

LIST OF TABLES

Table 1: Standards used for irrigation water suitability (Gupta and Gupta, 1987) 27

Table 2: Water quality index classification (Valentina, *et al*., 2018) 29

Table 3: UNBS and WHO standards for potable water 29

Table 4: ANOVA results of selected water quality parameters 33

Table 5: T-test results of selected water quality parameters 34

Table 6: Comparison of mean monthly water quality parameters with UNBS and WHO standards for potable water 37

Table 7: Site occurrence and mean ± Standard deviation of species abundance (number of individuals) of a given taxon m^{-2} of benthic macroinvertebrates along Pager River, Kitgum during a period of March to July. 38

Table 8: ANOVA results for benthic macroinvertebrates metrics (Mean ± Standard Deviation and p-value) 39

Table 9: T-test results for benthic macroinvertebrates metrics (Mean ± Standard Deviation and p-value) 39

ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
APHA	American Public Health Association
ASPT	Average Score per Taxa
BOD	Biological Oxygen Demand
CDM	Clean Development Mechanism
COD	Chemical Oxygen Demand
CSV	Comma Separated Values
DO	Dissolved Oxygen
DWD	Directorate of Water Development
E	Species Evenness
EC	Electric Conductivity
FC	Faecal Coliform
GPS	Global Positioning System
GUREC	Gulu University Research Ethics Committee
H'	Shannon-Weiner Index
HID	Health Inspector Division
IDW	Inverse Distance Weighting
IUSS	International Union of Soil Sciences
MAR	Magnesium Adsorption Ratio
MMIF	Multimeric Macroinvertebrate Index Flanders
NEA	National Environment Act
NEMA	National Environmental Management Authority
NSFWQI	National Sanitation Foundation Water Quality Index
NWSC	National Water and Sewerage Corporation
PAH	Polycyclic Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyls (PCBs)
PHC	Primary Health Care
S	Species Richness
SAR	Sodium Adsorption Ratio

SMEWW	Standard Methods for Examination of Water and Wastewater
SPM	Suspended Particulate Material
STORET	Storage and Retrieval
TBC	Total Bacterial Count
TDS	Total Dissolved Solids
UNBS	Uganda National Bureau of Standards
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations International Children Emergency Fund
UNWWD	United Nations World Water Development
USGS	United States Geological Survey
WFP	Water Framework Directive
WHO	World Health Organization
WQI	Water Quality Index
WQP	Water Quality Parameter

ABSTRACT

This study assessed anthropogenic activities along Pager River within Kitgum Municipality and their potential influence on the river water quality and biotic ecosystem. It also evaluated suitability of the river water for domestic and irrigation use. A survey was conducted to identify the anthropogenic activities along the river that are within 30m buffer zone. Water quality and benthic macroinvertebrate were analyzed at 4 selected sites along the river once per month for five months from March 2022 to July 2022. The study sites were selected at the upstream (before the municipality), within Kitgum municipality and after the municipality (downstream). The water quality parameters analyzed at each site were Temperature, pH, Turbidity, Electrical conductivity (EC), Total Dissolved Solids (TDS), Hardness, Nitrate, Calcium (Ca), Magnesium (Mg), Sodium (Na), Total Bacterial Count (TBC) and Fecal Coliform (FC). The Benthic macroinvertebrate metrics/parameters that were analyzed include; Taxonomic richness, Species abundance, Species richness (S), Species evenness (E), Shannon Weiner Index (H') and Average score per taxa (ASPT). The water quality and benthic macroinvertebrates data were analyzed using one-way ANOVA and student t-test. River water suitability for domestic use was determined using Water Quality Index (WQI) and for irrigation by Sodium Adsorption Ratio (SAR), Magnesium Adsorption Ratio (MAR) and EC. The finding from the survey conducted revealed that within Kitgum Municipality, the mostly practiced anthropogenic activities along the river bank with noncompliance with river bank regulation guidelines was sandmining, followed by agriculture, waste disposal, sanitary facilities, settlements and car washing. ANOVA and t-test results revealed that Pager River water (in terms of turbidity, FC and TBC) and aquatic environment were greatly compromised within and downstream the Kitgum Municipal area likely due to the anthropogenic activities. The study found that the river water quality was unsuitable for domestic use (WQI>100) but suitable for irrigation (SAR, EC and MAR within acceptable limits). The results of this study inform decision to provide necessary guidelines and policies that can be used to control or stop human activities which were found commonly practiced within the buffer zone along the Pager River to ensure that River Pager is sustainably conserved/protected to provide good quality water and other ecosystem services.

CHAPTER ONE: INTRODUCTION

1.1 Background

Water covers 71% of the Earth's surface and thus is vital for life (European Environment Agency, 2018). It is estimated that 96.5% of the water is in seas and oceans. Thus, only 2.5% of the Earth's water is fresh water, and 98.8% of this is held as ice and groundwater (USGS, 2019). Less than 0.3% of fresh water is contained in rivers, lakes and the atmosphere, while an even lower amount (0.003%) is in biological bodies and in manufactured products (Annan, 2015). Good quality water is very important in health development and apart from maintenance of life, it is also used for activities like cooking, generating hydropower, fishing, washing, industrial and commercial purposes to mention but a few. Therefore, its access and quality are of paramount importance (Ayraci & Hoda, 2015).

Human activities are of great concern on the quality of water resources in the world. These are two sided, that is, positive effects and the negative effects. Water **r**esources are natural sources of water that are potentially useful in agricultural, industrial, household, recreational environmental activities and human consumption (UNWWD, 2008). Examples include groundwater, rivers, lakes and reservoirs.

Causes of water pollution refer to the agents that determine the rate of pollution of the water bodies, wetlands or the environment (Javier, *et al*., 2017). These are biophysical, e.g. land use and land management including deforestation and tillage methods, socioeconomic, and political forces that influence the effectiveness of processes and factors of wetland degradation (IUSS, 1999). There is tremendous pressure on the natural wetland resources including water in the river due to increasing human population. To meet the demands of large population means the need for more food production, more requirement of energy, more water requirement, better social amenities for a reasonable quality of life and infrastructural development (Masese, *et al.*, 2012).

Kitgum Municipality is facing an increasing population and thus increasing demand for resources with Pager River inclusive (Ocungi, 2019). Densely populated human settlements in the area is inevitably producing large quantities of waste. This waste, if left unchecked, pollute rivers, streams and even groundwater resources. Anthropogenic activities along Pager River such as waste dumping and erecting of sanitary facilities along and within the river has possible

environmental and health impacts like contaminating water with disease-causing microorganisms and poisonous substances, obstruction of drains and loss of biodiversity. Also, as water comes in contact with decomposing solid waste, it will dissolve together with soluble inorganic and organic wastes producing polluted liquid known as waste juice (Angledis, *et al*., 2015). Waste water discharges from domestic settlements, industrial and commercial sources along the river and within the municipality town are likely to contain pollutants at levels that can affect the quality of the river when they are directed or washed into it.

Short-term or long-term, health effects from exposures to agricultural chemicals from gardens along the river are likely to have impacts which include severe symptoms like headaches, skin rashes, eye irritations and some chronic effects like cancer, endocrine disruption, birth defects (Vinay, *et al*., 2022). Eutrophication of the river is also a likely result of agricultural chemicals. Metals and solvents from industrial work and medical wastes dumped into the river are likely to pollute the river. These are pois onous to many forms of aquatic life and may slow their development, making them infertile or resulting into death. Soap together with the dirt, grime, grease, and oil from car washing flows into the river without treatment. Some soaps contain phosphates which can cause excess algae to grow in the river (Baker, 2012). Rearing animals along the river bunks can negatively affect the water quality through erosion and sediment transport into surface waters, through nutrients from urine and feaces dropped by the animals and fertility practices associated with production of high-quality pasture, and through pathogens from the wastes. Impermeable man-made surfaces due to construction of concrete and tarmac can cause the river to have a higher discharge due to higher amounts of surface runoff. This is likely to cause more flooding and waste/pollutant disposal by running water in the river (Chaudhary, *et al.*, 2018).

As is often the case with pollution, it is usually low-income communities that are disproportionately at risk because they draw their water directly from the rivers and wells. Accidental or illegal discharges from sewage pipes and runoff from farms and town areas introduce harmful pathogens in the water. Waterborne pathogens for example disease-causing bacteria and viruses from human and animal waste are also major causes of illness from contaminated drinking water. Industrial and agricultural pollutants like lead, heavy metals, pesticides and nitrate fertilizers also enter rivers and when ingested, they can cause health issues,

from cancer to hormone disruption to altered brain function. Children and pregnant women are particularly at risk.

According to the State of Environmnet Report (NEMA, 2019), poor water quality is not only a human health problem but healthy ecosystems rely on a complex web of animals, plants, bacteria, and fungi, all of which interact, directly or indirectly, with each other. Harm to any of the components of this web can create a chain reaction that can degrade entire aquatic environments. The report also notes that, eutrophication suffocates plants and animals and can create "dead zones" where dams, rivers and streams are essentially devoid of life and in some instances; these harmful algal blooms produce neurotoxins that affect wildlife. Chemicals and heavy metals from industrial and municipal wastewater are also toxic to aquatic life because they make their way up the food chain thus reducing an organism's life span and its ability to reproduce (Arnold & Gibbons, 2016).

This research focused on the anthropogenic activities within Kitgum Municipality, and how these activities affect water quality and aquatic biotic ecosystems in the Pager river. The study further looked at the suitability of the river water for domestic and irrigation use.

1.2 Statement of the Problem

According to Jiang, *et al.*, (2021), the rivers criss-crossing earth are choking up and anthropogenic factors are one of the prominent reasons. Agriculture, waste disposal, mining and dam construction emerge as some of the biggest contributors to this degradation. Chemical composition of major rivers such as Yangtze, Amazon, Mississippi and Congo have been altered by natural and majorly human activities. Historical data analysis pointed out that higher volumes of calcium, potassium, chloride and bicarbonates are flowing through river basins and estuaries. The polar and tropical regions are the worst-affected because most of the urbanization and agriculture are concentrated there.

East African rivers face pollution as a result of untreated industrial, domestic wastewater, solid waste and boat discharges thus, leading to high levels of eutrophication (UNEP, 2010). Increasing population and urbanization is leading to irresistible demand for water resources thus, putting an enormous strain on most rivers in Uganda flowing through urban areas (NEMA, 2019). These are characterized by poor solid and liquid waste disposal, runoffs from agricultural lands, roads, markets, industrial processes and construction sites which end up in water systems

for example River Rwizi in Southwestern Uganda (Nagawa, *et at.*, 2018). These pollutants can have deleterious consequences on the ecological balance and functioning of the receiving environment.

Like any other growing urban center, Kitgum Municipality which has a population of 56,714 (25.0% of the district population) (Kitgum Municipal Council, 2019) faces fast increasing population which has increased water resource use and demand. Pager River is one of the seasonal rivers and important water resources for the district. However, Ocungi (2019) reported that several residents dispose-off their waste in the river in anticipation that it will be washed away. The river bank which passes through the municipality is currently congested with plastic and food wastes and yet the river serves hundreds of people with water for domestic and agricultural use. These have left the water polluted and thus unsafe to humans, livestock and crops. According to Ayot (2021), 30 meters is the standard buffer area measurement for Pager River and has been demarcated. Activities outside the buffer is legally accepted. However, settlement, waste disposal, sandmining, chemical-aided agriculture, car washing among others are still within the demarcated buffer area. All these are likely to pollute the water and cause ecological disturbance. The pollution and ecological disturbance are likely to have led to reduced fish species, aquatic plant species and growth of water hyacinth downstream. With the aforementioned challenges, there was a need to assess the extent to which the increasing anthropogenic activities have affected the quality of water and aquatic ecosystem life in Pager River, Kitgum Municipality. Therefore, this study sought to evaluate the level of pollutants in water at different points along Pager River, Kitgum Municipality and how they affect the aquatic biotic ecosystem

1.3 Study Objectives

1.3.1 General objective

To investigate pollution and threats to conservation of biotic ecosystems in Pager River due to anthropogenic activities in Kitgum Municipality.

1.3.2 Specific objectives

i) To assess anthropogenic activities along Pager River in Kitgum Municipality with noncompliance to river bank protection guidelines

ii) To determine potential influences of anthropogenic activities on Pager River water quality.

iii) To assess the suitability of water from the river for domestic and irrigation use

iv) To determine potential influences of the anthropogenic activities on biotic ecosystem in Pager River.

1.4 Research Questions

i) What are the anthropogenic activities in Kitgum Municipality with noncompliance to riverbank regulation guidelines?

ii) What are the potential influences of the anthropogenic activities to water quality of the Pager River?

iii) What is the suitability of water from the river for domestic and irrigation use?

iv) What are the potential influences of the anthropogenic activities on biotic ecosystem in Pager River?

1.5 Significance of the Study

The study provides information useful for; Kitgum Urban Authority to properly plan for protection of riverbank, settlement along the river and use of water from the river, enhance environmental management practices which include among others; proper disposal of waste, minimization of human activities along riverbanks, and ecosystem restoration. It will also provide information to policy makers, local leaders and the local communities on the quality of the river and how their activities impact it

The study also contributes to the following global agenda and national policy or plan that is; Sustainable Development Goal (SDG) 6 which addresses the sustainability of water and sanitation access by focusing on the quality, availability and management of freshwater resources and also; National Development Plan III, Objective 237 which requires the sustainable management of water resources and wetlands, managing and mitigating natural and man-made hazards.

1.6 Ethical Considerations

In order to conduct the research successfully, the student sought GUREC approval first then visited the Municipal offices and introduced herself to the Municipal clerk and division clerks of

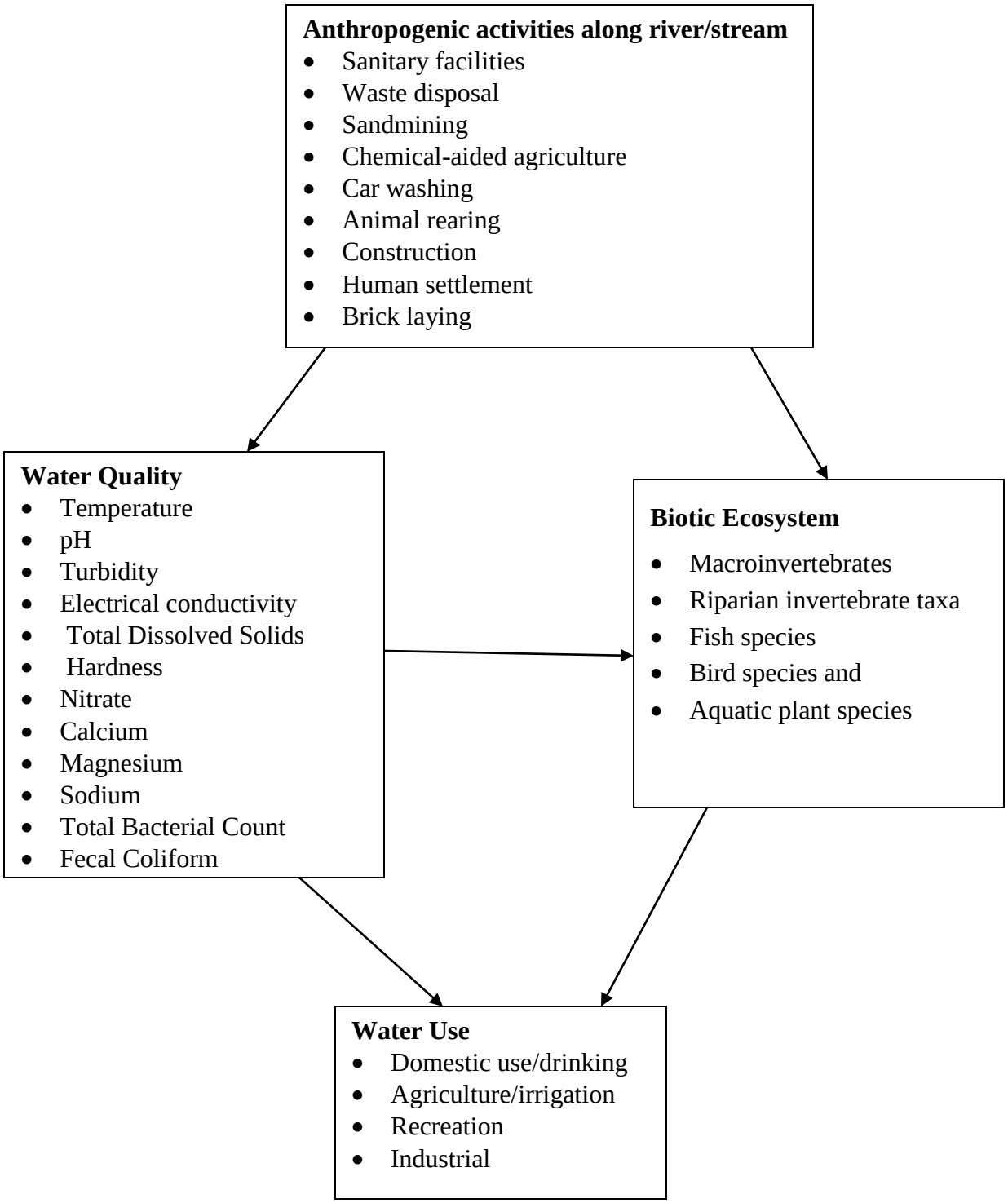
where the selected sites were located within the municipality. Permission was also sought from the Chief Administrative Officer of Kitgum District and sub-county clerks of Amida East and Amida West sub counties where selected sites outside the municipality were located. An introductory letter was used to explain the purpose of the research, unforeseen risks, and benefits of the subject. Two Research Assistants were used during data collection and their time was compensated with renumeration of 20,000/= per day. Permission was also sought from local councils before commencement**.**

1.7 Limitations of the study and possible way forward

The study was comprehensive and considerable finances were used to execute the study successfully. However, despite the envisaged limitations of logistical and financial difficulties, endeavors were made to get the required resources to complete the study within the time frame.

Time factor; was another hindrance because there was likely to be limited time period for the researcher to go to the field, make introductions, collect data, transport samples, interpret the findings and then write a scholarly report. This was handled by proper work plan development and in-time implementation. It was predicted that distance would be the greatest challenge for the research. This is mainly due to the fact that the study area was in Kitgum District yet the samples were to be tested in Gulu University which is about 100km apart and NWSC laboratory in Kampala which meant there would be transportation of samples for off-site testing for long distances thus risk of damage and sample quality alteration. In-time sample collection and travel were done to minimize the challenge. However, these limitations did not have substantial effects on the research outcome.

1.8 Theoretical Framework



CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter reviews the existing literature concerning the topic of the study. The literature is gathered in relation to anthropogenic activities in urban areas with potential negative impact on water quality of rivers, their potential influence on water quality's suitability for domestic and irrigation use as well as biotic ecosystems in rivers accessed from the books, journals, internet and other sources. The common anthropogenic activities in the study area include human settlement, agriculture, sandmining, car washing, livestock rearing, waste disposal, construction among others that form the basis for this literature review

2.1 The Anthropogenic Activities with Potential Negative Impact on Water Quality

Although water constitutes 71% of the earth's surface, only 0.3% of it is available as fresh water for human use. Moreover, the quality of fresh water in ground and surface systems is of great concern, as potable water needs to have appropriate mineral content. Ground and surface water quality in rural and urban environments is affected by both natural processes and anthropogenic influences. Because of this, water is becoming scarcer as the population increases across the world (Arias – Estévez, *et al*., 2018).

According to Stiglitz, (2019), the environmental impact of mining that is sandmining such as erosion, formation of sinkholes, loss of biodiversity, and pollution of surface water due to release of mineral ions into rivers. Besides creating environmental damage, the contamination resulting from water/river pollution also affects the health of the local population. Some mining methods may have significant impact on wetlands (Nuss & Eckelman, 2014).

Livestock rearing is another important cause of river pollution, especially by the Batuku tribe on the Semliki flats in Ntoroko County and the Basongora in Busongora County. Therefore grazing lands for livestock are an important form of land use in the region especially the grasslands on the Rift Valley floor (Raven, 2011). Therefore, livestock rearing also causes river pollution. Livestock farming can be an important source of phosphorus and nitrogen in streams, thus contributing to eutrophication of surface water resources (Haygarth, *et al*., 2018; Withers & Lord, 2012). Nonpoint source pollution such as fertilizer, pesticide and herbicide run-off and soil erosion due to land use and cover change is more difficult and expensive to control than point

source pollution (Baker, 2012).

Anthropogenic factors affecting water quality include impacts due to agriculture, use of fertilizers, manures and pesticides, animal husbandry activities, inefficient irrigation practices, deforestation of woods, aquaculture, pollution due to industrial effluents and domestic sewage, mining, and recreational activities. These anthropogenic influences cause elevated concentrations of heavy metals, mercury, coliforms and nutrient loads (Andres, *et al*., 2019).

The objective of irrigation is to supplement the natural precipitation and to protect crops against freezing or wilting, depending upon the location of the farm. Inappropriate irrigation can cause water quality problems. In arid/dry areas, for example, rainwater does not carry the minerals deep into the soil, leading to evaporation of irrigation water and overconcentration of salts in soils. Over-irrigating a field may lead to soil erosion, and transportation of nutrients, pesticides and heavy metals. It may reduce the natural surface flow in streams and rivers (Anderson, *et al*., 2015).

Urbanization is another factor that causes water pollution. Lack of opportunities and employment in the rural areas causes much youthful population to migrate to urban centers. Rapid and unplanned expansion of cities and towns to accommodate the rising population results in pollution of water bodies and urban environment by widening the gap between demand and supply of infrastructural services such as energy, housing, water, transport, communication, among other social amenities. This process then leads to dumping of wastes into the water causing water pollution (Wright, 2018).

The most common agricultural water pollution is loss of top soil that is washed from fields. Rainwater carries soil particles or sediments and deposits them in lakes or streams nearby, thus affecting water quality. Other pollutants such as fertilizers, pesticides, and heavy metals that stick to the soil particles are also washed into the water bodies (Hanxio, *et al*., 2022). These pollutants cause algal blooms and deplete oxygen, threatening aquatic life. Turbidity, a measure of the light-scattering effects of suspended particulate material (SPM) in water, increases with suspended sediment concentrations and loading rates. It also depends upon characteristics such as particle size distribution and refractive index and color of water (Nitasha & Sanjiv, 2014). The suspended solid concentration in streams is often higher in the spring and autumn than in the summer (Braskerud, 2011).

Urbanization is a pervasive form of land cover/land use alteration that is rapidly growing (Paul & Meyer, 2011). This involves conversion of croplands, forests, grasslands, pastures, wetlands and other cover types to residential, transportation, commercial and industrial uses, thereby increasing the areas of impervious surfaces (Tsegaye, *et al*., 2016). Impervious surfaces are quantifiable indicators that correlate very closely with increases in nonpoint (diffuse) sources of polluted run-off which degrades the quality of aquatic resources (Arnold & Gibbons, 2016). Urban areas are more polluted than rural ones due to industrialization, sewage discharge and other domestic activities (Buck, *et al*., 2014). Human activities such as discharge of industrial and domestic effluents, the use of agricultural chemicals, land use and cover changes are the major factors that influence surface water quality (Peters & Meybeck, 2020; Alam, *et al*., 2016; Hussain, *et al*., 2018).

Stream channelization aims to move, widen, narrow, straighten, shorten, cut off, divert, line or fill a natural or altered stream channel. It can lead to changes in the amount and speed of the water flowing through the channel (Nitasha & Sanjiv, 2015). Channelization may be done by lining the channels with concrete, excavating sand and gravel from the stream bed and sloping it back along the banks, or constructing culverts (Alam, *et al*., 2016). Channelization may affect the water quality in that it can lead to floods, wherein huge water run-off picks up pollutants such as phosphorous, nitrogen, pesticides, sediments and heavy metals. This affects the stream water quality, and the cost of drinking water treatment also increases. Removal of trees and vegetation along the stream bank may further increase the pollutants in streams, including nitrogen, phosphorous, bacteria, pesticides and sediment. There may be an increase in water temperature and consequently the dissolved oxygen in water may decrease. As temperature is critical to many aquatic species, death of fish may result (Anderisio & De Luca, 2019).

Sewage is the most important source of coliform bacteria, which are present in human faeces. An adequate faecal indicator does not reproduce outside the animal host. Escherichia coli and enterococci grow survive and establish their populations in natural environments such as freshwater lakes and streams (Power, *et al*., 2015), algal wrack, beach sand, soils and sediments, and plant cavities.

2.2 The Potential Influences of the Anthropogenic Activities on Water Quality of Rivers

The quality of surface waters is a sensitive issue as far as health is concerned. Urban, industrial

and agricultural activities lead to increases in water consumption (NEMA 2019). The anthropogenic activities degrade the surface water. This impairs its use for drinking, industrial, agricultural, recreation or other purposes (Carpenter, *et al*., 2018). Surface waters are prone to pollution, as they are used for wastewater disposal in most countries. Anthropogenic influences determine the quality of surface water in a region (Jarvie, *et al*., 2018).

Domestic and industrial activities are great sources of wastewater and solid waste which have negative impacts on water quality. The upper part of rivers due to anthropogenic activities such as inappropriate land use management including the poor wastewater infrastructure suffer water quality alteration. (Roosmini, et al., 2008) conducted their study in Java Island and chose Bengawan Solo River and Brantas River which are downstream of Citarum River as the samples in the study. Parameters assessed in the study were TSS, TDS, pH, DO, and hexavalent chromium. STORET method was used in the water quality assessment and the STORET value showed the significant differences in the water quality among the sites selected. The study concluded that Bengawan Solo River and Brantas River have been polluted from the upstream due to domestic and industrial activities this condition is related with the industrial and domestic activities in upper watershed.

Nizel & Nazrul, (2015) conducted a study to find out the level of pollution in Turag River and the health problem of the surrounding residents. Physicochemical water quality analysis was done and the parameters tested included DO, turbidity, BOD, hardness, TDS, and COD. Focus group discussions and key informant interviews were done. Secondary data was collected from books, and reports from Ministry of Environment as well as Engineering Department. The results showed that the water quality of Turag River would not be able to sustain the aquatic life and not suitable for domestic purpose. This was indicated by the very low dissolved oxygen (DO) levels and other measured parameters in the river since they were above the standard permissible limits. Health problems including skin, diarrhea, dysentery, respiratory illnesses, anemia and complications in childbirth are common in surrounding communities as well as respiratory problems and odor pollution.

Bhateria & Jain, (2016) indicate that water quality can be assessed by various parameters such as BOD, temperature, electrical conductivity, nitrate, phosphorus, potassium, dissolved oxygen, to mention a few. Heavy metals such as Lead (Pb), Chromium (Cr), Iron (Fe), Mercury (Hg),

among others. This is because they produce water or chronic poisoning to aquatic organisms thus are a concern. The water quality parameter (WQP) was measured using Hyperion in Lake Garda. Hyperion imagery is an operational use of Remote Sensing technologies related technologies which is integrated with traditional survey programmers and could provide useful information to implement the European Water Framework Directive (WFD). For Lake Garda, this was the deviation from a tropic level assessed with two causal elements and with one response parameter.

Alobaidy, *et al*., (2010) evaluated the historical changes in water quality. For that purpose, ten water quality parameters were selected which were: pH, dissolved oxygen, turbidity, conductivity, hardness, alkalinity, sodium, biochemical oxygen demand, nitrate and nitrite. Values used for each parameter are the mean value of the three sites under the investigation. The WQI was used to aggregate diverse parameters and their dimensions into a single score. All computed WQI values were characterized under ‘‘Excellent’’, ‘‘Good’’, ‘‘Poor’’, water quality depending on their values.

Bu, *et al*., (2014) used statistical and spatial analysis to determine the relationships between land use patterns and river water quality in the Taizi River basin, China during dry and rainy seasons. Correlation and multiple linear regressions were used to determine the relationship between vegetation and the river water quality. The study results provide a useful approach that uses landscape patterns to estimate water quality in rivers for water pollution control and land use management.

Şener, *et al*., (2017) studied the water quality of the Aksu River, the main river recharging the Karacaören-1 Dam Lake. Physical and chemical analysis of water samples were done from selected locations through flow path of the river. Results were compared with maximum permissible limit values recommended by World Health Organization and Turkish drinking water standards. The water quality for drinking purpose was evaluated using the water quality index (WQI) method. The study showed that the effects of punctual and diffuse pollutants dominate water quality. It also elaborates that the most effective water quality parameters are COD and Mg on the determination of WQI for present day study.

Sikder, *et al*., (2013) based on physicochemical parameters and dissolved metals levels in their study to compare water quality in rivers of developed and developing countries. Water samples

collected from selected sites were analyzed using ANOVA for least significant differences in both developed and developing countries. Principal component analysis was used to show correlations between water quality parameters and the different sites. The study showed evidence that dissolved metal, organic, and fecal pollutions in the rivers of developing countries are in somewhat dreadful condition in comparison with the rivers of developed country.

Zhao, *et al*., (2013), carried out a study on water pollution in the Taihu Lake basin in China. The study analyzes spatial patterns of urbanization and the distribution of river water pollution, and then uses the Geo Da bivariate spatial autocorrelation model to investigate the spatial correlation between urbanization and river water pollution at the scale of township units in 84 monitoring sections of the heavily polluted area. The study results showed that urbanization has adverse impacts on water pollution. The influence varies in different levels of development areas whereby the urban township units have the highest level of urbanization and highest pollution, but the best water quality; the suburban units have lower level of urbanization, but higher pollution and worse water quality, however the rural units have the lowest level of urbanization and lowest pollution, mainly affected by upstream pollution, but worst water quality.

Poor quality irrigation water reduces soil productivity, changes soil physical and chemical properties, creates crop toxicity and ultimately reduces yield. Miserendino, *et al*., (2011) studied the effects of land-use/anthropogenic activities on water quality, in-stream habitat, riparian ecosystems and biodiversity in Patagonian northwest streams. Chemical analysis was performed in the laboratory of the Adamawa State Water Board Yola, Nigeria between August and September 2010 employing standard methods, Atomic Absorption; Spectrophotometry for cations and conventional titration for anions. The analytical results were compared with the standards specification (WHO, 2006). The results show nitrate pollution but the other hydro chemical parameters fell within the recommended limits of World Health Organization (WHO, 2006) and thus, largely suitable for irrigation and domestic purposes.

According to Misaghi, *et al*., (2017), water quality parameters including Na^+, Cl^-, pH, HCO^- 3, EC, SAR and TDS can be employed for water quality analysis using the adjusted National Sanitation Foundation Water Quality Index (NSFWQI) formula. The NSFWQI formula is then used to calculate a final index value, and for each parameter an acceptable range in this value can then be determined.

Kawo & Karuppannan, (2018) studied 31 groundwater samples that were collected and analyzed to determine suitability of groundwater for drinking and irrigation uses. A spatial variation map of major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_3^-, NO_3^-, SO_4^{2-}, F^-, Cl^-) were produced using IDW interpolation in GIS. Water quality index using quality rating scale was used to evaluate the suitability of water for drinking purpose. Sodium Adsorption Ratio computation values showed that 97% of groundwater samples were in suitable class and the remaining 3% constituting doubtful class for irrigation use. The study also confirmed that geogenic process and anthropogenic activities such as urban sewages and fertilizers are factors governing groundwater chemistry.

The southern Sindh province of Pakistan adjoins the Arabian Sea coast where drinking water quality is deteriorating due to dumping of industrial and urban waste and use of agrochemicals and yet has limited fresh water resources. Memon, *et al.*, (2011) studied the drinking water quality of canal, shallow pumps, dug wells, and water supply schemes from the administrative districts of Thatta, Badin, and Thar. Physical, chemical, and biological (total coliform) quality parameters of the four water bodies were measured. Some parameters were below the standard permissible limits of World Health Organization while others exceeded. Some common diseases found in the study area were gastroenteritis, diarrhea and vomiting, kidney, and skin problems.

Azizullah, *et al.*, (2010) in their review discussed the major pollutants in drinking water in Pakistan, their sources and the consequent health problems. The data was extracted from various studies published in national and international journals as well as reports released by the government and non-governmental organizations.

2.3 The Potential Influences of the Anthropogenic Activities to Biotic Ecosystem of Rivers

Rivers have always played an important role in the development of human civilization. Human societies have economically benefitted in the form of development and increased economic wellbeing. However, hydrological alterations of rivers flow regime while benefitting human development in many ways have damaged the delivery of ecosystem services (Xuege, *et al*., 2022). As we fail to understand that the river ecosystem services are governed by flow regime and it is influenced by many biotic and abiotic factors which includes topography, land cover, climatic condition and anthropogenic modifications (Anjana, *et al*., 2019). These interactions are the biophysical basis for providing ecosystem services. The situation is further complicated by

multitude of water uses and stakeholders with conflicting interests (Adriano, 2016).

According to Miserendino, *et al*., (2011), macroinvertebrates are good indicators of land-use impact and water quality conditions and is useful tool to early alert of disturbances in streams. Their study confirmed that greater intensity of land-use has negative effects on water quality and stream habitat. Macroinvertebrate taxa, riparian invertebrate taxa, fish species, bird species, and aquatic plant species were studied. Results indicate that urban land-use produced the most significant changes in streams including physical features, conductivity, nutrients, habitat condition, riparian quality and invertebrate metrics.

Bu, Meng, *et al*, (2014) conducted a study in Jinshui River of the South Qinling Mountains, China. Multivariate statistical techniques and gridding methods were used to investigate the temporal and spatial variations of water quality and identify the main pollution factors and sources. Two-way analysis of variance (ANOVA) was used to study the significant temporal differences and spatial variabilities in the water samples and sample sites. Cluster analysis used to classify sampling sites into pollution level groups (no pollution, moderate pollution, and high pollution) based on similarity of water quality variables. Factor analysis was used to determine the total variance in parameters. The study suggested that the water pollution primarily resulted from domestic wastewater and agricultural runoff.

Wim, *et al*., (2010), studied that the Multimeric Macroinvertebrate Index Flanders (MMIF) as Water Frame Directive compliant method developed for the northern part of Belgium is based on the total number of taxa, the number of Ephemeroptera, Plecoptera and Trichoptera taxa, the number of other sensitive taxa, the Shannon–Wiener index and the mean tolerance score. The outcome of this MMIF was strongly correlated with the outcome of the Irish Biotic Index. Therefore, it should be possible to develop a similar multimeric index for macroinvertebrates to evaluate the biological water quality without much effort.

Aschelew & Otto, (2015) in their study described the development of a macroinvertebrate based biotic score system (ETHbios) for assessing the ecological status of rivers in the Ethiopian highlands. To define the ranges of the five river quality classes (high, good, moderate, poor and bad), the ETHbios values of sites were correlated with the corresponding ecological status of the sites derived by Multimeric Index.

Mereta, *et al*., (2013) developed a multimeric index based on macroinvertebrates to assess the ecological condition of natural wetlands in Southwest Ethiopia. The study concluded that MMI can be considered as a robust and sensitive tool that can be applied to evaluate the ecological condition of natural wetlands in Ethiopia, where wetland resources are under high pressure as a result of agricultural activities such as grazing and urbanization.

Desrosiers, *et al*., (2019) examined the accuracy of a multimeric approach based on 22 biological and ecological traits of benthic macroinvertebrate communities to assess toxic sediment pollution in streams. Data on chemical and fauna was collected from 150 selected sites on mountain streams. Additional 18 sites were not included in the multimeric tool development as a test data set. A toxic quality class (from 'high' to 'poor/bad') was pre-assigned to each site using the French water quality assessment system based on toxic substances (metals, PAH and PCB) in sediment. Each trait was described in multiple categories and described using a fuzzy coding procedure. The relative abundance of trait categories was calculated for communities at each site and nonparametric multiple comparison statistical procedure was used to compare relative abundances of trait categories between groups of sites assigned to different quality classes (like; high versus good; good versus moderate, to mention a few). The study proposes a statistical procedure to allocate sites to toxic quality classes from the attributes of its benthic macroinvertebrate community based on such sets of trait categories. However, it also concludes that there is need to increase the number of sites included in the development data set to improve the tool's precision, extend the procedure to additional stream types and validate the design at a larger spatial scale.

Patang, *et al*., (2018), in their study used benthic macroinvertebrates diversity as well as physical-chemical parameters to evaluate the water quality of a number of rivers in East Kalimantan province of Indonesia. Average Score per Taxon (ASPT) values and the National Sanitation Foundation-Water Quality Index (NSF-WQI) were used to compare the state of the rivers whereby; Karang Mumus River was categorized as polluted with Chironomus sp. and Melanoides tuberculata as codominant taxa, Jembayan River exhibited doubtful or moderate quality containing Melanoides tuberculata and Aplysia parvula as codominant taxa and finally Pampang River was found to be the cleanest river with Odonata and Baetidae families as codominant taxa.

2.4 River protection/buffer

The Uganda National Environment Act (NEA) 2019 prohibits people from using, erecting, reconstructing, altering, extending, removing or demolishing any structure or part of any structure in, on, under or over the river-bed as well as blocking or diverting any river from its course. It also prohibits the introduction of any plants, animal or microorganism, deposition of any substance into the river which is likely to have an adverse effect on the environment. It states that the concerned authority may, in collaboration with the relevant lead agency, authorize any of the activities subject to conditions prescribed. The NEA 2001 also prohibits activities in the protected zones along riverbanks which may adversely affect the river. Rivers such as Pager must have a protected zone of 30 m from highest watermark of the river as protected zone or buffer and 100m for the large rivers. Only activities which are sustainable are permitted in the buffer zones and must be strictly monitored. No activity shall be permitted within protected zones without the written authority of the Executive Director.

2.4 Conclusion

The literature review reveals that anthropogenic factors that greatly affect the surface water quality and biotic ecosystem include industrialization, agriculture practices (use of fertilizers, herbicides and pesticides), animal husbandry, sewage discharge and other domestic activities. Changes in land use pattern including changes in land cover also adversely affect water flow and quality of surface water. In rural environments, especially in developing countries, the anthropogenic influences are less profound due to less industrial and commercial activities. Therefore, a study that focus on anthropogenic activities in urban areas and their potential influence on surface water quality and biotic ecosystem are very critical to provide information that can be useful for the protection of the water body.

CHAPTER THREE: RESEARCH MATERIALS AND METHODS

3.0 Introduction

This chapter presents the methods and material that were used to conduct the research. It specifies the research strategy, sampling procedures, research instruments and data analysis techniques that were used to explore the underlying implications of anthropogenic activities on Pager River

3.1 Study Area

The study was carried out along Pager River in Kitgum municipality (Figure 1), Kitgum District. Kitgum Municipality has a population of approximately 56,714 (25.0% of the entire district population).

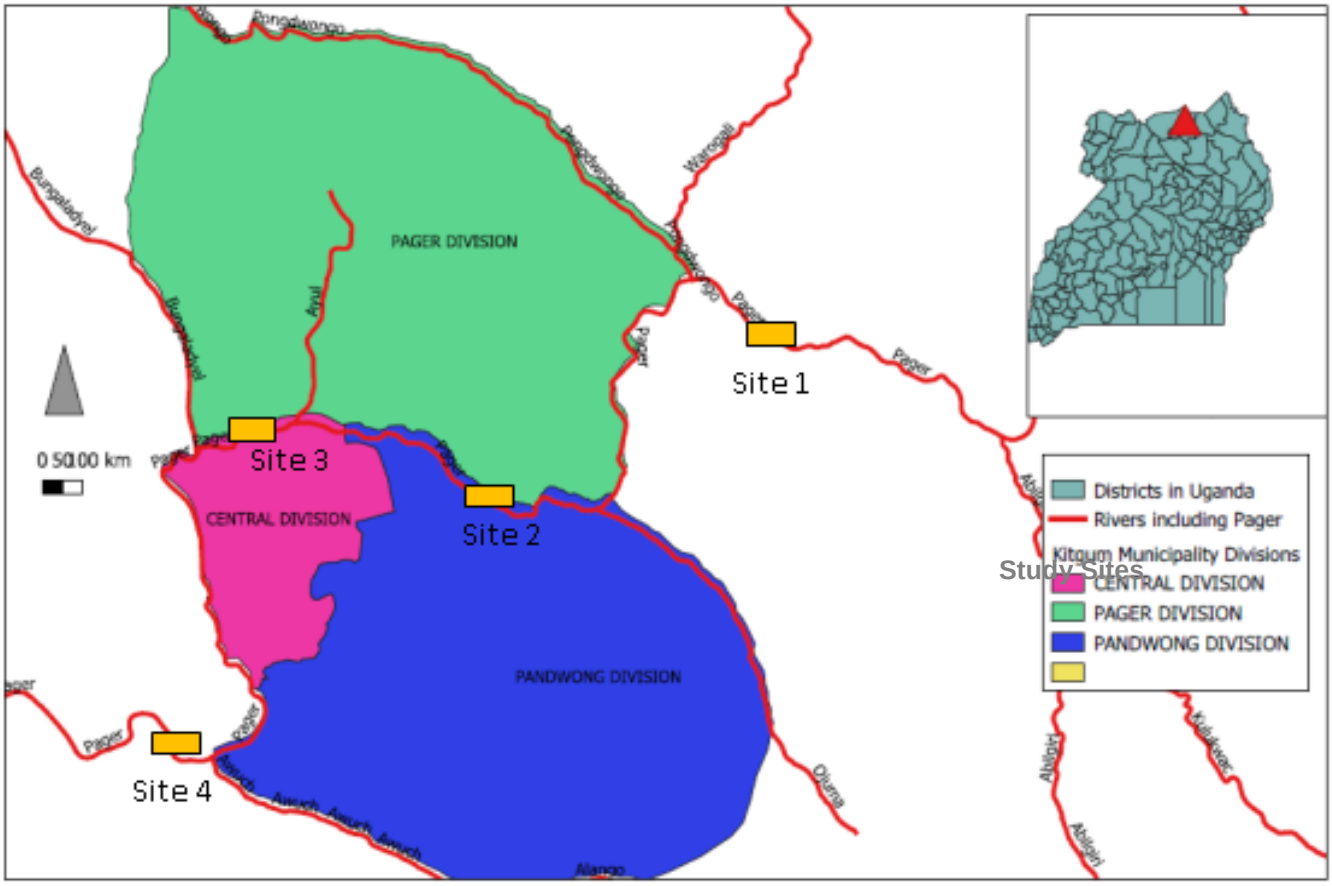


Figure 1 Map of Kitgum Municipality showing the study area and water sampling sites

The major socioeconomic activities in the area are trade, farming (crop, animal and fish), construction, sand mining, transportation and others like brick laying, manufacturing, agricultural product processing, bricklaying, stone quarrying among others are minimally practiced. Kitgum District is bordered by South Sudan to the north, Kaabong District to the east, Kotido District to the southeast, Agago District to the south, Pader District to the southwest and Lamwo District to the northwest. Kitgum Municipality, is located approximately 108 kilometres (67 mi), by road, northeast of Gulu, the largest city in the sub-region. This location lies approximately 460 kilometres (290 mi), by road, north of Uganda's capital, Kampala. The Global Position System points Kitgum on the coordinates; Latitude: 3.2783 Longitude: 32.8867.

3.2 Data Collection

3.2.1 Assessing anthropogenic activities along Pager River

The anthropogenic activities in Kitgum municipality along the river pager were assessed by conducting survey using structured check list and observation. GPS device was used to get the latitude and longitude that is the locations of activities with potential influence on water quality. Walks were taken along both sides of the river whereby all the activities with potential influence on water quality were observed, identified, recorded and their GPS readings taken. Only activities located within 30 m from the boundary of the river (buffer zone) were surveyed. The latitude and longitude, distance from the river bank and the cells where they are located were written on a survey sheet (Appendix 2).

The following anthropogenic activities were surveyed: sanitary facilities, waste disposal, agricultural activities, human settlement and construction, sand mining, bricks laying, car washing, animal rearing, tree nursery beds, motor garage and drainage channels. Those activities that were within the 30m buffer zone were identified during the survey. Sanitary facilities included latrines and bathrooms that were in use were identified. Some locations had multiple sanitary facilities so one GPS reading was taken for such facilities to avoid overlapping in the map. Waste disposal, including dumping sites were surveyed and recorded. Chemical enhanced agriculture covered only agricultural gardens which use chemicals. This means that gardens with totally rudimentary practices were not surveyed. Settlements targeted multiple houses in an area.

Single reading was made for each group of houses or homes. Active sandmining areas were recorded. The counts included only active mining areas excluding the abandoned ones. Car washing points for both cars and motorcycles along the river were surveyed. Animal housing facilities for goats, cattle and pigs were surveyed. These covered cattle kraals which were within the 30m buffer zone. This was done because most of the areas along the river with green vegetation were being used for grazing. Tree nurseries which use chemicals for pest and disease control were located along the river. Motorbike and vehicle garages were identified and single GPS recording was made for very closely located garages to avoid overlapping in the map. Recreation facilities that were identified included recreational gardens, bar and restaurant. Active bricklaying and construction areas were also recorded. The area involved making/constructing culverts, concrete slabs and bricks. Drainage channels that carry runoffs from the town center into the river were also surveyed.

3.2.2 Determining influences of anthropogenic activities on the water quality

To determine the potential impacts of anthropogenic activities in Kitgum Municipality on Pager River water quality, several study sites were selected along the river. Selected water quality parameters were then analysed at each site for a period of five months to cover both dry and wet seasons

3.3 Selection of study sites

Four water sampling sites were selected along the river for study using purposive sampling (Figure 3.1). One site upstream (Site 1), two sites within the Kitgum Municipality area, (Site 2 and Site 3) and one site downstream, (Site 4). Site 1 is located in Lukwor, Amida East sub county in an area which is relatively not disturbed by human activities, Site 2 and 3 are located within municipality where there are various human disturbances/activities and Site 4 are located in Auch, Amida West subcounty where the water flows out of the municipality. Site 1 was selected to analyze water quality and biotic ecosystems before the river enters the municipality where numerous anthropogenic activities occur along the river. The upstream (site 1) is the control point that was used for comparison of the water quality along the different sites in the river. The water quality parameters and biotic ecosystems at the control site were compared with those at sites 2 and 3 (within municipality) and then 4 (downstream) to determine any significant differences.

3.3.1 Water quality parameters and samples collection

The following selected major physiochemical and micro bacteriological water quality parameters were analyzed; electrical conductivity (EC), hardness, turbidity, total dissolved solids (TDS), total bacteria count (TBC), faecal coliform (FC), magnesium, calcium, sodium and nitrate. These water parameters were selected for analysis because of their association to the human activities or suitability as indicator for domestic and irrigation use. Turbidity, Total Dissolved Solids, total bacteria count and Faecal coliform are basic water quality parameters used to indicate safety of water sources for domestic use while electrical conductivity magnesium, calcium, and sodium are used to indicate suitability of water for irrigation use. Total bacteria count and faecal coliform are the common indicators of water contamination by sanitary wastes whereas nitrate is used as indicator for contamination by agricultural activities (fertilizers).

Water samples were collected from the upstream (site 1), study area (sites 2 and 3) and downstream (site 4) to determined variations of water quality along the river. The water samples were collected once every month from March 2022 to July 2022 covering part of dry and rainy seasons (giving sample size of 10 for each of the 4 sample locations and 40 samples in total). All the samples were collected between 8:00 AM to 12:30 PM and transported to the laboratory at Gulu University in a cooler box packed with ice and stored at 4°C for analyses before 48 hours. The samples were collected using 1000 ml plastic containers. The containers for bacteriological tests were autoclaved before use meanwhile containers for the physiochemical parameters were cleaned and rinsed several times with the river water before use.

3.3.2 Testing selected water quality parameters

Water quality parameters like pH and temperature were tested insitu; electric conductivity, hardness, turbidity, total dissolved solids, total bacteria count and faecal coliform were tested from Gulu University Laboratory. Hardness and TDS were derived through calculations. However, magnesium, calcium, sodium, hydrogen carbonate, and nitrate, were tested from the NWSC central laboratory in Bugolobi, Kampala because the laboratory at Gulu University did not have the equipment to test them. However, temperature, pH and turbidity were tested immediately after sampling as they would possibly change during storage and transport.

1. **Determination of Electrical Conductivity**

Electrical conductivity was determined by HANNA conductivity meter (model H1991000)

following the procedure used by Olajumoke et al., (2010). The conductivity meter electrode was dipped in each of the samples and the values were read out from the screen. Thorough rinsing and drying were carried out.

2. Determination of pH

PH was measured by HANNA pH meter (model H1991000) which was calibrated first by standard buffer solutions.

3. Determination of water hardness

Hardness was determined by calculation from results of magnesium and calcium using the equation given as hardness due to Calcium, mg/l, as $CaCO_3$ = 2.497 (Ca) + 4.118 (Mg)

4. Determination of temperature

Temperature measurement was onsite by submerging the thermometer two-thirds below the surface of the water. The measurement was done in a central flowing location. The thermometer was left to adjust to the water temperature for at least 1 minute before removing the thermometer from the water. The reading was taken and recorded

5. Determination of Turbidity

This was tested using turbidimeter. The sample was filled in the turbidity vial to the line of 15 ml. The cell was wiped with a soft, lint-free cloth to remove water spots and fingerprints then placed on a flat surface. The sample vial was put in the instrument cell compartment so its diamond mark aligns with the raised orientation mark in front of the cell compartment and the cover closed. An average of 10 measurements range were selected and readings were shown in NTU (Nephelometric Turbidity Unit). The light bulb icon flashed 10 times; once for each reading and the final average was displayed as numbers in NTU after the lamp symbol turns off

6. Determination of Total dissolved solid

Total Dissolved Solids (TDS) was calculated from electric conductivity result using the following equation (Olajumoke et al., 2010).

TDS = 0.64 x EC (Micro-mhos/cm)

Where Electrical Conductivity (EC) and TDS were expressed in µ-mhos/cm and mg/L, respectively**.**

7. Determination of Calcium

Because of the high pH used in this procedure titration was done immediately after adding alkali and indicator. 100 ml of sample was measured and transferred to a 250ml Erlenmeyer flask and 1 ml of 8N NaOH solution added to it. Burette was filled to mark with 0.01M EDTA acid. To each flask 0.1 -1.2 g murexide indicator was added. EDTA acid was added slowly from burette to one of the test portions in flask, mixed thoroughly by rotating flask. The colors in flask were continuously compared as the acid is added, and at the first appearance of permanent purple color in the test flask, adding the acid was stopped and burette reading taken.

8. Determination of Magnesium

Atomic Adsorption Spectrophotometer was used. To 15ml sample, 5 ml of Hydrochloric Acid (HCl) was added and the sample was heated on a hot plate until the volume has been reduced to from 20 ml to 15ml, making sure that the samples did not boil. The sample was cooled and filtered into 100-mL volumetric flasks and the filter paper was washed two or three times with water and brought to the volume. Using a 50-mL volumetric flask, 10 mL of lanthanum solution (5 % La), and sample aliquot was added and made to volume with HCl (1 + 99).

For the magnesium determination three volumetric flasks with sample aliquots was prepared to give about 0.1 mg/l magnesium, lanthanum solution (5 % La) to give 1 % La and magnesium standard solution to give final concentrations of 0, 0.1, and 0.2 mg/l of magnesium. The samples were atomized and absorbance readings for each were taken. Water was atomized in between each sample. Wavelength of 285.2 was used.

9. Determination of Sodium

Flame photometry for Na; This was done by placing 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 cm^3 respectively of the standard 100 ppm Na^+ ion solution in a series of 50 cm^3 volumetric flasks labelled from numbers 1 to 6. The volume of the solution was made up to the mark with distilled water to obtain standard solutions of 1, 2, 4, 6, 8 and 10 ppm Na solutions. The instrument was calibrated by aspirating the solutions in the flame. Again, 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 cm^3 of the standard 100 ppm Na^+ ion was placed in another series of 50 cm^3 volumetric flasks labelled from 1′ to 6′. In another 50 cm^3 flask, labelled as ‘Sample’, 10 cm^3 of the water sample was measured. 5 cm^3 of 100 ppm Li^+ ion standard solution was added to each of these flasks containing the standard solution and the sample. Distilled water was added to the solution to

make volume go up to mark and this gave standard solutions of Na^+ ions containing 1, 2, 4, 6, 8 and 10 ppm of the respective ions and 10 ppm each of the internal standard Li^+ ion. The standard solutions as well as the sample solution were then be aspirated one by one into the instrument and the readings for the Na^+ ions recorded.

10. Determination of Nitrate

Sample of 25ml was filled in a 25ml graduated mixing cylinder. One pillow Nitraver 6 content was added and covered with palm, held firmly and inverted several times to dissolve powder. Contents of one Nitraver 3 reagent powder pillow was added in the cylinder and covered with palm and inverted repeatedly for one minute to dissolve. After about 15minutes, a pink color developed if nitrate was present. Twenty-five ml of distilled water (blank) was poured into a 25 ml sample cell and the blank was treated the same way. The instrument manual procedure was followed. Wavelength of 507nm was used for measurements and the machine readings directly taken and recorded.

11. Determination of Total Bacterial Count

This was tested using the SMEWW standard method 9215D of membrane filtration (APHA, 2005). In this method, water samples were passed through membrane filter paper (0.45µm). The bacteria in the water sample were trapped to the filter's surface. The filters were then put in petri dishes (50 mm) with appropriate nutrients (Plate count Agar) and incubated at 35°C for 48 hours. During incubation, the trapped bacteria on the filters grew into a visible colony. After incubation, the petri dishes were removed from the incubator and the number of colonies of bacteria on the filter were counted using naked eyes and magnifying glasses. The number of colonies on the filter were an estimate of the total plate count in the water sample. Colonies with curved surfaces against white back ground were counted.

12. Determination of Faecal coliform

This was tested using membrane SMEWW standard method 9222B (APHA, 2005). Water sample of 100ml was passed through a membrane filter (0.45µm). The filter was removed and placed in 50mm petri dishes with laurel sulphate broth and covered. The petri dishes were then placed in an incubator and incubated at 44^0C for 12-16 hours. After incubation, the petri dishes were removed and allowed to cool for 10min. This was to allow false yellow color to be lost and

ensure that the yellow was only for the typical colonies. A magnifying glass and a counting pen were used to count the colonies. All the yellow colonies were counted, pale yellow colonies which were convex, dome shape colonies with a reflecting surface as true colonies were also fecal coliforms.

3.2.3. Determining the Influences of Anthropogenic activities on the Biotic Ecosystem

Benthic macroinvertebrates diversity metrics was assessed to investigate the influence of the anthropogenic activities on biotic ecosystem in Pager River. Benthic macroinvertebrates are the most commonly used worldwide as indicators of the impacts of anthropogenic factors on river ecosystem health (Kaayaa, *et al*., 2015; Deborde, *et al*., 2016; Alemu, *et al*., 2017). The samples of benthic macroinvertebrate were collected from the four sites in Pager River where water samples for water quality test are equally got at the upstream (site 1), urban area (site 2 & 3), and downstream (site 4).

1. Benthic Macroinvertebrate Sample Collection and Management

The stream bed sediment samples containing benthic macroinvertebrate were randomly collected from each site in three replicate samples from water runs within the mid-river channel. Sampling was done using a standardized multi-habitat rectangular kick-net of 50×25 cm aperture, attached to a 25 cm deep Nitex material of 500 μm mesh. The kick-net was vertically fixed at sampling points and using a tape measure and two wooden pegs, an area of 50×50 cm was demarcated at its immediate upstream position. The stream bed substrates were manually loosened within the 50×50 cm area for 2 minutes to dislodge and capture more mobile macroinvertebrate that drift into the kick-net. Three replicate samples collected from each site were pooled to one composite sample and preserved separately for each site in a white tray and identified onsite using naked eyes and magnifying lens. The field procedures were in line with the previous related studies of macroinvertebrates (Liz, *et al*., 2020; Ojija, *et al*., 2017). At the laboratory, benthic macroinvertebrates were identified to family level using a microscope and magnifying lens. The macroinvertebrate taxa identified were quantified as the number of individuals of a given taxon m^{-2}.

3.4 Data Analysis

3. 4.1. Analysis of anthropogenic activities along Pager River

The anthropogenic activities were mapped using QGIS (Quantum Geographic Information System). The longitudes and latitudes of the study sites, each activity plus the activity names were entered into spreadsheet, converted to/saved as CSV (Comma delimited). This is then uploaded to QGIS where the map of Kitgum Municipality is already extracted. A map of the study area is therefore derived with points showing the different activity locations, their concentrations, study sites, main roads, boundaries, Pager River, its tributaries and distributaries, and division boundaries. Bar graph was also used to present the information of the number of the different activities and comparison were made with National Environment Act (NEA) 2019.

3.4.2 Analysis of Water Quality Data

3.4.2.1 Potential influences of anthropogenic activities to Pager River water quality

Data for physicochemical parameters of water samples were presented as mean values and analyzed using statistical analysis. Microsoft Excel was used for statistical analysis of data. One-way ANOVA was used to establish whether there were significant differences in physicochemical and bacteriological water quality at the upstream (site 1), study area (sites 1 and 2) and downstream (site 4). Student t-test ($P<0.05$) was conducted to establish further which sites downstream to site 1 contributes significant differences in the water quality parameters. The t-tests were conducted for the water quality parameters with significance difference between the study sites identified from the ANOVA analysis. ANOVA and T-test were used because they produce the desired results and their ease of use and accessibility.

3.4.2.2 Suitability of Pager River Water Quality for Irrigation and Domestic Use

1. Analysis of Pager River water quality for irrigation purposes

The water quality of the river was assessed to determine its suitability for agricultural purposes. This meant it should be good for both plants and animals. Sodium Adsorption Ratio, Magnesium Adsorption Ratio and Electric conductivity were analyzed and the results were compared with national standards for irrigation water and World Health Organization standards. Sodium absorption (SAR) categorized as in Table 1.

Table 1: Standards used for irrigation water suitability (Gupta and Gupta, 1987)

Classification scheme	Categories	Range
Electrical Conductivity (EC) in µS/cm	Excellent	<250
	Good	250–750
	Permissible	750–2250
	Unsuitable	>2250
Magnesium Absorption Ratio (MAR)	Acceptable	<50
	Non-acceptable	>50
Sodium Absorption Ratio (SAR)	Excellent	<10
	Good	10–18
	Fair	>18–26
	Poor	>26

2. Determination of Sodium Adsorption Ratio (SAR)

The Sodium Adsorption Ratio gives a clear idea about the adsorption of sodium by soil. It is the proportion of sodium to calcium and magnesium, which affect the availability of the water to the crop. It was calculated using equation given by Richard, (1954) as:

$$SAR = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}}$$

Where, all the ionic constituents are expressed in meq/L

3. Determination of Magnesium Adsorption Ratio (MAR)

Magnesium content of water is considered as one of the most important qualitative criteria in determining the quality of water for irrigation. Calcium and magnesium maintain a state of equilibrium in most waters. More magnesium in water adversely affects crop yields as the soils become more saline (Nagaraju, *et al*., 2014). MAR was calculated using the equation below (Raghunath, 1987):

$$MAR = (Mg^{2+} \times 100) / (Ca^{2+} + Mg^{2+})$$

Where, all the ionic constituents are expressed in meq/L

3.4.2.3 Analysis of Pager River water quality for domestic use

Water portability for domestic use was determined by using Water Quality Index (WQI) and by comparing the concentration of tested parameters with the World Health Organization and

national standards. The water quality index aims at assessing the quality of water through a single numerical value, calculated on the basis of one system which converts all the individual parameters and their concentration, present in a sample into a single value. This method compares the quality of various water samples based on a single numerical value. Any result of water quality measurement can serve as an indicator of water quality (Galal, *et al*., 2021).

Under this study, WQI was calculated using the Weighted Arithmetic Index method. This is because in this model, data is incorporated from multiple water quality parameters into a mathematical equation that rates the health of a water body with number and reflects the composite influence of different parameters. It also requires a smaller number of parameters in comparison to all water for particular use, describes the suitability of both surface and ground water sources for human consumption (Cude, 2001).

The calculation of WQI was done using the following equation:

$$WQI = \frac{\sum QiWi}{\sum Wi}$$

The quality rating scale (Qi) for each parameter was calculated using the expression;

Qi = 100*((V actual – V ideal) / (S standard – V ideal)

Where;

Qi = Quality rating of ith parameter for a total of n water quality parameters

V actual = Actual value of the water quality parameter obtained from laboratory analysis.

V ideal = 0 (except pH = 7 and Dissolved Oxygen = 14.6 mg/L)

S standard = Recommended WHO WQI Standards of the water quality parameter.

After calculating the quality rating scale (Q_i), the Relative (Unit) weight (W_i) was calculated by a value inversely proportional to the recommended standard (S_i) for the corresponding parameter using the expression;

$W_i = k/Si$

$$k = \frac{1}{\sum 1/Si}$$

Where;

W_i = Relative (Unit) weight for nth parameter

S_i = Standard permissible value for nth parameter

k = Proportionality constant.

Results from the calculations were compared with the classification in Table 2.

Table 2: Water quality index classification (Valentina, *et al*., 2018)

WQI	Water quality status
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
Above 100	Unfit for human consumption

The mean values of the measured parameters for the study stations were compared to UNBS guidelines for natural potable water and the WHO standards for drinking water quality (Table 3).

Table 3: UNBS and WHO standards for potable water

Parameters	Units	UNBS Standards	WHO Standards
Temperature	˚C	Not specified	25-28
PH		5.5-9.5	6.5-8.5
Turbidity	NTU	25	25
Electric Conductivity	µS/cm	2500	1000
Total Dissolved Solids	mg/l	1500	500
Hardness	mg/l	600	600
Nitrate	mg/l	45	50
Calcium	mg/l	150	150
Magnesium	mg/l	100	100
Sodium	mg/l	200	200
Total Bacterial count	CFU/100ml	10	10
Fecal coliform	CFU/100ml	0	0

3.4.3 Analysis of Macroinvertebrate Diversity Metrics data

3.4.3.1 Potential influences of anthropogenic activities on biotic ecosystem

The benthic macroinvertebrate assemblages were characterized using the following diversity metrics:

1. Taxonomic richness – i.e., the percentage of occurrence of macroinvertebrate taxa among the

sites sampled.

2. Species abundance – the mean number of individuals of a given taxon m^{-2} and standard deviation at the sites.

3. Shannon-Wiener index (H′) – accounts for both abundance and evenness of the species present, where a higher H′ value indicates higher species diversity at a given site. It's calculated based on the formula: $H' = -\Sigma\ [(p\mathrm{i})\ (\ln p\mathrm{i})]$, where pi is the proportion (ni/N) of individuals of a specific species i found (n) divided by the total number of individuals found (N), ln is the natural log, Σ is the sum of the calculations, which is finally multiplied by −1.

4. Species richness (S) – total number of taxa.

5. Species evenness (E) – means, how close in numbers each species is distributed in an environment, calculated based on the formula: $E = H'/\ln(S)$, where H' is the calculated Shannon–Wiener diversity index and S = total number of species.

6. Average score per taxa (ASPT).

Therefore, lower macroinvertebrate diversity and ASPT scores are expected where habitat diversity is poor (Ochieng, et al., 2021). A one-way ANOVA accompanied by student t-test were performed to determine significant differences between site 1 and other sites (2, 3 and 4) for the benthic macroinvertebrate diversity metrics investigated.

3.6 Research Dissemination Plan

The findings from the study are to be shared with municipal council offices and the Environment Officer to enable them update their information and to discover the gaps in the policy about human-induced urban water resource pollution. The university retained a copy of approved dissertation in the university library for academic reference.

CHAPTER FOUR: PRESENTATION OF RESULTS

4.1 Introduction

This chapter presents results of anthropogenic activities identified along Pager River, variations of water quality along Pager River and variations of benthic macro invertebrates' metrics along the river.

4.2 Anthropogenic Activities identified along Pager River

Figure 2 shows the percentage of the anthropogenic activities identified along Pager River. The following anthropogenic activities were within 30 m in the river buffer zone; sanitary facilities, solid waste disposal, agricultural activities, human settlement and construction, sand mining, bricks laying, car washing, animal house, tree nursery bed, drainage channels and garage as indicated in Figure 3.

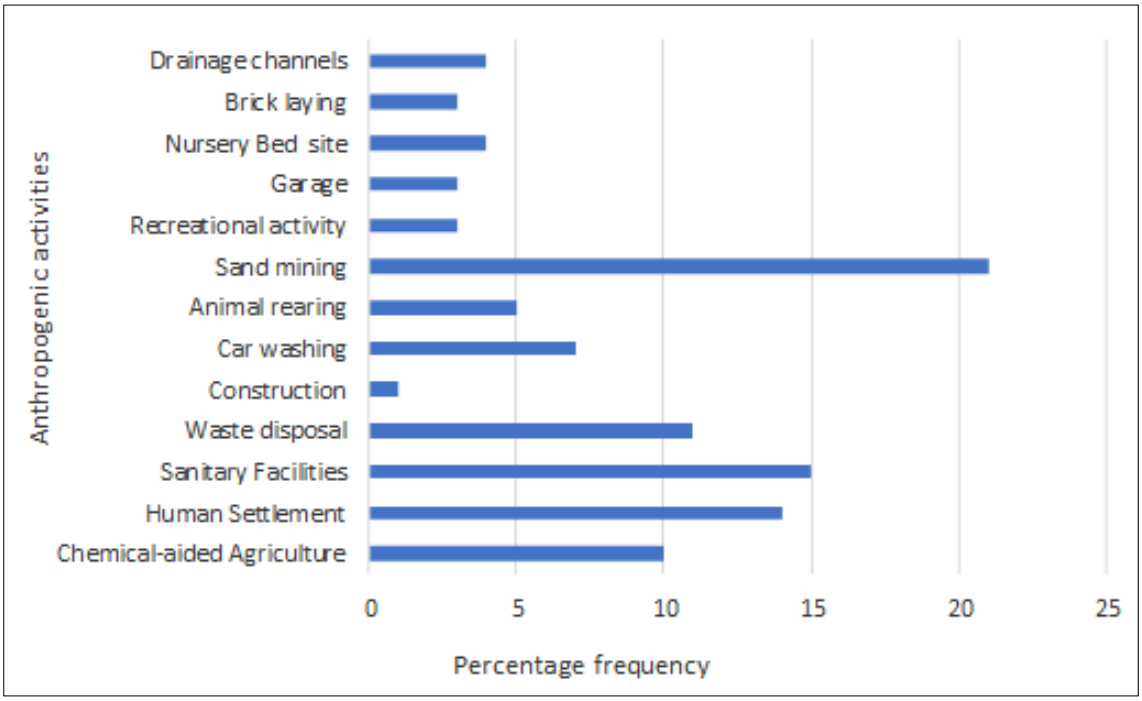


Figure 2: Percentage of Anthropogenic activities identified during survey along Pager River

The results indicate that sand mining recorded the highest occurrence (21%) followed by sanitary facilities, human settlement, waste disposal, agriculture and car washing respectively. Meanwhile, construction recorded the lowest occurrence (1%). Brick laying, recreational activity and garage were also relatively low. The map (Figure 3) shows locations of the anthropogenic activities along the river Pager with potential negative impacts on water quality and biotic ecosystem.

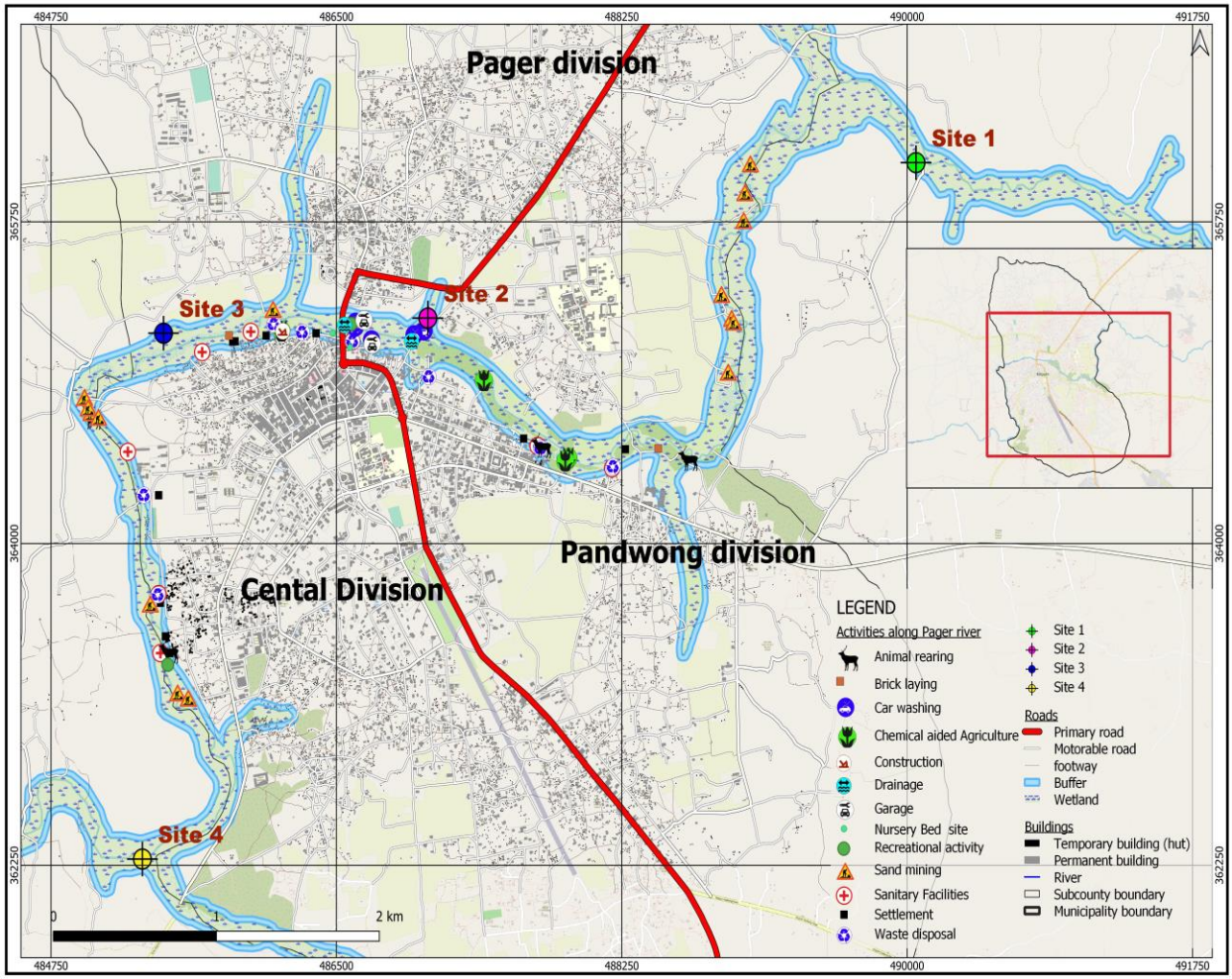


Figure 4: Locations of the anthropogenic activities along the river Pager with potential negative impacts on water quality and biotic ecosystem

The map (Fig 3) shows that sand mining was concentrated in the less developed parts of the municipality that is Nyanza and Jenge cells. Chemical aided agriculture, sanitary facilities and

car washing were concentrated in East ward B where site 2 was located, settlements were highest in Kony - Paco cell where site 3 was located and sand mining was highest in Nyanza cell which is adjacent to site 2. Waste disposal was highest in Kony - Paco and East ward B cells where sites 2 and 3 were located respectively.

4.3 Variation of Water Quality at different locations along Pager River

4.3.1 ANOVA and t-test results of selected water quality parameters

Table 4 presents ANOVA results and it shows that the water temperature, turbidity, pH, hardness, nitrate, calcium, magnesium and sodium values were not significantly different between study sites ($p \leq 0.05$) but EC, TDS, TBC and FC were significantly different between sites with p=0.003, p=0.003, 0.009 and 0.013 respectively. These results imply that only EC, TDS, TBC and FC varied by significant amount at the study sites.

Table 4: ANOVA results of selected water quality parameters

Water Quality Parameters	Mean and SD				ANOVA P-values
	Site 1	Site 2	Site 3	Site 4	
Temperature	26.16 ±1.35	26.48±1.26	26.68±1.02	26.06±0.9	0.817
Ph	7.178±0.42	7.262±0.23	7.242±0.29	7.102±0.14	0.312
Turbidity	21.872±9.86	33.33±21.44	26.112±10.75	24.184±12.87	0.634
EC	303.2±43.60	369.4±58.01	476.4±77.72	397±56.57	0.003*
TDS	194.048±27.91	236.416±37.12	304.896±49.75	254.08±36.21	0.003*
Hardness	63.148±10.01	82.696±28.05	74.576±36.17	70.816±15.11	0.658
Nitrate	0.972±1.26	1.338±1.5	1.314±1.55	1.254±1.51	0.978
Calcium	14.414±3.89	15.624±2.52	16.52±2.87	14.98±4.35	0.8
Magnesium	6.498±0.87	8.18±2.98	10.226±4.88	8.128±2.13	0.332
Sodium	14.114±2.87	17.59±3.9	19.84±3.44	19.95±5.03	0.11
TBC	188±89.27	430±171.76	556±105.26	270±222.49	0.009*
Faecal coliform	26.6±52.27	179.4±134.08	150.2±90.29	12.2±18.82	0.013*

* Indicate significant difference among sites at $p \leq 0.05$, EC=Electric Conductivity, TDS=Total Dissolved Solids, TBC=Total Bacterial Count. Site 1=upstream, Site 2 and Site 3 are within municipality, Site =downstream

Student t-test was used to further analyze if there were significant differences between the EC, TDS, TBC and FC at the study sites downstream (sites 2, 3 and 4) and upstream (site 1 as

control). Table 5 presents t-test results and it shows that EC, and TDS had significant differences between site 1 and 3 (p=0.002) and also site 1 and 4 (p=0.01) and TBC showed significant differences between site 1 and site 2 (p=0.03) and site 1 and 3 (0.000). FC showed significant difference between sites 1 and 2 (p=0.045) and site 1 and 3 (p=0.029). This means that EC, TDS, TBC and FC at study sites 2 and 3 did not have the same concentration with study site 1 (control). Therefore, it is likely that anthropogenic activities along the river in the areas within the Kitgum municipal impacted on the water quality.

Table 5: T-test results of selected water quality parameters

Parameters	Site 1	Site 2	P-value	Site 1	Site 3	P-value	Site 1	Site 4	P-value
EC	303.2	369.4	0.076	303.2	476.4	0.002*	303.2	397	0.01*
TDS	194.048	236.416	0.076	194.048	304.896	0.002*	194.048	254.08	0.01*
TBC	26.6	179.4	0.031*	26.6	150.2	0.000*	26.6	12.2	0.48
FC	26.6	179.4	0.045*	26.6	150.2	0.029*	26.6	12.2	0.578

***** Indicate significantly difference between Site 1 and the particular site at $p \leq 0.05$, EC=Electric Conductivity, TDS=Total Dissolved Solids, FC=Fecal Coliform TBC=Total Bacterial Count. Site 1=upstream, Site 2 and Site 3 are within municipality, Site =downstream

4.3.2 Water quality indicators for irrigation and domestic use

Water quality indicators for irrigation use

Figure 4 shows values of SAR, MAR and EC. Figure 4 shows the monthly SAR and MAR at the study sites. SAR was low (<4 meq/ml) in May but higher in other months (Figure 4 (a)), MAR was low (<30 meq/ml) in May but higher in other months (Figure 4 (b)) and EC was low (<350 µS/cm) in July and March but higher in other months (Figure 4 (c)). However, the EC, MAR and SAR values recorded in the study period fell within the standards for irrigation water (Table 1).

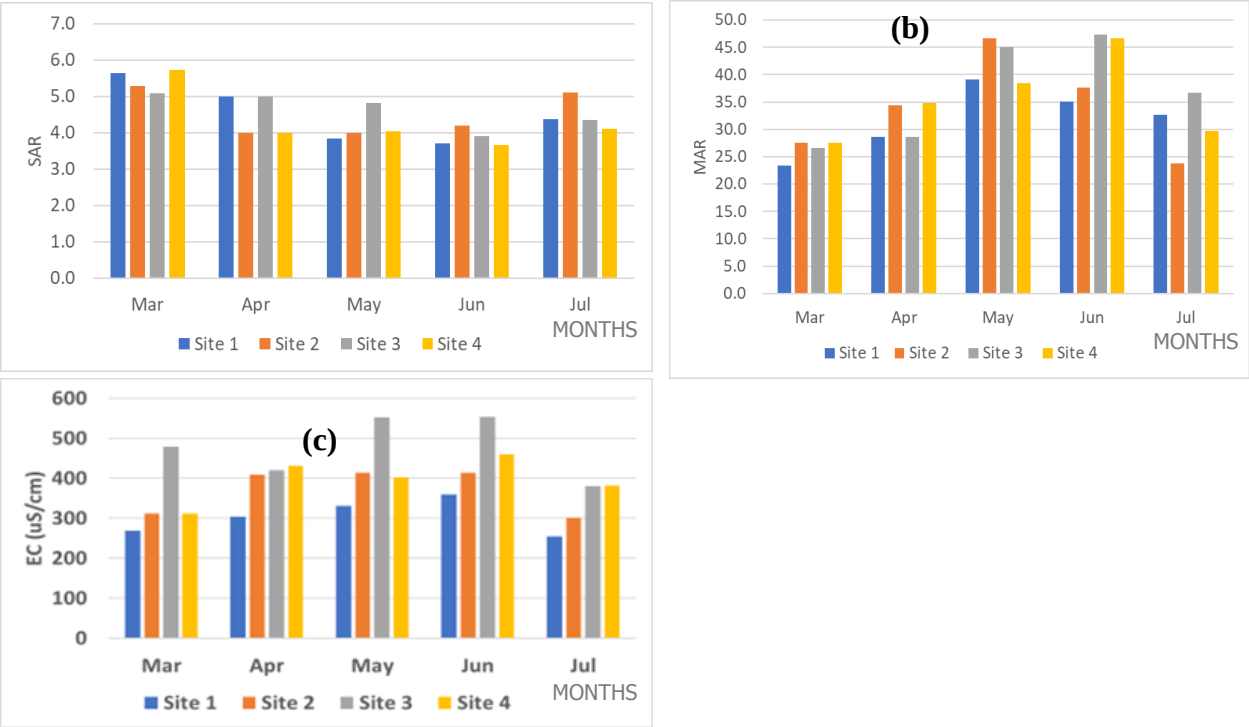


Figure 5: Monthly SAR, MAR and EC at the study sites

Water quality indicators for domestic use

Figure 5 shows monthly WQI. The WQI values in the study period were highest in July and lowest in March. Based on the WQI classification (Table 3), the WQI values for all the months and across all the study sites were more than 100, meaning that the water was unfit for domestic use for all the study period.

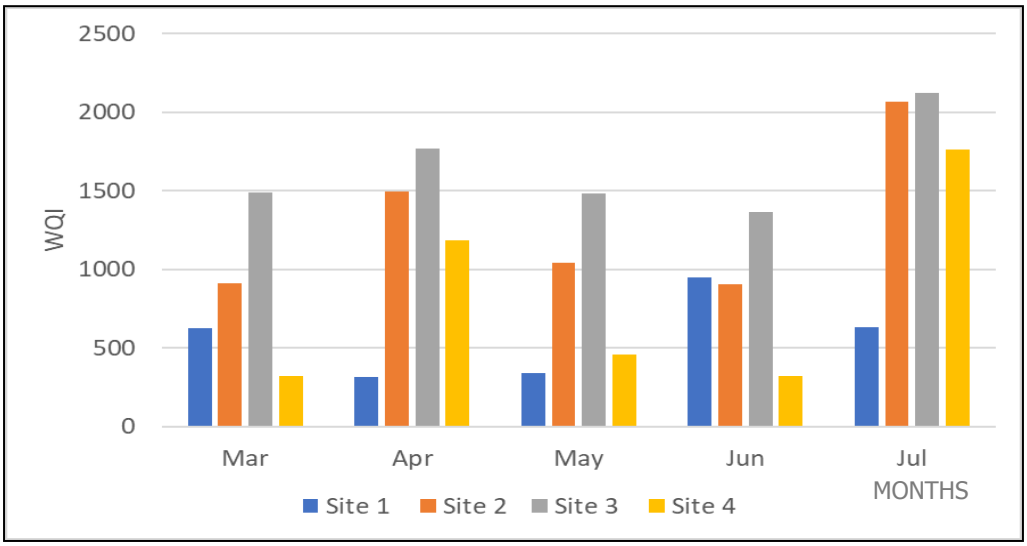


Figure 6: Monthly WQI at the study sites

Table 6 compares the values of the water quality parameters with WHO and UNBS standards. It can be observed that Turbidity, Fecal coliform and total bacterial count were water quality parameters above UNBS guidelines for potable natural water sources and the WHO standards for drinking water quality whereas the rest of the other water quality parameters were within acceptable limits/standards. Turbidity violated the standard in the month of March, April, and June whereas Fecal coliform and bacterial counted across all the months.

Table 6: Comparison of mean monthly water quality parameters with UNBS and WHO standards for potable water

Parameters	March	April	May	June	July	UNBS Standards	WHO Standards
Temperature (˚C)	27.93	25.35	25.33	26.45	26.68	Not specified	25-28
PH	7.4	6.92	7.31	7.07	7.29	5.5-9.5	6.5-8.5
Turbidity (NTU)	33.85*	39.18*	12.09	31.23*	15.53	25	25
EC (µS/cm)	342	390.75	424.25	446.5	329	2500	1000
TDS (mg/l)	218.88	250.08	271.52	285.76	210.56	1500	1500
Hardness (mg/l)	81.02	82.16	86.31	71.67	62.89	600	600
Nitrate (mg/l)	0.003	0.07	0.45	2.65	2.93	45	50
Calcium (mg/l)	20.05	14	15.39	12.95	14.53	150	150
Magnesium (mg/l)	7.15	6.48	11.63	9.5525	6.48	100	100
Sodium (mg/l)	22.65	14.68	14.39	18.45	18.88	200	200
TBC(CFU/100ml)	275*	400*	277.5*	295*	557.5*	10	10
FC (CFU/100ml)	111.5*	113.3*	83.75*	40.5*	111.5*	0	0

Values with * indicate that the parameter violates requirements of UNBS and WHO Standards for natural portable water

4.4 Variations of Benthic Macroinvertebrate metrics at different locations along Pager River

4.4.1 ANOVA and t-test results for selected Benthic Macroinvertebrate metrices

Table 7 shows species abundance and it indicates that a total of 659 individuals from 38 families in 9 orders were collected from the four sites during the study. Coleoptera, Pisullidae (9.6±6.88) was the most abundant at site 1 and Coleoptera, Elmidae (0.4±0.89) was the least abundant at site 1. The most abundant at site 2 was Trichoptera, Leptoceridae (3.8±0.45) and Odonata, Lestidae (0.4±0.89) as the lowest. Plecoptera, Lanaeidae (2.6±1.14) was the most abundant at site 3 while Trichoptera, Hydrosppsychidae (0.4±0.89) and Coleoptera, Dysticidae (0.4±0.89) were the least abundant. At site 4, Coleoptera, Hydrophilidae (4.6) was the most abundant while Ephemeroptera, Tricorythidae (0.4±0.55) was the least abundant

Table 7: Site occurrence and mean ± Standard deviation of species abundance (number of individuals) of a given taxon m^{-2} of benthic macroinvertebrates along Pager River, Kitgum during a period of March to July.

ORDER	FAMILY	COMMON NAME	Site 1	Site 2	Site 3	Site 4
Ephemeroptera	Heptagonlidae	Flat headed mayflies	6.8±2.39	0	0	0
	Tricorythidae	Stout crawlers	3.8±2.28	2±1.41	0	0.4±0.55
	Oligoneuridae	Brushlegged fly	4.8±3.70	0	0	0
	Teleganodidae	Spiny crawlers	3.4±3.78	0	0	0
	Eeptophlebidae	Prongills	0	0	0.6±0.89	1±2.24
	Baettidae	Small minnow flies	0	0	1±1.22	0
Trichoptera	Hyroppsychidae	Cased caddiflies	0	0	0.4±0.89	0
	Ecnomidae	Caseless Caddisflies	4.8±1.79	0	0	0
	Leptoceridae	Cased caddiflies	0	3.8±0.45	0	0.6±1.34
	Hydroptilidae	micro caddisfly	0	2±1.41	0	1.6±2.30
Coleoptera	Pisullidae	Cased caddiflies	9.6±6.88	0	0	0
	Helodidae	Marsh beetles	5.2±1.79	0	0	0
	Psephenidae	Water penny beetles	2.4±1.95	0	0	0
	Dystiscidae	Predacious diving beetles	0	2.2±1.92	0.4±0.89	3.4
	Hydrophilidae	water scavenger beetles	0	1.6±1.52	0.6±0.89	4.6
	Elmidae	Riffle beetles	0.4±0.89	0	0	0
Odonata	Chlorocyphide	Damseflies	0	0	0	0
	Aeshnidae	Dragon flies	0	1.4±2.07	0	2.6±3.13
	Caenidae	Cain flies	0	1.4±1.67	0	0
	Libellulidae	Dragonflies	0	0	0.6±0.89	2.4±2.30
	Coenagrionidae	Damseflies	0	0	1.2±1.30	0
	Gomphidae	Dragonflies	0	1.4±1.95	0	1.2±1.79
	Lestidae	Damseflies	0	0.4±0.89	0	0
	Protoneuridae	Damseflies	0	1.4±2.07	0	0
Diptera	Plecoptera	Stoneflies	4±2.92	0	0	0
	Perlidae	Stoneflies	4±.39	0	0	0
	Notonemouridae	Stoneflies	3.6±2.61	0	0	0
	Blepharoceridae	Netwinged midges	3±2.55	0	0	0
Hemiptera	Hydrometridae	Marsh treaders	0	2.8±1.92	0	0.8±1.30
	Gerridae	Pondskater	0	1.4±1.95	0	0
	Corixidae	Water boatmen	0	1.75±1.79	1.6±2.30	1±2.24
	Belostomatidae	Giant water bugs	0	0	1.6±1.52	1.2±1.79
Mytilidae	Unionidae	pearly mussels	0	1±2.24	2±1.87	1±2.24
Plecoptera	Planurbidae	Orb snails	0	0	0.8±0.84	0.8±1.10
	Lynaeidae	Pond snails	0	0	2.6±1.14	2.2±1.10
	Physidae	Pouch snails	0	0	1.6±1.82	2.4±2.61
Lepidoptera	Pyralidae	Aquatic caterpillars	1.4±1.67	0	0	0

Table 8 present ANOVA analysis result and Table 9 present t-test results. They show that; Species richness was lowest (6.2) at site 3 and highest (12) at site 1 with significant difference between sites 1 and 3 (p=0.005). Taxonomic richness was highest at site 1 (33.98±5.71) and lowest at site 3 (16.79±4.37). Species evenness were relatively similar at all sites although it was lowest (0.94) at site 3 and highest (0.96) at site 1 but showed no significant difference between sites. Shannon Weiner Index ranged was lowest at site 3 (1.69) and highest at site 1 (2.37) with significant differences between site 1 and 3 (p=0.005) then site 1 and 4 (p=0.014). Average score per taxa was lowest at site 3 (4.65) and highest at site 1(9.85) with significant differences between site 1 and all the sites (that is; with site 2(p=0.051), 3(p=0.016) and 4(p=0.024).

Table 8: ANOVA results for benthic macroinvertebrates metrics (Mean ± Standard Deviation and p-value)

Benthic Metrics	MEAN AND SD				ANOVA
	Site 1	Site 2	Site 3	Site 4	P-value
H’	2.37±0.18	2.13±0.12	1.69±0.37	1.96±0.24	0.003*
E	0.96±0.01	0.95±0.01	0.94±0.03	0.95±0.01	0.6*
S	12±2	9.6±1.34	6.2±2.68	8±2	0.002*
Taxonomic Richness	33.98±5.71	27.05±2.03	16.79±4.37	22.18±2.24	0*
ASPT	9.85±3.1	5.87±2.32	4.65±2.18	5.17±2.09	0.017*

* Indicates significant difference between Sites at p≤0.05. E=Species Evenness, H’=Shannon-Weiner Index, S=Species Richness, ASPT=Average Score per Taxa

Table 9: T-test results for benthic macroinvertebrates metrics (Mean ± Standard Deviation and p-value)

Matrices	Site 1	Site 2	P-value	Site 1	Site 3	P-value	Site 1	Site 4	P-value
H'	2.37±0.18	2.13±0.12	0.388	2.37±0.18	1.69±0.37	0.005*	2.37±0.18	1.96±0.24	0.014*
S	12±2	9.6±1.34	0.564	12±2	6.2±2.68	0.005*	12±2	8±2	0.144
ASPT	9.85±3.1	5.87±2.32	0.051*	9.85±3.1	4.65±2.2	0.016*	9.85±3.1	5.17±2.09	0.024*
Taxonomic Richness	33.98±5.7	27.05±2.0	0.034*	33.98±5.7	16.8±4.4	0.000*	33.98±5.7	22.18±2.2	0.003*

* Indicates significant difference between Site 1 and the particular site at p≤0.05. H’=Shannon-Weiner Index, S=Species Richness, ASPT=Average Score per Taxa

CHAPTER FIVE: DISCUSSION OF RESULTS

5.1 Introduction

This chapter discusses the results presented in chapter 4. The discussions focused on; (1) the main activities identified, their compliance to riverbank regulations guidelines and potential implications to water quality and ecosystems (2) the water quality parameters and Benthic Macro invertebrates which showed significance difference at the municipal area from the upstream values and possible reasons for the differences (3) suitability of the river water for domestic and irrigation use. Comparisons of the findings were made with previous study results as well.

5.2 Anthropogenic Activities along the Pager River with potential influence on Pager River water quality

The results of the study revealed that the dominant anthropogenic activities that violated the National Environment Regulations 2001 and NEA 2019 were; sand mining, sanitary facilities, human settlement, waste disposal, agriculture and car washing. Sand mining and waste disposal most likely cause blockage and sometimes diversion of the river course. Waste disposal is also a potential source of nutrients such as nitrate. Sanitary facilities, waste disposal, settlement, car washing, are the potential sources of pathogenic microorganisms that are likely causing adverse effects on the river water quality and subsequently aquatic life. Chemical aided agriculture and car washing are also likely to introduce toxic substances into the river due to leakage and runoffs.

Similar studies have urged that whereas some of the anthropogenic activities such as sanitary facilities are important healthy measures in urban and peri urban areas their growing number, distance to water resources, design and maintenance have led to increased water resource contamination (Chushugi, *et al*., 202). Okullo, *et al*., (2017) in his study in Isiolo county, Kenya reported that water resources exhibited high levels of contamination with microbial pathogens which were attributed to open defecation and generally poor sanitation. When the water with pathogens is consumed, it may affect human health and cause diseases like cholera, dysentery, typhoid, bilharzia among others. Competition for oxygen or oxygen demand also increases when pathogen levels are very high in water thus affecting aquatic life.

The waste disposed along the river constituted plastic, food, medical, mechanical, electronic, animal, human waste among others. These wastes have very diverse environmental and health effects. During rainy days, much of the wastes a few meters away are washed down into the river. This may lead to the increase and growth of high level of disease-causing microorganisms in the water.

Due to agricultural activities, nutrients from fertilizers and pesticides are washed down into the river during rains. Runoff washes soil and plant wastes to the river which lead to increase in nitrate levels as well as turbidity of the river water. Eutrophication may cause suffocation of aquatic organisms in the river leading to biodiversity loss. Xu, *et al*, (2022) reported that amount and intensity of fertilizer application have directly impact on the contamination of river water quality.

It was observed during the survey that the human settlement which were too close to the river (<30 m) were both temporary and permanent structures. However, settlements affect water quality due to the behavior of humans disposing both waste water and solid wastes into the river. These wastes released alters physicochemical and bacteriological quality of water such as turbidity, TBC, FC and TDS as well as harms aquatic life. In the absence of sanitation facilities, open defecation is practiced along the river. House construction along the rivers destroys river banks and causes sedimentation and destruction of the river's living ecosystem. Sand mining weakens riverbanks which can lead to flooding and also increase the possibility of sedimentation. Dredging for sand from the river physically disturbs the sediment, which increases suspended particles and raises the turbidity of the water. Hitchcock, *et al*., (1998) observed that dredging for sand in the river may cause very fine sand to travel up over 11 km from the dredging site, fine sand may travel up to 5 km, medium sand may travel up to 1 km, and coarse sand may travel less than 50 m. Sand mining in the river further interfere with fish population and other living organisms.

Car washing introduces dirty water containing substances such as soap, detergents, residue from exhaust fumes, gasoline, heavy metals, and motor oils in the river/stream which can affect water quality and aquatic life. The phosphates from soap can cause excess algae growth. Excessive algae smell bad, and deteriorates water quality. As algae decay, the process uses up oxygen in

the water that aquatic life needs for survival. According to Hashim & Zayadi, (2016), the enormous amount of water used to wash each car results in the release of untreated effluents into the surface water system. Physical disturbances involved in car washing also may destroy aquatic life.

5.3 Influence of Anthropogenic Activities on River Pager water quality

The results from ANOVA analysis revealed that only EC, TDS, TBC and FC were water quality parameters with significant variations at the study sites. Whereas, t-test revealed that the EC, TDS, TBC and FC in the river water increased significantly within and after the Kitgum municipal. From these results it can be concluded that anthropogenic activities along the river within Kitgum municipality had impacted on the water quality.

The observed mean EC values were lowest at site 1, followed by site 2 and 3 but highest at site 3. This could be due to the presence of 2 drainage channels at site 3 and 1 drainage channel at site 2 which transport the mineral irons and wastes roads and urban center, agricultural farms, sand mining plus wastes disposed into the water. EC level at site 4 was high possibly due to wash down from site 3 to downstream (site 4). This also explains the reason for the significant differences between site 1 and site 3 then also site 1 and site 4. The general level of EC at all sites especially site 1 could be due to sand mining which is generally practiced along the river irrespective of the location (urban or rural) and natural factors like the river's bedrock nature, soil and geology (Khatri & Tyagi, 2014). Kaushal, *et al*., (2017) in their study also found out that such human influences also increase levels of ions in river water. However, the recorded EC values did not exceed the WHO maximum permissible limits of 2500 μS/cm and UNBS standards for potable natural water. Therefore, the study results rightly indicate that water in the Pager River was not considerably ionized and has a relatively low ionic concentration level. Electrical conductivity in natural waters can occur naturally with charged ions such as calcium, magnesium potassium, chloride, sulphate, and nitrate among others which possibly explains the level of EC at site 1. These salts can also enter river water through sand mining, agriculture, drainage channels that transport road salts/ municipal runoffs and various wastes/wastewaters disposed into the river (Riva-Murray, *et al*., 2010) which possibly explains the reason for relatively higher EC levels in the site the other sites with more concentration of these activities.

The observed relatively high EC and TDS values at site 3 and the significant difference between

site 1 and site 3 were possibly due to pollution from agricultural, sand mining, waste disposal concentrated around that site and also municipal runoffs and drainage channels that enter into the river at and around that site. The somewhat higher level at site 4 and the significant difference between site 1 and 4 could be due to influence of the pollution activities from site 2 and 3 areas on downstream site 4. Similarly, Luvhimbi, *et al*., (2022) in their study recorded EC and TDS similar to results in this study. According to a study by the USGS (2014), a variety of human activities such as sewage, agricultural/pesticide runoff, urban runoff, and industrial effluent, contribute to increased concentrations of dissolved solids streams. The most prevalent dissolved solids are chloride, magnesium, calcium, phosphates, nitrates, sodium, and potassium. These occur naturally and are safe for the human body, and are mainly found in groundwater and fresh water which could be the reason for the presence of TDS at site 1. Some TDS components, including fluoride, lead, arsenic, and pesticides, can be extremely detrimental to human health and enter water through agricultural and urban runoffs, plant decompositions, waste disposal among others could be reason for relatively higher levels at site 2 and 3 and subsequently site 4.

However according to Sasikaran, *et al*., (2012), higher levels of TDS and EC are often harmful to aquatic life because dissolved salts can also dry out the skin of aquatic animals, which can be fatal. It can raise the temperature of water in which many animals cannot live. Significant site variation of TBC and FC recorded during the study period indicates significant distribution of bacterial and fecal contamination across sites. The very high TBC at site 3 and very high FC at site 2 were possibly attributed to pit latrines which are constructed less than 20 m from the river, the possible contamination from direct waste disposal, direct deposition of human fecal matter from swimmers and residents living near the river, surface and municipal runoffs in these 2 sites and the coliforms were probably transported to site 4, downstream. The detection of high FC counts in water samples indicates fecal contamination by people and warm-blooded animals at various points. It's visually evident that there are many open defecations fecal matter before and around site 2 than sites 3 which could be the reason for high fecal coliform levels in the sites. The reasons for the presence of fecal coliform levels in site1 is likely due to general rural open defecation behaviors and practices along streams. The total bacterial count levels in site 1 were likely due to decay of organic matter from dead leaves and grasses, among others. The TBC and FC levels were higher than WHO and UNBS recommended levels for potable natural water

(below 10 CFU/100ml for TBC and FC respectively). Their presence indicates the possibility of occurrence of pathogenic bacteria that cause diseases such as gastroenteritis, cholera, dysentery and typhoid fever after ingestion of contaminated water (Bwire, *et al*., 2020). Similar to our study results, previous studies by Saturday, *et al.*, 2021) around Lake Bunyonyi attributed high TBC and FC concentrations in the water close to sources from animals and sewage leakages, storm water runoff, sewage overflows, application of manure in the water catchment areas. It was found out that pit latrines enhanced bacterial contamination of adjacent water resources and that hydrogeological conditions played important role in the transport of fecal bacteria into the water. Onyango, *et al.*, (2018) also reported FC and TBC levels above WHO standards/limits due to human influence in their study on water Sources in Isiolo County in Kenya. Transportation of pathogens from the surface water to groundwater increases the vulnerability of groundwater (Jin & Flury, 2002). Diseases such as diarrhea, vomiting, cramps, nausea, headaches, fever, fatigue, and even death sometimes may occur in infants, children, elderly people, and people with weakened immune systems if this water is consumed (Some, *et al*., 2021). High microbial levels in water also lead to eutrophication thus depletion of oxygen. Subsequent low oxygen levels could possibly destabilize the aquatic habitat or ecosystem as a whole.

Turbidity in sites 2 and 3, somewhat exceeded the WHO and UNBS maximum value (25 NTU) except site 1 and 4 which were within the acceptable limits. Similar to this study results, Bwire et al., (2020) also reported mean turbidity values below and above WHO acceptable limits due spatial variations in urban and agricultural runoffs as well as waste disposal along a water resource. The somewhat higher values recorded in this study in sites 2 and 3 were likely attributed to continuous human influence such as cultivation, sand mining, drainage channels and waste disposal along and around these sites which accelerate soil erosion and sedimentation through surface runoff. The reason for turbidity level at site 4 being higher than site 1 but lower than sites 2 and 3 could be due to influence of human activities at sites 2 and 3. Inorganic and organic particles as small as clay, silt, algae, dissolved colored organic molecules, plankton, and other microscopic organisms can all contribute to the turbidity of water. Turbidity in rivers can be caused by natural occurrences such as heavy rains or windstorms. However, high turbidity can be caused by human activity in upstream areas for example, clear cutting, sand mining, urban runoffs and garden tillage causes soil to wash away into rivers and increase turbidity. Excessive

turbidity directly threatens human health since it acts as a shield for disease-causing pathogens. If not treated well, it leads to waterborne disease, which can cause intestinal sickness. High turbidity in drinking water makes the chlorine treatment less effective at water treatment plants as it shields the bacteria and other organisms. Increased turbidity in water also causes environmental consequences such as reduction in ecological productivity and habitat quality (Xu, *et al.*, 2022).

5.3.2 Suitability of water for irrigation

The results revealed that all indicators (EC, SAR and MAR) used to show suitability of water for irrigation complied with recommended standards. However, it should be noted that high EC would indicate salinity threat which affect plant water uptake and growth high SAR causes the soil's physical structure to break down and high MAR causes water infiltration problems (Johnson & Zhang, 1990). The relatively low EC levels in March was likely due to no rains. Run offs especially from agricultural land, soil erosion and sand mining can lead to influx of considerable amounts of inorganic pollutants into the river water which increase magnesium levels in water (Ojok, *et al.*, 2017). From the onset of rain in April, runoffs increased thus, increased EC, MAR and SAR. Akoachere, *et al*., (2019) in their study in Douala city, Cameroon reported higher EC, MAR, and SAR values in wet season than dry season but they were all within the suitable category for irrigation water. Similarly, Ukoha-Onuoha, *et al*., (2022) reported EC values between 128-552.38µS/cm in their study in Choba River in the Niger Delta Region of Nigeria which indicated that the water was suitable for irrigation. Similar results showing suitable levels of these parameters/indicators in river water was reported by Obeifuna & Sheriff, (2011) in their study in Yole area, Nigeria. Also, Mukiza, *et al.*, (2021) reported similar results of MAR ranging from 0.212-29.254 meq/l in their study at Nyandungu Wetlands, Rwanda.

5.3.3 Suitability of water for domestic use

WQI values were very high possibly due to the relatively very high EC, TDS, TBC and FC. The somewhat high WQI in April was likely due to high rainfalls and runoffs from waste sites, drainage channels, open defecation, unimproved sanitary facilities among other potential sources due to rainfall onset. The abnormally very high levels of FC and TBC in July could be due to more rainfall occurrences thus more runoffs and/or occasional disposal and deposits of wastes

and fecal matter into the river or point source. The slightly lower value in March was possibly due to limited movement of pollutants and runoffs which could have washed pollutants into the river since March is a dry season month in Kitgum (Appendix 4). A similar study by Krishan, *et al*., (2022) reported high WQI (>100) for River Gomti, Lucknow, India which was unsuitable for human consumption and domestic use due to influence of human activities such as animal, human, household, commercial, industrial and domestic waste water disposal into and along the river which increase TBC and FC levels in water. High WQI above recommended values show that the water is unsuitable for human consumption and pose human health threat such as outbreak of cholera, bilharzia, dysentery, typhoid, skin infections among others (Páll, *et al*., 2013).

5. 4 Influence of Anthropogenic Activities on River Pager Biotic Ecosystem

Anthropogenic activities such as waste disposal, chemical agriculture, sand mining, car washing, among others considered in this study pose threat to river aquatic ecosystems. They contribute to the introduction and dispersal of pollutants into the water body and subsequently change the conditions of the aquatic habitats and biodiversity life (Dudgeon, 2019). Benthic macro invertebrates at site 1 especially species of Ephemeroptera, Coleoptera, Odonata and Diptera were characterized by species with very low pollution tolerance with relatively higher abundance and taxonomic richness (Richardnson, 2019). This is an indication that site 1 is less polluted and has somewhat favorable environmental conditions for aquatic habitat. Unlike sites 2 and 3 which mostly had species with high pollution tolerance. This could be as a result of generally higher pollution levels and physical disturbance in these sites as seen in results objective 2 of this study. The reason for the relatively lower species abundance and moderate and less pollution sensitive species at site 4 is probably due to the pollution from sites 2 and 3 which could have altered the habitat and environmental conditions. According to Aura, *et al*., (2018) the presence and occurrence of species which are highly tolerant to pollution in sites 2, 3 and 4 indicate that Pager River is under environmental stress from anthropogenic pollution and disturbance. This explains the significant difference between site 1 and the rest of the sites in taxonomic richness.

However, species evenness, diversity and richness were generally low. Similar results were reported by Gichana, *et al*., (2015) in a study on anthropogenic disturbances on small rivers. Species evenness was not significantly different between study sites and this means the species

evenness was relatively the same in all the sites. The significant difference in Shannon Weiner index (diversity) between site 1 and site 3, then site 1 and site 4 indicate a likeliness of changes in the magnitude of pollution levels in these sites. This may have contributed to the low of diversity and evenness, and relatively high abundance of moderate and highly pollution tolerant species in sites 2, 3 and 4 (Tamiru & Asfwa, 2017). Also, FC and TBC levels were above WHO and UNBS standards and specifically very high at sites 2 and 3 yet they are great drivers of eutrophication in rivers thus, causing over growth, competition for oxygen and reduction of oxygen for aquatic life thus, unsuitable habitat. Findings by Matsiko, *et al*., (2013) also indicated that anthropogenic environmental stress especially within Tororo Municipality led to low diversity, richness and evenness. Also, the Shannon Weiner index (diversity) ranged from poor ($1<H'<3$) to moderate ($1<H'$) status (Welch, 1992), which corresponds with highly to moderately polluted waters (Ochieng *et al.*, 2021). The somewhat higher diversity level at site 1 is also likely to be due to minimal physical water disturbance and higher vegetation cover around the site unlike sites 2 and 3 and subsequently affecting site four downstream.

ASPT scores indicated that site 2, 3 and 4 are within the status of critically polluted to polluted unlike site 1 (Tumusiime, *et al*., 2019) thus, the significant difference between site 1 and the rest of the sites. Also, high ASPT score indicates good water thus containing a large number of high scoring taxa (Armitage, *et al*., 1983). According to the study, it's likely that the short-term dynamics of hydrological and physicochemical variables were generally less important than the overall random effects as drivers of macroinvertebrate-based metrics. However, the relevance of a random effect (site, time, their interaction) differed depending on the biological metrics analyzed. This was also reported by Laini, *et al.*, (2019) in Oglio River, Northern Italy.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusions

This study was constituted to determine: (1) the noncompliance of anthropogenic activities in Kitgum Municipality to riverbank regulation guidelines. (2) The potential influences of the anthropogenic activities to water quality and biotic ecosystems in the Pager River, and (3) the suitability of water from the river for domestic and irrigation use.

Results of the study revealed that, sand mining, sanitary facilities, human settlement, waste disposal, chemical aided agriculture, car washing, animal rearing/grazing, drainage channels, tree nurseries, garage, recreation activities and construction were the key human activities practiced along Pager River within the buffer/ protected. Off these activities, sand mining was the most highly practiced in the less developed parts of the municipality that is Nyanza and Jenge cell next to study site 2. Followed by chemical aided agriculture, sanitary facilities and car washing which were concentrated in East Ward B where study site 2 is located. Settlements and waste disposal also had relatively high concentration Kony - Paco and East Ward B cells where sites 2 and 3 are located respectively.

The selected water quality parameters were found to be below WHO and UNBS permissible limits except turbidity, FC and TBC with overall parameter values higher at sites 2 and 3 which are within the municipality. There were significant differences between site 1 and 3 in parameters like EC, TDS, TBC and FC and also between sites 1 and 2 in parameters like FC and TBC meanwhile only EC and TDS had significant difference between sites 1 and 4. This is an indicator of likely urban pollution due to the various anthropogenic activities along the river.

The results of the water quality analysis further indicate that the quality of water in Pager River is generally unsuitable for domestic use but suitable for irrigation purposes. WQI values were generally within the unsuitable levels as per WQI classification. This is further supported by the fact that the mean values for key parameters such as turbidity, TBC and FC were above WHO and UNBS permissible limits for drinking water and natural potable waters, respectively. The water was also suitable for irrigation. This is backed by the fact that EC, SAR and MAR values were within the suitable values for irrigation water.

Site 1 revealed high species abundance with pollution sensitive species more dominant other

than sites 2, 3 and 4 which had mostly pollution tolerant species. Species richness and Taxonomic richness were significantly different between site 1 and site 3. Shannon Weiner Index was significantly different between site 1 and 3 then site 1 and 4. Average score per taxa was significantly different between site 1 and all the other sites. Taxonomic richness, species richness, species abundance, species evenness, diversity and ASPT scores were highest at site 1 and lowest at site 3. This likely meant that Site 1 has the healthiest aquatic ecosystem/environment compared to the other 3 sites.

6.2 Recommendations

1. The current study findings are fundamentally important at both national and local level (Kitgum Municipality) for setting guidelines and policies so that River Pager can be sustainably conserved/protected to provide good quality water and other ecosystem services. These guidelines and policies can be used to control or stop key human activities such as sand mining, sanitary facilities, human settlement, waste disposal, chemical aided agriculture, car washing, animal rearing/grazing, drainage channels, tree nurseries and garage which were found commonly practiced along the Pager River within the buffer zone. These will improve:
   - Water quality which was found heavily polluted in terms of turbidity, FC and TBC within and downstream the Kitgum Municipal area.
   - Aquatic environment (Taxonomic richness, species richness, species abundance, species evenness and diversity) which was found greatly compromised within and downstream the Kitgum Municipal area.
2. Further research/studies investigate in detail the need, implementation and viability of the concept of ‘sanitation as a business in the municipal areas especially along the river be conducted to minimize waste disposal into the river.

REFERENCES

Adriano, D. (2016). *Water and Sanitation sector Report.* New York: Ministry of water and sanitation. Springer.

Akoachere, R., Eyong, T., Egbe, S., Yaya, O., Mbua, R., & Nwude, M. (2019). Characterization of Groundwater in the Basaltic Fractured Rock Aquiferous Formations of the Limbe Coastal Region of Mount Cameroon, SWR-Cameroon. *Journal of Environmental Science Current Research*.

Alam, M., Elahi, F., & Alam, D. (2016). Risk and water quality assessment over view of River Sitalakhya in Bangladesh. *Academy Open Internet Journal*, *19*, 1.

Alemu, T., Weyuma, T., Alemayehu, E., & Ambelu, A. (2017). Identifying riparian vegetation as indicator of stream water quality in the Gilgel Gibe catchment, southwestern Ethiopia. *Ecohydrology*, doi: 10.1002/eco.1915.

Allan, H. (2019). Effects of dissolved organic carbon and salinity on bioavailability of mercury. *Applied Environmental Microbiology*, *63*, 4267-4271.

Alobaidy, A. A., Maulood, B., & Abid, H. (2010). Application of Water Quality Index for Assessment of Dokan Lake Ecosystem, Kurdistan Region, Iraq. *Journal of Water and Resource Protection*, 792-798.

Anderisio, K., & De Luca, N. (2019). Seasonal enumeration of faecal coliform bacteria from the faeces of Ring-billed gulls(Laurus delawarensis) and Canada(Branta canadensis). *Application of Environmental Microbiology*, *65*, 5628-5630.

Anderson, K., Whitlock, J., & Harwood, V. (2015). Persistence and differential survival of feacal indicator bacteria in subtropical waters and sediments. *Application of Environmental Microbiology*(71), 3041-3048.

Andres, R., Fielding, D., Marland, G., Boden, T., & Kumar, N. (2019). Carbondioxide emissions from fossil fuel use. *Tellus*, *51*, 759-765.

Angledis, M., Markantonatos, P., & Bacalis, N. (2015). Impact of human activities on the quality of river water: The case of Evrotis River catchment basin, Greece. *Environ Monit Access*,

35, 137-153.

Anjana, E., Saket, P., Yong, J., & Pieter, v.-d. Z. (2019). Understanding the impact of anthropogenic activities on river ecosystem. *Geophysical Research Abstracts*.

Annan, K. (2015). *Water an Essential for Life.* General Assembly Report.

APHA. (2005). *Standard Methods for Examination of Water and Wastewater, 23rd Edition.* Washington DC: American Public Health Association, American Water Works Association, Water Environment Federation.

Arias-Estévez, M., López-Periago, E., & Martínez-Carballo, E. (2018). The mobility and degradation of pesticides in soils and the pollution of groundwater resources. *Agri Ecosystem Environment*(123), 247-260.

Armitage, P. D., Moss, D., Wright, J. F., & Furse, M. T. (1983). The performance of a new biological water quality score system based on macroinvertebrates over a wide range of unpolluted running-water sites. *Water Research, 17*(3), 333-347.

Arnold, C., & Gibbons, C. (2016). Impervious surface coverage:. *The emergence of a key environmental Indicator, 63*, 243-258.

Aschelew, L., & Otto, M. (2015). Benthic macroinvertebrates based new biotic score "ETHbios" for assessing ecological conditions of highland streams and rivers in Ethiopia. *Limnologica*, 11-19.

Aura, C. M., Raburu, P. O., & Herrman, J. (2018). Macroinvertebrates' community structure in Rivers Kipkaren and Sosiani, River Nzoia basin, Kenya. *Journa of Ecology and the Natural Environment, 3*, 39-46.

Ayot, J. (2021, 08 05). The State of Pager River, Kitgum Municipality.

Ayraci, E., & Hoda, N. (2015). Adsorption Kinetics and isotherms of pesticides onto activated carbon. *Chemosphere, 60*, 1600-1607.

Azizullah, A., Muhammad, N. K., Peter, R., & Donat-Peter, H. (2010). Water pollution in Pakistan and its impact on public health--a review. *Environment International*, 479-497.

Bachmat, Y. (2014). *Ground water as part of Water System.*

Baker, L. (2012). Introduction to nonpoint source pollution in the United States and prospects for wetland use. *Ecological Engineering, 1*(1), 1-12.

Berge, D., Field, E., & Hindar, A. K. (2017). Nitrogen retention in two Norwegian water courses of different trophic status. *Ambio, 26*, 286-288.

Bhateria, R., & Jain, D. (2016). Water quality assessment of lake water: a review. *Springer*, 161-173.

Boyer, E., Goodale, C., Jaworsk, N., & Howarth, R. (2012). Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern USA. *Biochemistry, 57*, 137-169.

Braskerud, B. (2011). The influence of vegetation on sedimentation and resuspension of soil paricles in small constructed wetlands. *Journal of Environmental Quality, 30*, 1447-1457.

Bu, H., Meng, W., Zhang, Y., & Wan, J. (2014). Relationships between land use patterns and water quality in the Taizi River basin, China. *Ecological Indicators*, 187-197.

Buck, O., Niyogi, D., & Townsend, C. (2014). Scale-dependence of landuse effects on water quality of streams in agricultural catchments. *Environmental Pollution, 130*, 287-299.

Bwire, G., Sack, D. A., Kagirita, A., Obala, T., Debes, A. K., Ram, M., . . . Orach, C. G. (2020). The quality of drinking and domestic water from the surface water sources (lakes, rivers, irrigation canals and ponds) and springs in cholera prone communities of Uganda: an analysis of vital physicochemical parameters. *BMC Public Health, 20*, 1128.

Călmuc, V. A., Călmuc, M., Țopa, M. C., Timofti, M., Iticescu, C., & Georgescu, L. P. (2018). Various Methods for calculating the Water Quality Index. Galati, Romania: ”Dunarea de Jos” University of Galati.

Carpenter, S., Caraco, N., Correl, D., Howarth, R., Sharpley, A., & Smmith, V. (2018). Nonpoint pollution of surface of waters with phosphorus and nitrogen. *Journal of Applied Ecology, 8*, 559-568.

Castillo, M., & Brunzel, S. (2020). Nutrient concentrations and discharges in a Midwestern agricultural catchment. *Journal of Environmental Quality, 29*, 1142-1151.

Chaudhary, B. S., Saroha, G. P., & Yadav, M. (2018). Effect of landuse and urbanization on hydrochemistry and contamination on hydrochemistry and contamination of groundwater from Taejon area. *Journal of Hydrology, 253*, 194-210.

Chushugi, D. U., Sonwa, D. J., Kahindo, J. M., Itunda, D., Chishugi, J. B., Felix, F. L., & Suhani, M. (2021). How Climate Change and Land Use/Land Cover Change Affect Domestic Water Vulnerability in Yangambi Watersheds (D. R. Congo). *Land*, 165.

Correll, D. (2019). Phosphorus: a rate limiting nutrient in surface waters. *Poultry science, 78*, 674-682.

Cude, C. (2001). Oregon Water Quality Index: A Tool for Evaluating Water Quality Management Effectiveness. *Journal of the American Water Resources Association*, 125-137.

Cundy, A., Croudace, I., Caerreta, A., & Irabien, M. (2013). Reconstructing historical trends in metal input in heavily-disturbed, contaminated estuaries:studies from Bilbao, Southampton. *Applied Geochemistry, 18*, 311-325.

Dale, V., Haeuber, R., Hobbs, N., & Huntly, N. (2020). Ecological principles and guidelines for managing use of land. *Ecological Applications, 10*, 639-670.

Deborde, D. D., Hernandez, M. B., & Magbanua, S. F. (2016). Benthic Macroinvertebrate Community as an Indicator of Stream Health: The Effects of Land Use on Stream Benthic Macroinvertebrates. *SCIENCE DILIMAN, 28*(2), 5-26.

Desrosiers, M., Usseglio-Polatera, P., Archaimbault, V., Larras, F., Methot, G., & Bernadette, P. A. (2019). Assessing anthropogenic pressure in the St. Lawrence River using traits of benthic macroinvertebrates. *Science of The Total Environment*, 233-246.

Dubrovsky, N., Burow, K., Clark, G., Gronberg, J., & Hamilton, P. (2020). The quality of our nation's streams and ground water. *US Geological Survey Circular*, 174.

Dudgeon, D. (2019). Multiple threats imperil freshwater biodiversity in the Anthropocene. *Current Biology , 29*(19), R960-R967.

European Environment Agency. (2018). Clean water is life, health, food, leisure, energy….

Environmental Information Systems , 1.

Ferrier, R., Edwards, A., Hirst, D., Littlewwod, I., Watts, C., & Morris, R. (2011). Water quality of Scottish rivers: spatial and temporal trends. *Science of the Total Environment, 265*, 327-342.

Galal, U. M., Stephen, N., & Agnieszka, O. I. (2021). A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators*.

Gergel, S. (2015). Spatial and non-spatial factors: when do they affect landscape indicators of watershed loading. *Lanscape Ecology, 20*, 177-189.

Gichana, Z., Njiru, M., & Raburu, P. O. (2015). Effects of human activities on benthic macroinvertebrates community composition and water quality in the upper catchment of the Mara River Basin, Kenya . *Lakers and Reservoirs: Research and Management, 20*, 128-137.

Gomez, E., Durillon, C., Rofes, G., & Picot, B. (2019). Phosphorus adsorption and release from sediment of brackish lagoons: pH, Oxygen and loading influence. *Water Resources, 33*, 2437-2447.

Goss, M., & Chen, S. (2020). Transport of nitrogen , phosphorus and micro-organisms from manure into surface and groundwater, Berlin. *Springer*, 31-55.

Gupta, K. S., & 1987, G. I. (1987). *Management of Saline Soils and Water*. New Delhi: Oxford and IBH Publishing Company.

Hashim, N. H., & Zayadi, N. (2016). Pollutants Characterization of Car Wash Wastewater. *EDP Sciences, 47*.

Haygarth, P., Chapman, P., Jarvis, S., & Smith, R. (2018). Phosphorus budgets for two contrasting grassland farming systems in the UK . *Soil use and management*(14), 160-167.

Hitchcock, D. R., Seiderer, L. J., & Newel, R. C. (1998). The Impact of Dredging Works in Coastal Waters: A Review of the Sensitivity to Disturbance and Subsequent Recovery of Biological Resources on the Sea Bed. *Oceanography and Marine Biology, 36*(127).

Hunsaker, C., & Levine, D. (2015). Hierarchical approaches to the study of the study of water quality in rivers . *Bioscience, 45*, 193-203.

Hussain, M., Ahmed, S., & Abderrahman, W. (2018). Cluster analysis and quality assessment of logged water at an irrigation project, eastern Saudi Arabia . *Journal of Environmental Management, 86*, 297-307.

Institute of Medicine. (2010). *The Intakes of Water, The National Academies press.* Washington: Virginia Tech,Publication 452-400.

IUSS. (1999). *Report of Second International Conference and Land Degradation and Desertification.* Thailand: International Union of Soil Science, Khon Kaen.

Jarvie, H., Whitton, B., & Neal, C. (2018). Nitrogen phosphorus an east coast British rivers speciation,sources and biological significance. *Science of the Total Environment, 210*, 79-109.

Jiang, W., Nan, X., Yichu, W., Wei, Z., Alistair, G. L., & Jinren, N. (2021). Global syndromes induced by changes in solutes of the world's large rivers. *Nature Communications*, 12.

Jin, Y., & Flury, M. (2002). Fate and Transport of Viruses in Porous Media. *Advances in Agronomy, 77*, 39-102.

Johnson, D., & Zhang, H. (1990). Classification of irrigation water quality. *Oklahoma Cooperative Extension Fact sheets*.

Johnson, L., Richards, C., Host, G., & Arthur, J. (2017). Landscape influences on water chemistry in Midwestern stream ecosystems. *Fresh water Biology, 37*, 193-207.

Kaayaa, L. T., Dayb, J. A., & Dallascd, H. F. (2015). Tanzania River Scoring System (TARISS): a macroinvertebrate-based biotic index for rapid bioassessment of rivers. *African Journal of Aquatic Science, 40*(2), 109-117.

Kagolo, F. (2012). *Report by the ministry of water and environment.* Ibadan: Institute of Tropical Agriculture.

Kaushal, S. S., Duan, S., Doody, T. R., Haq, S., Smith, R. M., Johson, T. A., . . . Stack, W. P. (2017). Human-accelerated weathering increases salinization, major ions, and

alkalinization in Fresh water across land use. *Applied Geochemistry, 2*(6), 121-135.

Kawo, S. N., & Karuppannan, S. (2018). Groundwater quality assessment using water quality index and GIS technique in Modjo River Basin, central Ethiopia. *Journal of African Earth Sciences*, 300-311.

Khatri, N., & Tyagi, S. (2014). Influences of Natural and Anthropogenic Factors on Surface and Ground Water Quality in Rural and Urban Areas. *Frontiers in Life Science, 8*, 23-39.

Kitgum Municipal Council. (The State of Environment Report). *2019.* Kitgum: NEMA.

Krejcie, R., & Morgan, D. (1970). Determining sample size for research activities. *Educational and Psycological measurement*.

Krishan, A., Mishra, R. K., & Khursheed, A. (2022). Assessment of water quality using water quality index: A case study of the River Gomti, Lucknow, Uttar Pradesh, India. *Urban Water Journal, 19*(5), 520-530.

Laini, A., Viaroli, P., Bolpagni, R., Cancellario, T., Racchetti, E., & Guareschi, S. (2019). Taxonomic and Functional Responses of Benthic Macroinvertebrate Communities to Hydrological and Water Quality Variations in a Heavily Regulated River. *Water, 11*(7), 1478.

Larson, S., Capel, P., Goolsby, D., Zaugg, S., & Sandstrom, M. (2015). Relations between pesticide use and riverine flux in the Mississippi river basin. *Chemosphere, 31*, 3305-3321.

Liz, P., Musonge, S., Boets, P., Lock, K., Ambarita, M. N., Forio, M. A., & Goethals, P. L. (2020). Rwenzori Score (RS): A Benthic Macroinvertebrate Index for Biomonitoring Rivers and Streams in the Rwenzori Region, Uganda. *Sustainability, 12*, 10473.

Luvhimbi, N., Tshitangano, T. G., Mabunda, J. T., Olaniyi, F. C., & Edokpayi, J. N. (2022). Water quality assessment and evaluation of human health risk of drinking water from source of point of use at Thulamela municipality, Limpopo Province. *Scientific Reports, 12*, 6059.

Masese, F., Raburu, P., & Kwena, F. (2012). Threats to the Nyando Wetland. In A. Docs,

Community Based Approach to the Management of Nyando Wetland, Lake Victoria Basin, Kenya (pp. 68-80). Kenya: Kenya Disaster Concern & VIRED International & UNDP.

Mateo, J. S., Marjani, S. Z., Turral, H., & Burke, J. (2017). *A Global Water-Quality Crisis and the Role of Agriculture.* Rome and Colombo: Food and Agricultural Organization and International Water Management Institute.

Matsiko, J., Mbabazi, J., & Ntale, M. (2013). Impact of municipal effluent on the water quality of receiving river: A case of River Aturukuku in Tororo District, Eatern Uganda. *American Open Analytical Chemistry Journal, 1-11*.

Memon, M., Soomro, S. M., Mohammad, S. A., & Kazi, S. M. (2011). Drinking water quality assessment in Southern Sindh (Pakistan). *Environmental Monitoring Assessment*, 39-50.

Mereta, S. L., Boets, P., Meester, L. D., & Goethals, P. L. (2013). Development of a multimetric index based on benthic macroinvertebrates for the assessment of natural wetlands in Southwest Ethiopia. *Ecological Indicators*, 510-521.

Meyer, J., Paul, M., & Taulbee, W. (2015). Stream ecosystem function in urbanization landscapes. *JN Am Benthol Soc, 24*, 692-612.

Misaghi, F. A., Fatemeh, D. A., Mostafa, R. B., & Baden, M. B. (2017). Introducing a water quality index for assessing water for irrigation purposes: A case study of the Ghezel Ozan River. *Science of The Total Environment*, 107-116.

Miserendino, L. M., Miguel, A., Di Prinzio, Y. C., Brand, C., & Adriana, M. K. (2011). Assessing land-use effects on water quality, in-stream habitat, riparian ecosystems and biodiversity in Patagonian northwest streams. *Journal of The Total Environment*, 612-624.

Mukiza, P., Bazimenyera, J. D., Niyonkuru, R., & Bapfakurera, N. P. (2021). Assessment of Irrigation Water Quality Parameters of Nyandungu Wetlands. *Journal of Geoscience and Environment Protection*.

Nagaraju, A., Sunil, K., & Thejaswi, A. (2014). Assessment of groundwater quality for irrigation: a case study from Bandalamottu lead mining area, Guntur District, Andhra

Pradesh, South India. *Applied Water Science*, 285-396.

Nagawa, G., Atukunda, G., Nuwabimpa, M., & Atwongyeire, D. (2018). Community perceptions towards the implications of human activity on River Rwizi, Uganda Sustainability. *International Research Journal of Earth Sciences*, 1-8.

NEMA. (2019). *The State of Environment Report for Uganda.* Kampala: National Environment Management Authority.

Nitasha, K., & Sanjiv, T. (2015). Influences of natural and anthropogenic factors. *Frontiers in Life Science*, 23-39.

Nizel, J. H., & Nazrul, I. M. (2015). Water Pollution and its Impact on the Human. *Journal of Environment and Human*.

Nuss, P., & Eckelman, M. (2014). *Population, urban development and environment in Uganda; a case of Kampala city and its Environment.* Kampal Uganda: Makerere University.

Obeifuna, G. I., & Sheriff, A. (2011). Assessment of Shallow Ground Water Quality of PindigaGombe Area, Yola Area, NE, Nigeria for Irrigation and Domestic Purposes. *Research Journal of Environmental and Earth Sciences, 3*, 131-141.

Ochieng, H., Gandhi, W. P., Magezi, G., & Okot-Okumu, J. (2021). Diversity of benthic macroinvertebrates in anthropogenically disturbed Aturukuku River, Eastern Uganda. *African Zoology*, 1–19.

Ocungi, J. (2019, 12 04). Kitgum Residents Dump Waste in Pager River,Uganda Radio Network (URN).

Ojija, F., Gebrehiwot, M., & Kilimba, N. (2017). Assessing ecosystem integrity and macroinvertebrates community structure: Towards conservation of small streams in Tanzania. *International Journal of Scientific & Technology Research, 6*, 02.

Ojok, W., Wasswa, J., & Ntambi, E. (2017). Assessment of Seasonal Variation in WaterQuality in River Rwizi Using MultivariateStatistical Techniques, Mbarara Municipality,Uganda. *Journal of Water Resource and Protection , 9*, 83-97.

Ojuk. (2019). Microbial communities and fecal indicator bacteria associated with Cladophora

mats on beach sites along Lake Michigan shores . *Apllied and Environmental Microbiology, 72*, 1932.

Okullo, J. O., Moturi, W. N., & Ogendi, G. M. (2017). Open Defeacation and its Effects on the Bacteriological Quality of Drinking Water Sources in Isiolo County. *SAGE journals, 11*.

Onyango, A. E., Okoth, M. W., Kunyanga, C. N., & Aliwa, B. O. (2018). Microbiological Quality and Contamination of Level of Water Sources in Isiolo County in Kenya. *Journal of Environmental and Public Health , Volume 2018*.

Páll, E., Niculae, M., Kiss, T., Şandru, C. D., & Spînu, M. (2013). Human impact on the microbiological water quality of the rivers. *Journal of Medical Microbiology 2013 Nov; 62(Pt 11): 1635–1640, 62*(11), 1635-1640.

Patang, F., Soegianto, A., & Hariyanto, S. (2018). Benthic Macroinvertebrates Diversity as Bioindicator of Water Quality of Some Rivers in East Kalimantan, Indonesia. *International Journal of Ecology*.

Paul, M., & Meyer, J. (2011). Streams in urban landscape. *Annual Review of Ecology, Evolution, and Systematics, 37*, 333-365.

Peters, N., & Meybeck, M. (2020). Water quality degradation effects on freshwater availability: impacts of human activities. *IWRA-Water International, 25*, 185-193.

Power, M., Littlefield-Wiyer, J., Gordon, D., Veal, D., & Slade, M. (2015). Phenotypic and genotypic characterization of encapsulated Escherichia coli isolated from blooms in two Australian lakes. *Environmental microbiology, 7*, 631-640.

Raghunath, I. I. (1987). *Groundwater. Second edition.* New Delhi, India: Wiley Eastern Ltd.

Raven, K. (2011). *Geochemistry of ground water in the Precambrian crystalline bedrock of Finland in relation to the reservoir rocks.* Finland: Water Reource Institute.

Richard, L. A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. . In L. A. Richard, *Agricultural Handbook No. 60* (pp. 7-53). Washington DC: US Department of Agriculture.

Richardnson, J. S. (2019). Biological Diversity in headwater streams. A review. *Water, 11*, 366.

Riva-Murray, K., Riemann, R., Murdoch, P., Fischer, J. M., & Brightbill, R. (2010). Landscape Characteristics affecting streams in urbanizing regions of the Delaware River Basin(New Jersy, New York, and Pennslyvania, US. *Landscape Ecology, 25*, 1489-1503.

Roosmini, D., Septiono, M., Putri, E., Shabrina, H., Salami, R., & Ariesyady, D. (2008). River water pollution condition in upper part of Brantas River and Bengawan Solo River. *Earth and Environmental Science*, 106.

Roston. (2001). Qualitative and Quantitative research methodology.

Sasikaran, S., Sritharan, K., Balakumar, S., & Arasaratnam, V. (2012). Physical, Chemical and microbial analysis of bottled drinking water. *Ceylon Medical Journal, 57*(3), 111.

Saturday, A., Lyimo, T. J., Machiwa, J., & Siajali, P. (2021). Spatial and temporal variations of faecal indicator bacteria in L ake Bunyonyi, South-Western Uganda. *SN Applied Sciences, 3*, 697.

Şener, Ş., Şener, E., & Davraz, A. (2017). Evaluation of water quality using water quality index (WQI) method and GIS in Aksu River (SW-Turkey). *Science of The Total Environment*, 131-144.

Shrestha, S., & Kazama, F. (2017). Assessment of surface water quality using a multivariate statistical technique: a case study of the Fuji River,Japan. *Environmental modelling and software, 22*, 464-475.

Sikder, T. D., Yusuke, K., Masaomi, Y., Yustiawati, Y. M., Shunitz, T., Dalkhjav, O., . . . Masaaki, K. (2013). River Water Pollution in Developed and Developing Countries: Judge and Assessment of Physicochemical Characteristics and Selected Dissolved Metal Concentration. *Soil Air Water*, 60-68.

Smith, R., Alexander, R., & Wolman, M. (2017). Regional interpretation of water monitoring data. *Water Resources Research, 33*, 2781-2798.

Smith, V., & Schindler, D. (2019). Eutrophication science: where do we go from here? *Trends in Ecology and Evolution, 24*, 201-207.

Some, S., Mondal, R., Mitra, D., Divya, J., Devvret, V., & Samanwita, D. (2021). Microbial

pollution of water with special reference to coliform bacteria and their nexus with environment. *Energy Nexus*.

Stiglitz, D. (2019). Pestcides classification and properties. *Analysis of pesticides in food and environment*, 1-34.

Tamiru, S. M., & Asfwa, S. L. (2017). Correlation Study of some physico-chemical parameters and benthic macroinvertebrates metrics on the ecological impacts of floriculture industries along Wedecha River, Debreit, Ethiopia. *Journal of Coastal Life Medicine, 30*, 433-440.

The State of Environment Report. (2019). *The South Africa State of Environment Report.* South Africa: The South African Edition.

Tsegaye, T., Sheepard, D., Johnson, A., & Tadesse, W. (2016). Development of chemical index as a measure of in-stream water quality in response to land-use and land-cover changes. *Water Air Soil Pollution, 174*, 161-179.

Tumusiime, J., Tolo, C. U., Dusabe, M. C., & Albrecht, C. (2019). Reliability of the Tanzania River Score System (TARISS) macroinvertebrate index of water quality: a case study of the river Mpanga system, Uganda. *Journal of Fresh Water Ecology, 34*, 541-557.

Ukoha-Onuoha, E., Fubara-Manuel, I., Bestmann, & K, M. L. (2022). Effect of Industrial Effluent on Irrigation Water Quality ofChoba River in the Niger Delta Region of Nigeria. *Journal of Ecology and Environmental Sciences, 2*, 362.

UN World Water Assessment Programme. (2008). *The United Nations World Water Development Report.* Kiev: Green Facts.

United Nations. (2011). *CIA The World Fact Book.* US: US Central Intelligence Agency.

United Nations Development Programme. (2021). *The SDGs in Action.* New York: UNDP.

UNWWD. (2008). *Water Resources Report.* Kiev: Green Facts.

USGS. (2019). *How Much Water is on Earth?* Colorado: Water Science School.

Valentina, A. C., Mădălina, C., Maria, C. Ţ., Mihaela, T., Cătălina, I., & Lucian, G. P. (2018). Various Methods for Calculating the Water Quality Index. *Analele Universității*

”Dunărea de Jos” din Galați. Fascicula II, Matematică, fizică, mecanică teoretică / Annals of the ”Dunarea de Jos” University of Galati. Fascicle II, Mathematics, Physics, Theoretical Mechanics, 171-178.

Vinay, M., Vijay, V., Balwant, S. R., Baljinder, K., Neelesh, B., Akansha, S., . . . Jose, M. C. (2022). Current status of pesticide effects on environment, human health and it’s eco-friendly management as bioremediation: A comprehensive review. *Frontiers in Microbiology*, 13.

Wallage, Z., & McDonald, A. (2016). Drain blocking is an effective treatment for reducing dissolved organic carbon loss and water colour in peatlands. *Science of the total Environment, 367*, 811-821.

Welch, F. B. (1992). *Ecological Effects of Wastewater. Applied limnology and pollutant effects(2nd Ed)* . New York: Chapman and Hall.

WHO. (2006). Guidelines for drinking water-water quality. In WHO, *World Health Organisation- 3rd Edition* (pp. 22-35). Geneva: WHO Library Cataloguing-in-Publication Data.

Wim, G., Lock, K., De Pau, N., & Geothals, P. L. (2010). Multimetric Macroinvertebrate Index Flanders (MMIF) for biological assessment of rivers and lakes in Flanders (Belgium). *Ecology and Management of Inland Waters*, 199-207.

Withers, P., & Jarvie, H. (2018). Delivery and cycling of phosphorus in rivers: a review. *Science of the Total Environment, 400*, 379-395.

Withers, P., & Lord, E. (2012). Agriculture nutrients input to rivers and groundwaters in the UK policy, environmental management and research needs. *Science of the Total Environment*(282), 9-24.

Wright, F. (2018). The Environmental Impact of Marine fish culture: towards a sustainable future. *Marine Pollution Bulletin, 31*, 159-166.

Wright, I. A., Wright, S., Graham, K., & Burgin, S. (2011). Environmental protection and management: A water pollution case study within the Greater Blue Mountains World Heritage Area, Australia. *Land Use Policy, 28*(1), 353-360.

Xu, H., Tan, X., Liang, J., Cui, Y., & Gao, Q. (2022). Impact of Agricultural Non-Point Source Pollution on River Water Quality: Evidence From China. *Frontiers in Ecology and Evolution*.

Xuege, W., Wen, C. M., Jun, L., Hongyan, L., Hongchao, L., Guangyi, M., & Dejun, B. (2022). Analysis of changes in the hydrological regime in Lalin River basin and its impact on the ecological environment. *Frontiers in Earth Science*.

Zhang, Q., Li, Z., Zeng, G., Li, J., Fang, Y., Yuan, Q., . . . Ye, F. (2019). Assessment of surface water quality using multivariate statistical techniques in red soil hilly region:a cas study of Xiangjiang watershed, China. *Environmental Monitoring and Assessment, 152*, 123-131.

Zhao, H., Xuejun, D., Becky, S., Bensheng, Y., & Xiaowei, J. (2013). Spatial correlations between urbanization and river water pollution in the heavily polluted area of Taihu Lake Basin, China. *Journal of Geographical Sciences*, 732-752.

APPENDICES

Appendix 1: Proposed Survey Checklist

S/N	ACTIVITY	POTENTIAL IMPACT	GPS LOCATION	LOCATION NAME (CELL)
01	Chemical-aided agriculture	Increase the concentration of nutrients, pesticides, and suspended sediments. Eutrophication Health issues e.g., headaches, skin rashes, eye irritations and some chronic effects e.g., cancer, endocrine disruption, birth defects).		
02	Human settlement	Waste water released alters physicochemical and bacteriological quality of water Solid and waste water disposed in the water harms aquatic life House construction along the rivers destroys river banks and causes sedimentation		
03	Sanitary facilities i.e., Latrines	Leaching of human waste into water affect the aquatic life and human health		
04	Waste Disposal	Infectious diseases Obstruction of drains Loss of biodiversity Contaminating water with disease-causing microorganisms and Poisonous substances		
05	Construction	Contaminate drinking water Impacts recreational waters Diminishes fishing Increases the risk of flood damage due to increased runoff and sedimentation		
06	Car washing	The phosphates from soap can cause excess algae to grow.		

S/N	ACTIVITY	POTENTIAL IMPACT	GPS LOCATION	LOCATION NAME (CELL)
		Grease, exhaust fumes, gasoline, heavy metals from rust, and motor oils harm aquatic and human life		
07	Animal rearing	erosion and sediment transport into the river nutrients from urine and feces dropped increase pathogen and algal growth		
08	Sand mining	Increase turbidity Destruct river banks thus flooding Possibility of sedimentation		
09	Milling/ Industrial activities	Direct discharges of waste water into the river causing water quality alteration Toxic waste can harm organisms or end up destroying an entire food chain of aquatic life		

Appendix 2: The GPS locations of anthropogenic activities along River Pager with potential negative impacts on water quality and biotic ecosystem

Activity site	Latitudes	Longitudes	Distance (meters)	Location (cell)	Activity site	Latitudes	Longitudes	Distance (meters)	Location (cell)
Agriculture	487923	364466	1	East Ward B	**Car washing**	487034	365146	0	Nyiki nyiki
Agriculture	487904	364450	4	East Ward B	**Car washing**	486973	365125	0	East Ward B
Agriculture	487405	364887	10	East Ward B	**Car washing**	486612	365167	0	East Ward B
Agriculture	486164	365157	16	Konypaco	**Car washing**	486712	365097	3	East Ward B
Agriculture	4861545	365202	3	Konypaco	**Car washing**	486614	365193	2	Ayul A
Agriculture	485965	365267	5	Ayul Mican	**Animal rearing**	485471	363417	3	Lulojo
Agriculture	485890	365204	3	Ayul Mican	**Animal rearing**	484995	364691	10	Jenge
Settlement	485410	364263	6	Lulojo	**Animal rearing**	488657	364465	10	Ginnery
Settlement	485421	363678	6	Lulojo	**Animal rearing**	487756	364534	5	East Ward B
Settlement	485452	363495	10	Lulojo	**Sand mining**	485359	363671	0	Lulojo
Settlement	485479	363404	10	Lulojo	**Sand mining**	485527	363188	1	Lulojo
Settlement	486375	365144	20	Konypaco	**Sand mining**	489039	366065	1	Nyanza
Settlement	485864	365099	10	Konypaco	**Sand mining**	489005	365908	0	Nyanza
Settlement	485878	365100	11	Konypaco	**Sand mining**	488998	365757	0	Nyanza
Settlement	488272	364513	25	Ginnery	**Sand mining**	488862	365355	5	Nyanza
Settlement	487648	364571	10	East Ward B	**Sand mining**	488924	365225	0	Nyanza

Activity site	Latitudes	Longitudes	Distance (meters)	Location (cell)	Activity site	Latitudes	Longitudes	Distance (meters)	Location (cell)
Settlement	486069	365131	10	Konypaco	**Sand mining**	488936	365205	0	Nyanza
Sanitary	485221	364499	5	Lamdogi	**Sand mining**	488903	364932	0	Nyanza
Sanitary	485410	363725	5	Lulojo	**Sand mining**	484995	364712	1	Jenge
Sanitary	485421	363404	15	Lulojo	**Sand mining**	485041	364687	2	Jenge
Sanitary	486715	365105	1	East Ward B	**Sand mining**	485592	363159	1	Ayul A
Sanitary	486596	365100	5	East Ward B	**Sand mining**	486112	365274	2	Jenge
Sanitary	488191	364410	3	Ginnery	**Sand mining**	484956	364795	1	Jenge
Sanitary	487734	364530	20	East Ward B	**Sand mining**	484978	364738	1	Jenge
Sanitary	486628	365197	8	Ayul A	**Recreational activity**	485466	363341	1	Lulojo
Sanitary	485975	365152	10	Konypaco	**Recreational activity**	486591	365194	3	Ayul A
Sanitary	485421	363678	5	Lulojo	**Garage**	486720	365086	2	East Ward B
Sanitary	485677	365041	20	Konypaco	**Garage**	486670	365215	15	Ayul A
Waste disposal	485317	364263	3	Lulojo	**Nursery Bed site**	486583	365067	2	East Ward B
Waste disposal	485403	363721	1	Lulojo	**Nursery Bed site**	487904	364450	4	East Ward B
Waste disposal	487064	364907	29	East Ward B	**Nursery Bed site**	486477	365144	1	Konypaco
Waste disposal	486596	365100	20	East Ward B	**Brick laying**	488496	364495	6	Ginnery
Waste disposal	488194	364418	1	Ginnery	**Brick laying**	485864	365109	5	Konypaco
Waste	487749	364518	6	East Ward B	**Drainage**	486961	365100	0	East

Activity site	Latitudes	Longitudes	Distance (meters)	Location (cell)	Activity site	Latitudes	Longitudes	Distance (meters)	Location (cell)
disposal									Ward B
Waste disposal	486288	365149	20	Konypaco	**Drainage**	486550	365188	0	Ayul A
Waste disposal	486114	365192	3	Konypaco	**Drainage**	486537	365215	0	Konypaco
Construction	486171	365155	16	Konypaco	**Site 1**	493097	365547		Oryang ojuma
					Site 2	486979	365126		East Ward B
					Site 3	486089	365235		Konypaco
					Site 4	485310	362284		Auch

Appendix 3: Actual Values for Physicochemical and Bacteriological Water Quality Parameters

Months	Sites	Parameters											
		Temp	**PH**	**Turbidity**	**EC**	**TDS**	**Hardness**	**Nitrates**	**Ca**	**Mg**	**Na**	**TBC**	**FC**
March	**Site 1**	28.1	7.87	24.4	268	171.5	78.13	0	20.8	6.36	17.9	200	120
	Site 2	28	7.39	34.5	311	199	127.92	0	19.2	7.28	22.5	300	200
	Site 3	28.1	7.36	34.9	478	305.9	26.19	0	17.6	6.36	23.5	500	120
	Site 4	27.5	6.99	41.6	311	199	91.85	0.01	22.6	8.6	26.7	100	6
April	**Site 1**	25	6.98	33.16	304	194.6	61.7	0.06	14.4	5.76	14.7	100	0
	Site 2	24.9	6.87	69.05	409	261.8	59.63	0.09	12.8	6.72	12.8	500	402
	Site 3	25.5	6.84	30.06	419	268.2	59.7	0.07	14.4	5.76	16.2	600	51
	Site 4	26	6.98	24.46	431	275.8	67.6	0.06	14.4	7.68	15	400	0
May	**Site 1**	24.9	7.15	10.7	330	211.2	62.48	0.2	12.14	7.81	10.2	110	5
	Site 2	25.5	7.38	15.6	413	264.3	91.4	0.7	15	13.1	14.9	350	120
	Site 3	25.9	7.4	13.4	552	353.3	123.97	0.5	21.1	17.31	17.2	500	200
	Site 4	25	7.3	8.66	402	257.3	67.39	0.4	13.3	8.3	15.3	150	10
June	**Site 1**	25.9	6.75	28.5	360	230.4	49.98	1.8	10.6	5.71	15.1	320	2
	Site 2	27	7.25	29.4	413	264.3	70.21	2.9	14.1	8.5	17.7	300	60
	Site 3	27	7.05	36.3	553	353.9	89.74	3	14.5	13	18	460	100
	Site 4	25.9	7.21	30.7	460	294.4	76.76	2.9	12.6	11	23	100	0
July	**Site 1**	26.9	7.14	12.6	254	162.6	63.45	2.8	14.13	6.85	12.7	210	6
	Site 2	27	7.42	18.1	301	192.6	64.32	3	17.02	5.3	20.1	700	115
	Site 3	26.9	7.56	15.9	380	243.2	73.28	3	15	8.7	23.1	720	280
	Site 4	25.9	7.03	15.5	381	243.8	50.48	2.9	12	5.06	19.7	600	45

Appendix 4: Daily rainfall record from March to July 2022

DATE	MARCH	DATE	APRIL	DATE	MAY	DATE	JUNE	DATE	JULY
01	Nil	01	Nil	01	4.0	01	Nil	01	12.8
02	Nil	02	Nil	02	2.9	02	Nil	02	1.6
03	Nil	03	Nil	03	0.5	03	Nil	03	2.5
04	0.8	04	Nil	04	9.4	04	Nil	04	Nil
05	Nil	05	Nil	05	Nil	05	Nil	05	Nil
06	Nil	06	2.9	06	Nil	06	7.7	06	10.3
07	Nil	07	Nil	07	5.1	07	38.7	07	Nil
08	Nil	08	Nil	08	4.7	08	22.2	08	1.2
09	Nil	09	Nil	09	Nil	09	0.3	09	2.2
10	0.2	10	Nil	10	1.0	10	Nil	10	Nil
11	Nil	11	TR	11	1.3	11	Nil	11	Nil
12	Nil	12	0.2	12	11.9	12	Nil	12	Nil
13	Nil	13	3.2	13	Nil	13	Nil	13	Nil
14	Nil	14	Nil	14	TR	14	0.5	14	0.3
15	Nil	15	35.7	15	Nil	15	Nil	15	1.6
16	Nil	16	TR	16	Nil	16	Nil	16	TR
17	Nil	17	Nil	17	Nil	17	Nil	17	7.0
18	Nil	18	6.2	18	43.7	18	1.9	18	1.4
19	Nil	19	23.4	19	Nil	19	1.0	19	5.2
20	0.3	20	8.1	20	Nil	20	3.7	20	0.6
21	TR	21	16.7	21	Nil	21	1.1	21	1.3
22	1.6	22	1.3	22	Nil	22	0.3	22	1.6
23	0.8	23	0.5	23	0.4	23	Nil	23	Nil
24	Nil	24	21.3	24	22.2	24	0.5	24	0.9
25	Nil	25	20.4	25	1.5	25	0.6	25	1.7
26	1.4	26	4.0	26	Nil	26	14.1	26	0.3
27	8.5	27	6.9	27	Nil	27	Nil	27	0.4
28	2.1	28	26.7	28	Nil	28	0.3	28	9.2
29	18.4	29	TR	29	Nil	29	10.4	29	8.2
30	Nil	30	Nil	30	4.2	30	1.3	30	
31	Nil			31	Nil			31	45.5

NOTE: TR => TRACE ie rainfall amount below 0.5mm

NATIONAL METEOROLOGICAL AUTHORITY
P.O. BOX 70, KAMPALA, UGANDA
7 DEC
METEOROLOGICAL STATION

MAR	APRIL	MAY	JUNE	JULY
TOTAL RAINFALL FOR MARCH AND ITS MEAN AVERAGE TOTAL = 32.2 Av $\frac{32.2}{31}$ Av = 1.0mm Raindays = 5	TOTAL = 177.5 Av $\frac{177.5}{30}$ Av = 5.9mm Rainday = 13	TOTAL = 112.8 Av = $\frac{112.8}{31}$ Av = 3.6 Raindays = 12	TOTAL = 104.6 Av = $\frac{104.6}{30}$ Av = 3.5 Raindays = 10	TOTAL = 115.8 Av = $\frac{115.8}{31}$ Av = 3.7 Raindays = 16

Appendix 5: Benthic macroinvertebrates field/sites counts

Benthic Macroinvertebrates results				
MARCH				
SITES	**ORDER**	**FAMILY**	**COMMON NAME**	**INDIVIDUALS**
SITE 1	Ephemeroptera	Heptagonlidae	Flat headed mayflies	6
		Tricorythidae	Stout crawlers	4
		Teleganodidae	Spiny crawlers	3
	Trichoptera	Ecnomidae	Caseless Caddisflies	5
	Coleoptera	Helodidae	Marsh beetles	3
		Psephenidae	Water penny beetles	1
	Odonata	Chlorocyphide	Damseflies	6
	Diptera	Plecoptera	Stoneflies	4
		Blepharoceridae	Netwinged midges	3
TOTAL	**5**	**9**	**9**	**35**
SITE 2	Trichoptera	Leptoceridae	Cased caddiflies	4
	Coleoptera	Dystiscidae	Predacious diving beetles	3
	Coleoptera	Hydrophilidae	water scavenger beetles	1
	Odonata	Aeshnidae	Dragon flies	1
		Caenidae	Cain flies	1
	Ephemeroptera	Tricorythidae	Stout crawlers	3
	Hemiptera	Hydrometridae	Marsh treaders	2
		Gerridae	Pondskater	3
TOTAL	**6**	**8**	**8**	**18**
SITE 3	Mytilidae	Unionidae	pearly mussels	2
	Odonata	Libellulidae	Dragonflies	2
	Plecoptera	Planurbidae	Orb snails	1
		Lynaeidae	Pond snails	2
TOTAL	**3**	**4**	**4**	**7**
SITE 4	Coleoptera	Dystiscidae	Predacious diving beetles	3
		Hydroptilidae	water scavenger beetles	2
	Odonata	Aeshnidae	Dragon flies	1
	Hemiptera	Hydrometridae	Marsh treaders	1
	Plecoptera	Planurbidae	Orb snails	2
		Lynaeidae	Pond snails	1
TOTAL	**4**	**6**	**6**	**10**
APRIL				
SITES	**ORDER**	**FAMILY**	**COMMON NAME**	
SITE 1	Ephemeroptera	Heptagonlidae	Flat headed mayflies	5
		Oligoneuridae	Brushlegged fly	6

		Tricorythidae	Stout crawlers	5
		Teleganodidae	Spiny crawlers	5
	Trichoptera	Polycentropodidae	Caseless Caddisflies	2
		Pisullidae	Cased caddiflies	7
	Coleoptera	Helodidae	Marsh beetles	5
		Elmidae	Riffle beetles	2
	Odonata	Chlorocyphide	Damseflies	4
	Diptera	Plecoptera	Stoneflies	3
		Blepharoceridae	Netwinged midges	2
	Lepidoptera	Pyralidae	Aquatic caterpillars	1
	Plecoptera	Perlidae	Stoneflies	2
		Notonemouridae	Stoneflies	2
TOTAL	**7**	**14**	**14**	**51**
SITE 2	Trichoptera	Hydroptilidae	micro caddisfly	2
		Leptoceridae	Cased caddiflies	3
	Coleoptera	Dystiscidae	Predacious diving beetles	1
		Hydrophilidae	water scavenger beetles	2
	Odonata	Gomphidae	Dragonflies	3
		Lestidae	Damseflies	2
		Protoneuridae	Damseflies	1
	Hemiptera	Hydrometridae	Marsh treaders	1
		Corixidae	Water boatmen	4
TOTAL	**4**	**9**	**9**	**19**
SITE 3	Mytilidae	Unionidae	pearly mussels	2
	Odonata	Coenagrionidae	Damseflies	3
	Coleoptera	Hydroptilidae	water scavenger beetles	1
	Plecoptera	Planurbidae	Orb snails	1
		Lynaeidae	Pond snails	1
TOTAL	**4**	**5**	**5**	**8**
SITE 4	Coleoptera	Dystiscidae	Predacious diving beetles	3
		Hydrophilidae	water scavenger beetles	6
	Odonata	Aeshnidae	Dragon flies	6
		Gomphidae	Dragonflies	2
	Ephemeroptera	Tricorythidae	Stout crawlers	1
		Eeptophlebidae	Prongills	5
	Plecoptera	Physidae	Pouch snails	2
		Lynaeidae	Pond snails	3
TOTAL	**4**	**8**	**8**	**28**
		MAY		
SITES	**ORDER**	**FAMILY**	**COMMON NAME**	

Site 1	Ephemeroptera	Heptagonlidae	Flat headed mayflies	11
		Oligoneuridae	Brushlegged fly	7
		Teleganodidae	Spiny crawlers	9
	Trichoptera	Ecnomidae	Caseless Caddisflies	5
		Pisullidae	Cased caddiflies	18
	Coleoptera	Helodidae	Marsh beetles	7
		Psephenidae	Water penny beetles	3
	Odonata	Chlorocyphide	Damseflies	4
	Lepidoptera	Pyralidae	Aquatic caterpillars	5
	Plecoptera	Perlidae	Stoneflies	9
		Notonemouridae	Stoneflies	6
TOTAL	6	11	11	84
SITE 2	Trichoptera	Hydroptilidae	micro caddisfly	2
		Leptoceridae	Cased caddiflies	4
	Odonata	Aeshnidae	Dragon flies	5
		Gomphidae	Dragonflies	4
		Protoneuridae	Damseflies	1
		Caenidae	Cain flies	2
	Ephemeroptera	Tricorythidae	Stout crawlers	1
		Baettidae	Small minnow flies	3
		Caenidae	Cain flies	2
	Hemiptera	Hydrometridae	Marsh treaders	6
		Hydrometridae	Marsh treaders	6
TOTAL	4	11	11	36
SITE 3	Mytilidae	Unionidae	pearly mussels	5
	Odonata	Coenagrionidae	Damseflies	2
	Ephemeroptera	Eeptophlebidae	Prongills	1
	Hemiptera	Belostomatidae	Giant water bugs	2
		Corixidae	Water boatmen	3
	Plecoptera	Physidae	Pouch snails	4
		Planurbidae	Orb snails	2
		Lynaeidae	Pond snails	3
TOTAL	5	8	8	22
SITE 4	Coleoptera	Dystiscidae	Predacious diving beetles	3
		Hydrophilidae	water scavenger beetles	2
	Mytilidae	Unionidae	pearly mussels	5
	Odonata	Aeshnidae	Dragon flies	6
		Gomphidae	Dragonflies	4
		Libellulidae	Dragonflies	3
	Hemiptera	Belostomatidae	Giant water bugs	4

		Corixidae	Water boatmen	5
	Plecoptera	Planurbidae	Orb snails	2
		Lynaeidae	Pond snails	3
TOTAL	5	10	10	37
		JUNE		
SITES	**ORDER**	**FAMILY**	**COMMON NAME**	
Site 1	Ephemeroptera	Heptagonlidae	Flat headed mayflies	6
		Oligoneuridae	Brushlegged fly	9
		Tricorythidae	Stout crawlers	6
	Trichoptera	Ecnomidae	Caseless Caddisflies	7
		Pisullidae	Cased caddiflies	14
	Coleoptera	Helodidae	Marsh beetles	7
		Psephenidae	Water penny beetles	5
	Odonata	Chlorocyphide	Damseflies	7
	Diptera	Plecoptera	Stoneflies	8
		Blepharoceridae	Netwinged midges	3
	Lepidoptera	Pyralidae	Aquatic caterpillars	4
	Plecoptera	Perlidae	Stoneflies	5
		Notonemouridae	Stoneflies	4
TOTAL	7	13	13	85
SITE 2	Trichoptera	Hydroptilidae	micro caddisfly	2
		Leptoceridae	Cased caddiflies	4
	Coleoptera	Dystiscidae	Predacious diving beetles	5
		Hydrophilidae	water scavenger beetles	4
	Ephemeroptera	Tricorythidae	Stout crawlers	3
		Baettidae	Small minnow flies	1
		Caenidae	Cain flies	4
	Hemiptera	Hydrometridae	Marsh treaders	3
		Corixidae	Water boatmen	3
TOTAL	4	9	9	29
SITE 3	Hemiptera	Belostomatidae	Giant water bugs	3
		Corixidae	Water boatmen	5
	Mytilidae	Unionidae	pearly mussels	1
	Plecoptera	Lynaeidae	Pond snails	4
		Physidae	Pouch snails	1
TOTAL	3	5	5	14
SITE 4	Trichoptera	Hydroptilidae	micro caddisfly	3
	Coleoptera	Dystiscidae	Predacious diving beetles	4
		Hydrophilidae	water scavenger beetles	6
	Odonata	Libellulidae	Dragonflies	4

	Plecoptera	Physidae	Pouch snails	6
		Lynaeidae	Pond snails	3
TOTAL	4	6	6	26
		JULY		
SITES	**ORDER**	**FAMILY**	**COMMON NAME**	
Site 1	Ephemeroptera	Heptagonlidae	Flat headed mayflies	6
		Oligoneuridae	Brushlegged fly	2
		Tricorythidae	Stout crawlers	4
	Trichoptera	Ecnomidae	Caseless Caddisflies	5
		Pisullidae	Cased caddiflies	9
	Coleoptera	Helodidae	Marsh beetles	4
		Psephenidae	Water penny beetles	3
	Odonata	Chlorocyphide	Damseflies	4
	Diptera	Plecoptera	Stoneflies	5
		Blepharoceridae	Netwinged midges	7
	Lepidoptera	Pyralidae	Aquatic caterpillars	2
	Plecoptera	Perlidae	Stoneflies	4
		Notonemouridae	Stoneflies	6
TOTAL	7	13	13	61
SITE 2	Trichoptera	Hydroptilidae	micro caddisfly	4
		Leptoceridae	Cased caddiflies	4
	Coleoptera	Dystiscidae	Predacious diving beetles	2
		Hydrophilidae	water scavenger beetles	1
	Mytilidae	Unionidae	pearly mussels	5
	Odonata	Aeshnidae	Dragon flies	1
		Protoneuridae	Damseflies	5
	Ephemeroptera	Tricorythidae	Stout crawlers	3
		Baettidae	Small minnow flies	1
	Hemiptera	Hydrometridae	Marsh treaders	2
		Gerridae	Pondskater	4
TOTAL	6	11	11	32
SITE 3	Coleoptera	Dystiscidae	Predacious diving beetles	2
		Hydrophilidae	water scavenger beetles	2
	Odonata	Libellulidae	Dragonflies	1
		Coenagrionidae	Damseflies	1
	Ephemeroptera	Eeptophlebidae	Prongills	2
		Hyroppsychidae	Cased caddiflies	2
	Coleoptera	Hydroptilidae	water scavenger beetles	1
	Hemiptera	Belostomatidae	Giant water bugs	3
	Plecoptera	Physidae	Pouch snails	5

		Lynaeidae	Pond snails	3
TOTAL	6	10	10	22
SITE 4	Trichoptera	Hydroptilidae	micro caddisfly	5
		Leptoceridae	Cased caddiflies	3
	Coleoptera	Dystiscidae	Predacious diving beetles	4
		Hydrophilidae	water scavenger beetles	7
	Odonata	Libellulidae	Dragonflies	5
	Ephemeroptera	Tricorythidae	Stout crawlers	1
	Hemiptera	Hydrometridae	Marsh treaders	3
		Belostomatidae	Giant water bugs	2
	Plecoptera	Physidae	Pouch snails	4
		Lynaeidae	Pond snails	1
TOTAL	6	10	10	35

Appendix 6: Introductory Letter

GULU UNIVERSITY

P. O. Box 166
Gulu - Uganda

TEL +256 471 432518
FAX +256 471 432094
Email: fae@gu.ac.ug
URL: www.gu.ac.ug

FACULTY OF AGRICULTURE AND ENVIRONMENT

29th April, 2022

To Whom It May Concern

This is to introduce to you **Amono Hope** who is a student of **Master of Science in Environmental Science and Natural Resources Management of Gulu University**. Hope is currently collecting data for her research project as part of the work in contributing to the fulfilment of the requirement for the award of the master program mentioned above. During data collection, Hope is expected to be interacting with the community and some key stakeholders of interest to her research project.

I therefore, request you to accord her and her team assistance where necessary so that they are able to complete the research.

Thank you

Sincerely

Dr. Labeja Richard Louis (PhD)

Head of Department of Environment and Natural Resources Management

Appendix 7: Gulu University Research Ethics Approval

GULU UNIVERSITY

P.O. Box 166, Gulu (U)
Website: www.gu.ac.ug
Email: gurec@gu.ac.ug

Tel: +256 471 432 096
Fax: +256 471 432 913
Mob: +256 772 305 621
+256 776 812 147

RESEARCH ETHICS COMMITTEE

Dear Hope Amono,

Re: Impacts of anthropogenic activities on water quality and biotic ecosystem in Pager River

I am pleased to inform you that at the **81st** convened meeting on **17/02/2022**, the Gulu University REC, committee meeting, etc voted to approve the above referenced application.
Approval of the research is for the period of **17/02/2022** to **17/02/2023.**

As Principal Investigator of the research, you are responsible for fulfilling the following requirements of approval:

1. All co-investigators must be kept informed of the status of the research.
2. Changes, amendments, and addenda to the protocol or the consent form must be submitted to the REC for re-review and approval **prior** to the activation of the changes.
3. Reports of unanticipated problems involving risks to participants or any new information which could change the risk benefit: ratio must be submitted to the REC.
4. Only approved consent forms are to be used in the enrollment of participants. All consent forms signed by participants and/or witnesses should be retained on file. The REC may conduct audits of all study records, and consent documentation may be part of such audits.
5. Continuing review application must be submitted to the REC **eight weeks** prior to the expiration date of **17/02/2023** in order to continue the study beyond the approved period. Failure to submit a continuing review application in a timely fashion may result in suspension or termination of the study.
6. The REC application number assigned to the research should be cited in any correspondence with the REC of record.
7. You are required to register the research protocol with the Uganda National Council for Science and Technology (UNCST) for final clearance to undertake the study in Uganda.

The following is the list of all documents approved in this application by Gulu University REC:

	Document Title	Language	Version	Version Date
1	Covid-19 Risk management Plan	English	2.0	2022-04-25
2	Protocol	English	2.0	2022-04-25
3	Informed Consent forms	Acholi	2.0	2022-04-25
4	Informed Consent forms	English	2.0	2022-04-25
5	Data collection tools	English	2.0	2022-04-25

Julaina A. Obika (PhD)
For: Gulu University REC,