ASSESSMENT OF THE EFFECTS OF INDUSTRIAL DEVELOPMENT ON SURFACE WATER QUALITY IN NAMANVE INDUSTRIAL AND BUSINESS PARK, MUKONO MUNICIPALITY

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19/U/GMSM/18972/PD

A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN CONSERVATION AND NATURAL RESOURCES MANAGEMENT DEGREE OF KYAMBOGO UNIVERSITY

OCTOBER 2025

DECLARATION

I Ntegereje Robert (Reg. 19/U/GMSM/18972/PD) declare that this dissertation presented for the award of a Master of Science in Conservation and Natural Resources Management Degree has not been wholly or partially submitted for any other degree or professional qualification.

Signature………………………………………Date…………………………………………

APPROVAL

This is to certify that the work presented herein this dissertation is the student's own and has been done under my guidance and is now ready for consideration.

Signature………………………………… Date……………………………………….

Dr. Juliet Kyayesimira

Signature………………………………… Date……………………………………….

Assoc. Prof. Bernard Barasa

DEDICATION

I dedicate this dissertation to my parents; my grandfather, Mzee Deo Nizeyimana, and my mother, Ms. Florence Mukamusoni.

ACKNOWLEDGEMENT

I wish to extend my profound gratitude to my supervisors, Associate Professor Bernard Barasa and Dr. Juliet Kyayesimira, for their intellectual guidance, constructive criticism, and unwavering commitment throughout the course of this research. Their mentorship and scholarly insights have been instrumental in shaping both the study and my academic growth.

I am equally indebted to the Department of Biological Sciences for the institutional support and guidance provided during the course of my study. I also acknowledge with appreciation the invaluable contribution of my research assistants during field data collection, as well as all respondents who participated in the questionnaire surveys and interview sessions, without whom this research would not have been possible.

I am grateful to my colleagues and course mates for their encouragement and collegial support, which created a conducive learning environment. I am particularly appreciative of my workplace colleagues, especially Mr. Bashir Byansi, for his support and understanding, which enabled me to balance professional obligations with the demands of this academic programme.

Finally, I extend sincere appreciation to my friends, Dusabe Daphine, Lydia Nayiga, and Diana Musabi for their constant encouragement and moral support, which sustained me throughout the study.

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LIST OF ACRONYMS

AOAC:	Association of Official Analytical Chemists
LAI:	Local Area of Impact (LAI)
LULC:	Land Use Land Cover
MANOVA:	Multiple Analysis of Variance
MOLSCLE:	Modules for Land Use Change Simulations
NEMA:	National Environment Management Authority
NIBP:	Namanve Industrial and Business Park
UIA:	Uganda Investment Authority

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ABSTRACT

Industrial parks adversely pollute the environment due to economic priorities, thus affecting essential community ecosystem services. This study assessed the trend in industrial expansion and its effect on surface water quality in Namanve Industrial and Business Park (NIBP). High resolution satellite historical images covering the study area were acquired from Google Earth Pro archives and used examine the spatial and temporal changes in the study area between 2014 and 2022 and the prediction of 2030 scenario. Water samples were also collected from the Namanve stream at four purposively selected locations in relation to the four Industrial Blocks and taken to the Makerere chemistry Laboratory for physicochemical and heavy metal properties' analysis. A household survey also ensured in the communities surrounding the Industrial Park to collect socioeconomic data on water sources' contamination status and the most significant drivers of surface water contamination. Satellite imagery data underwent supervised classification procedures in ArcGIS 10.8.2 and QGIS 3.28 to create land use and cover extent and change facets and predict future changes. Water quality laboratory results underwent descriptive and Multivariant statistical analysis whilst household survey data was analysed using multiple response procedures and Binomial statistical test analysis at inferential level. The study found a significant expansion of industrial activity between 2014 and 2022 (r^2=0.86), which was linked to substantial surface water contamination, marked by altered physicochemical parameters; highest turbidity levels (318±21) on the South Block C. The highest value pH levels (8.1±0.14) were recorded mid-stream and elevated heavy metal concentrations with the highest value recorded for Zinc (0.24±0.18) in the South Block B. Industrial development is a primary driver of this contamination but other drivers like runoff and waste disposal also contributed to water pollution significantly ($p \leq 0.05$). However, projections suggest a decline in industrial land use between 2022 and 2030, with natural cover regaining ground. This shift may potentially mitigate some of the negative impacts on surface water quality observed in the earlier period. The spatiotemporal variation in water quality highlights the need for continued monitoring and management of both industrial activities and other pollution sources to ensure the long-term health of the NIBP's aquatic ecosystem. Therefore, industrial infrastructural developments should be restricted in the area; there is need to enforce water decontamination measures through bioremediation and conservation of natural wetlands and; NEMA should enforce environmental regulations governing discharge of hazardous industrial and municipal waste.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Industrialisation is widely recognised as a key driver of economic growth and transformation. In Uganda, industrial development dates back to the colonial period, but periods of stagnation occurred in the 1970s and 1980s due to political instability. In the 1990s, the government embarked on economic recovery programmes, positioning industrialisation as central to national transformation (GoU, 2017). Subsequent national development frameworks, including the Uganda Vision 2040, identified industrialisation as a pathway to shift the economy from a peasantry-based to an industrialised and commercialised society (National Planning Authority, 2020).

To achieve these goals, the government established industrial parks across the country (GoU, 2017). However, because much public land in Uganda is wetland, and due to tenure constraints for settlement and agriculture, wetlands have frequently been allocated for industrial development (GOU, 2016; NSOER, 2019). Perceived as "wastelands" with limited direct economic benefits, wetlands are held in trust by the government and are often converted once existing industrial zones reach capacity (Barasa et al., 2021). By 2010, nearly all wetlands around Kampala had been converted for industrial purposes.

The Namanve Industrial and Business Park (NIBP) is one such development. Established in 1997 and covering about 894 hectares, it is managed by the Uganda Investment Authority (UIA). While such parks contribute to economic growth, many Ugandan industries still rely on outdated manufacturing technologies and lack functional effluent treatment plants (Angiro et al., 2020). This exposes adjacent ecosystems to large volumes of untreated industrial waste (Omara et al., 2019). Although national environmental regulations require Environmental and Social Impact Assessments

(ESIA) and ongoing monitoring (NER (National Environmental Regulations), 1999), weak enforcement often leads to poor compliance, with environmental damage only being recognised after significant degradation has occurred.

Industrialisation's environmental footprint is particularly evident in water pollution. Industrial wastes in solid, liquid, and gaseous form often enter the environment intentionally or accidentally (Ismail & Moustafa, 2016). When discharged without treatment, these wastes degrade sensitive ecosystems such as wetlands, rivers, and soils, threatening both biodiversity and human health (Kaur et al., 2021). Industrial effluents frequently alter key water quality parameters such as turbidity, electrical conductivity (EC), dissolved oxygen (DO), total phosphates (TP), chemical oxygen demand (COD), biological oxygen demand (BOD), and pH (Tyagi et al., 2020).

Heavy metal contamination is a particularly serious threat. Although some heavy metals occur naturally, industrial processes, especially those involving extractives, significantly increase concentrations of toxic elements such as lead, cadmium, chromium, copper, zinc, and mercury (Noreen et al., 2019). Once released, heavy metals can leach into surface and groundwater, accumulate in sediments, and enter food chains through bioaccumulation (Marrugo-Negrete et al., 2017). Because of their persistence, toxicity, and tendency to bioaccumulate, heavy metals pose severe risks to aquatic ecosystems and human health (Morais, 2012; Shah, 2017).

In Uganda, studies such as Sekabira et al. (2010) have reported elevated concentrations of lead and cadmium in urban streams, including those draining industrial areas like Nakivubo Channel. Comparable conditions exist around NIBP, where industrial discharges threaten nearby wetlands and water bodies. Heavy metal pollution not only kills vegetation and impairs wetland filtration functions (Iwar et al., 2021), but also jeopardises crop safety and potable water supplies for surrounding communities (Chu et al., 2013).

However, since earlier studies, significant industrial expansion has occurred in NIBP. This raise concerns that past water quality assessments may no longer reflect current conditions. Continuous monitoring of streams draining industrial areas is therefore critical for early detection of contamination and for informing management interventions. This study was undertaken to address this gap by assessing the extent of industrial development and the current status of water quality in streams around the Namanve Industrial and Business Park.

1.2 Problem Statement

The NIBP, Uganda's largest operational industrial hub, is situated along a wetland system that drains into Lake Victoria's Inner Murchison Bay; a critical water source for Kampala and neighbouring districts (Akurut et al., 2017). Since its establishment, rapid industrial expansion has altered the landscape through wetland infilling, vegetation clearance, and stream modification, raising concerns over potential impacts on water quality (Angiro et al., 2020). Previous studies (Angiro et al., 2020; Omara et al., 2019) have reported the presence of heavy metals and other pollutants in industrial effluents from NIBP and noted exceedances in some water quality parameters. However, these studies were limited in scope as they did not assess heavy metal concentrations in streams, nor did they capture the spatial and temporal extent of industrial development in recent years. With industrial activity continuing to intensify, the risk of contamination to nearby water bodies and consequently to public health remains high. There is therefore a critical need for an updated and comprehensive assessment that (i) maps recent industrial expansion, and (ii) evaluates current water quality, including heavy metal concentrations, in streams within the NIBP catchment. This study addresses these gaps using remote sensing and GIS for spatial analysis, alongside field-based water sampling and community engagement.

1.3 Objectives

1.3.1 General Objective

The main objective of the study was to evaluate the pattern of industrial development and its impact on surface quality within the Namanve Industrial and Business Park in Mukono Municipality.

1.3.2 Specific Objectives

i. To determine the spatial extent of industrial development in Namanve between 2014, 2018, 2022, and predicted period between 2026 - 2030.
ii. To determine the physicochemical properties (pH, EC, TP, DO, COD, & BOD) and heavy metal (Pb, Cr, Zn, Ni and Cd) contamination in surface water sources (streams) in Namanve Industrial and Business Park.
iii. To determine the perceived drivers of stream water contamination in Namanve Industrial and Business Park.

1.4 Hypotheses (H_o)

i. There is no significant change in the spatial extent of industrial development in Namanve industrial and business park between 2014, 2018, 2022 and predicted period of 2026 - 2030.
ii. There is no significant variation in the physicochemical characteristics (pH, EC, TP, DO, COD, & BOD) and heavy metals (Cr, Cd Pb, Ni, & Zn) concentrations in Namanve surface water/streams from the upper middle and lower reaches.
iii. Industrial development is not the most significant driver of surface water contamination in Namanve.

1.5 Significance of the Study

The study evaluated the state of the surface water quality in NIBP, which is drained by streams that supply water for residential purposes, washing of automobiles, irrigating flower farms, and cultivating yams and sugar cane by the nearby communities. The Namanve wetland also drains into inner Murchison Bay which is a major water abstraction point for water supplies in Kampala, Mukono and Wakiso (Akurut et al., 2017). Thus, the results of such assessment might be of paramount importance to all parties involved in water resources' management. The study reveals the magnitude of the water contamination risk from industrial wastes and effluents which may help in designing and/ or realigning waste management procedures to reduce such risk. These results ought to help the National Environment Management monitoring teams to assess industrialists' compliance with the environmental management regulations (NEMA, 1995) governing waste and effluent discharge into the environment (water bodies). The study results may also provide guidance on industrial parks establishment and environmental carrying capacity limits from the spatial extent changes over time, such that provisions for relocation are catered for prior to commissioning. Results on drivers of water contamination can help to establish the public health risk awareness among communities living around industrial parks. This may inform policy on environmental quality and management awareness campaigns to reduce exposure to health risks associated with use of contaminated water. This study is an addition to a body of knowledge on water quality monitoring that extends beyond physical properties to include heavy metal concentrations.

1.6 Scope of the Study

This study was conducted in NIBP which straddles between Wakiso and Mukono districts' boarder. This geographical scope was informed by the fact that industrial park is situated on a wetland and former forest reserve with hydrologic connectivity to an important water body – Lake Victoria

(Kiggundu et al., 2018). Besides, the area is surrounded by peri-urban informal settlements which rely on the local surface water resources for their livelihoods. In terms of content scope, the study involved assessment of the physicochemical characteristics and heavy metal concentrations in the surface water around the Namanve Industrial Park and the changes in industrial development. In addition, the study profiled awareness of water contamination drivers among the community members in the study area. Spatial data for assessing extent of industrial developments were for the period between 2014, 2018, and 2022. This formed baselined data for prediction of change by 2026 and 2030. This is because previous studies indicate that industrial developments have been taking place rapidly thus these time intervals would capture such short to mid-term spatial changes. For water quality and heavy metal and drivers of contamination assessments, primary data were collected during the months of August-September 2023.

1.7 Conceptual Framework of the Study

In this research, the conceptual framework (Figure 1.1) establishes connections between industrial development and associated waste discharge into surface water bodies around NIBP and other water quality alteration drivers (independent variable) and thus affecting surface water quality (dependent variable). It is envisaged that industrial development in terms of industrial buildings, ground excavations, spatial changes over space and time which changes can be captured from remotely sensed data and assessed through Land Use and Land Cover classification. These changes coupled with industrial effluent, sewerage, municipal waste, agricultural fields waste, mining site waste, storm/flood run-off and sedimentation alter surface water physicochemical parameters (e.g., pH, EC, TP, COD and BOD) increase heavy metal (Pb, Cr, Zn, Ni and Cd) concentrations beyond permissible limits. Further, communities, being the immediate user-community of the water resources have developed knowledge of major drivers/contributors to water quality deterioration, which be beneficial for informing science and can be used as a basis for remediation measures.

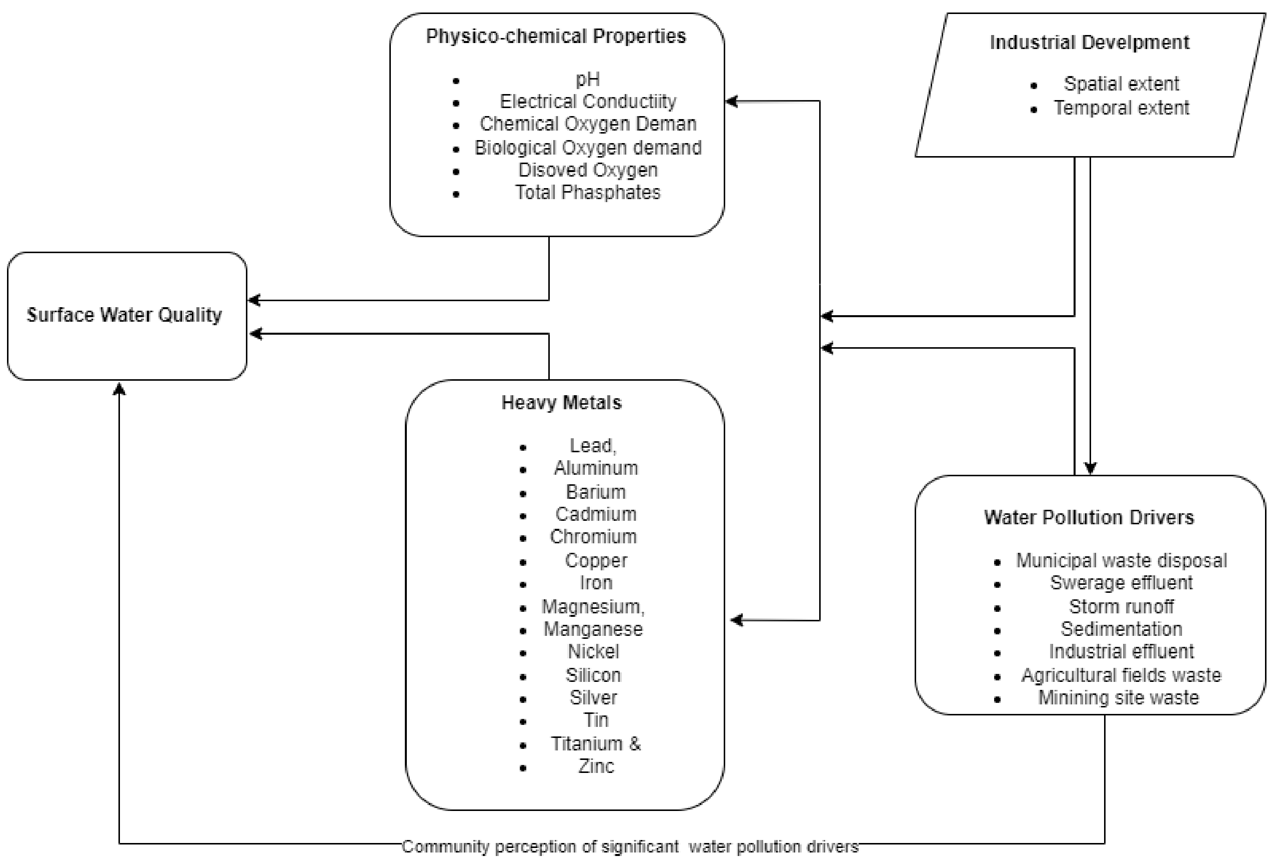


Figure 1.1: Adopted Conceptual Framework for the Study

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of scholarly works on industrial land use development vis-à-vis other land uses and cover (land use/cover change) and how such they affect water physiochemical properties and concertation of heavy metals. The chapter also includes a review of literature on water quality deterioration divers including industrial development.

2.2 Spatial Extent of Industrial Development and Land Use/Cover Changes

Rapid population growth globally increases demand for food, water, and land for settlement and industrial development to enable transformation environmental resource into better forms. According to Hassan and Nazem (2016), the dynamics of population growth that are associated with it, lead to changes in how the land and its resources are used. As land for agriculture becomes transformed by urbanization into built areas, wetlands within the vicinity become hosts on industrial hubs due to their lower value for commercial building development (Wasswa et al., 2019). Further, natural water courses become diverted and/ or drained to provide space for such developments whilst new areas are opened up for agriculture mostly forests, woodlands and grasslands because their high productivity (Sizo et al., 2015). Environmental quality has deteriorated as a result of globalization and rapid industrial expansion, which calls for a better knowledge of the connections between pollution, the environment and public health (Orubu & Omotor, 2011). With global efforts aimed at achieving faster economic growth, industrialization is inevitable causing land use/cover change leading to environmental degradation of versed forms including pollution (Meng & Dong, 2019). Mao et al. (2018) found that land quota system in Jiangyin and Shude in China allocated more land for industrial development to encourage economic growth of the urban fringes which host agricultural land, wetlands, and forests. Industrial developments destroy wetlands which would support degradation of organic pollutants and nutrients from domestic sewage and agricultural run-off, but also to remove metals from domestic, agricultural and industrial wastewater (Wang et al., 2022).

Uganda shares an industrial development agenda similar to that of other developing nations and although there are quite a number of bottlenecks, there has been steady transformation registered over the years (Buda & Ricz, 2023). The country's industrial base was laid back in the late 1980s while the state largely controlled much of the sector's activities. In the early 1990s, the main focus was economic recovery and stabilization under the nation resistance movement government with Jinja being the main industrial hub in the country (NDP, 2013). The later years saw a shift to an independent, integrated and self-sustaining economy supported by various policy frameworks such as the National Industrial policy that focuses on value addition, employment and competitiveness; the Buy Uganda Build Uganda (BUBU) that seeks to promote local production and consumption; and National Development plans (~IV) (MoICT, 2014).

The country's renewed resounding of the vision 2040 that envisions a transformed economy to a modern and advanced one bases its efforts on the industrialization drive (National Plannning Authority, 2020). There is no doubt that these motives have contributed to land use transformation especially in the specific areas which were designated for industrial hub developments. The goal of this study was to evaluate the spatial breadth of industrial development over the past decade in the Namanve Industrial hub, model changes for the next decade, and analyze the effects on surface water quality.

2.3 Surface Water Characteristics

2.3.1 Surface Water Resources

Surface water represents all water bodies present on the earth's surface, ranging from miniature ponds to vast oceans and everything in between (Kılıç, 2020). Water in streams, rivers, creeks, lakes, ponds, wetlands and reservoirs is generally referred to as blue water comprising of both freshwater and saltwater (Gabiri et al., 2020). These water resources are an integral part of the hydrological cycle and central in maintaining ecological systems functioning, human livelihoods and economic development (Edwards et al., 2015). Rainfall is the primary source of surface water, which is made up of both surface run-off and groundwater (Rani & Sreekesh, 2019). Population growth and growing industrialization are placing surface water under unreasonably high stress (Ministry of Water & Environment Water, 2019). The ideal option for extraction and wastewater discharge is surface water sources because of how convenient they are to obtain. Wastewater, which includes a variety of microorganisms, heavy metals, nutrients, radionuclides, pharmaceuticals, and personal care products, seeps into surface water resources, causing irreparable harm to aquatic ecosystems and to people who depend on such systems for ecosystem goods and services (Edokpayi et al., 2017). The amount of available water is decreased by these pollutants. Groundwater and surface water contamination is thought to be mostly caused by landfill leachate (Tyagi et al., 2020). An expanding variety of anthropogenic substances are contaminating surface waters, leading to the presence of complex pollutant mixes that might permanently harm aquatic ecosystems (Saravanan et al., 2021). Many of the factors that continue to have negative impact on these water resources such as water abstraction, accelerated erosion, and industrial expansion are essentially human-activities related (Chen et al., 2022).

2.3.2 Physicochemical Properties of Surface Water

Water quality is composed of physical, chemical, and biological constituents. pH, electrical conductivity, chemical oxygen demand and biological oxygen demand are just a few of the surface water's physicochemical characteristics. pH is a measurement of a solution's acid balance and is calculated as the negative of the logarithm to base-10 of the hydrogen ion concentration (Singh et al., 2017). During the day, when algae are consuming carbon dioxide for photosynthesis, pH in water with high algal concentrations can rise to as high as 10. An indicator of an ions' capacity to transmit an electric current in a solution is called electrical conductivity (EC). This capability is influenced by the temperature, total ion concentration, and ion presence. According Omara et al. (2019), chemical oxygen demand (COD) is the quantity of oxygen needed to totally oxidize organic matter in waste water and convert it to carbon dioxide and water. A characteristic of water quality in surface waters that is frequently measured is the Biochemical Oxygen Demand (BOD). It is the quantity of dissolved oxygen (measured in milligrams) required by living things to decompose organic materials in a sample of water (Akurut et al., 2017).

The physical, chemical, and biological constituents of surface water can be altered by discharge of untreated discharge such as industrial effluents. The most immediate alterations from such sources occur in pH, EC, and temperature. Praveena et al. (2022) reported higher pH values in surface water containing high alkaline or acidic effluents from textile industries. Similarly, EC is almost universally elevated in waters receiving industrial waste. Sekabira et al. (2010) found that EC levels in rivers near industrial areas in Kampala were significantly higher than in upstream, non-industrialized sections, indicating a high load of dissolved solids from manufacturing processes. Thermal pollution is also a concern, as many industrial processes use water for cooling and discharge it at elevated temperatures, which reduces the solubility of dissolved oxygen and adds stress to aquatic life (Muwanga & Barifaijo, 2006). The effect on the amounts of dissolved oxygen is arguably the most significant. Fish and other aerobic aquatic species depend on DO to survive. Chronically low DO levels, frequently dropping below the 5 mg/L threshold needed by the majority of aquatic wildlife, have been reported in research conducted throughout Uganda, especially in relation to the Nakivubo Channel, which drains Kampala's main industrial sector into Lake Victoria (Omara et al., 2019). The high BOD and COD of the effluents are directly related to this oxygen depletion. Industries including paper mills, food processing facilities, and breweries generate a lot of organic waste, which microorganisms use up a lot of dissolved oxygen as they break it down (Danquah et al., 2011). Additionally, one of the main causes of turbidity and total suspended solids (TSS) is industrial activity. Particulate matter concentrations are frequently high in wastewater from mining, textile dyeing, and the production of building materials. These suspended particles make the water murkier, which prevents sunlight from penetrating and prevents algae and aquatic plants from photosynthesising. The entire ecosystem is impacted by this disturbance at the base of the food chain (Beuel et al., 2016). Additionally, high TSS can damage aquatic creatures' gill systems and suffocate fish breeding areas.

Another significant area of concern is the loading of nutrients, primarily nitrates and phosphates, into surface waters. While also associated with agricultural and municipal waste, industrial sources are significant contributors. Industries involved in fertilizer production, food processing, and detergent manufacturing often discharge effluents rich in these compounds. Kiyemba et al. (2023) highlighted that the nutrient enrichment from industrial and urban sources is a key driver of eutrophication in the Inner Murchison Bay of Lake Victoria. This over-enrichment promotes excessive algal blooms, which, upon dying and decomposing, further deplete dissolved oxygen, leading to anoxic conditions, fish kills, and a severe loss of biodiversity

2.3.3 Heavy Metals

A metal is a generic term referring to a substance that is malleable, with high electrical conductivity and can easily lose electrons thereby forming cations (Sujaul et al., 2013). These substances can be found almost everywhere in the environment in varying concentrations (Khlifi & Hamza-Chaffai, 2010). On the other hand, heavy metals are precisely defined as metallic compounds and metalloids with a specific density larger than 5 g/cm^3 and are harmful to ecosystems at higher quantities (Jaishankar et al., 2014). When their concentration is low, they are important in supporting organisms' metabolism but when they are in high concentrations beyond the threshold, they become toxic (Nagajyoti et al., 2010).

Lead, chromium, copper, zinc, cadmium, and nickel are some of the most prevalent heavy metals in wastewater. According to (Jaishankar et al., 2014). , these metals pose significant dangers to human health. Heavy metals are mostly released into the environment as a result of human activities such as mining, sewage discharge, pest control chemicals, industrial waste disposal into water streams, and soil erosion. Lead is a naturally occurring, blueish grey substance that is typically found as a mineral combined with other elements, such as sulphur or oxygen, and ranges from 10 to 30 mg kg1 in the earth's crust (Shah, 2017). It is a metal that belongs to group IV and period 6 of the periodic table with an atomic number of 82, atomic mass 207.2, density 11.4 g cm3, melting point 327.4C, and boiling point 1725C (Shah, 2017). The typical mean Pb content for surface soils around the world ranges from 10 to 67 mg kg-1 and averages 32 mg kg-1. After Fe, Cu, Al, and Zn, lead comes in fifth place in the industrial production of metals (Sobahan, Mir & Zakaria., 2013). The common types of Pb that are released into the soil, groundwater, and surface waters are ionic lead, Pb (II), lead oxides and hydroxides, and lead metal oxyanion complexes. In the soil matrix, lead sulfide (PbS) is the most stable solid form and occurs under reducing conditions when higher levels of sulfide are present. Tetramethyl lead, a volatile organo-lead, can be produced in anaerobic conditions as a result of microbial alkylation (Singh et al., 2021).

The properties of chromium, a first-row d-block transition metal belonging to group VIB in the periodic table, include its atomic number 24, mass 52, density 7.19 g cm^3, melting temperature 1875 °C, and boiling point 2665 °C (Nazir et al., 2015). One of the less frequent elements, it only appears in nature as compounds rather than in its elemental form. The mineral chromite, $FeCr_2O_4$, which contains chromium, is mined as a major ore product. Major causes of Cr pollution include garbage disposal and discharges from electroplating procedures (Chen et al., 2018). The most prevalent type of Cr at contaminated locations is chromium (VI). With the right pH and redox circumstances, chromium can also exist in the +III oxidation state. Under anaerobic circumstances, which are frequently present in deeper groundwater, soil organic matter, S2 and Fe2+ ions can convert chromium (VI) to chromium (III) (Chen et al., 2018). When the pH is low, chrome (III), which is likewise more mobile, dominates. Below pH 5, chromium (III) adsorbs to clays and oxide minerals, while above pH 5, Cr (OH)3(s) forms and causes low solubility, which reduces chromium (III) mobility (Chen et al., 2018). Chromium mobility is influenced by the sorption properties of the soil, such as its iron oxide, clay, and organic matter contents. Surface run-off can carry chromium to surface waters in both its soluble and precipitated forms. Chromium compounds, both soluble and unabsorbable, can seep into groundwater from the soil. As soil pH rises, Cr (VI) leachability also rises.

According to Azimi et al. (2017), zinc is a transition metal that belongs to period 4, group IIB, with an atomic mass of 65.4, atomic number 30, melting point 419.5°C, and boiling temperature 906°C. Zinc is a naturally occurring element in soil (approximately 70 mg kg1 in crustal rocks), but anthropogenic additions are causing an unnatural rise in Zn concentrations. The majority of Zn is added during industrial processes such mining, coal and waste combustion, and steel processing (Mebane et al., 2020). Certain Zn amounts can be found in a variety of foods. Drinking water also contains a small quantity of zinc, which may increase if it is kept in metal tanks (Chen et al., 2018). The amounts of Zn in drinking water that can be harmful to your health may come from industrial sources or toxic waste sites. Because of the continued increase in Zn production worldwide, the environment is becoming increasingly contaminated by the metal (Chen et al., 2018). Fish that reside in Zn-contaminated streams can collect Zn in their bodies (Mebane et al., 2020).

With an atomic weight of 112.4, an atomic number of 48, a melting point of 320.9°C, and a boiling point of 765°C, cadmium is at the end of the second row of transition elements (Azimi et al., 2017). Cd is not recognized to have any vital biological functions and is one of the major three heavy metal toxins, along with Hg and Pb. Cd appears as the divalent Cd (II) ion in its compounds. In the periodic table, cadmium is located immediately below zinc, which is a crucial micronutrient for both plants and animals. This may contribute to Cd's toxicity in part because Cd's replacement of Zn, an essential trace element, may result in the disruption of metabolic functions. Ni/Cd batteries, which are rechargeable or secondary power sources with high output, long life, little maintenance, and great tolerance to physical and electrical stress, are where Cd is most commonly used. Detergents, phosphate fertilizers, refined petroleum products, and other items all include cadmium as an impurity. The unavoidable consequence of lead and possibly zinc refining is cadmium. The application of agricultural inputs such as fertilizers, pesticides, and biosolids (sewage sludge), the disposal of industrial wastes, or the deposition of atmospheric contaminants increases the total concentration of Cd in soils, and the bioavailability of this Cd determines whether significant plant Cd uptake occurs (Chen et al., 2018).

Nickel is a transition element with an atomic weight of 58.69 and an atomic number of 28. The metal can be found in low pH areas as the nickelous ion, Ni (II). It precipitates as stable nickelous hydroxide, Ni (OH) 2, in neutral to mildly alkaline solutions. This precipitate easily dissolves in acidic solutions, forming Ni (III), and in highly alkaline environments, it produces the water-soluble nickelite ion, HNiO2 (Chen et al., 2018). Nickel exists in the stable nickel-nickel oxide, Ni3O4, which is soluble in acid solutions, in highly oxidizing and alkaline circumstances. In alkaline solutions, other nickel oxides, such as nickelic oxide (Ni2O3) and nickel peroxide (NiO2), are unstable and break down by releasing oxygen (Mahfooz et al., 2019). However, in acidic environments, these substances disintegrate to form Ni2+. Only extremely small amounts of the element nickel are present in the environment, and while it is necessary in small doses, exceeding the maximum tolerated quantity can be hazardous. Ni is most frequently used as a component of steel and other metal goods. The main contributors to nickel pollution in soil include the metal plating industry, the burning of fossil fuels, nickel mining, and nickel electroplating. Nickel is discharged into the atmosphere by power plants and waste incinerators, where it undergoes precipitation processes before settling to the ground. Nickel typically takes a long time to leave the air (Chen et al., 2018).

Nickel can cause various kinds of cancer on different sites within the bodies of animals; mainly of those that live near refineries (Nagajyoti et al., 2010). Nickel can also end up in surface water when it is a part of wastewater streams. The larger part of all Ni compounds that are released to the environment will adsorb to sediment or soil particles and become immobile as a result. In acidic soils, however, Ni becomes more mobile and often leaches down to the adjacent groundwater. Microorganisms can also suffer from growth decline due to the presence of Ni, but they usually develop resistance to Ni after a while. Nickel is not known to accumulate in plants or animals and as a result, Ni has not been found to biomagnify up the food chain (Nagajyoti et al., 2010). For animals, Ni is an essential foodstuff in small amounts. The primary source of mercury is the sulphide ore cinnabar.

Lead is transformed into a variety of basic salts, such as Pb (OH) $_2$2PbCO$_3$, which was previously the most popular white paint pigment (Nagajyoti et al., 2010). A tiny element called zinc is crucial for maintaining human health. Birth malformations can result from zinc deficiency (Nagajyoti et al., 2010). Zn is present in substantial quantities in wastewater from manufacturing operations, which causes water pollution. Because metals are difficult to dissolve, heavy metal pollution in soil has received a lot of attention (Marrugo-Negrete et al., 2017). It is well known that urbanization and industrialization play a vital role in heavy metal contamination of water and soil. According to (El-Amier et al., 2017), they end up in the soil via leaching into it or by being carried into water streams by run-off from cities and industrial areas. The presence of heavy metals in soil is a product of the parent rock's natural weathering and pedogenic processes, and their amounts in natural resources are highly reliant on the parent material's geochemical makeup (Nagajyoti et al., 2010). Heavy metals can be found in industrial waste, cement, paint, scrap metal, oil and gas production waste, and maintenance waste, among other things. They have the potential to have a detrimental effect on soil and water quality (Sekabira; et al., 2010).

Heavy metals developed as a result of metals' bioaccumulation in lipids and blood from animals (Osibanjo & Adie, 2007). The cumulative release of untreated effluents into the surface and water bodies of the environment has a substantial effect on the water quality. Although animal dung is good for crops, Bello and Oyedemi (2017) found that it can substantially degrade water quality since it includes trace quantities of heavy metals. According to a study conducted in Kampala (Bakyayita et al., 2019), there are heavy metal concentrations in shallow groundwater. While individual studies have looked into short-term fluctuation to capture potential bulk discharges, past research on heavy metals in urban wastewater systems has centred on long-term (weekly or seasonal) variability (Dietler et al., 2019). Their buildup in the soil has historically been significant since they are persistent, non-biodegradable, and hazardous to biota if they exceed threshold values (Chandrasekaran et al., 2015). The combustion of fossil fuels (coal and oil) produces gases and aerosols that have a substantial detrimental effect on both human and environmental health by exposing individuals to heavy metals on particles like fly ash (Peters et al., 2005).

Pollution of the natural environment by heavy metals is a worldwide concern because these elements are indestructible, containing toxic effects on living organisms, particularly when they exceed threshold values (Chandrasekaran et al., 2015). Over the years, ecological problems have worsened in a symmetrical manner, with inefficient management typically to blame for the severe depletion of natural resources and the rise in illnesses transmitted through water (Osibanjo & Adie, 2007). In the study by Bakyayita et al. (2019), the majority of human-caused sources of heavy metals include the burning of fossil fuels, sewage sludge, and waste dumpsite leachates, as well as the use of automobile tires, brake pads, bearings, and radiators, as well as the mining, smelting, and processing industries. The main recipient of these metals is the soil, and their fate depends on the chemical and physical properties of the metal or its compounds, the type of soil, and its organic matter content (Nagajyoti et al., 2010). The high concentrations of heavy metals are attributed to wastes and industrial effluent deposited in the environment, which may result from machine wear, smith workshop waste, motor maintenance facilities, surface run-off, and industrial chemicals (Shah, 2017). Adsorption onto soil particles and soil organic matter causes retention of trace metals and reduces their transmission to the soil water, but when the soil is overladen or when the soil pH is lowered, trace metals' vertical mobility increases and contamination of groundwater occurs through the soil solution (Bakyayita et al., 2019).

Many approaches, such as the contamination factor, modified contamination degree, comprehensive potential ecological risk index, Nemerow comprehensive index, interpolation, principal component analysis, etc., have been used to assess the pollution and ecological risk in areas influenced by urbanization and industrialization (Chen et al., 2022). These techniques can be used to evaluate the distribution patterns of heavy metal pollution and ecological risk in the soils and water streams. Researchers investigated the levels of heavy metals in environmental samples using sophisticated instruments like Atomic Absorption Spectrometry, which shows that the environment has substantial amounts of heavy metals (Chandrasekaran et al., 2015).

The earth's crust naturally contains heavy metals, and living things require trace amounts of metals including cobalt, copper, iron, manganese, and zinc. However, living things may suffer if critical metal levels are too high (Ezekoye, 2013). Since they cannot be broken down or eliminated, they tend to build up in the soil and sediment. Mercury, a non-essential metal, presents a serious risk to people. Mercury is converted by bacteria in the water to methyl mercury, which adheres firmly to fish tissue and can induce mercury poisoning when consumed (Azimi et al., 2017). High levels of mercury can harm a person's nervous system, leading to health issues like memory loss, slurred speech, a lack of coordination, a loss of sensation in the fingers and toes, problems with reproduction, coma, and even death (Ezekoye, 2013).

The refractory nature of these heavy metals makes their leaching into ground water a significant source of worry. Significant amounts of heavy metals are present in soil. If these metals are mobilized to the extent that they reach the ground and surface water, they present an environmental or health hazard (Kaur et al., 2021). According to Benhamiche et al. (2016), industrial effluents and metal activities both contribute to lead (Pb2+) contamination, which is classified as "anthropogenic-toxic" pollution. Lead may also be transported via storm water run-off from upstream, air deposition, and exhaust fumes (Chen et al., 2022). Additionally, abandoned mining operations may be where the lead comes from. According to Benhamiche et al. (2016), Pb^{2+} and Zn^{2+} were probably produced by anthropogenic pollution and mineral rock erosion. The existence of significant industrial and domestic discharges accounts for the presence of heavy metals in soils and water (Kayode et al., 2018).

2.4 Drivers of Stream Water Quality Deterioration

2.4.1 Natural and Anthropogenic Sources of Water Pollution

According to the USDA (2003), water pollution is the term used to describe physical, chemical, and biological changes in water quality that have a negative impact on the environment, living things, and the suitability of the water for human use. Water is essential for life on earth, but once it undergoes alterations in its physical, chemical and biological properties beyond certain limits, it becomes unfit for various uses (Tyagi et al., 2020; Chen et al., 2022). At this point, water is considered polluted or contaminated and it can have serious effects to the very life that it supports. Polluted water can negatively affect fauna, flora and humans and the whole ecosystem processes and the services they provide. In many poor nations, such as those in East Africa, access to clean water is the single biggest factor that negatively affects people's overall health and life expectancy. The impurities that cause deterioration of water quality may be organic constituents like Algae blooms, and/ or inorganic like heavy metal concentrations (Ismail & Moustafa, 2016). Thus, the degradation of water quality is caused by both natural and anthropogenic activities that enhance the production and discharge of such contaminants into water systems (Tadesse et al., 2018). Although water contaminants can have their origins from natural sources, these are usually of a low magnitude compared to contamination arising from human actions.

Depending on water sources, contamination may be caused by faecal slug, sewerage effluent, municipal waste, agricultural fields waste, industrial waste, mining site waste, car washing bay waste, medical waste, storm floods and run-off, sedimentation, among other (Tadesse et al., 2018). These call for waste management practices but due to sluggish legislation and limited public awareness of the dangers of these wastes, there is continued mishandling of these wastes when makes them to reach water courses and fragile ecosystems like wetlands.

2.4.2 Impact of Industrial Development on Surface Water Pollution

Poor water quality is largely caused by the expansion of industrial activities to support the world economy. According to UNEP and The Pacific Institute (2010), businesses are to blame for the annual global discharge of 300–400 million tons of toxic sludge, heavy metals, solvents, and other trash into waterways. The quantity of water available for dilution and dispersion of contaminants, whether they have a natural or manmade source, is closely related to a number of water quality problems (Fayiga et al., 2018). Urbanization is probably going to have an impact on watersheds and catchment areas because of increased human encroachment through industrialization and agriculture (Zhu et al., 2018). Industrialization has an immense impact on the water quality in locations where factories are established (Soltani-Gerdefaramarzi et al., 2021). In as much as it has very many positive contributions, industrialization brings about negative effects such as surface water pollution resulting destruction of the delicate balance of bio-system accelerating the extinction of rare animals with associate public health challenges.

The impact of pollution on health in developing countries is very significant and much higher than in the developed world due to high populations and poor development such as improper management of solid waste by industrial establishments (Edokpayi et al., 2017). Despite being the least urbanized continent, Africa is known to have one of the greatest rates of urbanization with associated environmental degradation implications (UNEP, 2004). Africa experienced the highest decline in water quality relative to acceptability measures between the 1980s and 2000s, displaying a 30% decrease, according to a study by (Chen et al., 2022).

Industries in Uganda release wastewater into the environment, which causes pollution. Inventories conducted between 1990 and 2006 reveal that the majority of industries lack appropriate procedures for getting rid of waste chemicals and expired chemicals (Omara et al., 2019). There are two types of water pollution: point sources and nonpoint sources. More people contribute to the issue and are typically impacted, which makes management more challenging. Water for home and industrial uses is significantly provided by rivers. However, land use dynamics continue to have an adverse impact on river catchments, which has a negative impact on the health of rivers (Ayivor & Gordon, 2012).

2.5 Literature Summary and Gaps

The reviewed literature reveals that industrialization is associated with expansion of man-made infrastructure that interferes with ecosystems such as wetlands, forests, grasslands and river systems. Previous studies reveal that water quality is affected by several factors that act by either adding and/or altering chemicals, metals and organic constituents in the water. But little is known about how industrial development (in terms of physical expansion), the rise in waste production that results from it, and how these factors affect the physicochemical characteristics and heavy metal content in surface water sources. These studies also associate industrial wastes generally with water physicochemical properties and heavy metals in majorly natural streams, paying little attention to artificially drainage course which also form water supply sources for brick making, farm irrigation, flower farming and car washing.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

In this chapter, description of the study area, research methods and procedure followed to collect data analyse and present the study findings. It specifically details the location of the study area, key geographical aspects, research design and approach, sampling procedures, data sources, collection and analysis methods.

3.2 Description of the Study Area

3.2.1 Location

Namanve Industrial and Business Park is located on the border between Wakiso and Mukono districts on the Northern shores of Lake Victoria in Central Uganda (Figure 3.1). Longitudinally, it stretches between 32° 40′20″ - 32° 42′ 57″E and latitudinally between 0° 19′32″ - 0° 21′59″N. It is located approximately 15 km East of Kampala city. The NIBP covers approximately 890 hectares of land with the biggest stretch lying in Mukono district. It is subdivided into four blocks; ABC in the South and one block in the North (Omara et al., 2019). The analysis of the spatial extent of Industrial development over time was applied on an area stretching up 1.5 km from the four industrial blocks which was considered a zone of influence of industrial development.

3.2.2 Relief

The average altitude of Namanve Industrial Park area is 1,143 metres above sea level. It lies within the Lake Victoria drainage basin which is tilted in North-south direction (Akurut et al., 2017). The gently tilted relief here is interrupted by hilltop and broad valleys with an average difference of 180 metres, thus from the north to the south, relief varies considerably. Numerous hills dot the landscape, including Kole to the west, Buto on the northern edge, and Namiryango to the east, Kirinya and Bukasa hill to the south (Angiro et al., 2020). The southern section forms a deposition area from sediments brought down during flood storms.

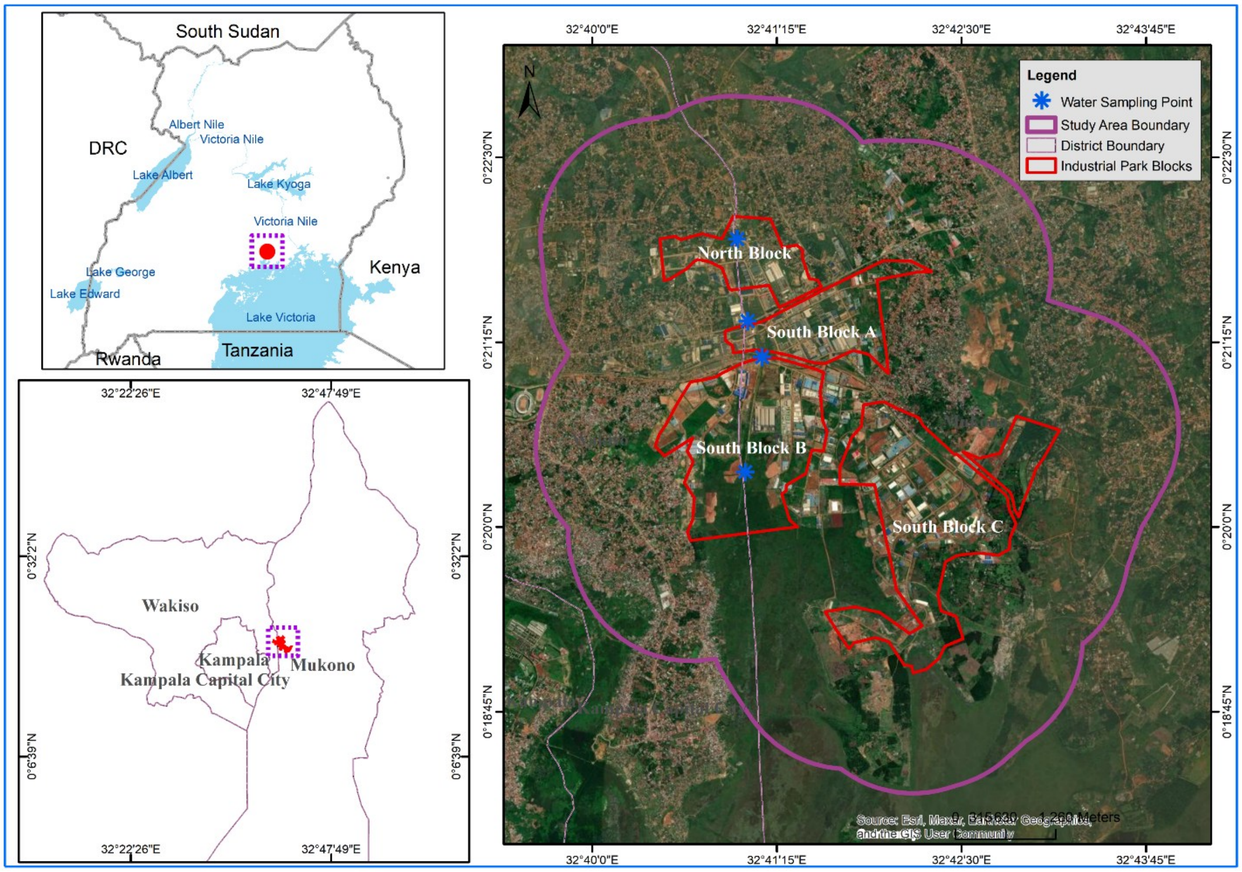


Figure 3.1: Location of study sites in Namanve Industrial and Business Park

3.2.3 Drainage

The area is mainly drained by Namanve river which flows from the North to the south as a result of the Lake Victoria drainage basin topography. It also hosts a wetland system concentrated on the southern section and connects to Murchison Bay and near Port bell via Kayobe wetland (Angiro et al., 2020). There are several drainage channels created around the industrial park for flood management but these tend to have concentration of water for a considerable period making them to appear like permanent streams (Kiggundu et al., 2018).

3.2.4 Climate

The Namanve industrial area falls under the Lake Victoria Basin Climate Zone (National Environment Management Authority (National Environment Management Authority (NEMA), 2008) which experiences an equatorial climate with minimal variations of rainfall and temperature occurring during the year. The climatic conditions here are influenced by latitudinal location near the equator and proximity to Lake Victoria. Annual rainfall amounts here vary between 1750mm and 2000mm (NEMA Uganda, 2010). Temperature ranges between 16˚C and 28˚C on average and the highest temperatures being registered in the Month of January whilst the lowest temperatures are registered in August. The area is also under the influence of westerly and north-westerly winds with diurnal dynamics brought about by the influence of Lake Victoria.

3.2.5 Land Use

The study area is mainly assigned to industrial development as the dominant land use type. However, the Namanve Central Forest Reserve is situated on the eastern bound of the industrial park (possibly for environmental easement) alongside other land uses in the neighbouring communities. These include settlement, small scale agriculture, hot culture and brick making in wetlands in the area. The major industries housed include Century Bottling Company, Tube and steal works, Roofings Uganda Ltd, Rwenzori, and several warehouses.

3.3 Research Design and Approach

This study was intended to collect spatial data for analysis of industrial development extent from sentinel satellite imagery, archived within the European Space Agency geoportal; water quality data from water samples tested in the field and in the laboratory; and socioeconomic data from households in the villages surrounding NIBP. The study was operationalized under a cross-sectional study design, following mixed quantitative and qualitative techniques. The design and approaches here enables a rich collection of diverse data on the key variables of the study. Industrial development extent and water quality parameters data were purely numeric thus calling for use of parametric statistical techniques while data of perception of water quality deterioration drivers were measured on both nominal and interval scales. This was obtained using a household survey administered to randomly selected house hold representatives (120 participants, taking 40 in every location close to the four sectors of industrial park).

3.4 Sampling and Sample size

3.4.1 Water Sampling

The study area was segmented into four sectors that is, N, N.E, NW, SW and SE Blocks. Spatial modelling of Industrial development between 2014 and 2022 and the projection of future scenarios considered a quadrant covering the original industrial complex allotted blocks but also covered the neighbouring villages within a buffer of 1km (area of influence). The area is drained by Namanve stream and other human created drainage channels. Therefore, water samples were collected from both the main Namanve stream and artificial water channels cascading through the industrial park. Sampling was purposively done in four locations corresponding to the pristine/upstream section (before flow through the industrial complex), midstream section (within the industrial complex) and in the lower influences (after flowing through the industrial facilities). This sampling put into consideration the hydrological gradient and major industrial structures' location thus increasing chances to capture water quality variations in relation to industrial development but also that arising from other factors. From the four locations, water sampling was conducted in four occasions during the months of June-July (dry season) and August-September 2023.

In total, 32 samples were drawn from across the industrial park for early morning (07:00 - 09:00) and evening (17:00 -18:00), peak industrial discharge periods to ensure accurate assessment of environmental impact (Kayiwa et al., 2022, Keith, 2017). These would reveal the timing for surface water contamination. Three water samples were drawn and placed in amber bottles (plastic) for each sampling occasion (season). Sub-samples for field analysis were separated from those that required laboratory procedures. These were kept in a temperature (at 4°C) box for onward transportation to the laboratory (Makerere University – College of Natural Sciences Lab) for analysis of physiochemical properties and heavy metals.

3.4.2 Household Participants Sampling

Households were selected using systematic random sampling from updated village household lists provided by local leaders, ensuring proportional representation from each settlement. Initially the cells close to the four sectors of the Namanve industrial complex were identified purposively and then households in these were sampled using random sampling procedures. A total of 120 household participants formed the study sample (with 40 participants from each of Kazinga Main, Kiwanga-Lwanda, Namilyango-Kisenyi, and Namataba cells. These are the communities surrounding the four blocks of the industrial park. Socio-economic data was collected using a face-to-face semi-structured household questionnaire (Appendix I) containing both open- and close-ended questions on water quality perceptions and drivers of water quality deterioration. The survey targeted households in four main settlements that is Kazinga Main, Kiwanga-Lwanda, Namilyango-Kisenyi, and Namataba; selected for their close proximity to the Namanve Industrial and Business Park and potential exposure to its environmental impacts. The sample size was determined based on a combination of statistical and practical considerations. Using Cochran's formula for sample size estimation for finite populations at a 95% confidence level and ±9% margin of error, a minimum of 110 households was required. This calculation assumed a 50% proportion for key variables to maximise variability and ensure representativeness (Nogbou & Nalugala, 2022). To account for potential non-response and incomplete questionnaires, the sample was increased to 120 households. This size was also deemed feasible given the time, resources, and field logistics available, while still providing adequate coverage across the four settlements.

3.5 Data Collection Methods and Instruments

3.5.1 Industrial Development in Namanve between 2014, 2018, 2022, and Predicting Future scenarios (2026 – 2030)

3.5.1.1 Satellite Data Downloading and Pre-Processing

The high-resolution multispectral satellite imagery targeted for analysis of the spatial extent of industrial developments were sourced from google earth archived images via the google earth pro desktop computer program. This data was preferred for use in this study due to it higher resolution (15*15cm) thus increased precision in discriminating surface features depending on their spectral reflectance signatures making it appropriate for land use/cover mapping (Alejandro & Aguilera, 2020). The images were from 2014 (base year) to 2022 taking an interval of four years to show the evolution of industrial developments and other landscape changes in the NIBP. Google earth pro provides access to high resolution data from commercial satellites like which are mosaicked to form a continuous surface (Turyahabwe et al., 2020). The program also allows access for historical satellite imagery of a place via the time-slider tool on its dashboard. Future industrial expansion scenarios were assessed for the next 8 years. This time was considered long enough for perceivable landscape transformations to be evident easily captured by space-based technologies. The collected data underwent preprocessing, processing and post-processing procedures using ArcGIS and Quantum Geographical Information Systems (GIS) spatial analysis tools. Preprocessing involved georeferencing (since downloaded google earth images come without geographical reference data) and clipping to derive data ready for industrial development extent analysis via land use/cover classification. The area of interest for spatial data clipping was delineated from the Local Area of Impact (LAI) around the four industrial blocks. A 1.5-kilometer buffer was created around the industrial blocks in ArGIS 10.8.2 using proximity analysis tool. A ring was created around each block but after, the boundaries were dissolved to unsplit the individual blocks polygons to have a single common boundary that was used in clipping the satellite images.

3.5.1.2 Satellite Data Processing

Google earth image processing involved use of user manipulative classification procedures (supervised classification) to group image pixels into different land use (to represent industrial development) and cover classes (Sánchez-Espinosa & Schröder, 2019). Targeted classes included industrial development (industrial buildings, ware houses, roads, settlements and other built-up infrastructure around NIBP – extending to 1.5 km buffer), wetland (areas covered with water and or hydrophytes), farmland (fields growing with crops, harvested or cleared for planting) and vegetation (including planted trees, woodlands, bushlands, grassland and tree plantation) these we grouped to clearly separate industrial land use from vegetative cover which is considered. The classes were merged and modified for the classification themes buy the National Biomass survey (National Forestry Authority, 2009). During field reconnaissance between 30 Ground truthing GPS points per class were collected and later incorporated to create a training data set for the supervised classification algorithms.

3.5.1.3 Satellite Data Post-Processing and Land Use /Land Cover Change Prediction

Post processing stage involved extraction of land use/cover areal statistics, change detection analysis and accuracy assessment using producer, user, overall accuracy and Kappa co-efficient (see formulae in equation in 1, 2, 3). GIS software provides functionalities to determine the area of the classification output. The land area is computed from the pixel size and count. From the classification outputs, computation of transitions across classes can also be analysed (Alawamy et al., 2020). Transition analysis enables comparisons of the spatial extent of LULC classes for different years to detect positive and or negative changes and the final conversion to/from class. Change detection in this study involved computation of transitions between 2014 and 2022 and the 2022-2030. Kappa statistics determine the degree to which the classification output reflect the actual classes on the area being represented (Rwanga & Ndambuki, 2017). At the post-processing stage, prediction modelling was also conducted from the final classification results. Future industrial development scenarios for 2026 and 2030 were assessed basing on land use/cover classification outputs for 2014 and 2022 as input data.

Producer accuracy = $\frac{\text{Correctly classified pixels in a class}}{\text{Total reference pixels for the class}} \times 100$ ....Equation (1)

User accuracy = $\frac{\text{Correctly classified pixels in a class}}{\text{Total classified pixels in that class}} \times 100$ ....Equation (2)

Kappa accuracy = $\frac{\text{Observed} - \text{Expected}}{1 - \text{Expected}}$ ....Equation (3)

3.5.2 Physicochemical Properties and Heavy Metal Concentration in Surface Water Sources around Namanve Industrial and Business Park

3.5.2.1 Physicochemical properties of surface water

The physicochemical water quality parameters targeted for this study included Total Phosphates, COD, BOD, pH, DO, and EC. These were considered because they are indicators of critical water quality with public health implications thus targeted for analysis in this study (Bhateria & Jain, 2016). Testing of pH, TDS, and EC were conducted right from the field whilst COD, BOD, DO, and Total Phosphates were tested from the Laboratory. Standard physicochemical analysis procedures (Rosenberg & Feminella, 2003) were followed for these tasks. pH, TDS, and EC were tested using a multiparameter portable pH/EC/TDS meter (HI9813-61) which comes with three separate probes for measuring the aforementioned parameters and the results are displayed on the device digital screen simultaneously. pH is unitless, EC were recorded in μScm^{-1} and TDS in mg/L. For COD that requires a strong chemical oxidant, potassium dichromate with such potential was used and the results recorded in mg/L. The procedure involved; use of 4 M H_2SO_4 to clean digestion tubes and caps, adding 2 ml of potassium dichromate solution into 2 ml of the water sample in the digestion tube, adding 2 ml of H_2SO_4/Ag_2SO_4 into the tube to form a layer of acid beneath the digestion solution, closing the cap tightly and swirling for a number of times to create mixture while keeping the tubes in a horizontal position. The tubes were then placed in an already heated oven with temperatures of 150°C for two hours after which the concentration was left to settle until the next day during which a spectrophotometer (DR 6000) was used measure and record COD. BOD which estimates water pollution from the oxygen utilised in nitrogenous compounds, inorganic matter and organic carbon removal from water was measured using conventional incubation method (according to Association of Official Analytical Chemists (AOAC), 2002). The procedure involved taking 50 ml sample of the solution, placing it in a 500 ml capacity bottle and filling it with dilution water to the mark. Organic free filtered air was then allowed into the bottle to permit water saturation and initial DO was estimated. One ml of phosphate buffers was then added into the saturated water solution to make a complete mixture. Determined samples of the solution were then added into separate BOD bottles and filled with dilution water to the mark, tightly covering the bottles and allowing for a five days incubation period at 20ºC. After the incubation, DO was established and then BOD was estimated using the formula (Equation 4);

$$BOD = \frac{(D1-D2)*500}{P} \quad \text{.......... Equation 4}$$

Where D1 represents initial dissolved oxygen during preparation, D2 represents dissolved oxygen after five days incubation P represents the quantity of the used sample, while 500 represents the capacity of the used BOD bottle.

Total Phosphates is measured in mg/l and were obtained by converting organically combined phosphorous to orthophosphate using a wet oxidation method to remove phosphorous. The steps involved started with taking a water sample of a specified volume, adding H_2SO_4, M, digestion reagent (1 ml, 0.04, and 5 ml respectively). After thorough mixing, 25 ml of the standard phosphate concentration and an equal amount of distilled water (blank) were prepared. The two were then heated at 120ºC for half an hour and later placement under room temperature. This was followed by adding and mixing 15ml of ammonium molybdate, 5 ml of potassium antimonyl tartrate, and 50 ml of 5 N H_2SO_4. Then, ascorbic acid of 1ml amount was added per sample and mixed vigorously and letting the solution to settle for 20 minutes. Using a spectrometer and at a wave length of 880 nm, the concentration was determined and the results were multiplied by the dilution factor to determine Total Phosphates.

3.5.2.2 Heavy Metal Concentration in Surface Water

Heavy metals including lead, chromium, nickel, Zinc and cadmium concentration in surface water were measured using a spectrophotometer (GF-AAS). The instrument houses an auto-sampler, a high-speed Deuterium, self-reversal for correcting the background noise. For each of the heavy metals, standard solutions at five separate absorbance and concentrations were measured and readied. Each specific heavy metal had a separate linear calibration curve aligned to the concentration ranges together with regression coefficients. Adsorption was measured for each of the heavy metals, segregated into separate AAS. Average concentrations were obtained from three occasions of repeated measurement. The calibration curves reveal concentration of heavy metals in surface water (Sekabira; et al., 2010). Cd Ni, Pb, Zn and Cr were analysed wavelength (λ) 228.8, 232.0, 283.3 and 357.9 nm respectively.

3.6 Data Analysis

3.6.1 Spatial Extent of Industrial Developments in Namanve between 2014, 2018, 2022, and 2030

3.6.1.1 Extent of Industrial Development between 2014, 2018, and 2022

Spatial data analysis involved discriminant analysis of the industrial development land use type's extent vis-a-vis cover and other non-built-up environment land uses. First, the land area statistics (in hectares) were computed from the classified images. In each LULC class, the pixel count was multiplied by the pixel size (area) and divided by the hectares' unit factor to obtain land area. The results were tabulated in excel followed by computation of percentages and changes over time by subtracting previous from current respective class area values. These were compared for the time intervals and the significance of the changes in extent were analysed using r^2 (Calvo de Anta et al., 2020).

3.6.1.2 Predicting Future Industrial Development between 2022 and 2030

Future industrial development scenarios for 2026 and 2030 were based on land use/cover classification outputs for 2014 and 2022. The analysis was undertaken in GIS software version 2.18.24 using the Modules for Land Use Change Simulations (MOLUSCE) plugin embedded within the afore mentioned version of QGIS (NextGIS & Asia Air Survey, 2014). The tool (MOLUSCE) houses algorithms for land use change simulation, correlation evaluation, transition potential modelling and provides for validation using kappa statistics. It bases the simulation process on initial (base year) and current land use data (factor raster) to predict future scenarios whose number is user-defined (NextGIS & Asia Air Survey, 2014). In this study, land use/cover raster for 2014 and 2022 were used to detect the change for two future scenarios (2026 & 2030).

3.6.2 Determining the Physicochemical Properties and Heavy Metal Concentration in Surface Water Around Namanve Industrial and Business Park

Data on physicochemical characteristics and heavy metals obtained from water sampling underwent statistical summarization using exploratory statistics and thereafter, influential analysis proceeded. A two-way Analysis of Variance (ANOVA) (Shaw & Mitchell-Olds, 1993) was applied where, physicochemical water quality properties and heavy metals (continuous dependent variable) were compared for location in relation to industrial infrastructure segments and water/stream channel location and also in terms of timing of sampling (categorical independent variables). ANOVA establishes the effect of a categorical independent variable on a continuous variable like water quality parameters that this study targeted (Klasson, 2019). ANOVA results would reveal the effect of industrial pollution on the quality of surface water in Namanve Industrial Park and the results would further be compared against the maximum permissible limits by NEMA and WHO for possible public health implications.

3.6.2 Drivers of Surface Water Contamination in Namanve Industrial and Business Park

Questionnaire survey data was cleaned for art-facts and encoded using Microsoft excels (version 2016) and later exported to IBM SPSS Version 26 for further analysis. Statistical analysis then commenced to generate frequencies/counts and percentages at preliminary stages. At inferential level, binomial statistical test was applied on this data. Binomial statistical analysis is a non-parametric procedure that tests the probability of the observed frequencies in a group of binary variables measured on a nominal scale such as yes and no using a test proportion (Rawlings & Dickey, 1998). The null hypothesis in the test states that observed frequency in a group of a binary variable is above (e.g. 60%) the test proportion such that it flagged if it is true. The test was aimed at establishing the significant drivers across the four sectors (North block, south blocks B1, B2 & B3) of the Industrial Park. The test proportion in this study was set at 90% which implies that if respondents were subjected to selection of a list of perceived significant drivers of surface water contamination, 90% (the large proportion) would select "Yes" and only 10% would indicate "No" if Socio-economic data statistical analyses were conducted in SPSS Version 26 and the outputs from these were displayed in graphic and tubular formats. The level of significance for statistical tests was 0.05 (95% confidence interval). Qualitative socioeconomic data from key informants was organized around main study themes on drivers of water contamination and used to reinforce results from quantitative analysis.

3.7 Ethical Considerations

A number of ethical issues arise in the research process which must be anticipated a prior and apt measures sought to address them. In this research, the major ethical issues relate to antiplagiarism, voluntary participation, informed consent by participants, participants anonymity/confidentiality and honesty in reporting of the results. First, materials used in the preparation of the thesis which were outsourced are dully referenced and sources acknowledged by way of full referencing. The participants were required to consent verbally to participate in the study. They also participated voluntarily. The intentions of the data collection and the study were disclosed to the respondents before being asked to agree or disagree to participate. The participants were also be assured of non-disclosure of their identity during the reporting of information gathered from them. Data gathered were secured and used for the intended academic purposes solely.

CHAPTER FOUR: RESULTS

4.1. The Spatial Extent of Industrial Development in Namanve Industrial and Business Park

4.1.1 Industrial Land Use/Cover Changes between 2014 – 2022

Results from industrial land use and cover assessment for 2014, 2018 and 2022 (Table 4.1 and Figures 4.1) indicate that in 2014, industrial developments covered approximately 35%, and was the dominant land use type. This was followed by small scale farmland (31%) and vegetation covered 20%. The least spatial coverage was under wetland cover type (13%). In 2018, industrial development remained the dominant land use with a spatial coverage of 38% flowed by small scale farmland (33%). Vegetation and wetland cover on the other hand had the least spatial extent in 2018 with 15% and 14% of the land being occupies by the two respectively. Industrial development (47%) and farmland (30%) remained the dominant cover types while vegetation (9%) and wetland cover (13%) remained under the least land extent. In terms of net change, industrial land use largely experienced positive changes in spatial extent through the study period that is 3% between 2014 and 2018 and 9% between 2018 and 2022. Agriculture land use also experienced positive changes (2%) between 2014 and 2018 but later registered a decline (-2) between 2018 and 2022. Vegetation and wetland cover on the other hand experienced negative changes throughout the study period and by 2022, approximately 6% of vegetation and 2% of wetland area had been lost. The results show that industrial development and farmlands in NIBP have been expanding over time but the rate of expansion is higher than that of farmlands which later started registered declines towards 2022. The R^2 results indicate that the LULC model explains ~87% of the variation in industrial development changes. This suggests strong confidence in the trend identified (a 9% increase). The model explains nearly 90% of the changes in wetland area. Even though the area change is minor (-21 units, 0%), the model reliably captures the trend while 63% of the changes in vegetation and the same percentage for changes in farmland are explained by the model.

Table 4.1: Industrial Land Use/Cover Changes between 2014 – 2022

Land use	**2014**		**2018**		**Change 2016 – 2022**		**2022**		**Change 2018 - 2022**		**R^2**
Class	Area (ha)	%	Area (ha)	%	AreaΔ	%Δ	Area (ha)	%	AreaΔ	%Δ	
Industrial development	1789	35	1949	38	160	3	2394	47	445	9	0.8666
Wetland	676	13	698	14	22	0	676	13	-21	0	0.8972
Vegetation	1040	20	781	15	-259	-5	478	9	-304	-6	0.6339
Farmland	1599	31	1676	33	77	2	1556	30	-120	-2	0.6252
Total	5104	100	5104	100			5104	100			

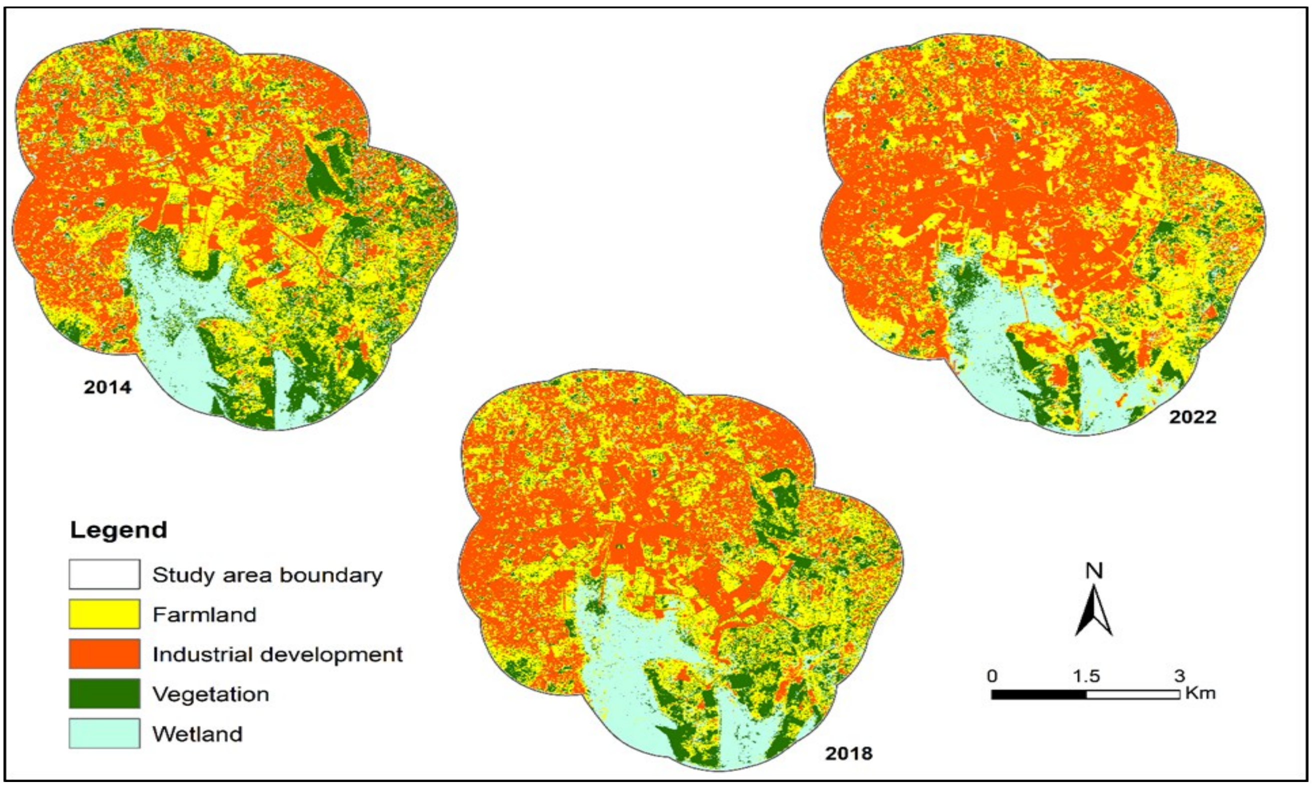
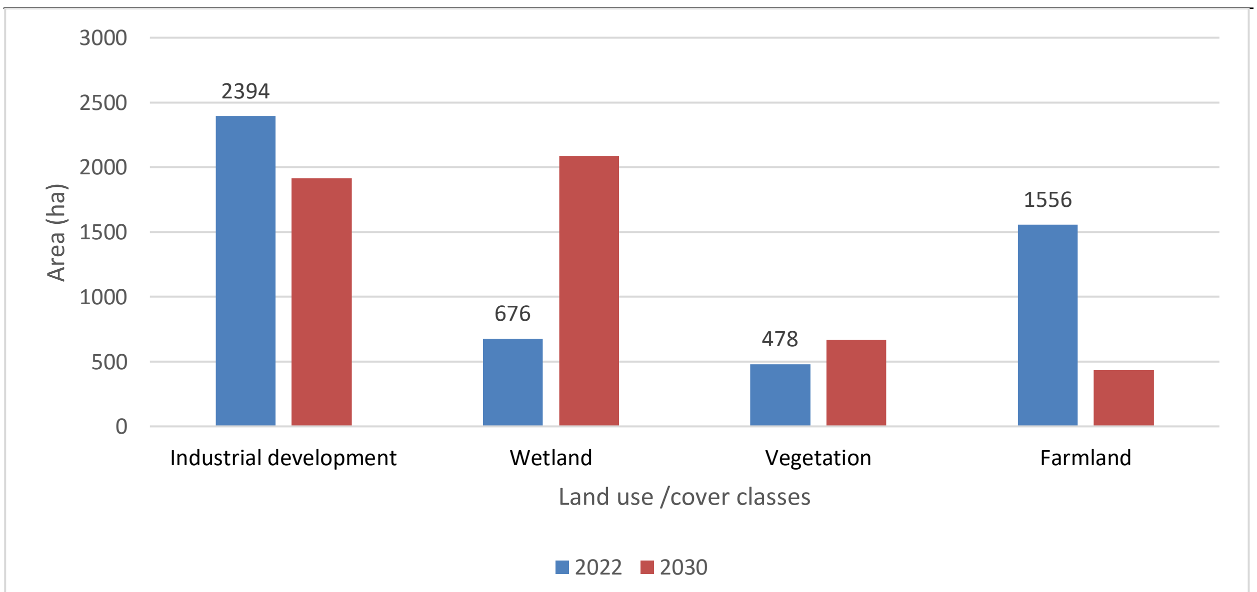


Figure 4.1: Industrial Land Use/Cover Extent in 2014, 2018, and 2022

For the prediction period 2022 and 2030 (Table 4.2, Figure 4.2), farmland and industrial areas are predicted to decrease by 21% and 10% respectively. This implies that farmland will drastically reduce more than industrial land use. On the other hand, vegetation cover and wetland extend will undergo expansion with wetland extent taking the biggest portion (28%) of the expansion. Thus, wetland will be the dominant cover industrial development, although will decline but it will remain the dominant land use in terms of spatial extent. The results imply that although farmland and industrial establishments have been expanding in the past decade, the trend is bound to change in favour of wetland and to a small extent tree cover. The negative change in industrial development will result in a positive change in wetland cover but at the expense of farmland.

Table 4.2: Industrial land use/cover changes between 2022 – 2030

Land use	**2022**		**2030**		**Change 2022 – 2030**	
Class	Area (ha)	%	Area (ha)	%	Area(ha)	%Δ
Industrial development	2394	47	1914	38	-480	-10
Wetland	676	13	2087	41	1411	28
Vegetation	478	9	668	13	190	4
Farmland	1556	30	435	9	-1121	-21
Total	5104	100	5104	100		



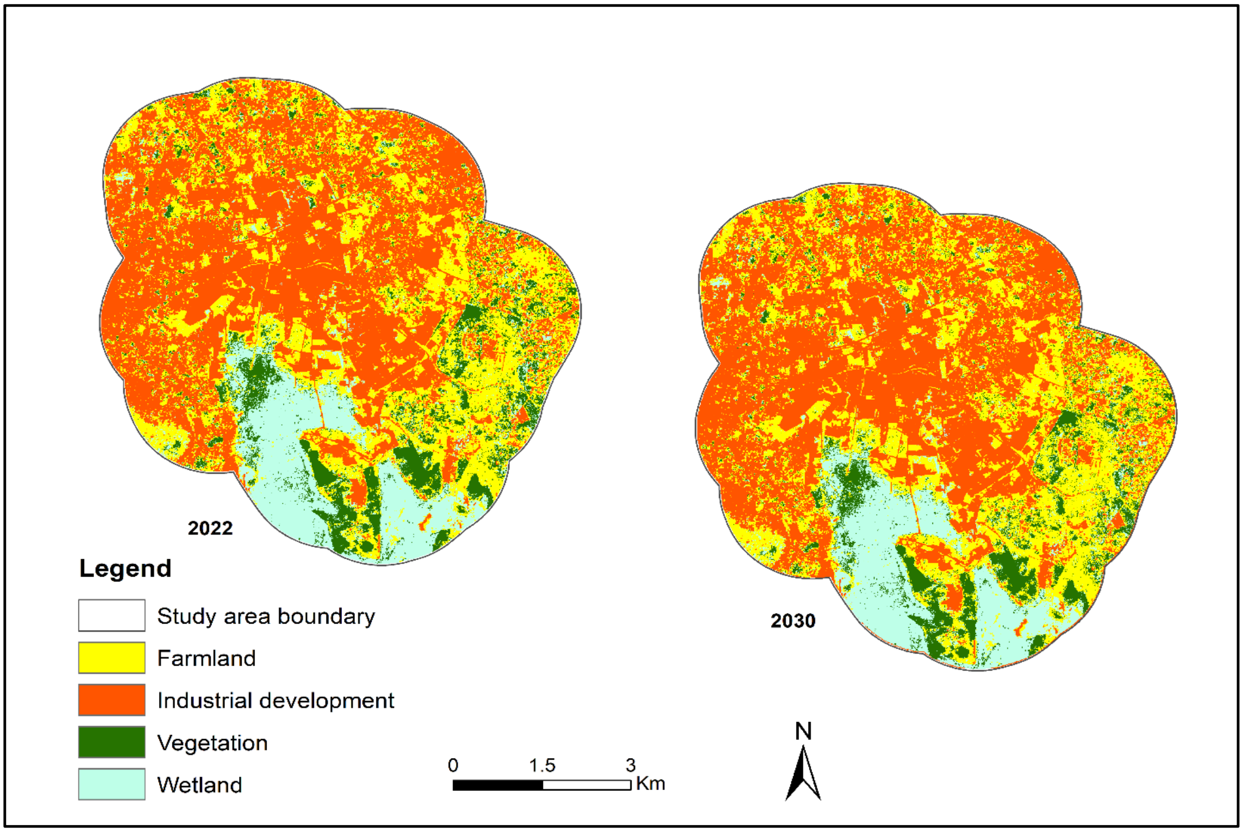


Figure 4.2: Industrial Land Use/Cover Change between 2022 and 2030

For the LULC changes over the years; 2014, 2018, 202 and 2030, the results show a linear trendline (R^2 0.8566) which reveals a strong linear relationship between industrial development and time with ~ 86% of the variance explained. the trend shows a strong, increasing pattern between 2014 and 2022 but with a decrease between 2022 and 2030. Despite a decrease between 2022 and 2030, the overall historical trend is statistically significant (Figure 4:3). Industrial development and agriculture land uses will register a declining trend between 2022 and 2030 while wetland and vegetation will reverse their trends and register an increase. This means that agriculture and industrial development will decline giving way to vegetation cover and wetland expansion.

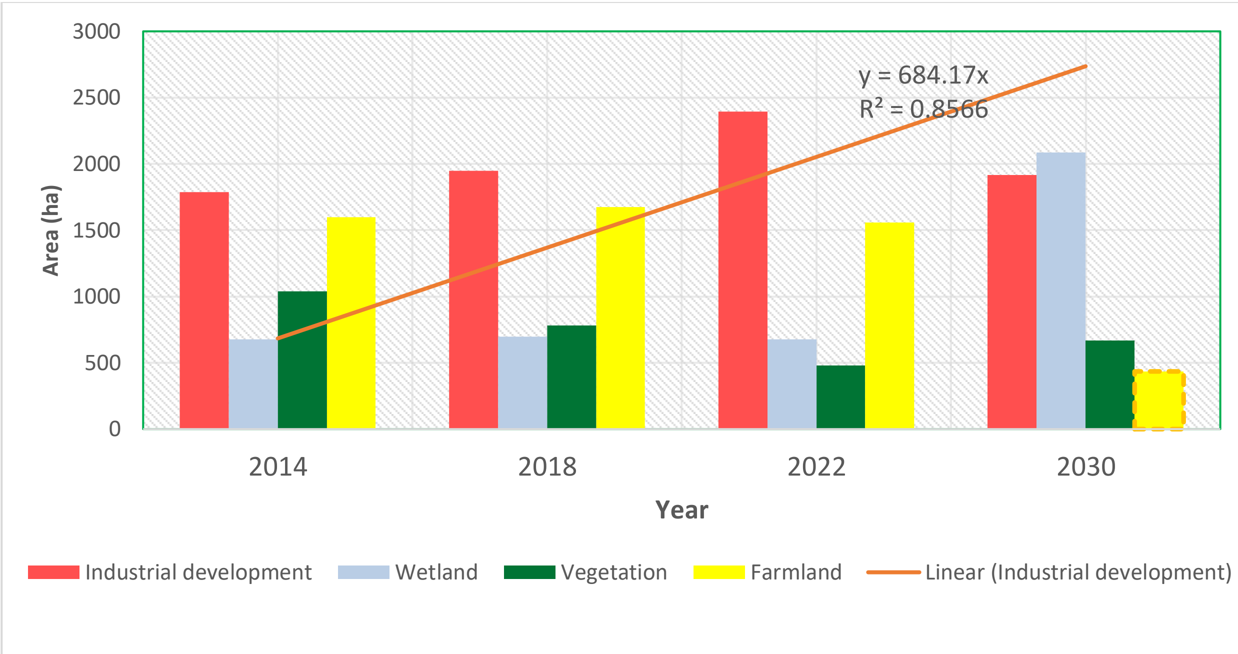


Figure 4.3: Trend of industrial development and LULC changes in Namanve Industrial and Business Park

4.1.2 Industrial land use/cover transitions between 2014 – 2022 and 2022 – 2030

Change detection results for 2014 and 2022 (Figure 4.4) show that the biggest transitions in terms of gain in land area occurred mainly in farmland and industrial development land uses while in vegetation cover and wetland areas experienced losses to farmland and industrial development. The biggest transition from industrial development went to farming while the biggest gains in industrial development transitioned from farmland and wetland. The results show that land transitions occurred mainly between industrial development and farmland. For the prediction period (2022 - 2030), farmland will lose much of its spatial extent to vegetation (Figure 4.5).

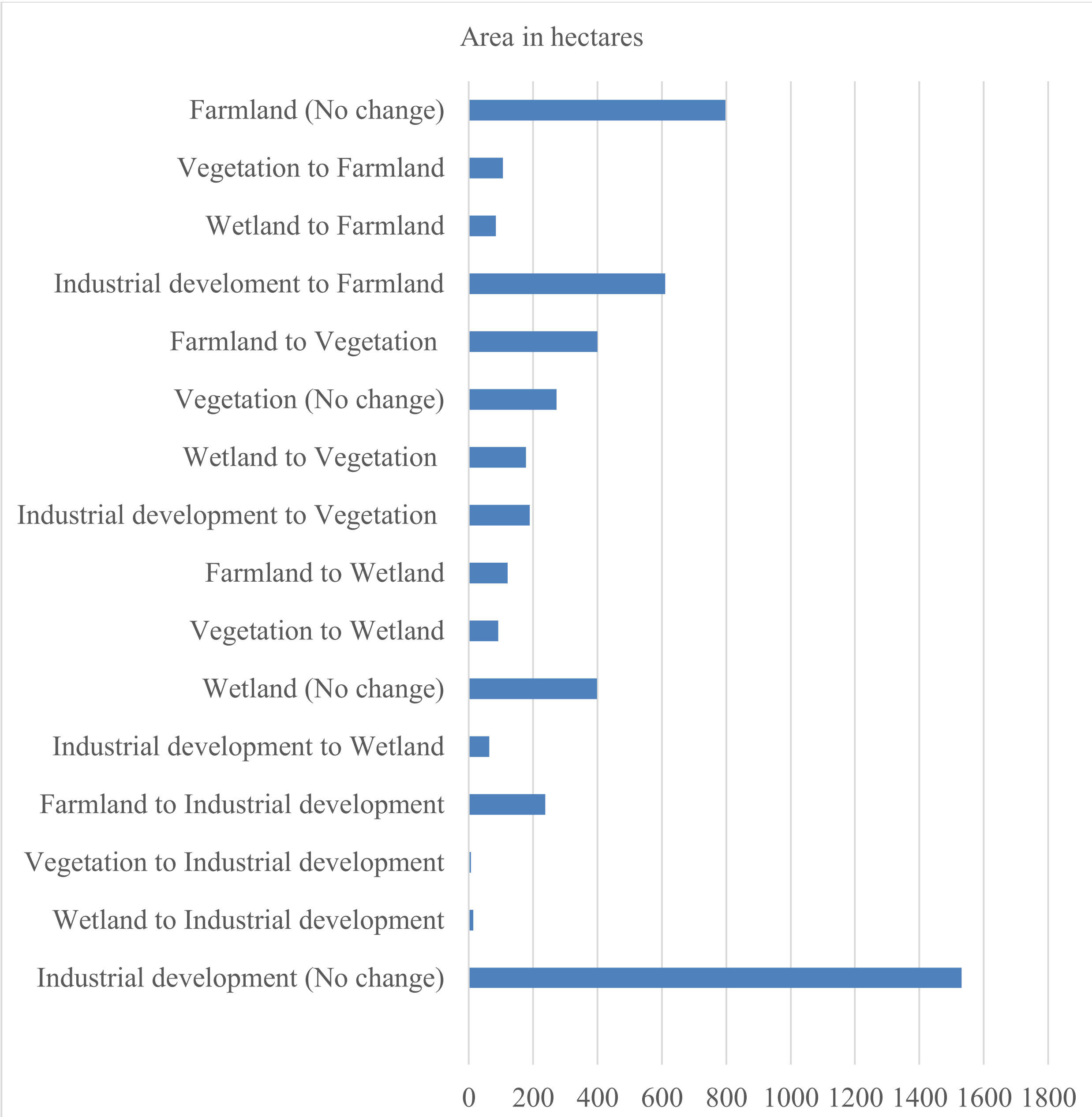


Figure 4.4: Land Use/Cover Transitions between 2014 and 2022

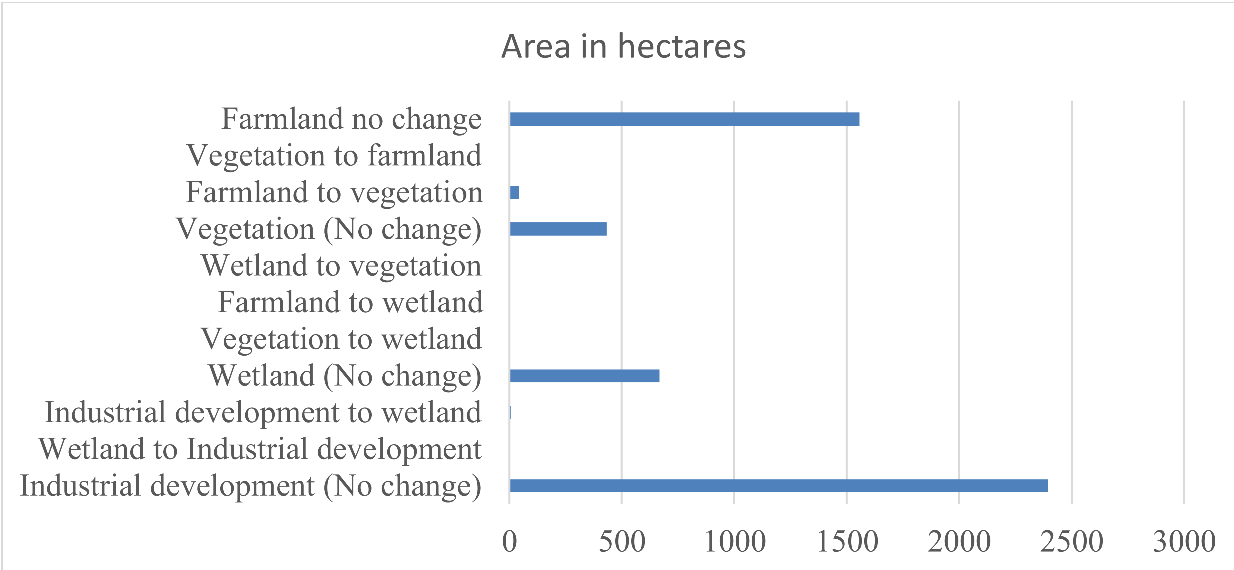


Figure 4.5: Land use/cover transitions between 2022 and 2030

4.2 The physicochemical properties and heavy metal concentration in surface water around Namanve Industrial and Business Park

This study involved physicochemical and heavy metal loads assessment in the surface water body passing through the NIBP. Water samples were collected from four locations corresponding to the four industrial blocks. The samples were analysed in the laboratory and the descriptive statistics (mean and standard deviation) of the parameters tested are presented in Table 4.3. The results reveal that the surface water turbidity levels were highest (318±21) on the South Block C, which is on the outlet of the industrial area. This means that as the stream runs through the industrial area, it gets contaminated by impurities that makes it turbid. Conversely, pH levels increased from the inlet (7.6±0.29) and climaxed in the mid-stream (8.1±0.14) before reducing as the water reached the outlet (7.4±0.2). Electrical conductivity was higher at the inlet than in the midstream but increased again in the centre of the industrial area before reducing at the exit point. Bicarbonates concentration was high on south block B just like Total Nitrogen. The values for the later are above the maximum permissible limits for effluent discharge in Uganda but also according to WHO standards. The test also showed that total suspended solids increased in the Namanve stream as one move from the upstream to the downstream. In terms of heavy metal concentration, nickel, zinc, cadmium and lead the Namanve were higher around the midstream and around the south Block B and C which means these have their origins from industrial activities. Although the results show increased concentrations physicochemical properties and heavy metal loads, most of them are still within the National Standards.

The water quality results were also subjected to an inferential statistical test (Multivariant analysis of variance) to establish effect of sampling location, sampling season and the interaction of these two variables on water quality around the NIBP and the results are presented in Table 4.4. The results reveal that all the assessed physicochemical and heavy metal water properties in Namanve stream significantly ($p<0.001$) varied over the four industrial blocks with the exception of Nickel whose variation was not statistically significant over the area. The results mean that water contamination levels in the study area are different increasing as one move downstream. The effect sampling season and combined effect of sampling and location was insignificant ($p>0.001$) to account for variations in water quality apart from on only four parameters including fluorides, ammonium, chromium and zinc. This means that seasonal changes account for the variations in these water quality parameters.

Table 4.3: Mean values for Water Quality Properties by Site/Location around NIBP

S/N	Physicochemical properties	Upstream (North Block)	Midstream (South Block A)	Industrial Area (South Block B)	Outlet (South Block C)	WHO standards	NEMA effluent discharge standards
1	Turbidity (NTU)	54±3.9	49±2	164±3.44	318±21	5	300
2	pH (pH units)	7.6±0.29	8.1±0.14	6.3±0.2	7.4±0.2	6.5–8.5	6.0-8.0
3	Electrical conductivity (µS/cm)	271±16.8	249.7±4	452±2	385±3.12	-	
4	Total dissolved solids (mg/l)	194±2	173±2.3	318±5	265.67±	500	1200
5	Total suspended Solids (mg/l)	31±0.6	36±0.6	183±2.1	156±2	-	100
6	BOD (mg/L)	3±0.04	1.4±0.43	81.3±1.03	61±20.34	3	50
7	COD (mg/L)	4.12±0.8	8±0.5	5.56 ± 0.3	4.4±0.4	10	100
8	Total Phosphate-P(mg/L)	9±0.4	3.42±0.3	0.28±0.23	4±0.06	-	10
	Heavy metals	**Upstream**	**Midstream**	**Industrial Area**	**Outlet**	**-**	
9	Nickel (mg/L)	0.02±0	0.07±0.1	0.17±0.3	0.06±.1	0.07	**1.0**
10	Chromium (mg/L)	0.01±0	0.01±0	0.02±0	0.02±	0.05	1.0
11	Cadmium (mg/L)	0.02±0.01	0.02±0.02	0.05±0.02	0.1±0.15	0.003	0.1
12	Zinc (mg/L)	0.04± 0	0.03±0	0.24±0.18	0.05±0	-	
13	Lead (mg/L)	0.05±0.01	0.05±0	0.09±0.01	0.09±0.01	0.01	0.1

Table 4.4: Multivariant Analysis of Variance of Water Quality in NIBP

A: Site (effect)	Turbidity	pH	EC (µS)	TDS (mg/l)	TSS	BOD (mg/L)	COD (mg/L)	TP (mg/L)
Sum of Squares	429885	15.3	246090	120131	169589	44766	4661513	3.1
Mean Squares	143295	5.1	82030	40044	56530	14922	1553838	1.0
F-Ratio	1198.84	135	595	2132.5	22958.7	148	1E+05	57.7
P-Value	<2e-16 ***	3.567e-15 ***	<2e-16 ***	< 2e-16 ***	<2e-16 ***	1.343e-15 ***	< 2e-16 ***	4.063e-11 ***
B: Season								
Sum of Squares	62	0.01	128	43	5	245	96	0.03

Mean Squares	31	0.003	64	22	3	123	48	0.02
F-Ratio	0.3	0.07	0.4658	1.1	1.0182	1.2	3.09E+00	0.86
P-Value	0.8	0.94	0.6332	0.3	0.3763	0.3	0.06394	0.44
AB Interaction								
Sum of Squares	747	0.35	1007	246	9	647	275	0.09
Mean Squares	124	0.06	168	41	2	108	46	0.01
F-Ratio	1.0	1.55	1.2	2.2	0.6	1.1	2.96E+00	0.81
P-Value	0.4	0.21	0.3	0.1	0.7	0.4	0.02616 *	0.57

A: Site (effect)	**Nickel**	**Chromium**	**Cadmium**	**Zinc**	**Lead**
Sum of Squares	0.1	1E-04	0.03	0.3	0.02
Mean Squares	0.0	3E-05	0.01	0.1	0.01
F-Ratio	1.6	2E+29	1.87	28.1	92.64
P-Value	0.2	< 2.2e-16 ***	0.16	5.032e-08 ***	2.469e-13 ***
B: Season					
Sum of Squares	0.07374	6.00E-04	0.009727	0.049448	0.0001371
Mean Squares	0.036869	3.00E-04	0.0048634	0.024724	0.0000686
F-Ratio	1.5123	1.35E+30	0.787	7.5791	1.1512
P-Value	0.2407	< 2.2e-16 ***	0.4666	0.0028097 **	0.3331
AB Interaction					
Sum of Squares	0.23	2.00E-04	0.04	0.14	0.00024
Mean Squares	0.04	3.33E-05	0.01		
F-Ratio	1.58	1.50E+29	0.98	0.02	0.00004
P-Value	0.20	< 2.2e-16 ***	0.46	7.40	0.68

The overall model results are shown in Table 4.5. The results show that in general, both location and season independently account for water quality variations in Namanve Industrial and Business Park. This means that whereas the Namanve stream gets contaminated as is it passes through different sections of the industrial park, some of the contamination is accounted for by seasonal changes.

Table 4.5: Multiple analysis of variance for physicochemical water properties

	Df	**Pillai**	**approx F**	**num Df**	**den Df**	**Pr(>F)**
A: Sampling location/Site	2	2.9965	1242.16	28		< 2.2e-16 ***
B: Sampling season	2	1.4331	3.45	28		0.0009354 ***
A: B: Interactive Effect	4	2.8863	1.60	24	64	0.0138607 *
Residuals	18					

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

4.3 The perceived drivers of surface water contamination in NIBP

Socio-economic data on significant drivers of water contamination in Namanve Industrial Park. Interviews were conducted with household representatives from 8 villages clustered around the four industrial blocks. Respondents involved in the study were at an average age of 32 years. Sixty-five (65) percent of the respondents were from the villages on the Mukono side while the rest were from the Wakiso side of the Namanve Industrial and Business Park. 29.1%, 21.4%, 16.2% and 33.3% of the respondents were from communities neighbouring the North Block, South Block A, South Block B, and South Block C respectively. 68% of the respondents were male. These residents (49.6%) believe that industrial development in their area has increased over the last decade at a rate of between 8 to 10%. The main land use/ cover type before industrialization according to them was wetland (70.1%) followed by bushland and built-up area. Cropland (1.7%) and grassland (3.4%) covered the least land area.

Table 4.6 shows that the communities relied on different water sources for various needs which varied slightly around the four industrial blocks, however, tap water (49%) was the most common source of water for drinking (79%), bathing (61%), washing (61%) and cooking (51%) by majority of the communities (49%). Water for farm irrigation on the other hand, mainly came from streams (35%) followed by wetlands (32%) and wells (24%). The trend was the same across the four industrial blocks. The result show that communities around NIBP trust the water that is supplied by the national distribution agency; the National Water and Sewerage Corporation. It was also shows that the industrial park area is connected to important utility services including water. The results could also mean that the communities are aware of the contamination levels of other water sources thus reducing over reliance on them for cooking, bathing, washing and drinking. However, there are pockets of community members who rely on surface water sources like streams and wells for washing and cooking which are highly susceptible to contamination from various sources hence exposing such communities to public health risk.

Table 4.6: Water sources and their uses by communities in NIBP

Water Source	Cooking		Washing		Bathing		Drinking		Firm Irrigation		Total	
	N	%	N	%	N	%	N	%	N	%	N	%
Wells	25	14	19	11	19	11	10	7	44	24	117	14
Stream/river	12	7	14	8	14	8	4	3	65	35	109	13
Wetland	14	8	4	2	4	2	2	2	60	32	84	10
Borehole	26	14	28	17	28	17	11	8	7	4	100	12
Tap water	93	51	103	61	103	61	106	79	9	5	414	49
Protected spring	12	7	10	5	-	-	2	2	2	1	26	3
Drainage channel	2	1	-	-	-	-	-	-	-	-	2	0
Total	184	100	178	100	168	100	135	100	187	100	852	100

In terms of pollution levels of the water sources, the residents perceived tap water, borehole and protected streams to be the least polluted sources while drainage channels, wetlands and streams were rated as either highly polluted of extremely polluted Table 4.7. These results imply that surface water sources without any form of protection are the most contaminated. On the overall, the communities around Namanve industrial areas consider protected water sources to be less (34%) or moderately (18%) polluted while surface water sources are perceived as highly polluted (33%) or extremely polluted.

Table 4.7: Perceived water source pollution levels in NIBP

	Pollution Level Rating							
	Less polluted		Moderately polluted		Highly polluted		Extremely polluted	
Water Source	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
Wells	36	30.8	26	22.2	26	22.2	29	24.8
Stream/river	4	3.5	39	33.9	45	39.1	27	23.5
Wetland	10	8.5	10	8.5	71	60.7	26	22.2
Borehole	63	53.8	31	26.5	19	16.2	4	3.4
Tap water	84	71.8	9	7.7	24	20.5	0	0
Protected spring	74	63.2	25	21.4	16	13.7	2	1.7
Drainage channel	4	3.4	4	3.4	68	58.1	41	35
Total Responses	**275**	**34**	**144**	**18**	**269**	**33**	**129**	**16**

The results on the perceived significant drivers of surface water pollution are presented in Table 4.8. The results reveal that industrial waste disposal (25%) is perceived by communities across the four industrial Blocks as the most significant contributor to surface water pollution. This is followed by storm floods (17%), municipal waste disposal and car washing bay discharge (12%). In terms of spatial differences, this perception is highest among communities close to the South Block C (29%) followed by those around the North Block and then those near the Southern Blocks A and B. Storm floods are perceived as significant contributor to water contamination mainly by communities on the South Block C (33%) and the North Block (32%). The contribution of stream sedimentation to surface pollution is majorly perceived by communities in the North and South Blocks. The least surface water contamination sources include sand and clay extraction, stream sedimentation, followed by medical waste disposal, brick making, sewerage disposal and agricultural fields waste discharge.

Table 4.8: Perceived drivers of water contamination in NIBP (n=117)

Drivers of water contamination	North Block		South Block A		South Block B		South Block C		Overall	
	N	%	N	%	N	%	N	%	N	%
Storm floods	23	32	19	26	6	8	24	33	72	17
River/stream sedimentation	4	44		0	2	22	3	33	9	2
Industrial waste disposal	30	29	20	19	17	17	36	35	103	25
Agriculture fields waste	11	28	4	10	4	10	20	51	39	9
Sewerage disposal faecal slug	11	32	7	21	7	21	9	26	34	8
Municipal waste dumping	17	28	10	17	6	10	27	45	60	15
Brick making	5	19	11	42	2	8	8	31	26	6
Sand/clay extraction	2	25	2	25	1	13	3	38	8	2
Medical waste	2	14	5	36	3	21	4	29	14	3
Washing bay waste discharge	14	29	13	27	8	17	13	27	48	12

To establish whether the industrial development effluent is the most significant driver of surface water pollution in line with the third study hypothesis, the survey responses were subjected to a binomial statistical test using a test proportion of 90% implying the probability that 90% of the respondents would rate a given water contamination driver as significant at 0.05 alpha level. The results (Table 4.9) reveal that industrial waste effluent ($p \leq 0.001$) would have the highest probability of being rated as the most significant driver. This is followed by storm flood run-off ($p=0.001$), municipal waste disposal ($p=0.002$), car washing bay waste discharge ($p=0.006$), agricultural fields waste ($p=0.016$) sewerage disposal ($p=0.028$). Brick making would be indicated as driver but less significance to water contamination ($P=0.065$). Sand/clay extraction, river/stream sedimentation, and medical waste disposal would be rated as less significant ($p>0.005$) drivers of water pollution. The results here reveal that industrial development with associate waste disposal is the most significant surface water contamination source in the NIBP. However, the results show that there are other sources of surface water pollution in the study area that would still contribute to water quality deterioration irrespective of whether there were industries or not. These include storm run-off which is climate related, municipal waste and sewerage disposal given the fact that study area is located at the suburbs urbanized environments with relatively dense settlements engaged in domestic and sewerage waste production activities.

Table 4.9: Binomial statistical test of the significant drivers of water contamination in NIBP

Driver		Category	N	Observed Prop.	Test Prop.	Exact Sig. (1-tailed)
Storm floods	Group 1	Yes	72	1	0.9	.001
River/stream sedimentation	Group 1	Yes	9	1	0.9	.387
Industrial waste disposal	Group 1	Yes	103	1	0.9	.000
Agriculture fields waste	Group 1	Yes	39	1	0.9	.016
Sewerage disposal faecal slug	Group 1	Yes	34	1	0.9	.028
Municipal waste dumping	Group 1	Yes	60	1	0.9	.002
Brick making	Group 1	Yes	26	1	0.9	.065
Sand/clay extraction	Group 1	Yes	8	1	0.9	.531
Medical waste	Group 1	Yes	14	1	0.9	.167
Washing bay waste discharge	Group 1	Yes	48	1	0.9	.006

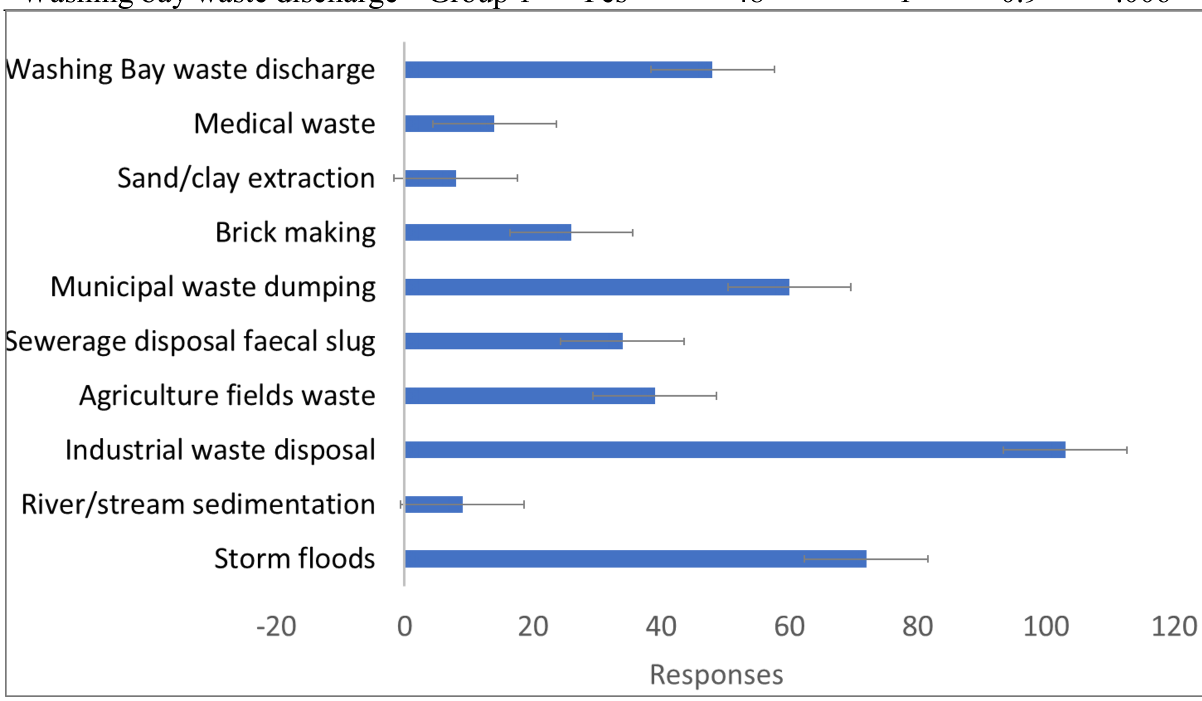


Figure 4.6: Overall perceived drivers of water contamination in NIBP

CHAPTER FIVE: DISCUSSION

5.1 Spatial and Temporal Extent of Industrial Development in Namanve Industrial and Business Park

The current analysis shows that during the period between 2014 to 2022; industrial development registered an upward trend within the Namanve Industrial and Business Park. This was in consonance with the general land use change and the geographical extension of industries that occurs elsewhere. The reported 8-10 % increase in industrial growth from 2014-2022 aligns with studies (Noreen et al., 2019), which points towards speedy industrial evolution and its environmental effects in developing areas. It has been observed that in every country where nation-building occurs, industrialization locates itself within designated areas, which, in most cases, transforms the land cover of the surrounding environments including natural ecosystems like grasslands and wetlands Bhattacharjee et al. (2021)'s study findings relate to this order of development process in which increase in economic activity spurs land use and cover changes. Abou-Taleb et al. (2020)'s study also show that rapid industrialization and urban development threaten the wetland ecosystems.

The current study results support those by Schug et al. (2020) who report that enhanced industrialization is accompanied by the increase and spread of population consequently leading to loss of natural cover. Further evidence is contained other studies (e.g., Xu et al., 2019; Zhang et al. 2019) which show that land cover and use type is affected negatively due to industrial development, especially wetlands and open water bodies. The current study established that the period between 2022 and 2030 will experience stagnation and later on decline in industrial development. This prediction appears to support of the concept that the fully occupied industrial zones are unable to be expanded anymore due to excessive control or a lack of space as explained by Anawar and Chowdhury (2020). Moreover, this stagnation is influenced by market forces since manufacturing activities may shift to relatively new and advanced areas with more competitive advantages (Fayiga et al., 2018), where the concentration of industries to a region causes environmental effects rendering settlement and industry unattractive within that region.

The finding that positive changes may occur in land cover types including wetland and vegetation after a decade of industrial proliferation are also supported by a number of other works as this study highlights. Simmonds et al. (2016) argues that vacated industrial sites are often replaced by grasslands and bushlands, which is an endogenous process of secondary succession. Such type of recovery processes has also been addressed by Anawar and Chowdhury (2020) who notes that the pressure of industrial activities on land can encourage slow recovery of the ecosystems, even if the recovery may cause changes in the wetland and open water cover by bushlands. The view that post-industrial be a possible way of natural cover types observed to be changing like this one in this study is supported by an observation in the USA among countries of the world. Ghosh and Das (2020) mention instances in which after-industrial land was colonized by vegetation markedly increasing biodiversity and ecosystem properties. Not only do such changes bring about modern societies, they may have deleterious impact on the wetlands and channel structures.

The results of this study are in agreement with the findings from studies on industrial development as well as the adverse effects this development has on nature. The projected decline in industrial activity and also the backtracking of the ecosystems is consistent with the trends highlighted in other studies, although such changes come at a cost especially in wetland and open water protection. This substantiates the fact that given the rapid industrialization that is likely to take effect going forward, good environmental practices will be paramount in ensuring that industrialization is not detrimental to the environmental components like wetlands, water bodies and vegetation cover.

5.2 Physicochemical Properties and Heavy Metal Concentrations in Surface Water around Namanve Industrial and Business Park

The results of the study showing pollution in the surface water sources, near Namanve Industrial and Business Park (NIBP) align with worldwide research on the environmental consequences of industrial development. The presence of physical and chemical contaminants as well as heavy metals was confirmed in the surface water bodies with the most elevated levels found close, to the central park region This trend matches the findings reported by Bashir and Praveen (2019) and Turyahabwe et al. (2022) who emphasize that industrial operations play a role in polluting water by discharging poorly treated waste materials into the environment. The effluents from industries typically carry elements such as metals and oils that can endanger water sources in regions lacking sufficient pollution management strategies.

It is not surprising that the current study found relatively low levels of contamination at the southern outlet of Block C. This may also be an indication that natural processes, such as wetlands, act to filter and degrade part of the pollutants before they leave the Industrial Park (An & Verhoeven, 2019). Wetlands protect water quality through sediment stabilization, nutrient cycling, and sopping up contaminants. Interestingly, wetlands are rather effective at cleaning the effects of such pollutants-heavy metals and excess nutrients-through natural filtration. Therefore, maintaining wetlands near outlets of industrial effluents may also be an important strategy for pollution reduction within surrounding water bodies. This is again evidenced by studies such as the one conducted by Mitsch and Gosselink (2015) who described wetlands as "nature's kidneys" since they play a very crucial role in improving water quality.

Another important result of this study is that significant spatial variations ($p<0.05$) were found in the levels of contamination across the different seasons, a fact that reflects the dynamic nature of pollution in industrial zones, which, due to seasonal changes in rainfall and water flow, determines the distribution of the pollutants. During the rainy season the resultant run-off increases and washes more contaminants into streams and rivers, thus increasing the pollutant loads (Andama et al., 2022). On the other hand, the reduced water flow that characterizes a dry season concentrates the contaminants and therefore increases their impacts on the environment. This knowledge of seasonal variation is important to understand exactly how pollution impacts develop and, at the same time, to execute mitigation measures considering this kind of temporal change.

One of the most alarming findings is that upstream surface water of the industrial park also contains heavy metal contaminants. This is indicative of additional sources of pollution other than the industrial park emanating principally from areas of densely settled urban surroundings around NIBP. Other studies, such as Turyahabwe et al. (2022) and Bashir et al. (2020) have shown that in urban areas, surface water is largely polluted by informal settlements, car washing bays, domestic waste disposal, and sewage discharges. In areas where waste management infrastructure may be unavailable, household and small enterprise pollutants often make their way into surface water systems, thereby causing considerable deterioration in water quality.

The presence of contaminants upstream indicates that surface water pollution in the area is not strictly an industrial problem but that it is also driven by unregulated urban activities. Urban wastewater, especially from densely populated settlements, is a well-known source of pollutants like nutrients, originating from fertilizers and detergents, pathogens, and hydrocarbons, which came from car washing and run-off (Kilama et al., 2021). These findings agree with those from other regions that identified an amalgam of industrial and urban pollution. For instance, the urban wastewater and run-off into the rivers and lakes in peri-urban areas were found by (Singh et al., 2021) to be significantly responsible for degradation of quality, thus adding to the general pollution load. Also, Bessho et al. (2019) observed that discharge from untreated sewage and domestic waste increases the levels of coliform bacteria and other pollutants in the surface water body; these further complicate the task of managing water quality.

Further, the cumulative impact of industrial and residential pollutants from these sources has enormous socio-ecological and public health consequences. Contaminated water results in a myriad of health effects linked to waterborne diseases such as cholera and dysentery (Mansur, 2021). Heavy metal contamination, in particular, presents a longstanding risk to human health because of its nature to bioaccumulate through food chains into serious health problems, including cancer, kidney failure, and neurological disorders (Ribbe et al., 2021). It is very important that contamination levels in surface water bodies are reduced, and this matter should not be treated solely as an environmental issue but also as one of the major priorities linked to public health.

Studies (e.g. An & Verhoeven, 2019; Mitsch & Gosselink, 2015) suggest that nature-based solutions such as wetland conservation and restoration, along with the implementation of stricter pollution controls in areas hosting industries, should be employed. Restoration or protection of wetlands provides for use wetland natural characteristics for water filtering, thus providing a buffer for ecosystems from industrial and urban contamination. This especially true for areas like NIBP, where there are many sources contributing to degradation in water quality.

Ecological measures, besides improved systems of waste management, would go a long way to address the upstream pollution from the settlements. Stringent regulations relating to waste disposal methods in areas of high population density and upgrading the sewage treatment infrastructure may reduce the load of pollutants entering the surface water body (Turyahabwe et al., 2022). Public awareness helps bring positive attitude changes in communities over better methods of waste management practices, reducing further burdens on the natural ecosystem. Therefore, the present study gives reason to the imperative need for multiple track strategies towards surface water pollution in the hinterland of industrial catchments. The intricate mixture of industrial effluent and upstream urban pollution necessitates not just ecological interventions in the form of wetland restoration but also infrastructural improvements and apt waste management (An & Verhoeven, 2019), amongst other experts show that in an efficient environmental management strategy that aims at reducing the amount of socio-ecological and public health risk related to polluted water, sources of pollution need to be taken into account along the entire spectrum.

5.3 Drivers of Surface Water Contamination around Namanve Industrial and Business Park

The physical, chemical and biological properties of surface water is susceptible to contamination from several sources and activities. To isolate the contribution to these contamination sources, this study sought the opinions of the community members living around the NIBP and from the analysis of their responses, it was established that, streams, wetlands, and created channels were the most contaminated water sources. The present study thus revealed that surface water pollution around NIBP is significantly high, and the most significant ($p>0.05$) contributor to this is industrial waste discharge followed by storm run-off, municipal waste disposal, waste from car washing bays, agricultural run-off and sewage disposal. These findings are therefore in agreement with other studies that have identified such activities as both potential and actual sources of water pollution. Bhatta et al. (2015) argues that there are always heavy metals and organic pollutants in industrial effluents, which cause immense damage to the quality of water, especially around the industrialized area. A study by Akhtar et al. (2021) pointed out that climate-change-induced flooding can mobilize pollutants from industrial and urban areas through storm events, resulting in increased amounts of toxic substances in surface water by many folds.

The storm run-off is also identified as the most significant contributors to surface water contamination, particularly in urban areas (Vardhan et al., 2019). The current study revealed that, within an urban setting, because of the smaller surface area for natural absorption and filtration, run-off increases and has a higher deposit of most of the pollutants into the receiving waters. In this regard, increases in population and urbanization are commonly associated with increased discharges of various contaminants, including triclosan and other pharmaceuticals, into surface water bodies (Zhu et al., 2018). The finding is in agreement with Kümmerer (2009), who observed that urban run-off is ordinarily a cocktail of pollutants capable of disrupting the self-purifying functions of water bodies.

Municipal waste disposal is well established in contribution to contamination in urban areas and this is also reported by Turyahabwe et al. (2022) who pointed out that the poor methods of waste disposal in the urban set-up led to the leaching of these pollutants into the adjacent water bodies. This is heightened by Krause et al. (2023) who observed that poorly managed waste collection points have leachate that contaminate both surface and ground water, hence posing severe health risks to the public and environmental hazards as well.

The present study revealed that car washing bays are a significant source of water pollution. The chemical discharges from these activities introduce oils, detergents, and heavy metals into streams and wetlands. This aligns with Bashir et al. (2020) study which pointed out that the washing of cars in urban areas has resulted in huge degradation of water quality. Similarly, Grünhäuser et al. (2021) emphasized the environmental impacts of automotive washing practices and the need for regulations that mitigate their impacts on local water bodies.

Agricultural runoff also emerged as a significant determinant of surface water contamination. Agricultural land use generally involves application of fertilizers and pesticides, which might get washed into water bodies during rainfall, causing nutrient loading, hence leading to toxic contamination (Kilama Luwa et al., 2021). This is supported by Zhang et al. (2019) study which indicated that agricultural run-off caused harm to water quality where nutrient-carrying runoff causes eutrophication that is characterized by excessive growth of photosynthetic organisms with oxygen consumption hence threatening the lives of other organisms

The current study revealed storm flood run-off as one of the most significant drivers of surface water contamination in NIBP. As asserted by Landrigan et al. (2020), storm flood run-off associated with extreme climate events including intensified rainfall increases surface water contamination. The study however reports other drivers such as land management and that direct influence of climate change cannot be explicitly elucidated. Such an assertion points towards the fact that no single factor can be blamed for surface water contamination. However, these results show the decision to establish an industrial park in NBIP attracted diverse activities and processes that facilitate water contamination.

The sources of pollution interact in a myriad of ways to form landscapes of contamination, particularly in urban landscapes where impervious surfaces enhance run-off. Through the synergistic relationship of various pollution sources, water quality deteriorates with increased urbanization (Khan & Himanchal, 2019). Kümmerer (2009) also gives a supporting argument on how interaction between urban and industrial activities provides an additive pollution load that makes the scientific management of water resources effectively challenging. Contaminated water is associated with various health risks ranging from simple waterborne diseases to chronic conditions such as those emanating from heavy metal exposure. Long-term exposure to heavy metals in water may result in developmental disorders and including cancer (Tchounwou, 2012). Thus, surface water pollution is an issue that needs attention not only for the well-being of the environment but for public health protection.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study examined the changing spatial extent of industrial development within the Namanve Industrial and Business Park between 2014 and 2030. Findings reveal a significant positive trend of industrial expansion from 2014 to 2022. However, projections for 2022-2030 indicate a reversal of this trend, with a predicted decline in industrial land use and a concomitant increase in natural cover, including wetland and bushland, potentially supplemented by tree plantations. Therefore, the hypothesis of no significant change in industrial spatial extent was rejected for the observed period (2014-2022) but accepted for the predicted period (2022-2030), suggesting a shift towards environmental restoration and potentially, a more balanced approach to industrial development within the NIBP. The study demonstrates the effective integration of satellite data, laboratory-based water quality data, and household perception data to assess the environmental impact of industrial development, thus a methodological contribution. It further showcases a practical application of open-source satellite data to assess historical land use change and predict future industrial expansion/contraction which contributes to the growing field of predictive modelling for sustainable natural resources management.

Analysis of surface water quality within the Namanve Industrial and Business Park demonstrates significant spatiotemporal variations in physicochemical properties and heavy metal concentrations. This rejects the null hypothesis of no significant variation between the upper, middle, and lower reaches of the surface water system, confirming that water quality differs significantly across these locations and over time. The spatiotemporal variation in water quality highlights the need for continued monitoring and management of both industrial activities and other pollution sources to ensure the long-term health of the NIBP's aquatic ecosystem. The study provides baseline data on water quality and heavy metal pollution in surface water bodies around NIBP which broadens the scientific understanding of how industrialisation affects fresh water ecosystems.

Industrial activities within the Namanve Industrial and Business Park are perceived by communities as major contributors to surface water contamination, significantly impacting both heavy metal concentrations and physicochemical parameters. While this supports the alternative hypothesis and rejects the null hypothesis that industry is not the primary driver of contamination, it's important to acknowledge the contribution of other significant pollution sources, including stormwater runoff, municipal waste disposal, car washing bay discharge, agricultural waste, and sewage disposal.

6.2 Recommendations

There is need to restrict establishment of new industrial structures in the Namanve Industrial and Business Park as those in existence are creating a huge environmental burden through clearance of vegetation cover, infilling of wetlands and streams creating ecological imbalances. Agricultural activities related to crop growing should be restricted as these are also increasing the pressure on the natural cover that is already under a huge burden of industrial expansion. The industrial regulatory authority should enforce an industrial decommissioning policy such that at closure in the future, industrialists put in place measures to reconstruct industrial infrastructure sites into natural environments. The study reveals that by 2030 decline/negative change will have set in in industrial development which means there should be plan for the areas that will have been vacated.

There is need to put in place measures to prevent surface water contamination such as bioremediation by maintaining natural and supported wetland systems on the lower stream side of the NIBP as the study showed that the stream water passing through the wetland sections gets rid of some of the contaminants. Stream, wetland and river channel water in the Namanve areas should be used strictly for construction purposes by communities and not for drinking, cooking, washing, and farm irrigation as these sources are highly polluted and may result into adverse health impacts if used.

The results showed that industrial effluent discharge is the most significant driver of surface water contamination. There is need to enforce environmental regulations related to discharge of industrial waste and hazardous substances in water sources. NEMA should conduct routine inspections and surveillance of the water sources at industrialists' activities. They should undertake routine monitoring of the waste discharge of procedures of the different industrialists to ensure compliance with the standards and regulations. The environmental regulatory authority should task industrialist to maintain waste management contingency plans.

In terms of future research endeavours, the current study was conducted in the Namanve Industrial area over a relatively short period and around the four Industrial Blocks. A future study could dive deeper into long time monitoring of water quality from the upstream up to the point of entry into Lake Victoria via the inner Murchison Bay. This would reveal the contribution to pollution of the industrial site's overall water quality of the Lake since it is a major water abstraction point for supplies in the wider urban areas of Kampala, Mukono and Wakiso.

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APPENDICES

Appendix 1: Questionnaire Survey of the Water Quality Assessment and Pollution Drivers Around Namanve Industrial and Business Park

I……………………………………….a student of Kyambogo University, I kindly request you to provide me information on industrial development and water quality. All your views and opinion with be kept unanimously. The data you provide will be instrumental in helping me to attain my Master's degree as indicated above under the Topic "**Assessment of the Effect of Industrial Development on Surface Water Quality in Namanve Industrial and Business Park**". The researcher therefore requests your consent to participate in this study and appreciates your maximum cooperation. Thank you.

A: Participant Background data

i) Household location

Location…………………………………

District……………………………………

Municipality/Division …………………………….

Parish/Ward …………………………

Village/Cell……………………………..

Coordinates: Latitude………………………Longitude………………Elevation…………………

ii) Gender: ☐ Male ☐ Female

iii) Age (absolute): _______

iv) How long have you lived/worked in Murchison Bay area? _________

v) What is your occupation? _____________

B. Industrial development extent in Namanve

i) How do you rate industrial development/expansion in you are in the last 6 years?

Very high (7-10%) ☐ High (5-7) ☐

Moderate (2-5%) ☐ Low (0-2) ☐

ii) What were the main dominant land uses and cover types in this area before industrialization

Grassland ☐ Wetland ☐ Built-up areas ☐

Bush ☐ Woodland ☐ Croplands ☐

Forest ☐ Plantations ☐

C. Water sources and quality

i) What are the sources of water for different uses in your household? **(Multiple response)**

a) Cooking
   i. Wells
   ii. Stream/river
   iii. Wetland
   iv. Boreholes
   v. Tap water
   vi. Protected spring
   vii. Drainage channel

b) Washing
   i. Wells
   ii. Stream/river
   iii. Wetland
   iv. Boreholes
   v. Tap water
   vi. Protected spring
   vii. Drainage channel

c) Bathing
   i. Wells
   ii. Stream/river
   iii. Wetland
   iv. Boreholes
   v. Tap water
   vi. Protected spring
   vii. Drainage channel

d) Drinking
   i. Wells
   ii. Stream/river
   iii. Wetland

iv. Boreholes
v. Tap water
vi. Protected spring
vii. Drainage channel

e) Farm irrigation
i. Wells
ii. Stream/river
iii. Wetland
iv. Boreholes
v. Tap water
vi. Protected spring
vii. Drainage channel

ii) How do you rate the pollution levels of the water from various sources?

a) Wells **(Single response)**
i. Very highly polluted Very polluted
ii. Highly Polluted
iii. Moderately polluted
iv. Less polluted

b) Stream/river **(Single response)**
i. Very highly polluted Very polluted
ii. Highly Polluted
iii. Moderately polluted
iv. Less polluted

c) Wetland **(Single response)**
i. Very highly polluted Very polluted
ii. Highly Polluted
iii. Moderately polluted
iv. Less polluted

d) Boreholes **(Single response)**
i. Very highly polluted Very polluted
ii. Highly Polluted
iii. Moderately polluted
iv. Less polluted

e) Tap water **(Single response)**
i. Very highly polluted Very polluted
ii. Highly Polluted
iii. Moderately polluted
iv. Less polluted

f) Protected spring **(Single response)**
i. Very highly polluted Very polluted
ii. Highly Polluted

iii. Moderately polluted
iv. Less polluted

g) Drainage channel **(Single response)**

i. Very highly polluted Very polluted
ii. Highly Polluted
iii. Moderately polluted
iv. Less polluted

iii) For the water sources considered polluted/ contaminated, what are the most significant drivers? (**Multiple response**).

i. Stormy flood run-off
ii. River sedimentation
iii. Industrial waste disposal
iv. Agricultural fields waste
v. Sewerage disposal/fecal slug
vi. Municipal waste dumping
vii. Brick making
viii. Sand/murrum extraction
ix. Medical waste disposal
x. Abattoir/slaughter houses waste
xi. Car washing bay waste.
xii. Others (specify)

Appendix: 2: Land Use/Cover Transition and Accuracy Assessment

Class	Industrial development	Wetland	Vegetation	Farmland	Total	User Accuracy (%)
Industrial development	65	0	0	0	65	100
Wetland	0	45	1	2	48	94
Vegetation	0	4	58	2	64	91
Farmland	0	2	0	34	36	100
Total	65	51	59	38	213	
Producer Accuracy (%)	100	88	98	89		
Overall accuracy	0.95					
Kappa	0.93					

Confusion/error matrix 2018

Class	Industrial development	Wetland	Vegetation	Farmland	Total	User Accuracy (%)
Industrial development	45	0	0	4	49	91.83673469
Wetland	1	55	2	2	60	92
Vegetation	0	3	74	8	85	87
Farmland	1	0	5	35	41	85
Total	47	58	81	49	235	
Producer Accuracy (%)	96	95	91	71		
Overall accuracy	0.94					
Kappa	0.92					

Confusion/error matrix 2022

Class	Industrial development	Wetland	Vegetation	Farmland	Total	User Accuracy (%)
Industrial development	68	0	0	0	68	100
Wetland	1	35	5	1	42	83
Vegetation	0	0	74	0	74	100
Farmland	3	0	2	27	32	84
Total	72	35	81	28	216	
Producer Accuracy (%)	94	100	91	96		
Overall accuracy	0.89					
Kappa	0.85					