EFFECT OF LAND USE ACTIVITIES ON WATER QUALITY, SOIL AND VEGETATION COVER FOR CONSERVATION OF RIVER WAMBABYA CATCHMENT, HOIMA DISTRICT

BY

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DECLARATION

I **MIREMBE WINNIE NABWAMI** certify that the contents of this research thesis are original, except where noted, and have never been submitted to any university or institution for an award.

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APPROVAL

We certify that the candidate worked on this thesis with our guidance.

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ACCRONYMS

BOD	:	Biological Oxygen Demand
COD	:	Chemical Oxygen Demand
Cd	:	Cadmium
Cr	:	Chromium
DWAM	:	Downstream Wambabya
EC	:	Electro conductivity
ESIA	:	Environmental and Social Effect Assessment
Fe	:	Iron
Mn	:	Manganese
Ni	:	Nickel
NO_3^-	:	Nitrates
Pb	:	Lead
PO_4^{3-}	:	Phosphates
RWCA	:	River Wambabya catchment Area
UWAM	:	Upstream Wambabya
WAM	:	Wambabya
WHO	:	World Health Organization
WWF	:	World Wide Fund for Nature
Zn	:	Zinc

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ABSTRACT

Increasing land use activities are greatly decreasing environmental quality of River catchments thus, making them susceptible to pollution and depletion. The land use activities such as human settlements, massive deforestation, oil infrastructural developments, conversion of wetlands into subsistence farmland, and agroforestry were increasing within River Wambabya catchment. However, there was no empirical evidence of the present status of the water quality, soil and vegetation cover in the river catchment hence necessitating a research study. The overall objective of the research study was to evaluate the effect of land use activities on the water quality, soil and vegetation cover for conservation of River Wambabya catchment, Hoima District. The specific objectives of the study were; to determine the effect of land use activities on the water quality (pH, EC, COD, BOD, Total phosphates, nitrates, Pb, Escherichia coli, and total coliforms) of River Wambabya catchment; to assess the effect of land use activities on the soil (pH, EC, Heavy metals-Pb, Fe, Mn, Zn, Ni, Cd) of River Wambabya catchment; and to determine the effect of land use activities on the vegetation cover of River Wambabya catchment over a period of 20 years (1998-2018). The study used a simple random sampling technique during collection of water and soil samples. Water quality and soil parameters were analyzed using American Public Health Association (APHA) standard analytical procedures. Heavy metals in water were analyzed using an Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) while soil heavy metals were analyzed using Mehlich- 3 extraction method buffered to pH 2.5. Vegetation cover change of 20 years (1998-2018) was analyzed using Landsat 8 images and ArcMap 10.8 version. Results showed that land use activities had significant effect on water quality BOD (p value of 0.021) at $p<0.05$. Subsistence farmland (7mg/l), and wetland (6mg/l) activities were the major contributors of high BOD levels. Land use activities also had a significant effect on the concentration levels of soil Zn (p value of 0.048), Ni (p value of 0.020), and Pb (p value of 0.037) at $p< 0.05$. Subsistence farmland, and agroforestry were the major sources of high Zn, Ni and Pb concentrations. lastly, land use activities had a significant effect on the vegetation cover of river Wambabya catchment. There was a drastic increase in built-up areas (5.38%), and subsistence farmland (1.04%) with a reduction in vegetation cover under Bushland (1.97%), forests (2.58%), grasslands (7.56%), open water (1.23%), wetlands (1.42%) and woodland (1.39%) over the 20-year period. Subsequently, natural resources conservation efforts are required in river Wambabya catchment area so as to improve its sustainability and co-existence with human livelihoods. Particularly, more conservation efforts are needed to halt the deteriorating water quality and reducing vegetation coverage of the catchment. Further in-depth studies can be conducted on the temporal variations of vegetation cover and bioaccumulation of heavy metals in the soils of the RWC due to the increasing mining and oil and gas development

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Globally, land has been converted into built up and agricultural areas as a result of increasing population and high demands for economic development (Du et al., 2018). Population growth has further triggered construction of hydraulic infrastructure for irrigation and other water requirements for the increasing globalization changes (Lu, 2020). People have continuously applied pesticides and fertilizers to enhance soil fertility, and crop production which ultimately affects water quality (Chen et al., 2021). Land use activities have increased nutrients, toxic elements, metallic pollutants deposited into river catchments thus affecting water quality (Cheng et al., 2022). The built-up areas have birthed an increase in impervious surfaces with water resistant elements (Delphin et al., 2016; Wang et al., 2020) which has led to increased surface run off, soil erosion, and non-point source contamination in river catchments (Lin et al., 2020). The increasing land use activities are greatly decreasing water quality of river catchments thus, making them vulnerable to pollution (Nyairo et al., 2015; Owuor et al., 2017). There is also increased amount of plant nutrients (Nitrogen and Phosphorus) and pesticides flowing into surface waters as a result of agricultural practices (Nafziger, 2009).

The soils in River catchments are being polluted by various heavy metals as a result of land use activities such as waste disposal, industrial activities, fertilizer and pesticide usage, sludge application and automobile exhausts (Namlı et al., 2010). The major heavy metals of concern include; Lead (Pb), Mercury (Hg), Zinc (Zn), Cadmium (Cd), Nickel (Ni), Copper (Cu) (WHO, 2011). Kooner et al., (2014) observes that heavy metals are naturally occurring in soils due to geological processes of the underlying rocks. In addition, natural ecosystems in Ethiopia have been transformed into subsistence farmlands due to deforestation thus affecting the capacity of soils to support ecosystem functions (Delelegn et al., 2017). Furthermore, (Wanjala et al, 2019) denotes that increasing human activities are increasingly discharging contaminants to the soil such as heavy metals and other toxins originating from industrial development and overpopulated settlements.

Environmental impacts of deforestation on vegetation cover have drastically increased (Caravaggio, 2020; Hite et al., 2021). Deforestation, extension of agricultural and infrastructural development projects within former forested areas have led to an increase in vegetation cover loss (Hishe et al., 2021; Oluwajuwon et al., 2021). In addition, the demand for agricultural land systems has exerted high pressure on forests thus altering vegetation cover in forest ecosystems in Africa (Kerr et al., 2007), particularly in Sudan (Omer, 2009).

River Wambabya catchment in Hoima District is an ecologically sensitive area and one of the main water resources (WWF-EARPO, 2009). The River catchment supports communities in Buseruka, Bugambe, Kiziranfumbi, and Kaiso-Tonya Sub-counties with water, biomass, agricultural land, and settlement. The River catchment harbors part of the 3429 hectares of Wambabya Central forest reserve, nine Megawatt (9MW) Kabalega Hydropower plant in Tonya Parish (WWF-EARPO, 2009), and water abstraction points for the construction of the Hoima International Airport an oil infrastructure (Newplan, 2016). However, there is limited evidence-based data on the effect of land use activities on the water quality, soil and vegetation cover of the catchment amidst the land use activities thus necessitating the proposed study to support conservation of the valuable ecosystem.

1.2 Problem statement

Land use activities such as massive deforestation, conversion of the catchment wetlands to plantations, oil infrastructure developments (feeder roads, oil pipeline, airport), poor waste management, human settlements, domestic and industrial water uses, and agricultural activities have greatly increased within River Wambabya catchment area amidst increasing population in Hoima District. In 2002, the National census enumerated the population of Hoima at 60,561 that drastically increased to 100,099 in 2014 and slightly to 122,700 people in 2020 (UBOS, 2020). This has culminated to an average population growth of 3.54% annually between 2014 and 2020 (UBOS, 2020). However, there is inadequate empirical evidence on the effect of land use activities on the water quality, soil and vegetation cover of River Wambabya catchment (RWC) Hoima District. Previous studies conducted by World Wide Fund for Nature Uganda (WWF-EARPO, 2009) mainly focused on the larger Lake Albert Catchment with minimal analyses on River Wambabya catchment that presents a conservation gap on the proposed area of study. The land use activities since increased from the last study in 2009 that pose effects on the water quality, soil and the vegetation cover of River Wambabya catchment area; hence necessitating the study to inform the current status of the catchment for proper catchment conservation. The study evaluated the effect of land use activities on the water quality, soil and vegetation cover for conservation of River Wambabya catchment, Hoima District.

Objectives of the study

1.3.1 General Objective

The study seeks to evaluate the effect of land use activities on the water quality, soil and vegetation cover for the conservation of River Wambabya catchment, Hoima District.

1.3.2 Specific Objectives

1) To determine the effect of land use activities on the water quality (pH, EC, COD, BOD, Total phosphates, nitrates, Pb, Escherichia coli, and total coliforms) of River Wambabya catchment.
2) To assess the effect of land use activities on the soil (pH, EC, Heavy metals-Pb, Fe, Mn, Zn, Ni, Cd) of River Wambabya catchment.
3) To determine the effect of land use activities on the vegetation cover of River Wambabya catchment over a period of 20 years (1998-2018).

Null Hypotheses

H_o1: Land use activities have no significant effects on the water quality of River Wambabya catchment.

H_o2: Land use activities have no significant effects on the soil of River Wambabya catchment.

H_o3: Land use activities have no significant effects on the vegetation cover of River Wambabya catchment over a period of 20 years (1998-2018).

1.5 Scope of the study

1.5.1 Content scope

The study evaluated the effect of land use activities on the water quality (pH, EC, COD, BOD, Total phosphates, nitrates, Pb, Escherichia coli, and total coliforms), the soil (pH, EC, Heavy metals-Pb, Fe, Mn, Ni, Cd) and vegetation cover of River Wambabya catchment in Buseruka sub-county.

1.5.2 Geographical scope

The study covered River Wambabya catchment area located in Hoima District; Bunyoro sub-region focusing on selected areas within Buseruka Sub county.

1.5.3 Time scope

The research study was conducted over a period of six (6) months from August 2020 to February 2021 for more data collection and better analysis of results.

1.6 Significance of the study

The research study sought to evaluate the effect of land use activities on the water quality, soil and vegetation cover for conservation of River Wambabya catchment. The study established the status of selected water and soil parameters with in the River catchment and the extent of vegetation cover loss over a period of 20 years across the development/industrial era Hoima District. The research study will inform Hoima district local government on effective management options of implementing the River Wambabya Catchment management plan for natural resources conservation. The study will form a foundation of literature, information and knowledge domain for conservation of water resources Hoima District.

1.7 Conceptual framework

The overall dependent variable for this research is the conservation of the RWCA with sub dependents of water quality, soil and vegetation cover. In the framework, land use activities directly affect soil and water quality and in return affects the development activities in the catchment vice versa while vegetation cover is directly affected by land use activities such as massive deforestation. All sub-dependent variables interact with each other in a functional ecosystem. Soil can affect the type of land use activities, growth and rejuvenation of vegetation cover, and ultimately the water quality differently within the catchment; an equivalent applies to the other sub dependent variables as shown in Figure 1.1 below;

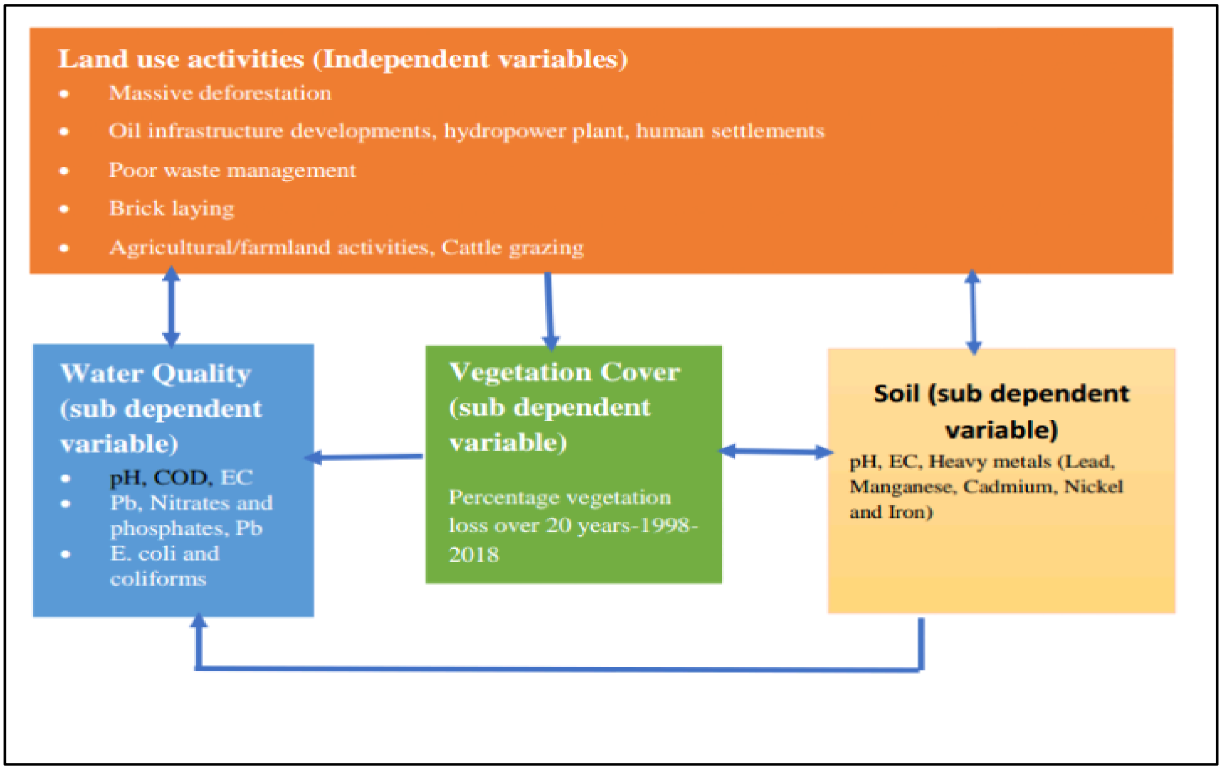

Figure 1. 1 Conceptual framework of the research study (author's concept)

1.8 Limitation of the study

1 Limited funds on hiring research equipment, and regular travels to the study area that affected in-depth data collection and analysis.

2 Security and health risks due to the sensitivity of the study area in relation to infrastructure developments that limited access to some areas of the catchment.

3 Restricted movements to border Districts (including Hoima) due to the country lockdown due to COVID19 Pandemic hence affecting timely water and soil sampling, and data analysis.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

Chapter two presents existing literature on the land use activities, and effects of land use activities on water quality, soil and vegetation cover in water catchments.

2.1 Effects of Land use activities on water quality and vegetation cover of River catchments

Giri et al., (2016), defines water quality as a dimension of water utilized for various purposes (domestic, artificial, husbandry, rest, and locale) using various parameters analogous as physiochemical and natural. River catchments give water for domestic and artificial operation encyclopedically (Masese et al., 2012). Land use change has a series of profound impacts on ecological processes, face runoff, and hydrological cycle, thereby affecting sluice water quality safety (Guo et al., 2021). Infrastructural developments analogous as Natural resource birth for mortal introductory conditions, and terrain transformation for agreements remain major global challenges (Lade et al., 2020). These land use conditioning largely impact on timber resources, climatic systems, functionality of ecosystems, cataracts and biodiversity loss (Steffen et al., 2018). still, land use exertion is dependent on climatic conditions that continuous vary across the globe's energy budget (Strapasson et al., 2017).

Water quality is essential for sustainable agricultural product, mortal good, and ecological home stability (Samways, 2022). The vacuity and quality of water resources are related to the sixth global thing on "ensure access to water and sanitation for all and its sustainable operation" of the UN SDGs (Huang et al., 2021;). Land use changes also affect face water run off natural and geochemical processes that affect into significant goods on water quality (Wagner et al., 2019). likewise, the development of agreements in communal areas and husbandry have negatively affected face water quality (Manfrin et al., 2016; Zhang et al., 2010) that has also reacted in changes in hydrological cycles, face runoff, and ecological process.

Fisher et al., (2000) noted an increment in the quantity of Nitrogen, Phosphorus, and fecal coliforms in husbandry areas of Upper Okoni Basin, Georgia. therefore, changing land use patterns lead to changes in face water runoff (Zhou et al., 2019), face water force affair (Wu and Haith, 1993), and water quality (Zhang et al., 2019), which is considered to be a major factor that change the hydrological system (Bateni et al., 2013). Impervious communal land shells analogous as domestic land, public installations land, artificial land, and cement pavements boost stormwater runoff by reducing downstream bare soil volume (Damanik- Ambarita et al., 2018). Increased nitrogen and phosphorus inputs in farmland and construction land are the main cause of eutrophication in sluice catchments (Karmakar et al., 2019).

There is a correlation between water quality in husbandry structures with the volume of soil loss to face water runoff, and the volume of plant nutrients (Nitrogen and Phosphorus) and pesticides that reach face waters (Nafziger, 2009). Land use exertion under urbanization and deforestation have led to adding soil erosion and thus contributing to deposit and nutrient loads in submarine ecosystems (Seitzinger et al., 2010). Heavy substance contamination in face and groundwater was due to the geology of the area, land use changes under communal, timbers and subsistence spreads using agrochemicals (Chauhan et al., 2014).

Bacteriological disquisition on potable water of Akaki- Kalitsub- megacity in Addis Ababa, Ziway, Bahir Dar and Nazareth (Adama) communal areas disclosed pollution of the water samples with total coliforms (TTC) and fecal coliforms (Desta, 2009). piecemeal of microbial pollutants, heavy substance impurities in water resources have greatly been recognized due to their poison at all attention situations (Adepoju et al., 2005; Marcovecchio et al., 2007). In East Africa, water courses and gutters are monstrously affected by the fast- growing urbanization and adding deforestation for subsistence husbandry and mortal agreement (Kobingi et al., 2009). Physiochemical pointers of water quality analogous as; pH, dissolved oxygen (DO), electrical conductivity (EC), nitrates, and total phosphorous (TP) are vital in assessing water quality (APHA, 1980).

The water catchments are homes for various natural diversity that bear ideal conditions for their survival and actuality (Ward et al., 2001 Cardinale, 2011) thus ecosystem variations produce risks to the biota (Dallas et al., 2004). Mati et al., (2005) observes that drastic land use land cover changes in the Mara River as a result of adding land- use exertion (Mango et al., 2010). mortal agreements and Nyayo Tea zones have converted the Mau timbers that were harboring Mara River (Awiti et al., 2001). further conditioning within the River catchment include forestry, beast, fisheries, tourism, communal development, conservation areas and extractives (Mango et al., 2010 Nyairo et al., 2015 Owuor et al., 2017). These land use exertions lessen the environmental quality of the conterminous riverine areas as budgets thus making them exposed to water contamination (Nyairo et al., 2015 Owuor et al., 2017).

Lake Victoria Catchment is the subsequent major freshwater resource globally covering 68,000 km2 and a catchment area covering over 193,000 km2, crossing five East African countries of Burundi, Kenya, Rwanda, Tanzania and Uganda (Charles et al., 2007). Lake Victoria Catchment has deteriorating water quality as a result of effluence, overexploitation of resources and technological developments impacting on biological diversity and therefore the overall function of the water catchment (Odada et al., 2004: Bakema et al., 2000).

River Rwizi in Uganda is one of the rivers that support a large percentage of the population, providing water for domestic use, agricultural and industrial usage (OECD annual report, 2008; Mugira, 2009). However, the effluence levels are constantly growing in the River Rwizi watershed as a result of industrial and domestic wastewater discharge or surface water runoff from agriculture and urban areas (Songa P et al.,2005). Furthermore, poor farming practices on the hills and valleys are accountable for increasing effluence in River Rwizi (Mugira, 2009).

According to the (Uganda Wetlands Atlas Volume II 2016), the Lake Albert wetland is an ecologically rich biological diversity area; an imperative bird area by Bird Life International; an Ecoregion by World Wildlife Fund for Nature; and a Key Biodiversity Hotspot by Conservation International. The basin is fed by Rivers such as; Muzizi, Nkusi, Wambabya, Waki, Waiga, Sonso, Waisoke and Semliki. High population density, oil and gas exploration and development have triggered drastic changes in urban development and investment.

Globally, environmental impacts of deforestation have drastically increased (Caravaggio, 2020; Hite et al., 2021). The illegal natural forest harvesting, extension of agricultural and infrastructural development projects within former forested areas have led to an increase in vegetation cover loss (Hishe et al., 2021; Oluwajuwon et al., 2021). Developing countries have registered high deforestation and forest degradation rates as a result of low per capita land and rigidity (Iftekhar et al., 2005; Fagan et al., 2020). In addition, the demand for agrarian land systems and increased conditioning of land use patterns have put high pressure on timbers which has led to altered foliage cover, changes to the composition and structure of timber foliage of conterminous timber ecosystems as well as negatively impacting on utmost African timbers ecosystems and mortal living over the once decades (Kerr et al., 2007), particularly in Sudan (Omer, 2009).

The vegetation cover features of the Nakivubo catchment in Kampala understood from Landsat standard false color complex (bands 432 RGB) and the classification interpretation data display clear indication of environmental degradation. (Charles *et al.*, 2007). The image interpretation showed that the indigenous forest enclosed a total area of 123.154km2 in 1986 and reduced to 5.887km2 in 2005. In 1989, urban settlements covered 0.516km^2 which drastically increased to 25.725km^2 in 2005. The Lake Victoria Basin is facing effects of land use activities from both anthropogenic and natural drivers which are vital to the sustainability of the resources and livelihoods of the communities.

2.2 Effects of land use activities on the soils of River catchments

Soil comprises of the physical, chemical and biological properties (Manpoong & Tripathi, 2019) that determine soil quality. According to (Minnesota Pollution Control Agency, 2022), soil physical properties include; temperature, color, density, porosity, texture and aggregate stability while chemical properties include among others the soil pH, conductivity, salinity, carbon, Potassium, Phosphorous, Sulphur, Nitrogen, trace metals and elements. Soil biological properties consist of organic matter, micro-organisms, enzymes, soil carbon, and nitrogen fixation (soil health nexus, 2023). These soil properties affect processes of infiltration, nutrient cycling, erosion, formation, suitability and biological activities. Soil quality is the ability of the soil to function within natural or managed ecosystems that support flora and fauna productivity, water and air quality, human health and habitation (Moges et al., 2013).

Land use changes are the main drivers of global environmental challenges and have significant effects on the soil physical, chemical and biological properties (Statuto, Cillis & Picuno, 2016). Land use change affect heavy metals accumulation, functionality of micro-organisms in the soil (Zhang et al., 2020), and soil contamination (Huang et al., 2018; Pacwa-Plociniczak et al., 2018). Qi et al., (2018) observed an increment in soil organic matter, cation exchange capacity, total nitrogen and nutrients (N, P, K) as a result of land use conversion from shrub to arable land and agriculture. Whereas, (Murty et al., 2002; Bruun et al., 2015) discussed the conversion of forest to agricultural land as a major effect on the soil properties. According to (Perrin et al., 2014; Reza et al., 2018), there were loss of soil carbon stocks as a result of land use change from forests to agriculture.

Heavy metal contamination in soils as a result of land use changes is a major environmental issue (Huang et al., 2018; Pacwa-Plociniczak et al., 2018). Fasinu et al., (2013) denote that industrial and urban developments and agricultural activities are increasingly discharging contaminants to soil, including heavy metals. Heavy metal natural occurrences in soils are often attributed to the characteristics of the parent rock, environmental management practices, particle size distribution, soil age and influences from the air that comes in contact with soil. Heavy metals have been used extensively in herbicides, pesticides or farm chemical throughout the world, to protect crops by eliminating pests and thereby increasing agricultural output (Aktar et al., 2009).

Pollution by heavy metals is gradually becoming an area of concern especially in sub-Saharan Africa, including Nigeria. Heavy metals have been used expansively in herbicides, pesticides or farm chemical globally, to protect crops by eradicating pests and thus increasing agricultural yields. This could be source of residual heavy metal content in agricultural soil (Defarge et al., 2018).

Waled et al., (2013) observes that Lead atomic number 82 is one of the utmost hazardous heavy metal among environmental toxins and is moderately harmful to human beings and the environment. Lead in soil reduces the output of crops, and also affects human health through the food chain, inhalation, and ingestion (Ricardo et al., 2003). Other heavy metals on the periodic table such as Cadmium atomic number 48, Manganese 25, Zinc 30, Nickel 28 and Iron 26 are similarly hazardous to soils, human health, water and vegetation of water catchments.

CHAPTER THREE: MATERIALS AND METHODS

3.0 Introduction

Chapter three of the report presents the materials and methods that were used during the study. The chapter indicates the study area, research design, sampling design, data collection methods, and data analysis and presentation.

3.1 Study area

River Wambabya catchment area is one of the largest water catchments in Hoima district covering a distance of 808km^2. The catchment forms part of the larger Lake Albert Eastern Catchment area in the Albertine Graben (WWF-EARPO, 2009). The Catchment receives an annual rainfall between 700 to 1500 mm per annum with an annual Temperature range of 18 - 30°C at Altitude range of 1,074-629m; and Latitudes;1° 25’ 0” N and 31° 5’ 0” E.

The catchment is drained by River Wambabya a perennial River through Hoima district in sub-counties of Kabwoya, Bugambe, and Buseruka with riparian woodlands, papyrus and wild animals into Lake Albert downstream. The research study was conducted in River Wambabya catchment area in Buseruka Sub-county Hoima district. Tributaries feeding into River Wambabya were considered during the research study. The study area is presented below in Figure 3.1.

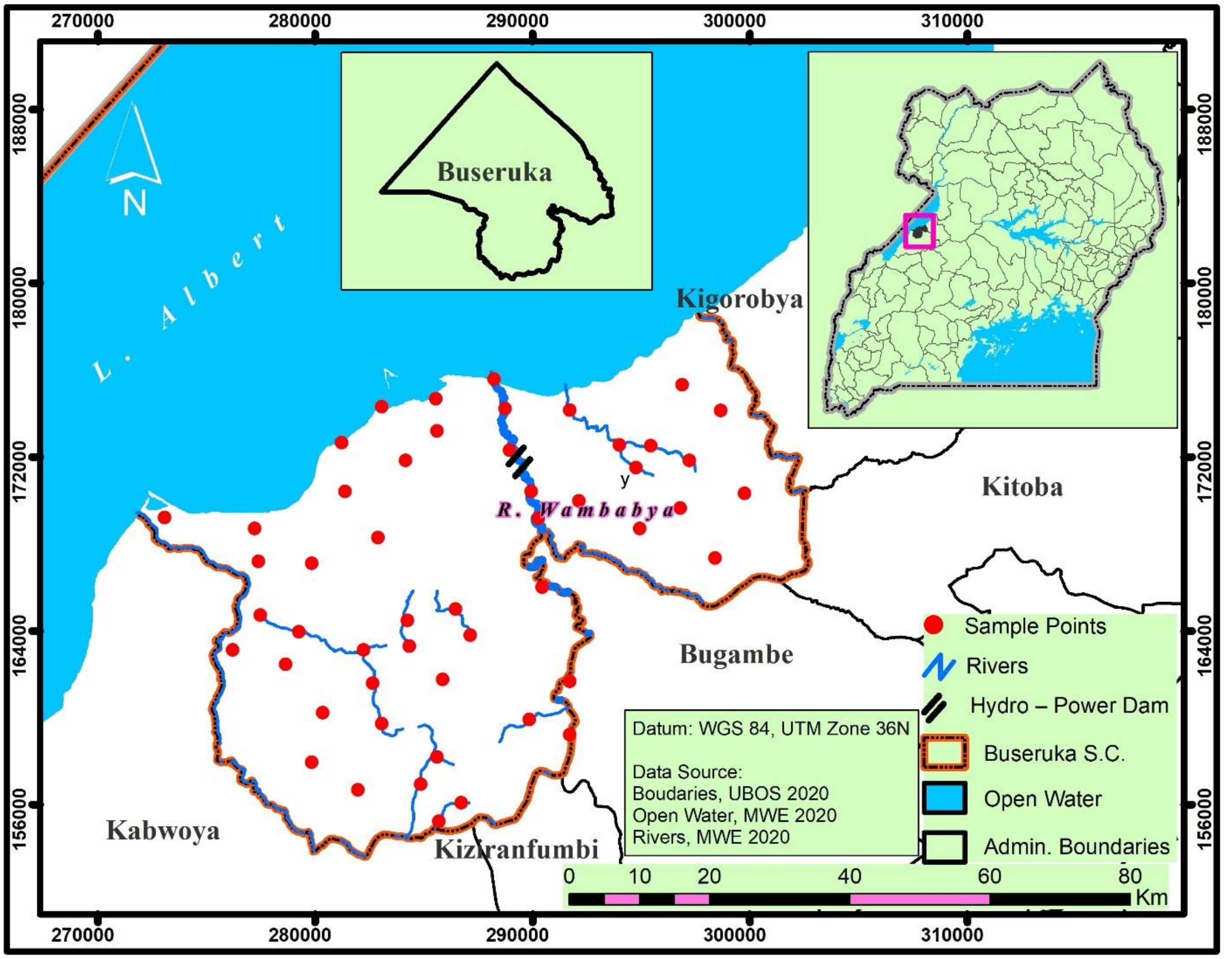

Figure 3. 1 Map of the study area in Hoima District.

3.2 Data Collection and analysis

3.2.1 The effect of land use activities on water quality of River Wambabya Catchment

3.2.1.1 Water sampling approach

Due to the inadequate resources to conduct a large-scale survey, simple random sampling technique was used (Meng, 2013). A total of forty (40) water samples were collected upstream, within River Wambabya and downstream River Wambabya. Different land use activities were recorded within a Kilometer.

3.2.1.2 Water sampling

Sampling sites upstream, and downstream river Wambabya catchment were selected. The sampling was done in the wet period of the area providing a total of 40 water samples from various land use areas. During the sampling, the following steps were undertaken;

a) Water samples were collected using a dip sampler at a depth of one meter and then poured into labeled 40-ml sterile bottles for water physiochemical analyses and into 20ml sterile bottles for bacteriological analyses.
b) The sterile bottles containing water samples were 40
c) The sealed bottles of water samples were placed in a cooler box and stored at 4 degrees Celsius.
d) The samples were then transported to the Ministry of Water and Environment Albert Management Zone Laboratory for laboratory analysis.

Plate 3. 1 water sampling in Tonya downstream river Wambabya

3.2.1.3 Laboratory analysis

The physicochemical and bacteriological parameters of water were analyzed in the laboratory in accordance with the MWE Standard Operating Procedures. A summary of the materials and methods for the water assessments is presented in Table 3.1.

Electrical Conductivity (EC); the water sample was poured into a beaker, then the probe of the pH/EC was dipped into the beaker with water sample. The reading was recorded in the workbook. The pH/EC meter was rinsed with distilled water, waited for it to stabilize before the next assessment.

pH; the water sample was poured into a beaker, then the probe of the clean pH/EC meter was dipped into the beaker with the water sample. A reading from the pH/EC meter was taken and recorded in the workbook. The equipment was rinsed with distilled water for the next assessment.

Biochemical Oxygen Demand (BOD); Biochemical oxygen demand was assessed using a BOD_5 day test kit. The test kit was used for digestion and monitoring oxygen changes in the water sample. Initial dissolved oxygen for the sample was taken before incubation. 25mls of the water sample were poured into BOD test bottles and then initial dissolved oxygen was measured. The water samples were then incubated at 68°F (20°C) for five days and the dissolved oxygen at the end of the five days was determined. The difference in dissolved oxygen between the initial measurement and the fifth day's measurement was taken to signify the biochemical oxygen demand. The measurements were recorded in the workbook.

Chemical Oxygen Demand (COD); 2.5ml of sample was measured and diluted up to 25ml using distilled water in a measuring cylinder then 1.5ml dichromate followed by 3.5ml of concentrated H_2SO_4 was added to the diluted sample. This totaled up to 30mls then the solution was placed in a file at a constant temperature of 150^0C for 2 hours to allow proper reaction of the solution. The COD readings were taken using DR5000 spectrophotometer and recorded in the workbook. Dichromate a hexavalent chromium salt is used to oxidize between 95-100% of organic material while concentrated H_2SO_4 offers the primary and secondary digestion catalysts for oxidizing the carbon during chemical oxidation process. The equipment was rinsed with distilled water for the next assessment.

Nitrates; 15ml of the water sample were placed in a mixing cylinder then one Nitraver 6 reagent powder pillow was added to the cylinder. The cylinder was closed for a 3minutes reaction. The cylinder was vigorously shaken during the reaction. 10ml of the sample were placed into a sample cell and one Nitraver 3 reagent powder pillow was added and a 30-second reaction time was allowed. The pink color showed presence of nitrate in the sample. A blank was prepared and 10ml of the sample were placed in the sample cell then the push ZERO was done for calibration of the Hach DR1900 Spectrophotometer (USA) equipment. The prepared sample was placed in the cell holder and push READ was done. The equipment was rinsed with distilled water for the next assessment.

Total phosphates; 20ml of the sample were placed in a clean 50-mL Erlenmeyer flask. One Potassium Persulfate Powder Pillow was added to the sample and mixed together. 2.0ml of sulfuric acid were added to the sample using a dropper. The solution was boiled for 30 minutes in a Hach DRB 200 digester (USA). After deionized water was added to keep the boiled liquid to 20ml. When the solution had cooled, 2.0ml of sodium hydroxide were added to the mixture then the digested sample placed in Hach DR1900 Spectrophotometer (USA). The reading from the equipment was recorded in the workbook. The equipment was rinsed with distilled water for the next assessment.

***E. coli* and total coliforms**; were analyzed using chromogenic media after incubation using an oven for 48 hours before counting colonies using a counter. Coliforms appeared in the form of pink colored colonies and *E. coli* appeared in form of purple color. They were represented in form of colony forming units per 100ml. All the results were recorded in the workbook. The equipment was rinsed with distilled water for the next assessment.

Lead (Pb); Lead concentration levels in the River water were determined using an Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Optima 2100DV, Perkin-Elmer, Norwalk, CT, USA). The results were recorded in the workbook. The equipment was rinsed with distilled water for the next assessment.

Table 3. 1 Materials and methods for water quality analysis

Sampling	Sampling tools	Parameter	Method
Simple random sampling. Forty (40) water samples were collected in the months of September and October 2020; a rainy season for Hoima District.	pH meter	pH	APHA, 2017
	EC meter	Electro Conductivity	
	DR5000 spectrophotometer	Chemical Oxygen Demand	
	BOD5 day test kit	Biological Oxygen Demand	
	Hach DRB 200 digester	Total phosphates	
	DR1900 Spectrophotometer Hach DR1900 Spectrophotometer	Nitrates	
	Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)	Lead	
	Chromogenic media	*E. coli* and Total coliforms	

3.2.2 The effect of land use activities on the soil of River Wambabya Catchment

3.2.2.1 Soil sampling approach

Simple random sampling technique was used (Meng, 2013) during collection of soil samples. A total of forty (40) soil samples each weighing 500grams were collected upstream, within River Wambabya and downstream River Wambabya using a soil Auger at 5-9 centimeters depth depending on the terrain of the sampling area. Different land use activities were recorded within a kilometer.

3.2.2.2 Soil sampling

Soil sampling sites upstream, midstream and downstream river Wambabya catchment were selected. The sampling was done in the wet period of the area providing a total of 40 soil samples from various land use areas. During the sampling, the following steps were undertaken;

a) Soil samples were collected using a soil auger at a depth 5-9 centimeters into polyethene bags (Plate 3.2). This was also dependent on the terrain of the area.
b) The labeled polyethene bags were a total of 40.
c) The polyethene bags were sealed and stored at 4 degrees centigrade.
d) The soil samples were then transported to the BIOSPORE NARL Kawanda laboratory for analysis.

Plate 3. 2 Soil sampling within River Wambabya Catchment using a soil auger

3.2.2.3 Laboratory analysis

The physicochemical parameters of the soil were analyzed in the laboratory in accordance with the Standard Operating Procedures. A summary of the materials and methods for the soil assessments is presented in Table 3.2.

Soil pH and EC; analyzed using HACH Aqueous Extraction Method were 4 scoops of each soil sample measuring 5-grams was placed in 50ml plastic beaker. Measured 20ml of deionized was added to the 50ml beaker with soil sample then stirred together for 30minutes. Then the sample was used to determine the soil pH and EC using a digital Hach multi parameter meter (HQ40D model) (Hach company USA). The equipment was rinsed with distilled water for the next assessments.

Heavy metals; soil samples were analyzed for the Phyto-available forms of Pb, Cd, Ni, Fe and Mn using Mehlich- 3 extraction method buffered to pH 2.5 (Mehlich, 1984). A pH of 2.5 aided in avoiding reaction of Ca and F to form a CaF_2 precipitate. The fluoride enabled the extraction of phosphates related with Fe while ammonium nitrate (NH_4NO_3) effectively extracted exchangeable cations. The parameters were later quantified using a Microwave Plasma Atomic Emission Spectrometer (MP-AES) at their respective wavelengths. The results were recorded in a workbook. All the equipment was rinsed with distilled water before the next laboratory assessment.

Table 3. 2 The materials and methods for soil assessments

Sampling	**Sampling tools**	**Parameter**	**Method**
Random Forty (40) soil samples were collected in the months of September and October 2020; a rainy season for Hoima District.	Soil Auger Digital Hach multi parameter meter	pH	HACH Aqueous Extraction Method
		EC	
	• Soil Auger • digital Hach multi parameter meter (HQ40D model) • Microwave Plasma Atomic Emission Spectrometer	Heavy metals (Lead, Iron, Manganese, Nickel, and Cadmium)	Mehlich 3 extraction method

3.3.2.4 Data analysis

SPSS version20 was used to calculate the water quality and soil parameter values. Descriptive statistics were used to present the findings (mean, standard deviation, coefficient of variance). The variability of soil and water quality parameter values was assessed using an analysis of variance (ANOVA) with a 95% confidence level (Tahiru et al., 2020, Nepomuscene et al., 2018) in order to determine the impact of land use/cover on water quality and soil parameters.

The test compared the mean of the soil and water quality parameters across the different land-use activities. The test assumed that variance of the dependent (outcome) variable was constant across the groups being compared (homoscedasticity) and that the dependent variable is approximately normally distributed with mean μ and variance σ^2.

For cases where the assumptions were violated, a non-parametric test known as Kruskal-Wallis *H*-test was applied. The test compares medians among k independent groups ($k > 2$) and was formulated based on ranks rather than actual observations (Daniel, 1990). Non-parametric tests like Kruskal-Wallis are generally robust to departures from normality and homoscedasticity and are less sensitive to outliers or extreme values.

Setting the hypotheses

For ANOVA, the null hypothesis was: the means for soil/water parameters are equal across the land-use activities (H_0: $\mu_1 = \mu_2 = \ldots = \mu_k = 0$). The alternative hypothesis is: the means for soil/water parameters are not all equal across the land-uses (H_1: $\mu_i \neq 0$ for some i).

For Kruskal-Wallis test, the hypotheses are: H_0: The k samples/groups come from identical populations (all group medians are equal) versus H_1: At least one of the samples/ groups comes from a different population than the others (the median differs for at least one group).

a) ***Formulating the test-statistic***

For the ANOVA, the model was formulated as follows:

$$\left[y_{ij} = \mu + \alpha_i + \varepsilon_{ij} \qquad i = 1, 2, \ldots k \quad j = 1, 2, \ldots n \right] \qquad \text{Equation (1)}$$

Where y_{ij} was value of water/soil sample from the i^{th} land-use activity and j^{th} observation; μ was the grand mean; α_i was the effect of the i^{th} land-use activity; ε_{ij} was the random error. The model assumed that the error terms were independent and identically distributed as normal with zero mean and constant variance, that is: $\varepsilon_{ij} \sim N\ (0, \sigma^2)$. The resultant test statistic was computed as shown below:

$$\left[F = \frac{MS_{Between\ groups}}{MS_{Within\ groups}} \right] \qquad \text{Equation (2)}$$

where $MS_{Between\ groups}$ = Mean square between groups; $MS_{Within\ groups}$= Mean square within groups

For the Kruskal-Wallis test, the test statistic was obtained as follows:

$$H = \left[\frac{12}{n(n+1)} \sum_{i=1}^{k} \frac{R_i^2}{n_i} \right] - 3(n+1) \qquad \text{Equation (3)}$$

where R_i denotes the sum of the ranks of the observations in group i, where i = 1, 2, …, k; and n was the total number of observations; k = number of groups. The distribution of the Kruskal-Wallis test statistic (H) approximates a chi-square (χ^2) distribution with k-1 degrees of freedom, if the null hypothesis was true and if the number of observations in each group was 5 or more.

b) *Setting the decision rule*

Choosing α = 5% as the level of significance, the null hypothesis was rejected on condition that the probability value (p) associated with the test-statistic (F or H) is less than 0.05.

c) *Post hoc analysis (pairwise comparison of the means)*

ANOVA F-test and Kruskal-Wallis H-test only tell that at least two groups were significantly different. They could not tell you which specific groups of the independent variable were statistically different from each other. So, there was need to follow up these tests with a post-hoc test. Following the rejection of the null hypothesis of equal means by ANOVA (F-test), pairwise separation/ comparison of means was done using Tukey's honestly significant difference (HSD) at 5% level of significance to identify the statistically significant means.

$$\left[HSD = q\sqrt{\frac{MS_{Within\ groups}}{n}} \right] \qquad \text{Equation (4)}$$

$MS_{Within\ groups}$ = Mean square within groups; q = studentized-range statistic with degrees of freedom associated with $MS_{Within\ groups}$; and n = number of observations in each group. Two means were considered statistically/significantly different from each other if their difference was equal to or greater than the HSD computed value. For the case of Kruskal-Wallis test, the post-hoc test was carried out using Dunn test to determine which specific groups were statistically significantly different from each other. Dunn test investigated the hypothesis that samples from any two groups have the same distribution. All the analyses were run using SPSS version20.

3.2.3 The effect of land use activities on the vegetation cover of River Wambabya catchment

3.2.3.1 Data collection procedure

The USGS earth explorer website (https://earthexplorer.usgs.gov/) provided high-resolution Landsat 8 images with spatial resolution of 30m for the research region. The data was attained through the analysis of multi-temporal satellite imageries which were registered to depict land use land cover status of three study periods 1998, 2008, and 2018 at an interval of ten years each so as to clearly classify LULC indicating land use/cover change from 1998 to 2018 in diverse land use classes such as indicated in table 3.4.2 below of the River Wambabya in Buseruka Sub County.

Table 3.2.3. 1 Satellite imagery datasets acquired

Dataset	**Date of Acquisition**	**Bands**	**Resolution**	**Source**
Landsat 8 OLI/TIRS SC2 L2	28/12/1998	Multi-Spectral	30m x 30m	USGS
Landsat 8 OLI/TIRS SC2 L2	10/05/2008	Multi-Spectral	30m x 30m	USGS
Landsat 8 OLI/TIRS SC2 L2	19/09/2018	Multi-Spectral	30m x 30m	USGS

3.2.3.2 Processing

The land cover in the study area was classified into eight main classes according to Anderson *et al.*, (1976): (1) Built up areas, (2) Bushland, (3) Forests, (4) Grassland, (5) Open Water, (6) subsistence Farmland, (7) Wetlands, and (8) Woodland.

Table 3.2.3. 2 Land use land cover classification

Land use classes	Description
Built up areas	Settlements such as residential and industrial, infrastructure such as roads, bridges, hydro power plants.
Bush land	Land covered with herbaceous, shrub and brush, lightly settled land.
Forests	Natural and man-made forests
Grassland	Area dominated with grass vegetation
Woodland	Low-density forests supporting underlying shrubs, herbaceous plants including grasses. Open habitat with enough sunlight.
Open water	Water streams, Rivers and the lake.
Subsistence Farmland	Small scale farming or mixed farming with crops for household survival
Wetlands	Seasonal and permanent wetlands, swamps, peats, forested and non-forested wetland.

After extraction of satellite images for River Wambabya catchment area, the boundary of the catchment was digitized including boundaries of River distributaries and sub distributaries feeding into River Wambabya within the catchment, areas occupied by land use activities such as infrastructure (roads, houses, bridges, railways) using geo-spatial analysis tools in Arc Map 10.2. The selected georeferenced GIS points for the ground truth surveys were analyzed for image accuracy classification with the main outputs of the analysis as;

a) Land use/vegetation cover maps indicating changes from periods 1998-2018.

b) Percentage vegetation cover changes versus land use classes.

ANOVA was used to analyze between land use classes of LULC changes analysis with soil and water quality from factor loadings of Principle Component Analysis (PCA). Using ANOVA, the analysis aimed at determining and verifying the existing LULC classes that react as pollutant sources and cause effect on soils and water quality and cause contamination (Hua, 2017), along

River Wambabya catchment in Buseruka sub county. The interpretation between images provided changes in “- from, -to” information. Comparison of the classified images of two different data sets were achieved using cross-tabulation in defining the qualitative and quantitative characteristics of changes for the periods from 1998 to 2008 and 2008 to 2018. The degree of change and percentage of changes was expressed using the following formula;

$K = F - I,$

$$\left[A = \frac{(F - I)}{I} * 100 \right]$$

Where; where *K* was degree of change, *A* was percentage of change, *F* is first data, and *I* was reference data.

3.2.3.3 Post classification

In execution of land use land cover change detection, a post-classification detection method was used. A change matrix was used in the analysis of results with the help of ArcGIS software. Quantitative aerial data of the overall land use land cover changes as well as gains and losses in each character between 1998 and 2018 was compiled. Change detection analysis of land use change was done using pixel-by-pixel assessment of land use maps generated from satellite image classification, change matrix was created to show quantitative information of changes visually represented on an image map.

CHAPTER FOUR: RESULTS

4.0 Introduction

The results revealed various land use activities existing in the catchment including; subsistence farming (maize, beans), animal (cattle, goat, sheep) grazing, agroforestry, human settlements (houses and trading centres), brick making, Kabalega hydropower plant, motor car/cycle washing bays, constructed oil roads (Kaiso-Tonya road), Wambabya bridge, and on-grid powerlines. There existed water abstraction points along the River Wambabya for domestic and industrial use, forest deforestation and conversion to subsistence farmlands, water transport and fishing on lake Albert downstream the catchment. Some of the land use activities are summarized in Table 4.0.1 and Plates 4.0.1-4.0.6.

Table 4.0. 1 sampling site and description of land use activities

Site/location	Land use classes recorded	Land use activities
Wanga, Kahindi, Kihombya	Wetland, agroforestry, subsistence farmland	maize, beans, cassava growing, high voltage powerlines, feeder road, human settlements
Bugambe, Katengeta, Kijubya	Wetland, built up areas, subsistence farmland, forest, agroforestry	Flowing river Wambabya, farming gardens, papyrus growing, pine, eucalyptus growing, forest, water abstraction points
Buseruka, Wambabya, Rwamutonga	Wetland, Built-up area, subsistence farmland	Wambabya bridge, cattle grazing, farming gardens, water abstraction points, Wambabya trading center, Kaiso-Tonya road, washing bay, river Wambabya (main)
Tonya	Open water (towards Lake Albert), wetland, built-up area, woodland, bushland	Fishing, papyrus growing, cattle grazing, powerline, network must, Kabalega Hydropower plant, houses

Selected plates showing land use activities carried out within River Wambabya catchment

Plate 4.0. 1 Maize plantation in Buseruka sub county Wambabya village

Plate 4.0. 2 Section of Kabalega Hydropower plant in Buseruka

Plate 4.0. 3 A boat used as means of transport downstream River Wambabya catchment

Plate 4.0. 4 Community water abstraction area for domestic use

Plate 4.0. 5 Cattle grazing near Tonya B wetland on River Wambabya downstream

Plate 4.0. 6 Water abstraction vehicle stationed at Wambabya bridge

4.1: To determine the effect of land use activities on the water quality of River Wambabya catchment

The water parameters considered in this study included pH, EC (µS/cm), COD (mg/l), BOD (mg/l), Total Phosphates (mg/l), Nitrates (mg/l), Lead (mg/l), *E. coli*/CFU 100mls (colony forming units in 100mls) and Total Coliforms/CFU 100mls (colony forming units in 100mls).

Results from Kruskal-Wallis test (table 4.1.1) revealed that only BOD (p value of 0.021) was significantly affected by land use activities at $p<0.05$. The other water parameters such as pH (p value of 0.423), EC (p value of 0.24), COD (p value of 0.209), Pb (p value of 0.452), Total phosphates (p value of 0.321), Nitrates (p value of 0.496), *E. coli* (p value of 0.131) and Coliforms (p value of 0.195) were not affected by land use activities as their p values were greater than 0.05.

Table 4.1. 1 Test for equality of medians in water quality parameters (by land use)

Water quality parameters	**Land-use activity**	**Frequency**	**Median**	**Mean rank**	**Test statistic (*H*)**	**Significance (*p*-value)**	**National Standard***
Potential of Hydrogen (pH)	Subsistence farmland	3	6.5	22.83	4.94	0.423	6.5-8.5
	Built-up area	10	7.3	21.95			
	Forest	7	6.4	14.86			
	Agroforestry	8	6.5	17.50			
	Open water	5	7.7	28.70			
	Wetland	7	7.5	20.64			
Electro-conductivity	Subsistence farmland	3	36.0	15.00	6.75	0.240	400
	Built-up area	10	30.4	15.90			
	Forest	7	34.7	17.71			
	Agroforestry	8	85.5	20.81			
	Open water	5	105.0	29.20			
	Wetland	7	97.0	25.64			
Chemical Oxygen Demand	Subsistence farmland	3	22.0	22.00	7.16	0.209	100
	Built-up area	10	25.5	20.50			
	Forest	7	30.0	26.29			
	Agroforestry	8	24.5	24.31			
	Open water	5	8.4	10.10			
	Wetland	7	18.0	17.14			
Biological Oxygen Demand	Subsistence farmland	3	7.0	34.17	13.23	0.021	50
	Built-up area	10	4.0	16.45			
	Forest	7	4.0	21.00			
	Agroforestry	8	4.0	15.69			
	Open water	5	3.0	14.20			
	Wetland	7	6.0	29.93			
Total Phosphates	Subsistence farmland	3	0.11	25.83	5.86	0.321	10
	Built-up area	10	0.09	24.60			
	Forest	7	0.08	22.43			
	Agroforestry	8	0.08	17.81			
	Open water	5	0.11	21.90			
	Wetland	7	0.06	12.50			
Nitrates	Subsistence farmland	3	0.13	17.50	4.38	0.496	20
	Built-up area	10	0.09	16.55			
	Forest	7	0.18	24.07			
	Agroforestry	8	0.50	23.88			
	Open water	5	0.67	25.40			
	Wetland	7	0.09	16.50			
Lead	Subsistence farmland	3	0.005	16.50	4.72	0.452	0.1
	Built-up area	10	0.026	22.40			
	Forest	7	0.007	14.29			
	Agroforestry	8	0.013	18.31			
	Open water	5	0.037	24.00			
	Wetland	7	0.041	25.71			
E. coli	Subsistence farmland	2	22.5	15.50	7.10	0.131	0
	Built-up area	3	12.0	7.83			
	Forest	.	.	.			
	Agroforestry	6	18.5	13.25			
	Open water	2	15.5	9.00			
	Wetland	6	10.5	6.33			
Total Coliforms	Subsistence farmland	2	44.5	14.50	6.05	0.195	0
	Built-up area	3	17.0	6.67			
	Forest	.	.	.			
	Agroforestry	6	38.5	13.25			
	Open water	2	37.5	9.75			
	Wetland	6	18.0	7.00			

*National Environment (Standards for Discharge of Effluent into Water or Land) Regulations, 2020

The study findings showed that BOD was highly affected by subsistence farmland (7mg/l), followed by wetland (6mg/l), then built-up areas (4mg/l), forest (4mg/l), agroforestry (4mg/l) and open water(3mg/l) as represented in the figure 4.1.1 below;

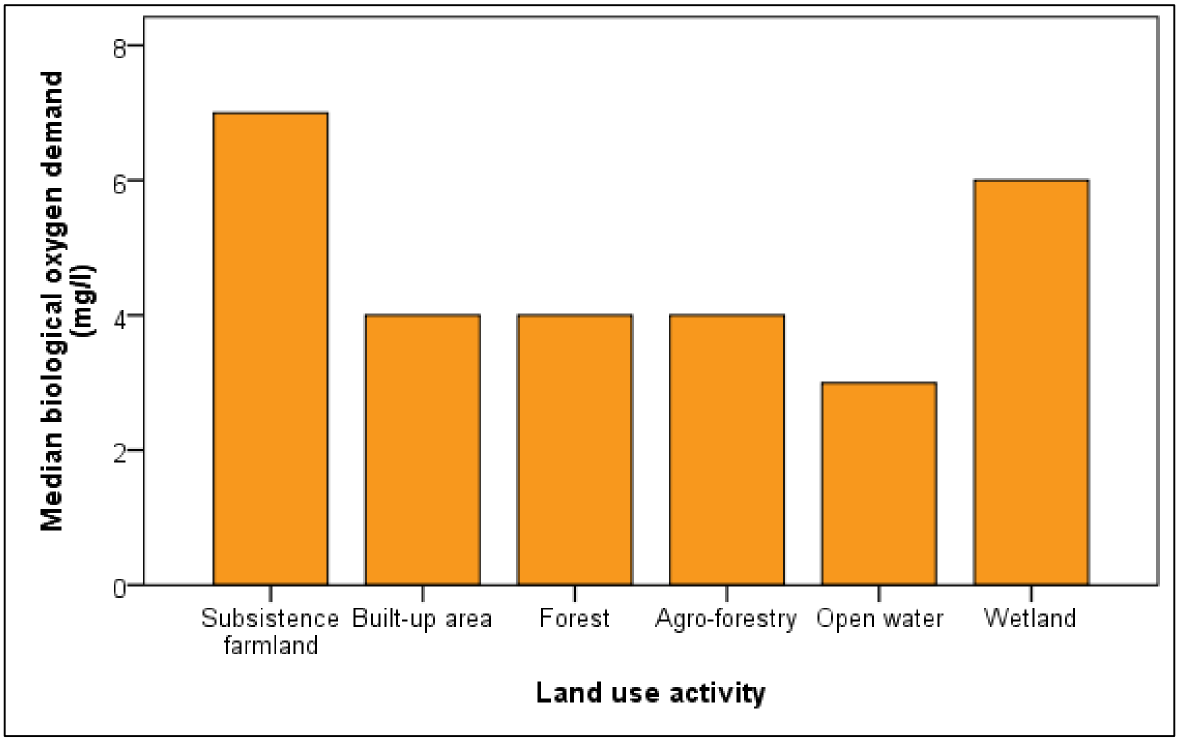

Figure 4.1. 1 Bar chart comparing median biological-oxygen-demand by land-use activity

The descriptive statistics (table 4.1.2) using Coefficient of Variation (CV) to analyze water quality showed that EC (104.7), COD (135.1), total phosphates (120.8) and nitrates (143.2) were highly variable (CV > 100%), an indication of the presence of outliers or extreme values in the observations; the other parameters such as; pH (10.1), BOD (39.8), Lead (74.2), *E.coli* (45.3) and Total coliforms (56.5) showed moderate variation.

The quality of water sampled at different streams (upstream, midstream and downstream) of River Wambabya catchment showed an average of; pH (7.0), EC (93.6µS/cm), COD (29.7 mg/l), BOD

(5.0 mg/l), Total Phosphates (0.13 mg/l), Nitrates (0.62 mg/l), Pb (0.024 mg/l), *E. coli* (16.4 CFU 100mls), and total coliforms (31.7 CFU 100mls).

Apart from *E. coli* and total coliform results (table 4.1.2), that are greater than 0 of the national standards, the other parameters were within the water quality national standards for Uganda.

Table 4.1. 2 Descriptive summary statistics for water quality parameters

Water quality parameter	**No. of obs.** (*n*)	**Mean ± Std. Dev.**	**Median**	**CV (%)**
Potential of Hydrogen (pH)	40	7.0 ± 0.71	7.1	10.1
EC (µS/cm)	40	93.6 ± 97.96	87.0	104.7
COD (mg/l)	40	29.7 ± 40.13	21.0	135.1
BOD (mg/l)	40	5.0 ± 1.99	4.0	39.8
Total Phosphates (mg/l)	40	0.13 ± 0.157	0.09	120.8
Nitrates (mg/l)	40	0.62 ± 0.888	0.13	143.2
Lead (mg/l)	40	0.024 ± 0.0178	0.022	74.2
E. coli/CFU 100mls*****	19	16.4 ± 7.43	15.0	45.3
Total Coliforms/CFU 100mls*****	19	31.7 ± 17.91	26.0	56.5

**Parameter adjusted for TNTC (too numerous to count)* *CV: Coefficient of Variation*

4.2 To assess the effect of land use activities on the soil properties of River Wambabya catchment

The soil parameters considered for the study included; EC (mS/cm), pH, Zn (ppm), Ni (ppm), Pb (ppm), Mn (ppm), Fe (ppm), Cd (ppm). The results from Kruskal-Wallis test (table 4.2.1) showed that Zn (p value of 0.048), Ni (p value of 0.020) and Pb (p value of 0.037) were significantly affected by land-use activities and that their p values were less than 0.05 as presented in table 4.2.1. The remaining soil parameters including EC (p value of 0.128), pH (p value of 0.352), Mn (p value of 0.209), Fe (p value of 0.180) and Cd (p value of 0.237) showed a P value greater than 0.05 thus were not affected by land use activities.

Table 4.2. 1 Test for equality of medians in soil parameters (by land-use)

Soil parameter	Land-use activity	Frequency (f)	Median	Mean rank	Test statistic (*H*)	Significance (*p*-value)	National Standard*
Electro-conductivity	Subsistence farmland	3	0.05	14.67	8.57	0.128	0.2
	Built-up area	10	0.11	25.50			
	Forest	7	0.06	14.93			
	Agroforestry	8	0.05	14.25			
	Open water	5	0.09	23.60			
	Wetland	7	0.11	26.36			
Potential of Hydrogen (pH)	Subsistence farmland	3	5.7	24.83	5.56	0.352	4.6-9.0
	Built-up area	10	5.5	21.50			
	Forest	7	4.7	15.36			
	Agroforestry	8	4.3	15.56			
	Open water	5	5.0	21.90			
	Wetland	7	5.7	27.00			
Zinc	Subsistence farmland	3	18.0	29.67	11.20	0.048	300
	Built-up area	10	11.0	21.10			
	Forest	7	10.0	17.86			
	Agroforestry	8	13.0	28.81			
	Open water	5	10.0	16.80			
	Wetland	7	8.0	11.50			
Nickel	Subsistence farmland	3	30.0	27.00	13.35	0.020	50
	Built-up area	10	9.0	18.10			
	Forest	7	9.0	17.64			
	Agroforestry	8	18.0	31.63			
	Open water	5	11.0	20.30			
	Wetland	7	4.0	11.43			
Lead	Subsistence farmland	3	128.0	26.33	11.82	0.037	100
	Built-up area	10	70.5	21.40			
	Forest	7	88.0	23.36			
	Agroforestry	8	118.0	28.19			
	Open water	5	53.0	11.40			
	Wetland	7	55.0	11.57			
Manganese	Subsistence farmland	3	82.0	23.67	7.16	0.209	2000
	Built-up area	10	17.5	19.70			
	Forest	7	79.0	26.14			
	Agroforestry	8	18.0	22.56			
	Open water	5	38.0	22.60			
	Wetland	7	10.0	10.79			
Iron	Subsistence farmland	3	2900.0	27.33	7.59	0.180	50000
	Built-up area	10	230.0	14.25			
	Forest	7	557.0	21.00			
	Agroforestry	8	1119.5	28.06			
	Open water	5	490.0	17.80			
	Wetland	7	631.0	19.29			
Cadmium	Subsistence farmland	3	2.0	21.00	6.79	0.237	3
	Built-up area	10	2.0	22.40			
	Forest	7	2.0	21.43			
	Agroforestry	8	2.2	21.44			
	Open water	5	3.0	26.40			
	Wetland	7	2.0	11.36			

*The National Environment (Minimum Standards for Management of Soil Quality) Regulations, 2001

For the case of Zinc, the following land activities affected its concentration in the soil in the order of; subsistence farmland (18.0ppm), agroforestry (13.0ppm), built up area (11ppm), open water (10ppm), forest (10ppm), and wetland (8ppm) (Figure 4.2.1). The following activities affected the concentration levels of Nickel in the soil in the order of; subsistence farmland (30.0ppm), agroforestry (18.0ppm), open water (11.0ppm), forest (9ppm), built up area (9ppm), and wetland (4ppm) (figure 4.2.1). Land use activities affected Lead concentration levels in the soil in the order of; subsistence farmland (128.0ppm), agroforestry (118.0ppm), forest (88.0ppm), built up area (70.5ppm), wetland (55ppm), and open water (53ppm) (figure 4.2.1).

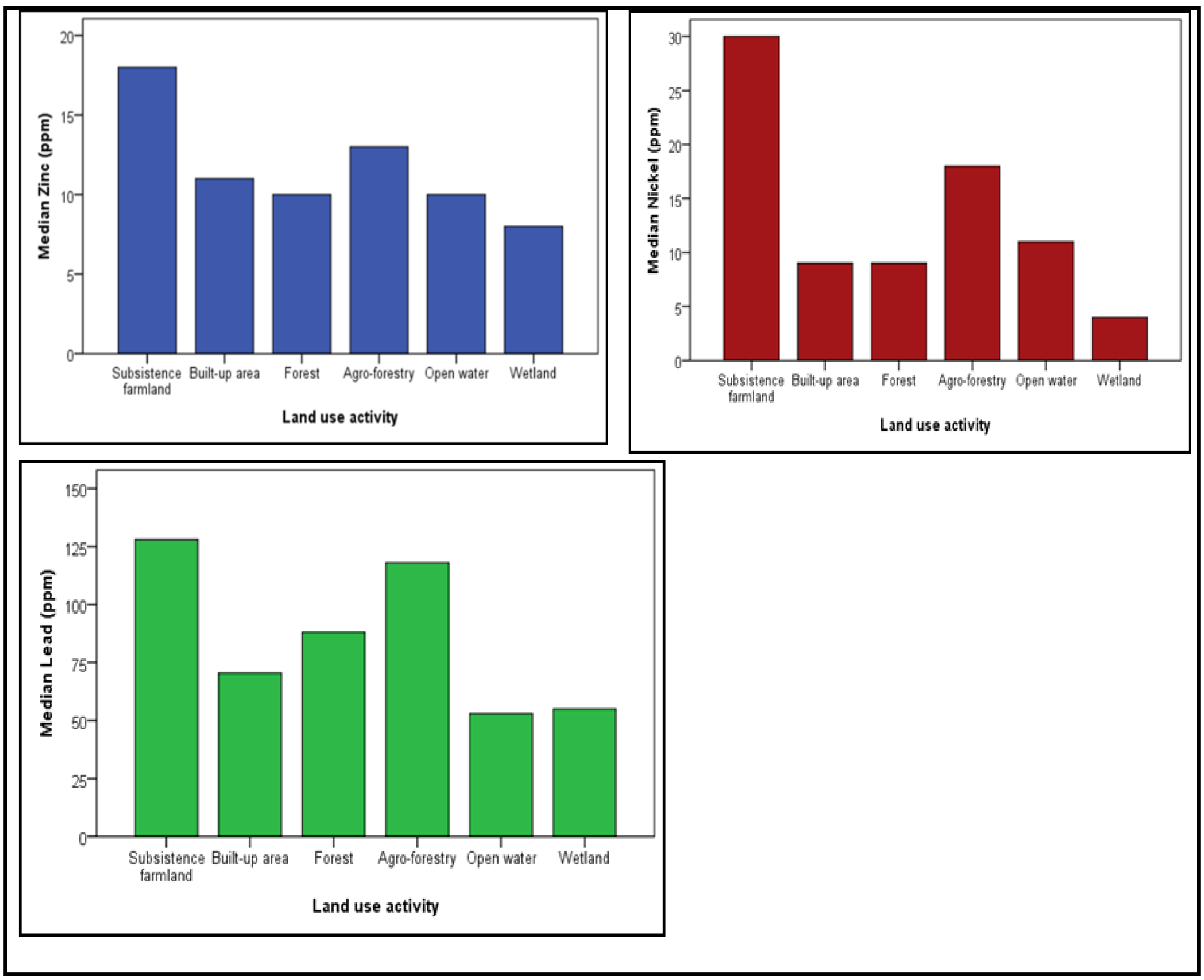

Figure 4.2. 1 Bar charts comparing median Zinc, Nickel, and Lead by land-use activity

The descriptive statistics (table 4.2.2) revealed that the soil parameters in River Wambabya catchment generally exhibited a high degree of variability particularly EC (75.0), and heavy metals such as manganese (158.3) and iron (97.7) (CV ≥ 75%). These parameters were also found to be highly skewed (skewness ≥ 1.48) with EC (1.828), Mn (2.41), and Fe (1.48) an indication of the presence of outliers/ extreme values in the observations. The other soil properties were moderately variable and fairly skewed. The mean values for soil parameters were; EC (0.12 mS/cm), pH (5.2). Zn (11.5 ppm), Ni (12.5 ppm), Pb (77.4 ppm), Mn (62.7 ppm), Fe (791.9 ppm), and Cd (2.3 ppm).

Table 4.2. 2 Descriptive summary statistics for soil properties

Soil parameter	**No. of obs. (*n*)**	**Mean ± Std. Dev.**	**Median**	**CV (%)**
Electroconductivity (mS/cm)	40	0.12 ± 0.090	0.09	75.0
Potential of Hydrogen	40	5.2 ± 0.82	5.4	15.8
Zinc (ppm)	40	11.5 ± 4.48	10.0	39.0
Nickel (ppm)	40	12.5 ± 8.71	10.0	69.7
Lead (ppm)	40	77.4 ± 30.00	70.5	38.8
Manganese (ppm)	40	62.7 ± 99.23	17.0	158.3
Iron (ppm)	40	791.9 ± 773.81	529.0	97.7
Cadmium (ppm)	40	2.3 ± 0.57	2.0	24.8

CV: *Coefficient of Variation*

4.3 To determine the effect of land use activities on vegetation cover of River Wambabya catchment

Land use classes per percentage land use/cover in the years of 1998, 2008, 2018 were presented in table 4.3.1. The study area was defined to have eight major land use and land cover classes such as; built up areas, grassland, forests, subsistence farmland, open water, bush land, wetlands and woodland. The results revealed that land use had significant effects on the vegetation cover of River Wambabya catchment over a period of 20 years (1998-2018).

The total area covered by built up areas and subsistence farmland increased over the 20 years (1998-2018). In 1998, subsistence farmland covered a total area of 90.01 km^2 (9.17%) that drastically increased to 181.68km^2 (18.51%) in 2008, and slightly increased to 198.34 km^2 (20.21%) in 2018. Whereas, built up areas were at 23.63 km^2 (2.41%), in 1998, increased to 38.41 km^2 (3.91%) in 2008, and extremely augmented to 73.79 km^2 (7.52%) in 2018.

Forests covered an area of 37.87 km^2 (3.86%) in 1998, significantly declined to 13.61 km^2 (1.39%) in 2008 and further to 12.52km^2 (1.28%) in 2018. Wetlands in River Wambabya catchment covered a total area of 20.48 km^2 (2.09%) in 1998, severely dropped to 10.95 km^2 (1.12%) in 2008, and significantly reduced to 6.56 km^2 (0.67%) in 2018. Further still, bushland was at 65.27 km^2 (10.89%) in 1998, reduced to 56.63 km^2 (5.77%) in 2008 and further dropped to 45.98km^2 (4.68%) in 2018.

The total area for open water was 592.64 km^2 (60.38%) in 1998, however, slightly dropped to 590.8 km^2 (60.20%) in 2008 and further to 580.52 km^2(59.15%) in 2018. Grassland was at 110.63 km^2 (11.27%) in 1998, and reduced to 58.03km^2 (5.91%) in 2008 and then to 36.45km^2 (3.71%) in 2018 respectively. Furthermore, the total area under woodland was at 40.91 km^2 (4.17%) in 1998 that slightly dropped to 31.33 km^2 (3.19%) in 2008 and to 27.28km^2(2.78%) in 2018.

Table 4.3. 1 Land Use Land Cover Classes with the total areas and percentages

Class	**Total Land use/cover Area in $km^2$and Percentage**					
	1998	**%**	**2008**	**%**	**2018**	%

Built Up Areas	23.63	2.14	38.41	3.91	73.79	7.52
Bush land	65.27	6.65	56.63	5.77	45.98	4.68
Forests	37.87	3.86	13.61	1.39	12.52	1.28
Grassland	110.63	11.27	58.03	5.91	36.45	3.71
Open Water	592.64	60.38	590.8	60.20	580.52	59.15
Subsistence Farmland	90.01	9.17	181.68	18.51	198.34	20.21
Wetlands	20.48	2.09	10.95	1.12	6.56	0.67
Woodland	40.91	4.17	31.33	3.19	27.28	2.78
Total	**981.44**	**100**	**981.44**	**100**	**981.44**	**100**

The land use land cover changes over 20 years (1998-2008-2018) were further presented as maps in Figure 4.3.1. The total area for built up areas (legend color red) and subsistence farmlands (legend color light green) increased significantly while area under wetlands (shaded light blue) drastically reduced, and open water (in blue) slightly reduced over the 20 years. Forests (green), grasslands (light brown), bushland (purple), and woodland (pink) also decreased over the 20 years as shown in the figure 4.3.1 below;

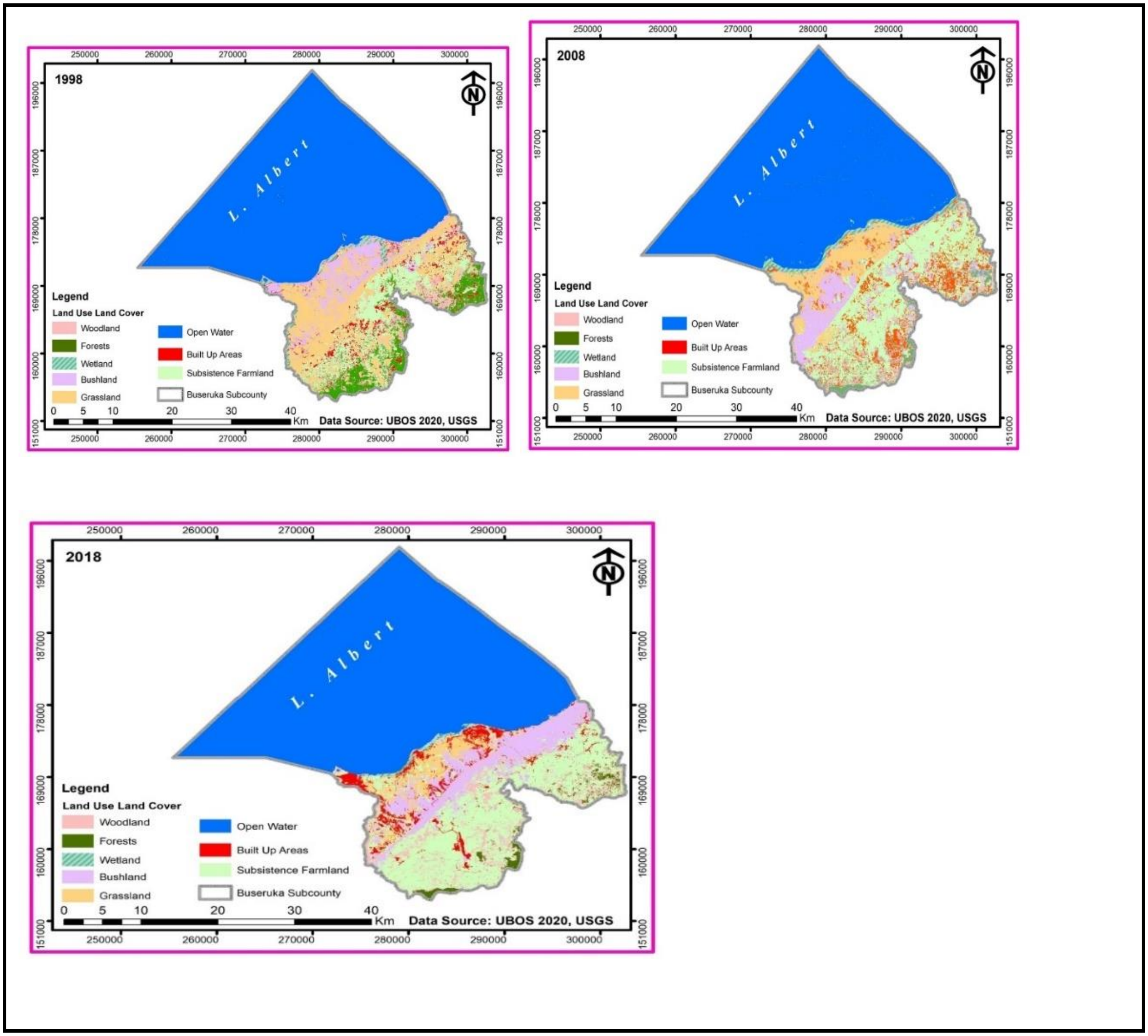

Figure 4.3. 1 LULC maps of the study area for the years 1998, 2008, and 2018

CHAPTER FIVE: DISCUSSION

5.0 Introduction

This chapter discusses the findings from the preceding chapter by objectives and compares them to findings from other writers relevant for the study. Land use activities under a) subsistence farmland included growing of maize and beans and animal grazing; b) built up areas such as washing bays, crop growing; houses, roads, powerlines and emergence of urban centers; c) natural forests, d) man-made tree plantations under agroforestry, and e) open water had land use activities such as fishing, use of boat transport, water abstraction while f) wetland had activities such as fishing, crop growing and human encroachment for settlement.

5.1 To determine the effect of land use activities on the water quality of River Wambabya catchment

Land use activities had a significant effect on the BOD of the water in river Wambabya catchment. The highest BOD levels were recorded in order of subsistence farmland, wetland, built up areas, forest, agroforestry and lowest under open water (Table 4.1.1). BOD is an indicator for total organic content accessible to organisms and chemical to impulsively react with oxygen (Walter et al., 2010). The high BOD recorded under subsistence farmland may be attributed to the effluents from fertilizers and pesticides used in subsistence farming for maize, beans and tree growing that are sources of nutrients such as Nitrates and phosphates (Charles et al., 2011). Subsistence farming activities introduce ions and metals from fertilizers and alternative agrochemicals (Clenaghan et al., 1998; Laar et al., 2011a, b). Scholars have also found that untreated farming wastewater was discharged directly from intensively cultivated rice farmland into environmental surface water bodies, leading to further deterioration of water quality (Minh et al., 2020). Relatedly, land use activities such as subsistence farming have caused water quality deterioration in Europe's Baltic Sea (Gustafsson et al., 2012), Chesapeake Bay in the USA (Simpson, 2010), and the Australian Great Barrier Reef (Waterhouse et al., 2010).

As built up areas increase in the river catchments, the natural environment is destroyed and altered, and peak flows and runoff subsequently increase drastically (Han et al., 2017; Pankaj, 2021). This changes the spatial and temporal patterns of surface runoff and the hydrological cycle processes in built up areas thus affecting the water quality (Han and Jia, 2017; Pankaj, 2021). According to (Shi et al., 2017; Pankaj, 2021), built up areas are considered as major contributors to deteriorating water quality in catchments due to the increased industrialization, infrastructure developments. Further still, (Lu, 2020) denotes that the construction of reservoirs and hydropower dams for human water consumption issues alters both the water resources storage and the natural degradation process of water pollutants. Harmful substances that should have been degraded naturally by wetlands and rivers are stored, bio-accumulated and fermented in artificial dams, leading to deterioration of water quality (Xu et al., 2020).

Additionally, the increasing built up areas such as houses, urban centers as a result of population increase (UBOS, 2020), infrastructural developments including oil roads, transmission powerlines and displacement of people from the oil refinery area in Kabaale Buseruka to neighboring villages (Global Rights Alert, 2015) have resulted into high dependence on water resources for livelihoods. However, land use activities had no significant effect on other water quality parameters such as pH, EC, COD, Pb, Total phosphates, Nitrates, *E. coli,* and coliforms as their p values were greater than 0.05 (Table 4.1.1). The non-significant effect can be attributed to minimal land use activities in the area. The non-significant effect of land use activities on water quality could also indicate that wetlands and the open water resources still have high ability to breakdown chemicals, absorb lead levels and maintain nutrient concentrations and conductivity.

5.2 To assess the effect of land use activities on the soil of River Wambabya catchment

Land use activities had a significant effect on the concentrations of Zn, Ni, and Pb in the soil of river Wambabya catchment. Significant changes in soil properties as a result of land use activities may affect soil microbial structure and ecological functions (Zhang et al., 2020). According to (Guo et al., 2017), soil microbial community structure was significantly affected by both soil properties and Heavy Metals, such as pH, Pb, and Zn. Further still, heavy metals affect plant growth, metabolism of organisms in the soil and affect natural biochemical reactions (Hassan et al., 2013).

Significant Ni concentrations were observed under subsistence farmland and agroforestry that may be attributed to the use of fertilizers and pesticides in crop and tree growing. The findings are in tandem with (Mcllveen et al., 1994) who attributed Nickel levels to usage of fertilizers and pesticides in crop and trees growing, and waste disposal from houses and urban areas under built up areas. High Nickel levels may also result from reduced soil pH due to a decline in the use of soil lime in agricultural soils, and acid precipitation (Cempel et al., 2005).

The geology of Hoima District could also be a source of Ni, that naturally occurs in the earth (Hussain et al., 2013), Nickel comes from rock and soil weathering, forest fires, combustion of fossil fuels, burning of waste and sewage. Existence of Nickel is also attributed to the ferralitic nature of Hoima soils that are generally acidic (HDD, 2015). This is also a characteristic of Oxisols and therefore the Leguminosae grown within the area like beans, peas that have tolerance to and hyper accumulation of Nickel levels (Kabata- Pendias et al., 2007).

Significant Lead concentrations were recorded under subsistence farmland and agroforestry which may be attributed to use of fertilizers in crop and tree growing. Lead could also emanate from solid waste disposal, automobile exhausts, fertilizers and sludge application under built up areas and subsistence farmland (Khan et al., 2007) as a result of increasing built up areas inform of houses, urban centers, industries and other infrastructural developments. Zeng et al., (2007) stated that Pb was a major heavy metal pollutant in the earth's crust abundant. Heavy metals have an inhibitory influence on soil enzymes (Khan *et al.*,2007) and negatively affect biological properties of soils, (Huang and Shindo 2000) that may also affect the conservation of the River catchment soils. All the reported lead levels across the land use activities were within the permissible limits of 100ppm (national standards*) apart from Pb levels under subsistence farmland and agroforestry that were above the limits at 128.0ppm and 118.0ppm respectively. This is an indication of moderate contamination of the catchment with lead.

Significant Zinc levels in soils under subsistence farmland and agroforestry may be attributed to use of fertilizers for high crop yields in the River catchment. Zinc is a vital micronutrient; constituents many proteins and an enzyme co factor for plant growth especially in production of beans, and maize (Broadley et al.,2007). Plants take up Zinc as a divalent ionic form (Zn2+), while zinc natural presence depends on the parent rock materials and the acidity of soils. However, Zn is phytotoxic to plants and its uptake through the root systems may pose health risks to end consumers (Bolan et al.,2014) thus the need to manage its levels in soils as a result of human activities.

According to (Tutu et al., 2008), the high acidic pH observed in acid mine drainage from gold mining industry tailings is a cause of elevated heavy metals such as Ni, Pb, and Zn (Da Silva et al., 2004). Relatedly, various studies (Moges et al., 2013; Yitbarek et al., 2013; Denboba, 2005) indicated that land use changes such as deforestation, overgrazing resulted into soil erosion and thus severe deterioration in quality of soils. The study findings (Cempel et al., 2005) are also in tandem with the current research study results that indicated lower pH levels between 4.3 and 5.7 across the land use activities that accounted for acidic soils within the River Wambabya catchment.

However, land use activities indicated a non-significant effect on the concentrations of EC, pH, Mn, Fe and Cd. This may be attributed to the minimal land use activities compared to the surface area of the river water catchment under subsistence farming such as crop growing and animal grazing, built up areas such as urban centers, houses, agroforestry with ecological capacity of open water, forests and wetlands to act as sinks for the stated parameters.

5.3 To determine the effect of land use activities on vegetation cover of River Wambabya catchment over a period of 20 years (1998-2018)

Land use activities had a significant effect on the vegetation cover of river Wambabya catchment. There was a drastic increase in area under subsistence farmland and built up areas with a decline in the area under natural resources (forests, grasslands, bushland, woodland, open water, and wetlands). This could be attributed to population increase (UBOS, 2020) under built up areas in river Wambabya catchment area in Buseruka sub county. The population in Buseruka sub county increased from 43,018 people (National Housing and Census, 2014) to 52,100 people in 2020 thus accounting for a 17.43% population increase in six (6) years (UBOS, 2020). Increase in population attracts need for settlements, livelihoods, farming lands for food crops under subsistence farmland, where communities are forced to reclaim wetlands and encroach on riverbanks for settlements, livelihoods such as fishing, carry out deforestation for firewood/biomass, timber for economic trade, destroy bushlands for settlements, and woodlands for cattle grazing and setting up of farmlands.

Furthermore, increasing population (National Housing and Census, 2014) is attributed to the growth of urban/trading centers in Buseruka sub county were local communities end up degrading natural resources such as wetlands, and encroaching on forest resources to set up trading centers or even washing bays for economic activities. Some natural resources like man-made plantations, and local community forests are traversed by infrastructure developments such as the Hoima International airport, oil refinery, transmission powerlines, roads like Kaiso-Tonya oil road, and Wambabya bridge. The infrastructural developments opened up these natural resources (wetlands, bushlands, woodlands, grasslands, and forests) for human settlements, urban trading centers, animal farms hence leading to encroachment on their natural ecosystems as envisaged in the declining coverage of these natural resources.

In tandem with the study findings, (Bell et al., 2018) indicates that growing population has resulted into urban development, upsurge in subsistence farmland, and settlement houses thus exerting pressure on natural resources such as forests, and wetlands. Several studies elsewhere (Wiyo et al., 2015; Mzuza et al., 2017; Bell et al., 2018) also linked population increase to deforestation where forest loss coupled with subsistence farming were major causes of land use change leading to augmented soil erosion and sedimentation in River catchments

Globally, environmental impacts of deforestation have drastically increased (Caravaggio, 2020; Hite et al., 2021). The high deforestation, expansion of agricultural and infrastructural development projects within former forested areas have led to an increment in vegetation cover loss (Hishe et al., 2021; Oluwajuwon et al., 2021). Developing countries have registered high deforestation and forest degradation rates as a result of low per capita land and rigidity (Fagan et al., 2020). In addition, the increasing demand for agricultural land has asserted high pressure on forests which has led to altered vegetation cover, changes to the composition and structure of forest vegetation of adjacent forest ecosystems as well as negatively impacting on most forest ecosystems and human in Africa (Kerr et al., 2007), particularly in Sudan (Omer, 2009).

High wetland loss over the 20 years could be further attributed to human encroachment in the wetlands for livelihoods such as crop and tree planting under subsistence farmland and agroforestry that result into their conversion. Relatedly, a substantial acreage of the Buzi Headwaters in Zimbabwe was altered by land use activities such as agroforestry, subsistence farming that dominated the landscape accounting for 44.6% in 2009 and 46% in 2017 (Chemura et al.,2020). However, (Sirami et al.,2010) in southern Europe indicated uncontrolled land use activities such as, subsistence farming, and animal grazing, mainly at higher elevations, with the consequent return of shrublands or forest.

The expansion of built up areas such as urban centers, Kaiso-Tonya oil road infrastructure, transmission powerlines, and rapid population growth could be a driver of wetland loss in the last 20 years. The expansion of physical infrastructure developments such as roads, hydropower dams, bridges can have great influence on the vegetation cover (Yigitcanlar et al., 2010). Furthermore, the economic activities in Buseruka sub county such as crop and tree growing, animal grazing, fishing under subsistence farmland (Oil in Uganda, 2012b) have increased annotations that subsistence farming and human settlements are the main drivers of land cover changes in tropical areas (Betru et al., 2019; Xu et al.,2019).

Furthermore, (Elizabeth et al., 2019) denotes that built up areas with oil and gas developments in Uganda have impacted, degraded and altered the vegetation cover, and plant community growth patterns. These changes in the vegetation cover have implications on wildlife flora and fauna related to changes in feeding habits, breeding and growth. Oil and gas developments such as refinery, oil roads, and well pads have exacerbated the loss in biodiversity habitats, noise pollution, and animal deaths (Elizabeth et al., 2019). Government of Uganda and Tanzania embarked on the 1443km construction of the East African Crude Oil Pipeline (EACOP) from Buseruka in Hoima to Tanga Port (Barlow, 2020). The pipeline transects various vegetation cover and habitats in protected areas which posed effects on vegetation cover. This is in tandem with (Bilen et al., 2008) who associates oil pipelines with various forms of pollution thus threatening ecosystem health.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Land use activities had a significant effect on water quality BOD in River Wambabya Catchment. BOD levels were observed highest in subsistence farmland and least under open water land use classes. Increasing water quality BOD levels revealed an increment in the disposal of nutrients and organic wastes from subsistence farming practices such as use of fertilizers and pesticides that compete for dissolved oxygen during bio-decomposition.

Land use activities had significant effects on the concentrations of Zn, Ni, and Pb in the soil. Zn and Ni concentrations were highest in subsistence farmlands and least under wetland while Pb levels registered high concentrations under subsistence farmland and least under open water. This indicated moderate pollution of soils potentially emanating from the geological weathering of rocks, combustion of the fossils fuels (oil and gas), use of pesticides and chemical fertilizers thus affectig natural biochemical processes.

Land use activities significantly affected the vegetation cover of RWCA over the past 20 years (1998-2018). Increase in human population led to vegetation cover changes in River Wambabya Catchment; highest changes were perceived in subsistence farmlands, and built up areas. The vegetation cover changes showed drastic decline in areas under forests, grasslands, bushlands, woodland, open water and wetlands as a result of increasing land use activities between 1998 and 2018.

6.2 Recommendations

Subsequently, natural resources conservation efforts are required in river Wambabya catchment area so as to improve its sustainability and co-existence with human livelihoods. Particularly, more conservation efforts are needed to halt the deteriorating water quality and vegetation coverage of the catchment. This can be accomplished by supporting environmentally sustainable and culturally suitable management initiatives such as sustainable farming practices that may limit encroachment and increase vegetation regeneration, enhance water quality and soils in the water catchment.

The research was conducted for a short period of time with limited monitoring of the dynamics and effects of the various land use activities thus future long-term research is recommended. The research should be linked to the various physiochemical attributes of water quality, soil and vegetation cover so as to amalgamate into a landscape conservation approach of River Wambabya catchment and other water resources within the larger lake albert catchment management system. Further in-depth research can also be conducted on the temporal variations of vegetation cover and bioaccumulation of heavy metals in the soils of the RWC due to the increasing mining and oil and gas developments.

Hoima District should plan its infrastructural developments (in built up areas) in a sustainable manner aimed at managing poor disposal of pollutants from industrial and domestic wastes, over exploitation of and encroachment on the limited natural resources in the water catchment area.

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APPENDIX

A. Soil/Water Sampling Data Sheet River Wambabya Catchment

Sample No………………………………………………...

Media sampled……………………………………………

Date…………………………………………………….

District………………… Sub county………………

Village……………………………

Item Sampled: Soil………………………Water……………………

<table>
<tr><td>GPS points

Latitude:

Longitude:</td><td>Altitude</td><td>Accuracy</td><td>Weather

Conditions</td><td>Accessibility</td></tr>
<tr><td colspan="3">Land use type:</td><td colspan="2">Land use activities</td></tr>
</table>

B. Field Research Photos

Plate B. 1 Soil sampling using the soil auger

Plate B. 2 Soil sample from a wetland

Plate B. 3 section of vegetated River Wambabya

Plate B. 4 degraded area in Tonya Village

Plate B. 5 water abstraction point

Plate B. 6 telecommunication mask in Tonya B

Plate B. 7 River Wambabya in Rwamutonga

Plate B. 8 River Wambabya through a wetland

Plate B. 9 Wambabya bridge and Kaiso Tonya road

Plate B. 10 Signpost for Kabalega hydropower station

Table C. 1 Raw data on Land use activities in selected sampling sites of the study area

Site Name	Village	Type	Land use	Land use description (measured in a distance of 1 hectare)
Wambabya Wanga wetland	Wanga	Tributary	Man-Made forest	medium tree canopy and growing stage
				common species; man-made eucalyptus, pine and jackfruits
				Man-made forest with no disturbance
				no built-up places
				average cultivation, farmers were clearing land for the planting season
				existence of a wetland; has papyrus, some parts transformed to yams growing

Wambabya Kahindi wetland	Kahindi	Tributary	Agriculture	Medium tree canopy at medium growing stage
				Low vegetation cover
				Common species; eucalyptus, papyrus
				Manmade forest no disturbance
				Existence of bricklaying
				Built up Houses
				A feeder road
				High voltage powerlines
				Existence of yam gardens
				Land was being cultivated for the planting season
				Existence of cattle grazing
				There was a wetland with papyrus
Wambabya Kihombya wetland	Kihombya	Tributary	Man-made forest	Low tree canopies at high growing stage
				Medium vegetation –shrubs
				Manmade Forest
				Access road
				Houses
				Banana plantations, Eucalyptus
				No bare land
				No grazing
				Soils are clay loam
				Papyrus in wetland
Wambabya River (main 1)	Bugambe	Main river	Forest	Dense homogeneity
				Medium tree canopy at High growing stage
				Existence of thicket, woody shrubs
				Average forest disturbance
				Existence of a water abstraction point, access road and small bridge
				Average cultivation
				Existence of wetland with papyrus
				Clay loam soils
				Medium clouds, no rain, difficult accessibility and medium sunshine
Wambabya Katengeta wetland	Katengeta	Tributary	Man-Made forest	Sparse homogeneity
				Medium tree canopy at medium growing stage
				Vegetation-Eucalyptus at medium stage
				Manmade forest with mature and young trees with average disturbance

				Existence of brick laying, houses, bridge, powerlines and access road
				Partly degraded with bare land,
				Eucalyptus trees
				Existence of a wetland with papyrus
				No rain, medium clouds and sunshine with difficult accessibility
River Kijubi (tributary)	Kijubya	Tributary	Built-up area	Sparse homogeneity
				Medium tree canopy at medium growing stage
				Average forest disturbance
				Existence of a trading Centre, brick laying and access road
				Existence of erosion
				No rain, difficulty accessibility with medium clouds and sunshine
River Kijubya (tributary)	Kijubya	Tributary	Forest	Dense homogeneity with high tree canopy at high growing stage
				Existence of vegetation
				Average forest disturbance
				Brick laying and houses
				Existence of agricultural activities
				Wetland with papyrus
				Conditions during sampling: No rain, easy accessibility, medium sunshine and clouds
Wambabya Tonya wetland	Tonya A	Main river	Built-up area	No tree canopies, open space,
				Low vegetation with scattered shrubs, papyrus in wetland and water plants
				Existence of scattered human settlements
				Infrastructural developments e.g. telecommunication Mast
				Boat transport
				Cattle/goat/sheep grazing
				Fishing from wetland and lake Albert
				Bare land
				The area is gently flat (below the escarpment)
				Clear clouds, high sunshine, no rain and difficult accessibility
Wambabya Tonya B wetland	Tonya B	Main river	Built-up area	No forest
				Open space
				Scattered shrubs

				Water plants and papyrus in the wetland
				Houses
				Boat transport
				Fishing
				Cattle, goat/sheep grazing
				Conditions: High sunshine, no rain, no clouds, difficult accessibility
Wambabya river (Main 2) Tonya A	Tonya A	Main river	Forest	Sparse vegetation
				Scattered species
				Medium tree canopy at high growing stage
				Existence of construction camp for Kabalega Hydro powermDam
				Water falls
				Near river bank-degraded bare land due to cattle grazing
				Cattle grazing
				Conditions: High sunshine, no rain, difficult accessibility and no clouds
River Wambabya Bridge	Buseruka	Main river	Built-up area	Low and medium tree canopies and medium growing stage
				Herbaceous species
				Existence of a Wambabya Bridge
				Upcoming trading centre
				Charcoal burning
				Washing Bay for motorcycles
				Cattle drinking point
				Banana and maize plantation
				Kaiso-Tonya Tarmac road
				Conditions: No rain, no clouds, easy accessibility, medium sunshine
River Wambabya (main 3)	Buseruka	Main river	Forest	High tree canopy at high growing stage
				Grassland
				Water abstraction for domestic use
				Man-made farm
				Wetland with water plants
				Difficult accessibility (needed prior approvals)
				Low clouds, low rains (drizzles), difficult accessibility, medium sunshine
Wambabya Main	Buseruka	Main river	Open water	Water abstraction point for communities, wetland, grassland

Katengeta wetland 2	Katengeta	Tributary	Man-Made forest	Sparse homogeneity, Eucalyptus at medium stage, powerlines, access road, wetland
Wambabya Kahindi wetland2	Kahindi		Agriculture	Man-made forest at medium canopy growing stage, yam gardens, access road, high voltage powerlines, built-up houses
Wambabya Wanga wetland	Wanga		Man-made forest	eucalyptus, pine, medium agriculture, wetland
River Wambaya-main -4	Bugambe		Forest	dense homogeneity, thicket, agriculture, old tree canopies
Kijubi wetland 2	Kijubya		Builtup area	trading centre, access road, gullies, agriculture/cultivation
River Kijubya (Tributary)2	Kijubya		Forest	average vegetation, flowing water, average agriculture
River Wambabya			Wetland	papyrus, flowing river, yams, tree canopies
Wambabya (tributary)			Man-made forest	medium tree canopies, eucalyptus, pine trees, houses
Wambabya (tributary)			Wetland	Papyrus, bricklaying, houses
River Wambabya			Open water	flowing river, feeder acess road, agriculture on average
Wambabya			Builtup area	Feeder access road, houses, man-made plantations/forest
Wambabya (tributary)			Builtup area	bricklaying, feeder access road, houses, power lines
River Wambabya Main 5			Forest	flowing river, water culverts, forest with natural trees,
River Wambabya-Rwamutonga A	Rwamutonga		Wetland	feeder road, papyrus, yam plantations, cultivated areas
Rwamutonga wetland	Rwamutonga		Wetland	feeder road, papyrus, yam plantations, cultivated areas
River Wambabya-Rwamutonga B	Buseruka		Built-up area	man-made forest, plantations/agriculture, shrubs,
river Wambabya main 6	Buseruka		Open water	Built up area, flowing river, natural forest, water abstraction for nearby communities, small water culverts, shrubs

River Wambabya-Main 7	Buseruka		Man-made forest	eucalyptus, fruit trees, feeder road, agriculture fields, flowing river
River Wambabya main 8	Buseruka		Man-made forest	eucalyptus, fruit trees, feeder road, agriculture fields, flowing river
River Wambabya Bridge2	Buseruka		Built-up area	flowing river, temporary homesteads, access road, cattle grazing, small washing bay for motorbikes
Main river wambabya9	Buseruka		Open water	Flowing river, natural forest, Kabalega hydropower station, access road, powerlines
River Wambabya bridge 3	Tonya A		Built-up area	Wambabya bridge, abstraction point for domestic water use, agriculture on average scale
River Wambabya main10	Tonya A		Open water	water plants, thorny plants, flowing water (river Wambabya) at moderate speed
Tonya A wetland2	Tonya A		Wetland	Papyrus, built up area (scattered houses), water transport
River Wambabya Tonya A	Tonya A		Bareland	natural tree canopies, shrub species, small water culverts, water plants, goat rearing, degraded area by cattle and goat grazing
River Wambabya - Tonya B	Tonya B		Wetland	Papyrus, open water (river Wambabya and lake albert), water transport (local boats)
River Wambabya Tonya B2	Tonya B		Wetland	Papyrus, open water (river Wambabya and lake albert), water transport (local boats)