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ECOLOGICAL QUALITY OF MUNI LAGOON AND ITS TRIBUTARIES IN EFFUTU MUNICIPALITY OF CENTRAL REGION, GHANA

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INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES

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ECOLOGICAL QUALITY OF MUNI LAGOON AND ITS TRIBUTARIES IN WINNEBA MUNICIPALITY OF CENTRAL REGION

BY

TWUMASI ANKRAH KWARTENG

(10704529)

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILMENT OF THE AWARD OF DEGREE OF DOCTOR OF PHILOSOPHY IN ENVIRONMENTAL SCIENCE

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OCTOBER, 2023

DECLARATION

I, Twumasi Ankrah Kwarteng, hereby declare that this thesis is my work produced from research undertaken under supervision and that all the sources that I have used or quoted have been indicated and acknowledged using complete references. It has not been submitted before for any degree or examination at any other university. I accept full responsibility for any error in the work and the bearing in which it has taken.

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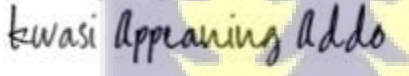
Signature:  Date: 30th October, 2023

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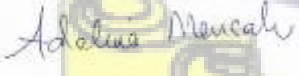
Signature:  Date: 30th October, 2023

DR. ADELINA MENSAH

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DEDICATION

I dedicate this thesis to my lovely wife and children.

ABSTRACT

Muni Lagoon, located in Winneba in the Effutu Municipality, has two main tributaries, which are Pratu and Ntakofa Rivers. The Muni Lagoon catchment area provides a lot of benefits to residents in the area, including hunting, farming, fishing, and gathering of wood fuel. The lagoon area is the habitat of most plants and animals and serves as birds feeding spot. However, anthropogenic activities such as agricultural and industrial activities are deteriorating the quality of Muni Lagoon and its two tributaries. The study evaluated the heavy metal, physicochemical, and pesticide residual quality of Muni Lagoon and its tributaries. It also looked at how anthropogenic activities affected the provision of ecosystem services in the catchment area of the Muni Lagoon. The mixed method approach was employed to gather and evaluate both qualitative and quantitative data. In the study, 36 water samples each were collected from Muni Lagoon, River Pratu, and River Ntakofa for physicochemical analysis. Also, 36 samples each of sediments and water were collected from the three water bodies for heavy metal analysis, and 36 samples each of water and sediment were collected for pesticide analysis. Furthermore, 240 fish samples (black chin tilapia (*Sarotherodon melanotheron*) and *Tilapia guineensis*) were collected for heavy metal (120 fish) and pesticide (120 fish) analyses. These fish types are mostly consumed by people in the study area and hence sampled for the study. The collected samples were labelled and placed in a cold box before sending them to the laboratory for analysis. In addition, 384 respondents from four communities in the study area were conveniently sampled to respond to a questionnaire on provisioning ecosystem services in the Muni Lagoon catchment area. The four communities involved in the study were purposively selected because most people depend on the lagoon and its tributaries for their livelihood. The physicochemical parameters were analysed using the analytical procedure described by the American Public Health Association (1998). The water, sediment, and fish samples used for heavy metal analysis were acid digested and analysed using Nexion 2000

ICP-MS. Again, sample preparation, extraction, cleanup, and analysis of pesticide samples were done using the QuEChERS method. Gas chromatography GC-2010 equipped with 63Ni electron capture detector (GC-ECD) was used to analyse the extract for organochlorines and pyrethroid residues, while Gas chromatographic- flame photometric detector (GC-FPD) was used to determine organophosphate pesticides at their various operating condition. From the obtained data, the weighted arithmetic Water Quality Index (WQI) model was used to estimate the quality of surface water. The heavy metal pollution index and Geo-Accumulation Index (Igeo) were used to evaluate the various heavy metal accumulations in water and sediment samples, respectively. The Pesticides Quality Index (PQI) was used to assess pesticide quality in water and soil samples. Bioaccumulation Factor (BAF) was used to evaluate the degree of fish contamination by heavy metals and pesticides in the studied fish samples. The USEPA risk assessment model was used to determine daily exposure intake, non-carcinogenic and carcinogenic risks. Data from all samples were analysed using SPSS (version 25) for both descriptive (like mean and standard deviation) and inferential statistics. The variations in physicochemical, heavy metal, and pesticide residual levels in water, sediments, and fish at a 95% confidence level were established through inferential statistics like principal component analysis (PCA), linear regression, one-way analysis of variance (ANOVA), and Pearson correlation coefficient. The results revealed that most of the physicochemical parameters were above the WHO (2018) and GSA (2017) permissible values in Muni Lagoon and its tributaries. The WQI of the Pratu River was 249.98, and it suggests that the water from the river is unfit for drinking and irrigation purposes. Muni Lagoon and Ntakofa River had water quality indices of 71.612 and 66.05, respectively, and were within the class, which indicates poor water quality. Heavy metals were detected in Muni Lagoon and its tributaries. The Pratu river and Muni lagoon recorded As values greater than the WHO (2018) permissible value

of 0.01 mg/L, while concentrations of Cd, Cr, Ni, and Pb in water samples of Muni lagoon and Ntakofa river at the time of the study were below their respective WHO values. On the other hand, the Pratu River recorded higher values of Cr, Ni, and Pb, which were above their recommended values. The Heavy metal pollution index (HPI) for the Ntakofa river was 6.899, while that of Muni lagoon was noted to be 51.85. These two values were below the critical value of 100, suggesting that the Ntakofa River and Muni lagoon have low levels of heavy metals. Contrarily, the HPI value of the Pratu River was more than 100, indicating that the river is unsuitable for consumption. Arsenic (As) and Cadmium (Cd) concentrations in sediment samples were higher in the Pratu River than those recorded in Muni Lagoon and Ntakofa River. Some of the heavy metals were below their accepted levels, and they include Co, Cu, Ni, and Se. The concentrations of Ba, Cr, Mn, and Zn in sediment samples from Pratu River were higher as compared to those recorded in Ntakofa River and Muni Lagoon. The mean Igeo value of heavy metals pollution in sediment samples from Pratu River was within the index class of 5 ($4 \leq Igeo \leq 5$), indicating heavily to extremely contaminated or polluted. The mean Igeo value of heavy metals in sediment samples from Ntakofa River was within index class 4 ($3 \leq Igeo \leq 4$), indicating heavily contaminated or polluted. Again, the mean Igeo value of heavy metals in sediment samples from Muni Lagoon was within the index class 2 ($1 \leq Igeo \leq 2$), indicating moderately contaminated sediment samples. In the principal component analysis (PCA), forty-four (44) components were extracted, and out of these, the first six (6) components cumulatively explained 93.89% of the total variations among physiochemical and heavy metal parameters. These six components were therefore retained in the model. The high loadings and high correlation values of heavy metals suggest a common source of origin. In this study, the source of pollution in water bodies was linked to anthropogenic activities such as industrial and agricultural activities, as well as domestic waste discharges into

water bodies. The negative and positive loadings reflect the mixed sources of pollution from anthropogenic and natural sources. Organochlorine and pyrethroid pesticides were not detected in water and sediment samples from Muni Lagoon, Pratu, and Ntakofa Rivers were not detected. In addition, pesticides were not detected in fish samples. Apart from the detection of chlorpyrifos (an organophosphorus) in Ntakofa sediment samples, no organophosphorus was detected in either water or sediment samples from Pratu River, Muni Lagoon, or Ntakofa River. Human health risk assessments revealed that heavy metals in fish are likely to cause non-carcinogenic effects in children since their HI value exceeded 1 and was greatly influenced by As and Co. However, the HI for the adult population was less than 1 and which indicates no adverse non-carcinogenic health risk to the adult population through the consumption of fish from Muni Lagoon. In cancer risk assessment among the adult population, only As was likely to pose carcinogenic effects, while As and Cr were noted to pose carcinogenic effects in the children population since their CRI values exceeded 10^{-4}. The respondents involved in the social survey revealed that ecosystem services have been negatively impacted in the Muni catchment area due to human activities. From the regression analysis, encroachment/Building, firewood collection, and agricultural activities have significantly deteriorated ecosystem services in the study area. To ensure the sustainable use of water bodies in the Muni catchment area, it is recommended that the EPA and, Water Resource Commission should periodically monitor all industrial activities taking place close to the Muni catchment area to ensure that their waste effluents do not pose health hazards to the public and the environment.

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CHAPTER ONE
INTRODUCTION

1.1 Background to the study

The Muni Lagoon is among the six internationally recognised coastal wetlands (Ramsar site) under the Convention on Wetlands because of the role it plays in promoting human livelihood development and the ecosystem (Atubiga & Donkor, 2022). The lagoon ecosystems encompass diverse habitats at the interface between land and sea, including estuaries, salt marshes, and mangroves. Muni Lagoon, like all other coastal lagoons, is a critical zone of ecological significance because it plays a multifaceted role in supporting biodiversity, serving as essential breeding and nursery grounds for various marine species (Inácio et al., 2018). In addition, it provides fertile land for agricultural activities, a nesting site for migratory birds and wildlife, trees for timber and fuel wood, and a recreational site for human benefits (Jisha & Puthur, 2021).

The Muni lagoon is fed by two rivers (Pratu and Ntakofa rivers), and these rivers supply it with fresh water. The presence of these water resources in the muni catchment area makes it a highly productive environment due to the variety of ecosystem services it provides, including cultural, economic, and social benefits, yet a diverse set of interconnected stressors is a challenge to its sustainability (Davies-Vollum et al., 2024). In order to maintain the integrity of the ecological quality of the Muni catchment area, it is important to monitor the water quality of these water resources as well as the provisioning of ecosystem services in the area.

Water quality is the acceptability of water for a specific use established by its chemical, physical, and microbiological qualities (Spellman, 2013; Alley, 2007). When water parameters of lagoons and rivers exceed safe limits when impacted by natural or human activity, they pose threats to human and environmental health. Among these parameters are physical and chemical contaminants, which are regulated for exposure or have acceptable levels set by nations and

international organisations such as the World Health Organisation (WHO) and the Centers for Disease Control (CDC) (Akter et al., 2019).

Highly polluted water bodies have most of their physical, chemical, and microbiological parameters exceeding permissible levels, and these are attributed to human activities (Tripathi et al., 2022; Davies-Vollum et al., 2024). According to Tripathi et al. (2022), anthropogenic activities, including agriculture, urbanization, industrial activity, and population increase, have caused the quality of many water sources (rivers, lagoons, lakes, and streams) to decline. Additionally, the demand for freshwater resources has increased due to natural processes like soil erosion and climate change (Delpla & Rodriguez, 2017). In a similar study, Whelan et al. (2022) reported that climate change, coupled with human activities, has decreased the quality of most rivers and lagoons, resulting in spatiotemporal changes in pH, temperature, sedimentation, heavy metals, harmful organic compounds, nutrients, and pesticides. To protect water resources and enhance public health, it is crucial to monitor the quality of environmental water bodies and pinpoint any potential causes of pollution.

When the conditions of water resources like Muni lagoon and its tributaries exceed their maximum thresholds, they are likely to impact negatively on the health of their consumers, and as a result, regular water quality monitoring is necessary to ensure the safety of drinking water and the consumption of fish from these water bodies. Sustainable management of high-quality water is one of the Sustainable Development Goals (SDGs), which presents a challenge to policymakers and WASH professionals, especially in light of industrialization, changing climatic conditions, rising population, poverty, and the adverse effects of human development (Akter et al., 2019).

The existence of humans and several other species depends on healthy water bodies in their ecosystems. For instance, lagoons provide migrating birds with a place to rest, fish for food, and wood for fires, among other ecosystem resources and services (Tagliapietra et al., 2020). The sustainability of different water sources in their natural state of non-pollution supports human and environmental health. Ironically, the irresponsible use of water resources is putting these ecosystems in danger of environmental collapse (Junk et al., 2013; Ramsar Convention Secretariat, 2014).

According to Aderinola et al. (2009), many lagoons are predominantly polluted by anthropogenic waste supplies since there are insufficient waste management techniques in place. As a result, heavy metals may enter surrounding water bodies through leachates from garbage sites. Major contaminants, including heavy metals, have been found in several lagoons across the world (Hamid et al., 2020; Nasehi et al., 2013). Because of their toxicity, persistence, and negative impacts on both human health and marine life, heavy metals are harmful (Mitra et al., 2022; Saha & Hossain, 2011). Currently, neither humans nor animals have any concrete analytical procedures for removing heavy metals from their bodies. Heavy metals in aquatic systems like rivers and lagoons are therefore a great concern.

Crop yields are increased, and crops are protected from pests using pesticides in agriculture. Pesticides pose a threat to food safety, living things, and the ecosystem since they can spread from sprayed areas to nearby lands, air, and water bodies. Research into these agents destiny in the environment has been sparked by this. Additionally, as their use has grown, concerns have been raised about their detrimental effects on non-target species like humans (Pathak et al., 2022).

At the global level, WHO estimated in 2016 that 13.7 million deaths, amounting to 24% of deaths and 23% of disease burdens, were attributable to modifiable environmental factors, among which were chemicals released into the environment (like water, air, and soil) due to human activities (WHO, 2024). Also, the report indicated that chemical risk is still growing, with evidence of an estimated 1.6 million deaths in 2016 from exposure to selected chemicals. Again, other chemicals or groups of chemicals recognized by WHO to be a public health concern, like hazardous pesticides, are being introduced into the environment through human activities (WHO, 2024). According to a WHO report for 2022, about 1.7 billion people are at risk of drinking water contaminated with chemicals since it poses a significant health threat to them (WHO, 2022). In addition, Nutrient and chemical pollution in water resources significantly threatens ecosystem health globally and is aggravated by anthropogenic activities (Ripanda & Miraji, 2022). Similarly, human activities have increased in the catchment areas of most rivers in many African countries and are likely to be contaminated with chemical pollutants and nutrients.

Numerous coastal lagoons in Ghana and other countries have experienced severe human interference, which has led to significant hydrological changes, increased anthropogenic nutrient delivery, and changes in coral reefs (Zhang et al., 2014). Lagoons can become contaminated when rivers that flow through populated regions and numerous agricultural areas discharge their contents into them, which are likely to contain solid waste, heavy metals, and pesticide residues. According to Whelan et al. (2022), rivers and lagoons are particularly susceptible to the effects of anthropogenic activities and climate change. Concerns about the environment and public health arise from the enrichment of heavy metals and pesticide residues in water, sediment, and fish in rivers (Oguguah et al., 2017; Lee et al., 2023). This study investigates the ecological quality

(physicochemical, heavy metals, and pesticide residues) of Muni lagoon and its two tributaries, which pass through towns, agricultural, and industrial areas.

1.2 Justification of the study

The Ghana Statistical Service (GSS) (2021) has reported that agriculture accounts for more than 50% of employment in Ghana and over 20% of the country's GDP. Although this is the case, Ghana agricultural practices are still primitive, which has led to low productivity. To increase yields and productivity, Ghanaian farmers have turned to using pesticides and fertilizers. According to Adonadaga et al. (2020) and Moss (2008), the use of outdated farming practices, such as excessive use of fertilizers, pesticides, and herbicides in farming, as well as poorly managed animal farming operations, has contributed to the contamination of surface water like rivers, streams, and lakes in Ghana.

Freshwater supplies, both in terms of quantity and quality, are deteriorating with time (Yeleliere et al., 2018). The contamination of Ghana water resources, particularly its freshwater, is mostly brought on by the presence of heavy metals, chemical contaminants, and pesticide residues, with estrogens serving as an example of a developing contaminant (Amoah, 2007; Abass et al., 2017).

According to Abagale et al. (2019), vegetable farmers frequently employ pesticides and locate their crops close to water sources. According to them, many pesticides are used by vegetable farmers to control pests on their farms, and most of them frequently acquire misguided information from other farmers on how to handle or apply agrochemicals properly, leading to the abuse of use of agrochemicals and their consequent environmental contamination. When it rains, residues of these agrochemicals are carried by runoff, which subsequently contaminates nearby rivers, streams, lakes, and lagoons. Abagale et al. (2019) reported that garden eggs and okro from the

Tono site, as well as tomatoes and pepper from the Pungu site, recorded high levels of organochlorine residues (2.232-5.112 ng/g), and this was attributed to excessive use of pesticides as well as the use of pesticide contaminated water in the Tono site for irrigation. The study also revealed that soil samples taken from the farm included pesticides such as organophosphates, -HCH, and endosulfan. According to Northern Presbyterian Agricultural Services and Partners (NPAS) (2012), Ghanaian farmers are using illegal or restricted pesticides. Additionally, it has been reported that local agrochemical merchants in the Bawku Municipality were selling lindane, DDT, dieldrin, and aldrin, among other prohibited pesticides (Laary, 2010). The use of these restricted chemicals in farms pollutes nearby water bodies used for drinking and irrigation since they are washed and carried by runoff to contaminate them.

Farmers, consumers, and traders who work in the food supply chain all suffer negative consequences from the use of pesticides. Due to farmers ignorance of the types of pesticides used and the dangers associated with them, the number of people who will suffer as a result of excessive pesticide use is predicted to rise (Kwakye et al., 2019). In addition, Northern Presbyterian Agricultural Services and Partners (2012) claimed that the increased use of cheap, incorrectly labelled, and contaminated pesticides in Ghana is a result of lax enforcement of pesticide laws as well as the fervent desire of pesticide users and sellers to maximize their profits. Pesticide abuse and usage on crops and farms have also been reported (Amoako et al., 2012; Dinham, 2003). The abuse of pesticide usage in farms has the potential to contaminate rivers, lakes, and lagoons close to these farming sites.

Because of illegal mining practices, Ghana freshwater resources are becoming contaminated with heavy metals (Mantey, 2017). The water treatment plant in Kyebi has been forced to close by the authorities due to the high pollution of the Birim River. The issue was comparable to that of the newly established Juaben communities, where shoddy fishing techniques had led to the contamination of freshwater supplies (Mantey, 2017).

Despite historically using minimal chemicals to treat water from the Volta River, the Ghana Water Company now uses more chemicals as a result of increased river pollution (Mantey, 2017). Again, Mantey (2017) reported that the Densu River, which draws its source from Western Accra, has been polluted owing to farming activities and industrial waste discharges. These results demonstrate that water is increasingly scarce and of low quality as a result of fast population growth, urbanization, and a variety of uses including irrigation, fisheries, industrial operations, mining, and ecosystem support services (Ministry of Water Resources, Works and Housing, Ghana, 2007; Yeleliere et al., 2018).

Some Ghanaian communities pollute lagoons and rivers with nutrients and heavy metals by discharging household and industrial waste into them. This method is slowly depleting Ghana water resources because the effluents are often not treated, which increases the nutrients and contaminants in our water bodies. Algal bloom is one result of nitrogen and phosphorus enrichment in our water bodies (Misra et al., 2016; Osei et al., 2019).

Rivers and lagoons in Ghana are being polluted with chemical pollutants like heavy metals and pesticides due to Human activities. According to Yeleliere et al. (2018), the majority of Ghana

rivers no longer meet safety standards due to unregulated mining and agricultural activities. In their report, Yeleliere et al. (2018) listed trace metals and pesticide residues among key water contaminants in water bodies found in Ghana. Water bodies like rivers and lagoons, which are manageable natural resources, can experience reduced pollution by taking a few actions.

Numerous lagoons and rivers in Ghana have been endangered by pollution, which has resulted in the degradation of those water bodies. As a result, majority of the nation lagoons now have less capability for producing fish (Addo et al., 2012). Agriculture, modernisation, and industrialization are factors in the heavy metal pollution of lagoons, which limits the ability of coastal water bodies to live sustainably (Addo et al., 2012; Tripathi et al., 2021). Because of the negative effects it has on people and wildlife, researchers, governments, and the general public are very concerned about heavy metal exposure in the environment, whether it is through inhalation or eating tainted food (Mitra et al., 2022; Fosu-Mensah et al., 2017). Further, attempts at economic evaluation of coastal lagoons highlight the need for more stringent regulatory limitations on the use of Ghana coastal lagoons as well as the importance of regular monitoring to support decision-making. This explains why monitoring water quality and assessing the ecological integrity of coastal wetlands are issues that the scientific community in Ghana is concerned about. Evaluation of the lagoon water quality is a crucial first step in any strategy to stop the threat of environmental pollution.

Lagoon pollution has become a serious problem in Ghana (Essumang et al., 2009) because it deteriorates the habitat for fish and depletes their numbers. Since a large portion of human protein nutrition comes from lagoons and other bodies of water, they suggested that unchecked chemical activities in them expose people to health risks. Consumers in areas where contaminated water is

used to irrigate vegetables are in danger because pesticides can accumulate in the tissues of fish and vegetables, where they can bioaccumulate over time (Rahaman et al., 2018).

In addition, pesticides and heavy metals found in the sediment of rivers and lagoons have the potential to contaminate fish and other aquatic organisms when their levels exceed recommended limits (Singh et al., 2022). Similarly, with increased industrialization and vegetable farming in the Muni catchment area, levels of pesticides and heavy metals in sediment and water have the potential to increase. This therefore has the potential to contaminate fishes in them because they exist in a variety of habitats and have a variety of feeding habits, making them susceptible to pollution when found in water or sediment that has been tainted with pesticides and heavy metals. Wei et al. (2014) found that compared to pelagic fish, benthic fish species tended to accumulate contaminants in sediment at a higher rate (Ccanccapa et al., 2016).

The high degree of illiteracy among farmers, according to Imoro et al. (2019), is the primary cause of the widespread non-adherence to pesticide application recommendations by farmers. According to Imoro et al. (2019), high pesticide amounts were found in soil and water samples due to nonadherence to pesticide use regulations by farmers. In a similar study, four organophosphorus residues were discovered in soil and water samples by Fosu-Mensah et al. (2017), in varying concentrations. Farmers in the Muni catchment area are not different from those reported by Imoro et al. (2019), and so monitoring the levels of pesticide residue and heavy metal levels in water resources is appropriate.

1.3 Statement of the problem

The United Nations has asserted that fertilizer and pesticide runoff from agricultural fields contribute greatly to marine pollution, followed by improper garbage disposal and then discharge

of untreated sewage (UN, 2017; Sturesson et al., 2018). In lagoons, rivers, and oceans, pollution caused by nutrients like nitrogen and phosphorus is becoming more and more of an issue (UN, 2017). According to Doamekpor et al. (2018), rivers and lagoons in Ghana are used as sinks and dumping grounds for the discharge of industrial waste. These actions have increased the amount of heavy metals present in lagoons (e.g., Chemu, Sakumo II, and Kpeshie). Similarly, some studies (Tay et al., 2009; Dorleku et al., 2019; Okyere et al., 2023) have reported on physicochemical and heavy metals parameters in Muni Lagoon, but many did not focus on the tributaries.

In Winneba, local populations depend on Muni Lagoon wetlands for fishing, hunting, farming, grazing, and fuel wood obtained from the eastern fringe of the wetland's mangrove forest (Wiegle, 2016; Ramsar Convention Secretariat, 2016). Due to increased development, Muni-Pomadze is being gradually encroached upon (Ramsar Convention Secretariat, 2014). The lagoon area is used by farmers, cattle herders, salt farmers, sand and stone extractors, and crab catchers. Due to the lagoon's importance as a bird feeding ground, tourists and other leisure seekers come to view birds. Additionally, some communities and animals in the Muni Lagoon catchment area use the tributaries as a source of drinking water, while vegetable farmers use them for irrigation. During the Aboakyir festival, the forest at the western side of the Muni catchment area serves as the location for the live catch of deer by the Effutu people. The lagoon quality is being negatively impacted by the numerous anthropogenic activities nearby. In addition, the Muni Lagoon is acknowledged as a wetland, which reduces flood risks and purifies water. Again, it is recognised as a wildlife area in Ghana. The wetland is managed and conserved because of these factors (Davies-Vollum et al., 2019).

Even though there are rules and regulations in place to protect and preserve the wetland resource base, there is still a risk of damage to the places (Ghana Wildlife Division, 2007). There needs to be more effort put into managing water, forestry, and land resources than has already been made by the Water Resource Commission, the Ghana Forestry Commission, and the Lands Commission. According to Mensah et al. (2018), there were no systematic and purposeful efforts to manage the Kpeshie, Muni-Pomadze, and Sakumono wetlands. In addition, the study discovered that incorrect fishing methods, house garbage discharge, farming, improper human and industrial waste disposal, and residential garbage disposal all enhance the danger of contamination in these wetland environments.

The Muni wetland catchment area has problems with resource exploitation and waste management, particularly with plastics (Davies-Vollum et al., 2019). In addition, in a field survey of the Muni catchment area, the researcher observed fish pond farming, farming along the banks of the rivers feeding the Muni Lagoon, small-scale industries (block-making factories, generator repairs), bushfires, the flow of domestic effluents into rivers, and abandoned illegal mining locations. All these human activities impact Muni Lagoon and its tributaries. This is in consonance with that reported by Tiakor (2015), Dzakpasu (2019), and Davies-Vollum et al. (2019). The water quality and long-term viability of the Muni Lagoon and its tributaries may be threatened by these unsettled conditions. Consequently, both locally and globally, the wetland value may decrease (Amatekpor, 1994).

The economy of Ghana, which is still in the development stage, is built on the extraction of natural resources, which has led to the depletion of water resources, including lakes, rivers, and lagoons.

The Muni-Pomadze wetland is found in Ghana's coastal savannah region. It is one of the world five officially recognised coastal wetlands in Ghana (e.g., Keta, Owabi, Songor, and Sakumo Ramsar sites). The Muni wetland is internationally recognised due to its potential ecological benefits as a breeding and nesting ground for local and migratory water birds (Ramsar, 2002). Wetlands are susceptible to degradation (Allotey, 2000**).** According to Wuver and Attuquayefio (2006), unsustainable human activities upland may be largely to blame for the destruction of the Muni wetland and the areas surrounding it. Although human activities have increased in the Muni Lagoon catchment area (Davies-Vollum et al., 2024), very little is known about provisioning ecosystem services that have been negatively influenced.

According to Gordon and Biney (1994), 32.5 percent of the land in the Muni Lagoon catchment region is used for agricultural activities. Current studies conducted by Tiakor (2015), Dzakpasu (2019), as well as Salami and Sulemana (2021) have reported on a lot of agricultural activities occurring around the Muni Lagoon catchment area at the northern portion of the lagoon along the main Accra to Cape Coast trunk route, where the soils are favorable for agriculture. This location is where two major rivers joining the lagoon pass. Gordon et al. (2000), Dzakpasu (2019) as well as Salami and Sulemana (2021) found that farmers in the Muni area use agrochemicals like pesticides and fertilizers, which can pollute nearby water bodies. Salami and Sulemana asserted that the high usage of fertilizers and pesticides in the area can be attributed to the numerous vegetable farms. Most of the previous studies (Gordon et al. (2000), Tay et al. (2009), and Tiakor (2015) described Muni Lagoon as not polluted, and limited studies have been conducted on the quality of Pratu and Ntakofa rivers. With increased agriculture and the establishment of a paper recycling factory in the area, it is important to monitor the quality of the Muni lagoon and its

tributaries since limited studies have assessed variations in levels of physicochemical properties, heavy metals, and pesticide residues in Muni Lagoon and its tributaries.

Pesticides have recently gained recognition as useful farming inputs for both crop and livestock farming, but the proper handling of these pesticides has gotten less attention (Tudi et al., 2021). However, exposure to pesticides by living things can have negative health effects due to bioaccumulation or direct application (Alengebawy et al., 2021). There are numerous health issues associated with pesticide exposure, including leukemia, birth defects, moderate skin irritation, tumors, genetic changes, coma or death, blood and nerve diseases, endocrine disruption, and disruptions to both men and women reproductive systems (Nyantakyi-Frimpong et al., 2016). Also, fever, skin irritation, skin illnesses, respiratory issues, headache, abdominal pain, diarrhoea, and asthma are additional top pesticide-related health issues (Nyantakyi-Frimpong et al., 2016).

Farmers usually lack training in handling agrochemicals like pesticides and fertilizers, which are a silent killer in food and water (Northern Presbyterian Agricultural Services and Partners, 2012). The increased agricultural and other anthropogenic activities in the Muni catchment area can impact the lagoon and other ecosystem services negatively. New factories have also been constructed close to the tributaries of Muni Lagoon. The Nixin paper mill industry is one of them. Chemical waste is irresponsibly dumped into the Pratu River, a tributary of Muni Lagoon, by the Nixin paper mill (Zubaida, 2021; Salami & Sulemana, 2021). There are also some commercial farms in the area, including Casa de Ropa Farms. According to reports, the Pratu River, a tributary of Muni Lagoon, receives the waste discharge from the Casa de Ropa sweet potato factory in Bedwadze (Salami and Sulemana, 2021). These human activities can contaminate water bodies

with heavy metals and pesticides, which can subsequently pollute the fish in the water resources. The consumption of fish from aquatic ecosystems contaminated with hazardous chemicals threatens public and environmental health (Adeloju et al., 2021). In this study, the physicochemical parameters, heavy metals, and pesticide residues of Muni Lagoon and its tributaries water quality were evaluated.

1.4 Main Objective

The study primary objective was to evaluate the heavy metal, physicochemical, and pesticide residue concentrations in water, sediment, and fish from Muni Lagoon and its tributaries.

1.5 Specific Objectives of the Study

The study specific objectives were to:

1. Assess the physicochemical characteristics of water from Pratu River, Muni Lagoon, and Ntakofa River.
2. Determine heavy metal levels in water and sediment of Pratu River, Muni Lagoon, and Ntakofa River.
3. Assess pesticide residual levels of water and sediment of Pratu River, Muni Lagoon, and Ntakofa River.
4. Examine heavy metal and pesticide residual levels in fish from the Muni Lagoon.
5. Determine the human health risks associated with the dietary intake of fish in terms of heavy metals and pesticide pollution in Muni Lagoon.
6. Assess the influence of anthropogenic activities on provisioning ecosystem services in the Muni Lagoon catchment area.

1.6 Significance of the Study

The results of the study will reveal the physicochemical characteristics of water samples collected from Muni Lagoon, Pratu River, and Ntakofa River. It will help identify the different sources of physical and chemical contaminants in the Muni catchment area, which will help design mitigation approaches. Also, it will reveal the distribution and contamination of heavy metals in the water and sediment of the various water bodies in the Muni catchment area. The study will help identify specific heavy metals that have high potency to result in environmental and public health issues in the Muni catchment area. The results from the study will help locate the possible sources of heavy metal contamination, which will help design appropriate strategies to reduce heavy metal pollution in the water and sediment of Muni Lagoon and its tributaries.

Again, the study will help identify pesticides that are likely to cause environmental and public health issues in the Muni catchment area. It will also reveal the distribution and contamination of pesticides in the sediment of the various water bodies in the Muni catchment area. The study will help locate the possible sources of pesticide contamination that will help design appropriate strategies to reduce pesticide residual pollution in the water and sediment of Muni Lagoon and its tributaries.

In addition, fish analysis will reveal contamination of fish by heavy metals and pesticides in the Muni lagoon. The levels of heavy metals and pesticides in fish will help to ascertain whether the fish in the lagoon are wholesome for human consumption. It will also reveal which heavy metals and pesticide residues have entered the food chain and are likely to bioaccumulate in humans and other organisms to cause health problems among people in the Muni catchment area.

The result will enable the Wildlife division of the Forestry Commission, the local people, and the Water Resource Commission to know which ecosystem services have significantly deteriorated in

the Muni Ramsar site. This will help them to intensify their monitoring and education programmes so as to protect the resources in the Muni catchment area. Again, the results will reveal various anthropogenic activities influencing the provisioning of ecosystem services. The information will help authorities of the reserve area to design strategies suitable to protect the forest, rivers, and other living organisms in the Muni catchment area.

1.7 Organisation of the Thesis

The thesis was organised into chapters. The first chapter of the study serves as an introduction and establishes the overall background for the study. Chapter one discusses the justification, statement of the problem, objectives, and importance of the study. The second chapter contains an in-depth analysis of the research literature. This article goes into great detail about the current level of research on this subject. Chapter three provides a description of the study area and the methodology employed in the study. The research results and discussions are presented in Chapters four and five, respectively. Finally, chapter six presents the conclusions of the research.

CHAPTER TWO
LITERATURE REVIEW

2.0 Overview

The related literature on physicochemical parameters, heavy metals, and pesticide residues of Muni lagoon and its tributaries has been presented in this chapter. It also discusses the Environmental and public health impacts of these variables.

2.1 Physicochemical parameters

2.1.1 pH

pH measures the hydrogen ions in water. Hydrogen and hydroxyl ions are the main ionic components of water. Water is neutral when both ions are equal in amount. The water becomes more acidic as hydrogen ions exceeds the number of hydroxyl ions. It also becomes basic when the hydrogen ions are less than the hydroxide ions concentration. pH spans from 0 to 14 on a logarithmic scale, with pH equal to 7 indicating neutral, pH below 7 indicating acidic, and pH above 7 indicating basic. The majority of aquatic species have a pH tolerance range of 6.5 to 8.5 (WHO 2018; GSA, 2017). Water with a low pH is dangerous, while water with a high pH has an unpleasant taste. Acidic conditions can cause toxic heavy metals to leak into the water. Mining activities and acid rain both have the potential to reduce the pH of water bodies.

In an aquatic medium, the organisation of biological communities and the bulk of different chemical processes that take place are determined by pH (plants, animals, microorganisms). The majority of lakes and various types of running water have a pH between 6.5 and 8.5; however, a pH below 4 or beyond 10 provides unfavourable living circumstances in aquatic systems (Ami & Tadi, 2018). Among these unfavourable conditions are irritation of the skin and eyes at low pH and discharge of mucous membranes at too high pH. This suggests that when the pH of water

resources in the study area is very low, people who use the tributaries as drinking water are likely to experience irritation in their throats. Also, the use of water with a pH between 10 and 12.5 causes hair filaments to swell (WHO 2018). When exposed to low pH levels in sensitive people, gastrointestinal discomfort might happen. Again, epithelial cells suffer irreversible and significant damage below pH 2.5. Furthermore, pH may indirectly affect human health because it affects the degree of metal corrosion and impacts how well water is disinfected. In order to ensure the safety of people who depend on water resources in the study area, assessing whether their pH values lie within recommended limits is vital. pH values between 6.5 and 8.5 are recommended by the WHO (2018) and GSA (2017).

2.1.2 Electrical Conductivity (EC)

The ability of water to carry an electric current depends on several factors, including the amount of dissolved chemicals, ionic charge, ionization capacity, motility, and temperature. EC indicates the degree of mineralization of the water, which varies according to the quantity of dissolved salt, and is frequently influenced by temperature, which affects salt dissolution in water (Benrabah et al., 2016). The EC value should not exceed 1500 S/cm, according to Ghana Standard Authority and WHO guidelines (WHO 2018; GSA, 2017). With increasing human activities and disposal of waste effluent into Muni Lagoon and its tributaries, ions in domestic wastewater due to bathing and washing, as well as ions carried by runoff from agricultural fields in the area, may increase the levels of conducting ions in water resources, thereby elevating EC values.

The health of the water body and its accompanying biota may deteriorate as a result of a discharge or other disturbance if there are significant changes in conductivity that exceed 1500 S/cm. Generally, human activity increases the number of dissolved particles entering streams, thereby increasing conductivity. Conductivity also displays the existence of dissolved ions and monitors

salinity, which has a significant impact on water flavour. Higher ionizable salts in water cause high electrical conductivity (Jain & Agarwal, 2012), which inhibits seed germination in plants, resulting in decreased agricultural yields (Kumar & Kumar, 2013).

2.1.3 Total Dissolved Solids (TDS)

Total dissolved solids, which are expressed in mg/L, are the number of mobile charged ions, such as salts, minerals, or dissolved metals, in a given volume of water (Gebresilasie et al., 2021). The Total dissolved solids (TDS) include substances such as magnesium, phosphate, sodium, bicarbonate, sulphate, calcium, nitrate, and organic ions that have dissolved in water (Rameshkumar et al., 2019). These minerals may impart an unappealing flavour and diluted colour to water. This is a crucial standard for water use. A high TDS value in water indicates that it has been severely mineralized.

TDS is recommended for consumption, with a maximum allowed of 1000 mg/l and a preferable limit of 500 mg/l (WHO, 2018). The potential effects of consuming water with high TDS on health are not well understood. Early epidemiological research indicated that low TDS in drinking water may have positive effects, even though only a few studies have reported on its detrimental effects. Consumers typically accept water with TDS levels under 1000 mg/litre, though this differs depending on the circumstances (Meride & Ayenew, 2016; WHO, 20018).

Consumers dislike the taste of high TDS water, and it creates excessive scaling in heaters, boilers, and household appliances. Also, extremely low TDS presents an unpalatable taste to consumers due to its insipid flavour (WHO, 20018). The dissolved solids cause water to be toxic through elevated salinity and changes in ionic composition. Salinity increases have been proven to reduce biodiversity, alter biotic ecosystems, exclude species that are less tolerant to salt, and have acute or chronic consequences at particular life stages (Weber-Scannell et al., 2007).

2.1.4 Total Suspended Solids (TSS)

The quantity of solid particles present in a specified water volume is known as total suspended solids. TSS measures all suspended solids, including organic and inorganic materials. According to Rügner et al. (2013), TSS is a measurement of the total solids in a body of water and takes settleable solids into account. TSS are good markers of the physical and aesthetic decline of surface water quality, as well as other contaminants. High TSS concentrations in water are linked to a reduction in photosynthetic activities due to obstructing the passage of sunlight by particles, as well as the movement of contaminants like mercury, hydrophobic organic compounds, and phosphorus (Rügner et al, 2013).

TSS can deplete dissolved oxygen (DO) by raising surface water temperature due to greater solar energy absorption by particulates (Naveedullah et al., 2016). Higher levels of suspended solids (SS) can impact fish and invertebrates' reproduction (Naveedullah et al., 2016). TSS also serves as a breeding ground for dangerous microorganisms and has been linked to bacterial contamination (Henning et al., 2014). TSS has no recommended value according to the WHO or the GSA. Suspended solids in water, on the other hand, cause a variety of problems in the aquatic environment (de Oliveira et al., 2018).

2.1.5 Turbidity

The relative clarity or transparency of a liquid is measured by its turbidity, which also serves as a sign of the water's light-scattering and light-absorbing properties (Oboh & Agbala, 2017). It is brought on by silt and other suspended particles in the water. Particulate matter includes sediment, especially fine organic and inorganic debris, clay and silt, algae, soluble coloured organic compounds, and other microscopic creatures. It changes the colour of water and encourages microbial multiplication, lowering the water quality (Olumuyiwa et al, 2012). Higher turbidity is

associated with wet seasons, whereas lower turbidity is associated with dry seasons, and it is mostly brought on by silt deposition into the aquifer (Oluyemi et al., 2014). The permissible guideline for turbidity according to WHO (2018) is 5 Nephelometric Turbidity Units (NTU). The visual value of lakes and streams can be diminished by high turbidity, which reduces options for recreation and tourism. The price of treating water for use in food processing and drinking has the potential to increase. It can harm fish and other aquatic species by decreasing the available food, destroying breeding grounds, and interfering with gill function.

Turbidity may obstruct the filtration of water during water treatment by prematurely fouling the filter. Also, it can impair the efficacy of chemical disinfection by creating oxidant demand, UV irradiation by inhibiting light transmission, and both by giving protection to bacteria in aggregates or within other particles (Soros et al., 2019).

2.1.6 Alkalinity

Alkalinity describes a solution's capacity to neutralize acids to the carbonate or bicarbonate equivalence point (Boyd, 2016). The stoichiometric summation of the bases in solution, HCO_3^-, CO_3^{2-}, and OH^-, determines the alkalinity. The amount of each is determined by the pH of the water; lower pH favours HCO_3^-, while higher pH favours a transition from HCO_3 - to CO_3^{2-} to OH^-. Increased alkalinity can suggest that the system is recovering from its acidity. The main source of bicarbonates, which are responsible for alkalinity in natural streams, is the partitioning of CO_2 from the atmosphere and the weathering of carbonate minerals in rocks and soil. Various weak acid salts that are typically present in trace amounts include borate, silicates, ammonia, phosphates, and other organic bases.

The most common source of alkalinity is the weathering of carbonate minerals, which is why it is expressed in mg/L $CaCO_3$. Alkalinity measurements are used to assess the estuary's capacity to neutralize acidic pollutants from rainfall or wastewater. If a body of water lacked this ability to neutralize acids, any acid added to it would result in a quick change in pH. The buffering capacity of water is vital to support aquatic life. The capacity of the estuary to neutralise acids will differ between the freshwater reaches and the salinity-higher regions (Voluntary Estuary Monitoring Manual, 2006). According to Omer (2019), water with good buffering action protects fish and other aquatic organisms due to sudden changes in pH and lessens a water's vulnerability to acid rain. In a related investigation, the mean alkalinity value was 1057.14 ± 499.52 mg/L, with ranges between 400 and 2000 mg/L (Apau et al., 2012). They added that Na^+ dominance is required for significant HCO_3^- alkalinity to occur.

Alkalinity impacts water quality by giving a bitter taste to water and can cause skin and eye irritation in humans when present in significant amounts (Buridi & Gedala, 2014). It also alters the colour of water, rendering it unsafe for consumption. Scale (lime) development in plumbing can be exacerbated by water with high alkalinity (more than 150 mg/L). The lower the alkalinity, the more corrosive the water will be (WHO, 2008). The allowable level set by the GSA (2017) and the WHO (2018) is 150 mg/L.

2.1.7 Chemical Oxygen Demand (COD)

Chemical oxygen demand is the amount of (dissolved) oxygen needed to oxidise and stabilise the sample solution (Saleh & Kayi, 2021). It determines the amount of oxidizer organic and inorganic matter in a given water sample (Mortada et al., 2023). The amount of oxygen required to break down contaminants in the water is measured by chemical oxygen demand. The COD is a frequently used indication of how easily organic and inorganic substances oxidize in water bodies, sewage

effluents, and industrial unit effluents. The COD test is non-specific since it cannot distinguish between organic and inorganic oxidizable materials. Similarly, because some organic molecules are not oxidised by the dichromate technique, but some inorganic compounds are, it does not show the total organic carbon present (Hur & Cho, 2012).

2.1.8 Biochemical Oxygen Demand (BOD)

The Muni Lagoon and its tributaries are surface water bodies that are polluted from both point and non-point sources. Some of these pollutants are organic, while others are inorganic. In water, microorganisms are responsible for the breakdown of organic compounds in water and so estimating the BOD of Muni lagoon and its tributaries is essential to assess organic contamination. The biological oxygen demand (BOD), also known as biological oxygen need, is the quantity of dissolved oxygen required (i.e., demanded) by aerobic biological organisms to break down organic material present in a given water sample at a particular temperature during a given time (Li & Liu, 2018). BOD is the measurement of the strength of the waste since it is related to the amount of organic matter in water. It is a frequently used indicator that represents the level of organic contamination in wastewater and is used for monitoring water quality, pollution control, and water management. The more harmful the pollution, the greater the BOD value.

The 5-day biochemical oxygen demand (BOD_5) is the most widely used method for calculating the quantity of oxygen required for aerobic bacteria to break down organic matter in wastewater over five days at a constant temperature of 20°C (Pisarevsky et al., 2005). High BOD levels are caused by the rapid decomposition of biodegradable organic waste and the associated loss of dissolved oxygen in water-quality bodies (Hur & Cho, 2012). According to Ansah et al. (2011), the release of excessive amounts of organic matter into surface waters may cause a considerable

reduction in oxygen levels, which will cause fish and other oxygen-dependent aquatic or marine creatures to perish.

A high BOD in a water sample implies a high level of organic materials. In research by Abdullahi et al. (2021), samples taken from areas near livestock farms had elevated BOD concentrations. This might be because animal wastes and manure disintegrate and seep into neighboring water sources, lowering dissolved oxygen levels and raising BOD levels. In their investigation, Abdullahi et al. (2021) reported a BOD level of 7.99 mg/L. This score indicates that there are 7.99 mg/L of biodegradable organics in water, which can be broken down by microbes. A high BOD value indicates that the quality of water is low (Bertelkamp et al, 2014). As a result, larger values imply more microorganisms and a lower dissolved oxygen value. Furthermore, a higher BOD number indicates poor water quality.

2.1.9 Total Iron, Fe^{2+} and Fe^{3+}

Apart from Aluminum, iron is the next element abundant in the earth crust. Iron is the major constituent of many igneous and sedimentary rocks. In solid states, oxides and sulphides of iron are common since the ions of Fe^{3+} and Fe^{2+} combine readily with oxygen and sulfur compounds (Yilmaz et al., 2017). Iron (II) salts are unstable in water and quickly change into the insoluble iron (III) hydroxide that gives water its reddish-brown colour. Such water becomes objectionable to consumers and has the potential to stain sinks as rust-coloured silt. The suggested limit for iron in water is 0.3 mg/l (ppm), which is established on appearance and taste instead of health effects. Iron is a vital trace metal in living organisms (WHO, 2018).

Iron-containing water encourages the growth of iron bacteria, which get their energy from oxidizing ferrous iron to ferric iron. Water containing more than 0.3 mg/L can discolour clothing and plumbing fixtures (WHO, 2018).

Also, Iron is necessary for the production of several enzymes, including those that create myoglobin and haemoglobin, and its absence results in anaemia and a decline in well-being. However, it leads to serious health issues in people, like infertility, heart disease, liver cancer, diabetes, and liver cirrhosis (Kumar et al., 2017). Rivers may become contaminated with iron naturally or as a result of domestic and industrial wastes (Kumar et al., 2017).

2.1.10 Calcium

Calcium in water at high concentrations is mainly due to the dissolution of limestone, calcite, gypsum, and dolomite minerals. Calcium Aluminosilicate decomposition also releases calcium in drinking water, but occurs in smaller quantities. Calcium is one of the essential nutrients for human and animal growth. It supports the formation of strong teeth and bones, resulting in the reduction of bone fractures. People who ingest enough calcium have a lower chance of developing high blood pressure (WHO, 2018). People with insufficient calcium in their bodies are more likely to develop hypertension and stroke, nephrolithiasis (kidney stones), insulin resistance, coronary artery disease, and obesity. Because of its buffering abilities, calcium in the form of calcium hydroxide helps to keep the pH of water stable. The maximum calcium concentration that can be tolerated is 200 mg/L (WHO, 2018).

The amount of calcium in the water can optimize the body ability to absorb it. Water is frequently drunk throughout the day. According to epidemiological studies, there is a negative relationship between water hardness and cardiovascular mortality as well as hypertension (Yousef et al., 2019).

Calcium and magnesium are the main minerals that affect the hardness of water. However, the health of humans benefits from these minerals (Thomas, 2010; Rapant et al., 2017).

Apart from the natural source of Ca contamination in rivers due to the dissolution of limestone and other minerals, effluents from industries and domestic wastewater, which are discharged into rivers, contribute to high Ca levels. For instance, Erkan and Engin (2019) reported that paper recycling mills use high amounts of calcium carbonate and discharge water that contains high calcium ions.

2.1.11 Magnesium

Magnesium is found naturally in minerals like epsomite, magnesium limestone, and magnetite. The dissolution of these minerals liberates magnesium in water. Water usually contains more calcium than magnesium since magnesium is less both in terms of both abundance and quantity. In surface waters, magnesium aluminosilicates can decompose to release magnesium into solution. Magnesium is an important nutrient required for the proper functioning of the body. For instance, it serves as a cofactor for more than 350 enzyme reactions; many are used for energy metabolism as well as in the synthesis of nucleic acids and proteins (Kožíšek, 2003). Magnesium levels in humans can be influenced by water consumption. When drinking water containing higher amounts of magnesium and sulfate is consumed (usually above 250 ppm) possible laxative effect may be experienced by consumers (WHO, 2018).

Epidemiological studies indicated a relationship between hypertension and cardiac disease with the intake of “soft water”, less magnesium consumption, and protection against cardiovascular disease with a high intake of “hard water”, which contains a higher concentration of magnesium

(Geleijnse *et al.*, 2005; Rapant et al., 2017). There is no health-based quantity for the consumption of Magnesium since scientists have not recorded any hazard related to magnesium toxicity. Like calcium, magnesium contributes to water hardness. The WHO (2018) maximum guideline value for magnesium contaminant level is set at 150 mg/l. Magnesium in hard water is renowned for its cardioprotective properties, particularly in the prevention of malignant arrhythmias and coronary vasospasm, which can lead to sudden cardiac death. Magnesium also aids in preventing stroke, preeclampsia, metabolic syndrome, diabetes, hypertension, and other chronic diseases (Tamboli et al., 2011). Even a small dose (6 mg/L) can prevent cardiovascular mortality due to its potency (Tamboli et al., 2011; Rapant et al., 2017).

Magnesium and calcium in water from Pratu and Ntakofa Rivers used for drinking are necessary for human health. A significant portion of bones and teeth is made of calcium. Additionally, it affects heart and muscle contraction, the normal operation of the conducting myocardial system, neuromuscular excitability (i.e., lower), intracellular information transmission, and blood coagulability (WHO, 2018). Magnesium is essential for about 350 enzymatic processes, including glycolysis, ATP metabolism, potassium, sodium, and calcium transport across membranes, the synthesis of proteins and nucleic acids, neuromuscular excitability, and muscle contraction (WHO, 2018).

2.1.12 Sulphates

Sulphate contaminates natural water systems when industrial wastes from mining, wood preservation, and acid rain are introduced to them. Karabacak et al. (2020) stated that gypsum ($CaSO_4 \cdot 2H_2O$), barium sulphates ($BaSO_4$), and epsomite ($MgSO_4 \cdot 7H_2O$) are major sulphate

sources in water upon dissolution. Fertilizers and natural sources, such as volcanoes, also contribute to sulphate presence in the water. Sulphates can impair the taste of drinking water when the concentration is very high and can be noticed by consumers. At such levels, the laxative effect can be experienced by unaccustomed people who drink the water. The WHO (2018) defined the aesthetic sulphate value at 500 mg/L, but the threshold concentration for sulphate to become detectable in drinking water is 250 mg/L (WHO 2018).

According to Prascal et al. (2006), magnesium sulphate ($MgSO_4$) is high in seawater, and this might be due to the dissolution of sulphate salts in water naturally. In addition, the discharge of domestic and Industrial waste also influenced the sulphate concentration in Muni Lagoon. In a similar study, according to Apau et al. (2012), residential wastewater that enters the Kpeshi Lagoon is the main source of pollution. They observed that the lagoon's sulphate concentration ranged from 7820 to 16598 mg/L. The discharge of detergents and soap water into water bodies from adjacent communities is to blame for the high quantities of sulphate in the water (Njoku et al., 2015).

When a higher amount of sulphate is taken by dietary absorption, the levels of methaemoglobin and sulphaemoglobin in human and animal bodies are altered, causing dehydration, diarrhoea, and catharsis. (Sharma & Kumar, 2020). Drinking water should have a sulphate concentration below 500 mg/L since there is a likelihood of causing a purgative effect in humans at levels above this value. On the other hand, the natural background sulphate levels in the majority of water sources are consistently quite low, ranging from 0.1 to 10 mg/l. According to research by Dorleku et al. (2019), sulphate concentrations in the Pra basin were between 1.60 and 96.2 mg/L, which was less

than the WHO's recommended limit of 250 mg/L. Dehydration, gastrointestinal discomfort, and catharsis are a few unfavourable physiological outcomes of excessive sulphate ingestion. Additionally, too much sulphate can increase water hardness and corrode drinking water distribution systems. Sulphate in water may be converted to H_2S in anaerobic conditions, which gives the water source an unpleasant egg smell (WHO, 2018).

2.1.13 Nitrate and Nitrite

Nitrate and Nitrite are most commonly identified in the environment. They usually contaminate groundwater and surface water. The oxidation of nitrogen by microorganisms releases nitrate and nitrite naturally into the environment. Lightning, to a minor extent, produces nitrate. Human activities that can introduce these substances into water bodies include wastewater treatment, agricultural activities, and waste discharges from industries (Health Canada, 2013). Nitrate leakage into rivers was caused by increased agricultural productivity, animal manure application, and sewage sludge effluent (Apau et al., 2012).

Nitrate is a widespread pollutant present in both groundwater and surface water that can cause major health problems if taken in large quantities. Nitrate has no colour, odour, or flavour. Natural nitrate levels can be tolerated, but excessive amounts can damage surface and groundwater. Some of the most frequent sources of nitrate in surface and groundwater are fertilizers, livestock manure, and human waste from septic and municipal wastewater systems. The most frequent locations for high nitrate in soil are rural and agricultural areas (Sahoo et al., 2016).

Nitrates are more stable and can be reduced by certain microbes to produce nitrites, which can pose health threats to humans. Nitrite ions present in water constitute a primary toxicity to humans. Methaemoglobinemia, which occurs through the oxidation of normal haemoglobin in the presence of these elements to produce methaemoglobin, is of health concern, especially to children (WHO, 2018). As a result, the blood's ability to carry oxygen to the body's tissues is compromised. Cyanosis, stomach and colo-rectal cancer, and asphyxia are more severe disorders brought on by nitrate intoxication (Uba & Aghogho, 2001). Nitrite-nitrogen has a limit of 1 mg/L (equal to 3 mg/L nitrite ion), while nitrate-nitrogen has a recommendation value of 10 mg/L (corresponding to 50 mg/L nitrate ions) (WHO, 2018).

2.1.14 Phosphates

Phosphorus as an element exists in nature as Phosphate, and it is abundant in a lot of phosphate minerals like hydroxyapatite and fluoroapatite. In geology, phosphate is known as a rock or ore that contains phosphate ions. Mined phosphate ores are mainly used to manufacture fertilizers, animal feed, and industrial applications like detergents (Smit et al., 2009). The dissolution of phosphate minerals in water bodies, as well as anthropogenic influences like agricultural activities, industrial activities, home sewages, runoff from animal feedlots and fields, affect the phosphate levels in water (WHO, 2018). Phosphates are an important nutrient for plant growth, but their presence in water bodies, even in small quantities, leads to algal bloom (Ohio EPA, 2018).

The promotion of eutrophication in water by phosphate ion discharge offers serious environmental problems. The three kinds of phosphorus that are available are orthophosphate, polyphosphates, and organic phosphorus (associated with organic molecules). Orthophosphate can be precipitated using chemical techniques. After biological processing, orthophosphate can be produced from

organic phosphorus and polyphosphates. There are many points and non-point sources of phosphate contamination in groundwater. Natural processes that break down rocks and minerals, erosion and sedimentation, agricultural runoff, and direct animal or wildlife input are examples of non-point sources. Sewage effluents and industrial discharges are examples of point sources (Singh, 2016).

In most aquatic bodies, phosphorus is acknowledged as the limiting nutrient. Thus, preventing eutrophication and maintaining water quality requires reducing phosphorus intake (Holman et al., 2008). A small amount of phosphorus may encourage the growth of algae and aquatic plants, causing the water system to become eutrophic (Suteja & Purwiyanto, 2018). Also, large amounts of phosphate in surface water can lead to eutrophication (Braga et al., 2022). According to the WHO (2018) guideline for water, a phosphate level of 0.5 mg/L is appreciable.

2.1.15 Chlorides

One of the minerals that contributes largely to the presence of chloride in the earth crust is halite (NaCl), formed mainly from the evaporation of seawater. Other salts that contribute to chloride ions in small quantities are potassium chloride (KCl) and calcium chloride ($CaCl_2$). The dissolution of these salts in water generates chloride ions in the water. Human waste, agricultural fertilizers, and industrial discharges also introduce some chloride ions in varying degrees into water bodies. The sources of chloride in surface and groundwater include run-off, which includes landfill leachates, road de-icing salts, the use of inorganic fertilizers, septic tank effluents, irrigation drainage, animal feeds, industrial effluents, and seawater intrusion in coastal areas (Omer, 2019).

Chloride is not poisonous to humans, but at high chloride content, it can impart a salty taste and cause corrosion problems. Also, there is an increased cost of treating water with elevated concentrations of chloride ions (Kelly *et al.*, 2012). Most vegetation along water bodies, as well as some aquatic life, becomes damaged when the amount of chloride ions in surface water exceeds a low concentration of 210 mg/l (Kaushal *et al*., 2005).

The potability of water would be severely harmed if the chloride concentration were greater than 600 mg l/L. This is the maximum concentration that can be found in drinking water. Groundwater chloride levels ranged from 80 to 7400 mg/L, indicating saline water (Hosseinifard & Aminiyan, 2015). Chloride ions in drinking water have no known health risks, but excessive quantities can give most people a salty taste. People are normally unaffected by chlorides; however, the sodium component of table salt has been linked to renal and heart illness (Omer, 2019). This suggests that when the levels of chloride ions in Pratu and Ntakofa Rivers are high, their taste is likely to be salty and pose renal health problems to consumers. In the paper industry, Chlorine used for bleaching pulp generates enormous toxic chemicals as it utilizes chlorine for brightening the pulp. This activity also increases the concentration of chloride ions in paper mill effluent discharge (Shankar Singh & Tripathi, 2020).

2.1.16 Potassium

Potassium makes up 2.59 percent of the planet's crust, and it is the seventh most abundant element on Earth. It is extremely reactive and does not form naturally as a free metal (Burkhardt & Brüning, 2002). However, potassium can be introduced into water bodies like Pratu and Ntakofa Rivers naturally through weathering of rocks and from anthropogenic sources like wastewater discharges.

Potassium has a crystal structure, is thermally and electrically conductive, and oxidises quickly in damp air. It has a melting point of 63.5 degrees Celsius, a boiling temperature of 759 degrees Celsius, and a density of 0.89 grammes per cubic metre at 20 degrees Celsius (Lide, 2004). Potassium in water from Pratu and Ntakofa Rivers is necessary for humans when ingested at normal levels, but at high concentrations in drinking water, it can be harmful to health. Potassium can be found in a variety of places in the environment, including natural waterways. Other potassium sources of contamination include agricultural non-point sources and industrial sewage discharges (typically point sources), both of which are more easily controlled through monitoring (Myers & Ludtke, 2017).

Potassium supports the body's proper functioning and includes protecting the heart, regulating blood pressure, muscle contraction, protein dissolution, and nerve stimulus, among other things. On the other hand, persons with kidney disease or other conditions, including coronary artery disease, diabetes, heart disease, hypertension, or who are taking drugs that interfere with the body's normal potassium management, may experience negative health effects from increased potassium exposure (Arega, 2020). The WHO (2018) regulations state that 12 mg/L of potassium is the maximum amount that should be present in water. Arega (2020) found that potassium levels in water samples ranged from 20.83 to 27.51 mg/L, and that all of these values were above the WHO acceptable limit for potassium.

2.1.17 Sodium

Sodium is an abundant alkaline element found in large quantities in the crust of the earth. It can also be found dissolved in water in a variety of quantities due to its strong solubility. Most nations' water supplies have more sodium than that recommended by WHO (250 mg/L). Mineral deposits,

Saline intrusion, sewage effluents, ocean spray, and salt used in road de-icing are some of the different ways that water can get contaminated with sodium ions (Atiqah et al., 2017). Additionally, water treatment agents like sodium bicarbonate, sodium fluoride, and sodium hypochlorite can raise salt levels to as much as 30 mg/L when combined (Atiqah et al., 2017). Domestic water softeners can also cause salt levels to exceed 300 mg/L (WHO, 2018).

Sodium (Na) is an essential element needed for proper body function, including fluid regulation, nerve impulse transmission, muscle contraction, and relaxation. Consuming too much sodium raises blood pressure, which in turn increases the risk of cardiovascular illness, kidney disease, and bone demineralization (Austgen, 2006). Additionally, consuming too much sodium increases the risk of high blood pressure, stroke, and heart disease (Thompson et al., 2022).

2.1.18 Aluminium

The third commonly occurring metallic element, aluminum, makes up 8% of the earth crust (Fernandez-Davila et al. 2012). In the environment, it can be found as complexes, hydroxides, oxides, and silicates. A wide range of foods, as well as the air and water, contain aluminum. Due to the weathering of rocks and minerals, aluminum is naturally present in the environment (WHO, 2018). Anthropogenic discharges, which include air pollutants, wastewater effluents, and solid waste, are typically associated with industrial activities like the production of aluminum (Hart et al., 2021).

Aluminum is used in a variety of products, such as kitchenware, cans, food and drink packaging, dyes, baking powder and anti-acids, water purification techniques (Fernandez-Davila 2012), cosmetics, pharmaceuticals, paper, and herbicides (Schmitz 2006; Callister, 2007). Al in the water

may have come through inadvertent releases of coagulants made of aluminum during the process of purifying drinking water (Svobodova et al. 2008). $Al_2(SO4)_3$ and $NaAl(OH)_4$ are two examples of preparations that contain aluminum and are used to remove cyanobacteria from reserviours (Jancula et al., 2011). Based on physicochemical and mineralogical factors, the amounts of aluminum in natural streams can vary greatly. Near-neutral pH waters normally have dissolved aluminum concentrations of 0.001 to 0.05 mg/l, although more acidic or organic matter-rich waters can have values of 0.5–1 mg/l (Hart et al., 2021; WHO, 2018). This implies that the solubility of Al in water rises as the water's acidity rises. The WHO recommends 0.2 mg/L of aluminum in water (WHO, 2018).

Aluminium is regarded as a non-essential metal because it is not necessary for the survival of fish and other aquatic organisms. Aluminium concentrations above a particular point can hinder a species' capacity to regulate ions and restrict respiratory functions. Aluminium sensitivity is lower in aquatic plants than in fish and other aquatic organisms. Fish deaths following Al exposure are also related to an inflammatory response to Al-hydroxides, which involves excessive mucus production and disruption of O_2 and CO_2 diffusion (Slaninova et al., 2014). High levels of Al, according to Nilsen et al. (2010), can pose several risks to freshwater ecosystems. The researchers discovered that cationic Al species are hazardous to fish like Atlantic salmon (Salmo salar) as well as other aquatic species like molluscs, crustaceans, and amphibians in rivers and lakes (U.S. Environmental Protection Agency, 2018). Furthermore, high levels of Al in locations where people rely on groundwater for drinking water may cause human health problems such as Alzheimer's disease (Flaten, 2001), particularly in private household water wells where well owners are responsible for ensuring their water is safe to consume. Additionally, high Al concentrations in

water pose problems for water treatment facilities and increase the risk of dialysis encephalopathy in patients with chronic kidney disease (Health Canada, 2021).

2.2 Heavy Metals

2.2.1 Arsenic (As)

Arsenic (As) is one of the elements that belongs to the metalloid group. The non-metallic properties of arsenic dominate because it easily forms an anion. In an oxidation state of +5, arsenic resembles phosphorus, a fact that has implications for its reactivity with soil, as well as its possible toxicity. The other oxidation states of arsenic include −3, 0, and +3. The oxidation state of As in arsines and metal arsines is -3, and these forms are particularly unstable under oxidising circumstances. When the oxidation state of As reaches +5 under aerobic conditions and the pH is between 2 and 3, arsenic acid (H_3AsO_4) is produced. This molecule dissociates into $H_2AsO_4^-$ and $HAsO_4^{2-}$ when the pH rises to between 3 and 11 (Smedley & Kinniburgh, 2002).

Arsenicals are commercially and industrially used in making alloys, transistors, and lasers, as well as the processing of glass, textiles, pigments, metal adhesives, paper, and wood preservatives (WHO, 2018). A naturally occurring element in the earth's crust, arsenic (As), can be found in water, soil, rocks, and air (Singh et al., 2015). Because arsenic can be harmful to people, plants, and animals, its presence in water is a problem for the environment. Arsenic in drinking water at high levels harms public health (Shanker et al., 2021).

The environment is exposed to arsenic through both natural and artificial mechanisms (Chen & Costa, 2021). Volcanoes and eroded arsenic-bearing rocks, including lollingite (FeAs2), orpiment

(As_2S_3), realgar (AsS), and arsenopyrite (FeAsS), are typical examples of arsenic natural sources (Saha & Rahman, 2020), whereas agriculture, livestock, and industrial activities are examples of anthropogenic sources. Arsenic is known to be released into the environment by smelting iron ores, pulp and paper production, fuel burning, mining, cement production, and waste disposal (Adeloju et al., 2021).

Cancer risks are among the negative impacts of inorganic arsenic exposure on people. Skin illnesses such as melanosis (hyperpigmentation), leuco-melanosis, keratosis, and hyperkeratosis are also typical side effects of drinking arsenic-contaminated water (Tchounwou et al., 2019). In addition, chromosomal abnormalities, diabetes mellitus, heart failure, cirrhosis, goitre, gangrene, hypertension, myocardial degeneration, peripheral neuropathy, liver enlargement, and skin malignancies are also health effects of arsenic intake (Yunus et al., 2011). Additionally, areas where arsenic-contaminated water is used have been associated with an increase in foetal loss and newborn deaths (Sohel et al., 2010). Arsenic contamination of vegetables and rice grains due to irrigation and soil is another impact (Rahman & Hasegawa, 2011). Arsenic's phytotoxic effects, on the other hand, might result in a significant drop in agricultural production (Adeloju et al., 2021). The allowable quantity of arsenic in the surface water is 0.01 mg/L, according to WHO (2018) and GSA (2017).

2.2.2 Boron (B)

In its impure state, boron is an amorphous yellow or brown powder that exists as a solid at room temperature in the form of monoclinic black crystals. Boron has specific gravities of 2.37 for its amorphous form and 2.34 for its crystalline form. Boron is a relatively harmless metalloid, save for situations where it is subjected to strong oxidizing agents. Sodium perborates are hydrolytically

unstable persalts because they have characteristic boron-oxygen-oxygen links that react with water to form hydrogen peroxide and stable sodium metaborate.

Boric acid and borates are used in the production of glass (e.g., borosilicate glass and fiberglass), flame retardants, soaps and detergents, cosmetics, and mild antiseptics. Pharmaceuticals, boron neutron capture therapy, agricultural fertilisers, and pesticides have all used borates, boric acid, and perborates (Perez, 2018). Soils and sediments can absorb waterborne boron. The sole significant mechanism determining the fate of boron in water is likely to be adsorption–desorption processes. The amount of boron adsorption is determined by the pH of the water as well as the amount of boron in the solution (WHO, 2018).

The body absorbs boron through the skin, respiration, and nutrition (especially damaged skin). The full scope of Boron's role is not yet known. It has been demonstrated that boron has positive effects on the human skeletal system's calcium-phosphorus metabolism. Osteoporosis and bone decalcification are prevented by boron's promotion of the body's calcium uptake and retention (Miggiano & Gagliardi, 2005). Along with aiding in the treatment and prevention of arthritis, boron supplementation also benefits cognitive function and psychomotor response.

The health of people could be harmed by too much boron (Bialek et al., 2019). The permissible upper intake levels (UL) of boron are 3, 6, 11, and 17 mg/day for children ages 1-3, 4-8, 9-13, and 14-18 years, respectively. The daily UL for adults is 20 mg/day (Bialek et al., 2019). The daily consumption of this nutrient, which does not pose a threat to the general public's health, is known as the upper boron intake level. The acute lethal dose of boron for humans is 0.4–0.9 g/kg body weight (Bialek et al., 2019). Borax levels of 0.3 mg/L were deemed safe by the World Health Organization in its second edition of "Guidelines for Drinking Water Quality" (WHO, 1993). The

WHO has recommended that the previously agreed maximum of 2.4 mg/L for the amount of boron in drinking water be modified (WHO, 2018).

2.2.3 Barium (Ba)

Alkaline earth metal barium is categorized under Group IIA on the periodic table. Its silver-white colour changes to silver-yellow when it is exposed to air. Barium as an element does not exist as a unit in nature but occurs as compounds with other elements. The principal ore deposits are witherite (barium carbonate) and barite (barium sulfate). Barium compounds are also present in igneous and sedimentary rocks (USEPA, 2005; ATSDR, 2007).

Ore deposits of barium compounds found in nature are mostly barium sulphate and barium carbonate. Groundwater sources may be contaminated by the leaching and erosion of natural deposits. Mined barium sulphate ore is used in a variety of industries. It's mostly used in the oil and gas industry to manufacture drilling muds, which keep the drill bit lubricated and make drilling through rock simpler. Glass, Paints, tiles, bricks, and rubber are some of the manufactured products made with barium sulphate (Verbruggen et al., 2020). Barium compounds, such as barium chloride, barium carbonate, and barium hydroxide, are raw materials used to make ceramics, oil and fuel additives, sugar refining, insect and rat poisons, sealants, barium greases, papermaking, and the preservation of limestone artifacts. They are also used to treat boiler water and produce sealants. Barium sulphate is occasionally used by doctors to conduct diagnostic procedures and obtain X-ray images of the intestines and stomach (USEPA, 2005).

Barium is not regarded as a necessary component of human nutrition. Barium induces vasoconstriction by directly stimulating the arterial muscle, peristalsis by violently stimulating

smooth muscles, paralysis, and convulsions by stimulating the central nervous system at high concentrations. Between 3 and 4 g is the acute hazardous oral dosage (WHO, 2018). Following oral exposure to soluble barium salts, many case reports show gastroenteritis, hypokalemia, severe hypertension, cardiac arrhythmia, skeletal muscular paralysis, and death (USEPA, 2005). In surface water, the recommended value for barium is 0.7 mg/L. (WHO, 2018).

2.2.4 Cadmium (Cd)

The permanence and toxicity of cadmium in surface water, such as Muni Lagoon and its tributaries, pose a serious environmental risk. It is chemically related to zinc and occurs in nature as a sulphide with zinc and lead. Cadmium3 is mostly utilised as an anticorrosive that is electroplated onto the steel. In polymers, cadmium sulphide and selenide are often employed as pigments (WHO, 2011). A significant contributor to environmental cadmium contamination is fertilizers manufactured from phosphate ores. Cadmium's solubility in water is greatly influenced by its acidity; when acidity increases, cadmium that is suspended or attached to sediment may dissolve.

Cadmium is a persistent source of pollution because it is utilized as a corrosive reagent in industry and as a stabilizer in PVC products, Ni-Cd batteries, and color pigments (Genchi et al., 2020). Burning fossil fuels, the use of phosphate fertilizers, and the smelting and refining of metals (e.g., copper and nickel) are all examples of anthropogenic sources of Cd in the environment. Cadmium is a pollutant that is also discovered in electronic waste recycling and nonferrous metal smelters. The increase in Cd levels in the living environment (atmosphere, soil, and water) has been caused by several processes, including volcanic activity, the increasing erosion and abrasion of rocks and soil, and forest fires (Casado et al., 2008).

The organ that is most susceptible to long-term oral cadmium exposure seems to be the kidney. Cadmium disrupts the proximal tubules' ability to perform resorption, which results in tubular

proteinuria, or an increase in the excretion of low-molecular-weight proteins from the urine. Chronic anemia may arise from long-term exposure to cadmium-contaminated drinking water (Cd). Under these circumstances, Cd builds up in the kidney, increasing the risk of cancer and cardiovascular disease (Burke et al., 2016).

Cadmium (Cd), as a non-essential transition metal, is toxic and threatens the health of living organisms in the environment (Genchi et al., 2020). It is an environmental pollutant that originates from both industrial and agricultural sources. The primary routes of cadmium absorption are through the consumption of contaminated food and beverages, as well as, to a lesser extent, inhalation and cigarette smoking. Cadmium has a lengthy half-life of roughly 25 to 30 years and accumulates in both plants and mammals. Epidemiological studies suggest that exposure to cadmium at work and in the environment may increase the risk of developing cancers of the pancreas, lungs, breast, nasopharynx, kidneys, and prostate. The presence of cadmium in the environment has also been linked to an increased risk of osteoporosis. The kidneys and liver are particularly vulnerable to the damaging effects of cadmium. This may be because these tissues are capable of producing metallothioneins (MT), Cd-inducible proteins that protect cells by tightly binding potentially damaging cadmium ions. Oxidative stress brought on by this xenobiotic may contribute to several liver and kidney illnesses. Given that these organelles are crucial in the production of reactive oxygen species (ROS) and are one of the main intracellular targets for cadmium, mitochondrial injury is a real concern (WHO, 2016).

Cd is typically absorbed through the respiratory system and, less rarely, through the digestive system and gastrointestinal tract. According to Tinkov et al. (2018), cadmium enters the body through erythrocytes and albumin, travels to the bloodstream, and then builds up in the kidneys,

liver, and gut. During nursing, cadmium is gradually eliminated from the body through the kidneys, urine, saliva, and milk. In humans, exposure to Cd can lead to several adverse effects, including kidney and liver damage, pulmonary emphysema, testicular injury, osteomalacia, and harm to the adrenals and hemopoietic system (Tinkov et al., 2018). Additionally, a connection was found between the blood and urine Cd exposure markers and peripheral artery disease, coronary heart disease, stroke, and aberrant lipid profiles. Cadmium is a human carcinogen and has cytotoxic effects that can result in apoptosis or necrosis. According to Mezynska and Brzóska (2018), exposure to cadmium in the workplace or environment has been associated with malignancies of the lungs, breast, prostate, pancreas, urinary bladder, and nasopharynx. A Cd level of 0.003 mg/l is advised by the WHO (2018) and GSA (2017).

In various studies, the presence of cadmium in Ghana's water bodies has been proven. Water samples from Nangodi had cadmium values ranging from 0.001 to 2.227 mg/L with a mean of 0.534 ± 0.088 mg/L, while those from Tinga had concentrations ranging from 0.002 to 0.071 mg/L with a mean of 0.023 ± 0.008 mg/L (Cobbina et al., 2012). The average Cd levels at every monitoring site were above 0.003 mg/L for drinking water set by the WHO (2018). Mean river water cadmium levels at Apapam, Bunso, Kibi-Deaf, and Obronikrom, respectively, were found to be 0.006, 0.008, 0.008, and 0.010 mg/L in a similar study of artisanal gold mining villages in Ghana's Kibi traditional area (Asamoah-Boateng, 2009). Cd levels varied from below detection limits to 0.223 mg/L in the Nangodi watershed, but they varied from below detection limits to 1.700 mg/L in Datuku (Cobbina et al., 2013).

2.2.5 Chromium (Cr)

The earth crust contains large amounts of chromium (Cr), which has oxidation states ranging from +2 to +6. Trivalent (III) and hexavalent (VI) states are the most common in compounds. The trivalent state of Cr contained in soils and rocks is usually in small quantities (ATSDR, 2012). Refineries, nonferrous base metal smelters, urban stormwater runoff, leather tanning businesses, effluent streams from pulp and paper mills, and power plant discharges are all anthropogenic sources of Cr in the environment (Health Canada, 2016; Tumolo et al., 2020). Cr and its salts are also employed in the manufacturing of pigments and paints, catalysts, fungicides, ceramics and glass, photography, and the creation of chrome alloys and Cr metals, as well as chrome plating and corrosion control (ATSDR, 2012). Cr is also found in minor levels in rocks and soils, with some of it being released into groundwater as a result of weathering and erosion (Thompson et al., 2017; Health Canada, 2016).

In addition, Cr (VI) environmental contamination is receiving more attention, according to Brasili et al. (2020), because it is widespread throughout the world and has significant concentrations in water and soil as a result of natural and anthropogenic processes. Mines and metalworks, the production of steel and metal alloys, paints, the processing of wood and paper, dyeing, and the rise in the concentration of chromium in wastewater are just a few examples. Additionally, the manufacturing of second-generation fertilizers, waste byproducts from burning coal or municipal trash for energy, and other factors all contribute to the elevated Cr (VI) level in water and soil (Yang et al., 2020).

When chromium in hexavalent compounds is released into the environment, it is harmful to people, plants, animals, and microorganisms (Alemayehu et al., 2011). The dose, duration, and extent of exposure influence human health risk to a pollutant. Exposure to chromium for an extended period

can impair the eyes, blood, immune system, skin, and respiratory system, even in low quantities, such as those seen in the workplace (Zhang et al., 2014; Tumolo et al., 2020). On a cellular level, chromium's genotoxic effects result in DNA damage, oxidative stress, and other damage that might cause tumors (Wise et al., 2019).

The oxidation state of chromium has a significant impact on its health hazard (Bharagava & Mishra, 2018). Cr (III) is a trace element of nutritional significance that is both safe and challenging to absorb. Among the foods high in chromium are potatoes, broccoli, whole-wheat flour, garlic, basil, and mussels. Trivalent chromium enhances insulin function and receptor affinity, reducing the chance of developing diabetes (Shanker, 2019). Therefore, a lack of it results in problems related to glucose intolerance and glucose metabolism. Additionally, a trivalent chromium excess above the permissible level can be hazardous and carcinogenic over the long term (EFSA Scientific, 2010).

The most toxic form, Cr (VI), causes internal bleeding and respiratory issues in addition to harming the liver and kidneys. According to the International Agency for Research on Cancer, it is a human carcinogen (IARC, 2012; Tumolo et al., 2020). The air we breathe, the food we eat, or the water we drink can all introduce Cr (VI) into our bodies. Luckily, the body has areas and strategies for reducing Cr (VI) toxicity, which is connected to specific physiological fluid reduction processes. These routes involve a variety of tissues, including bronchial trees, blood epithelial lining fluid, pulmonary alveolar macrophages, saliva, intestinal bacteria, liver, stomach acid, saliva, and saliva (De Flora et al., 2016; Ray, 2016). The chromium intake limit proposed by the WHO (2018) and GSA (2017) is 0.05 mg/L.

2.2.6 Cobalt (Co)

Cobalt exists in several oxidation states, with +2 and +3 being the most common. However, the Co^{2+} form of cobalt is less reactive. Cobalt ions, such as Co^{3+}, react with a range of acids to generate salts. The natural environment contains large amounts of cobalt, and human activity can also produce cobalt. Sulfur and arsenic compounds are present in it in trace proportions. Welding, diamond tools, grinding, chemical catalyses, and nuclear power plants are just a few of the industrial applications for this element (Czarnek et al., 2015). Cobalt found in nuclear power plants is ^{58}Co and ^{60}Co. These two types of photons have high energy and can be utilised in radiation to treat tumours (Gault et al., 2010). In addition to being used to make industrial paints, cobalt is also used to make chemical catalysts, ceramics, and plant-based alloys (Czarnek et al., 2015). Pottery, ceramics, and glass all employ cobalt as a colourant. Excessive concentrations of these transitional metal ions, on the other hand, might be poisonous. Convulsions, for instance, have been linked to the salts of cobalt and nickel (Wright & Welbourn, 2002).

Excessive cobalt levels in the body can cause dermatitis, cardiovascular repercussions, thyroid damage, vision problems, heart problems, impaired lung function, and thyroid health issues (Dolara, 2014). Animal studies suggest that children may absorb more cobalt from food and drinks containing cobalt (ATSDR, 2004). Additionally, only a part of the cobalt ions are eliminated by urine; instead, they may enter the bloodstream and build up in the heart, kidney, liver, pancreas, lymphatic tissue, and spleen. This metallic debris may have direct toxicological impacts in the future (Khan et al., 2011). Co concentrations up to 0.05 mg/L can be used as a general guideline (WHO, 2018; GSA, 2017).

Khan et al. (2011) reported that the average Co content in water samples varied from 0.332 to 0.393 mg/L. They discovered that Co concentrations in water samples from Gulbahar were highest

(0.393 mg/L), while those from Tarnab were lowest (0.332 mg/L). The overall mean concentration of Co in these samples was 0.368 mg/L. Co concentrations differ between different localities. Cobalt in every sample was noted to be more than the permissible level of 0.05 mg/L (WHO, 2018).

2.2.7 Copper (Cu)

Copper is a trace metal that can be found in both monovalent (cuprous) and divalent (cupric) cations. It is malleable, ductile, and electrically efficient. It can be used for a variety of business purposes because of its versatility. Electrical cables, pipes, fittings, kitchen utensils, coins, valves, and construction materials are all made of copper. Copper compounds are employed in electroplating, azo dye production, and engraving, as well as in fungicides, algicides, insecticides, and wood preservatives. Copper compounds can be used as a nutrient in fertilisers and animal feeds to help plants and animals thrive (ATSDR, 2002).

Copper is necessary for optimal health and should be ingested in tiny amounts every day by everyone. Copper poisoning is a real possibility and can irritate your nose and throat when inhaled in large amounts. If taken in high amounts, copper can cause diarrhea, nausea, and vomiting, which can lead to poisoning. Extremely high quantities of copper can kill you by killing off your kidneys and liver (ATSDR, 2004; Taylor et al., 2020). Copper may be a tumour promoter through modulating oxidative phosphorylation, even though it is not regarded as a carcinogen (Taylor et al., 2020). Copper is recommended at 2.0 mg/L by the WHO (2018) and the GSA (2017).

Doamekpor et al. (2018) conducted a study in Sakumo II Lagoon, Chemu Lagoon, and Kpeshie Lagoon in Ghana and detected the presence of copper in these important water bodies. The Copper concentrations in the water samples ranged from Kpeshie, Chemu and Sakumo II lagoons were 2.87- 3.95 mg/L, 8.32-9.39 mg/L, and 6.10-6.84 mg/L, respectively, in the dry season. The wet

season had higher measured copper values than the dry season. They claimed that heavy metals like copper are naturally introduced into the environment through forest fires. The anthropogenic activities that contaminate the environment with heavy metals like copper include the discharge of untreated wastewater into water sources and the excessive use of fertilisers and pesticides. This shows that aquatic bodies like lagoons are susceptible to anthropogenic activities (Hering et al., 2010).

2.2.8 Manganese (Mn)

In the Earth's crust, manganese, a transition element, frequently coexists with iron. Despite not being present in nature in its pure (elemental) form, it is a component of over 100 minerals (ATSDR, 2012). There are 11 distinct oxidation states of manganese, with Mn^{2+}, Mn^{+4}, and Mn^{+7} having the most ecological and physiological significance. Manganese may produce a broad variety of complexes by reacting with other elements such as oxygen, sulphur, and chlorine, as well as carbonates and silicates (ATSDR, 2012).

Manganese can enter surface and groundwater naturally through the weathering of rock and soil, as well as through anthropogenic sources such as landfill leaching, industrial discharges, and mining operations. The pH of the soil and/or the water, the reduction potential of the water, and, to a lesser extent, the mineralogy of the soil, oxidative microbial activity, and the amount of organic matter all affect the kind of manganese ion in the soil (Ljung & Vahter, 2007). Fertilizers and ceramic glazes both include manganese compounds (ATSDR, 2012). Dry-cell batteries, fireworks, and glass all employ manganese dioxide and other manganese compounds.

Mn is required for action inside cells. All of the enzymes that use Mn as a cofactor are pyruvate carboxylase, arginase, glutamine synthetase (GS), and Mn superoxide dismutase (Mn-SOD). Mn is essential for several processes, including growth and development, digestion, reproduction, antioxidant defense, energy synthesis, immunological response, and modulation of neuron activity via metalloprotein. Because Mn is present in practically all meals, Mn deficiency is rare. On the other hand, Mn poisoning could be caused by excessive metal exposure. When levels are too high, Mn builds up in the brain, bones, kidneys, pancreas, liver, and other organs. Some of the molecular routes for Mn toxicity include abnormal autophagy, misfolded proteins, oxidative stress, endoplasmic reticulum stress (ER), mitochondrial dysfunction, and other metal homeostasis issues (Kim et al., 2002). Manganism is a sickness that occurs when Mn accumulates in the brain's basal ganglia area and causes symptoms similar to Parkinson's disease (Shakoor et al., 2018). Manganism can harm the brain if it is caused by prolonged Mn overexposure. Nerve damage in the cortex and subcortical brain, particularly the basal ganglia, causes manganism (Rawson et al., 2017; Agustina et al., 2020). The WHO (2018) and GSA (2017) have set a permitted limit of 0.4 mg/l for Mn in water.

Surface and underground water sources have both been discovered to contain manganese. Agustina et al. (2020) reported that the average Mn concentrations in drinking water in the Depok City neighborhoods of Bojongsari, Cipayung, and Sawangan were 1.20 mg/L, 1.35 mg/L, and 1.38 mg/L, respectively. Depok City's Mn values were 0.22 mg/L, with a range of 0.0015 mg/L and 82 mg/L (Anjani, 2019). Once more, breast milk was found to contain high levels of manganese (Klein et al., 2017).

2.2.9 Nickel (Ni)

The ferromagnetic metal nickel (Ni) has a high melting point. Although it can display oxidation states of +1, +3, or +4, it often forms a compound by donating two valence electrons. Metallic Ni is not harmed by water, but it is promptly harmed by nitric acid and slowly by weak hydrochloric or sulfuric acid. Alkali hydroxide fusion does not damage nickel. Many Ni salts, including acetate, chloride, nitrate, and sulphate, are water-soluble. In contrast, carbonates and hydroxides are not, and sulphides, disulphides, subsulphides, and oxides are almost insoluble (WHO, 2018). There is no characteristic flavor or aroma to Ni or its compounds. There were no standards for the taste or smell of Ni compounds in water (ATSDR, 2005).

Rocks containing nickel ore dissolve, allowing nickel to enter groundwater. Ni from metals in contact with drinking water, such as pipes and fittings, also leaches into the water. The majority of the time, Ni is used in alloys with other metals and nonmetals. Ni alloys have a variety of properties, including hardness, strength, heat resistance, and corrosion resistance. Ni and Ni salts are used for a variety of purposes, including electroplating, as catalysts, in Ni-cadmium batteries, in coinage, in welding supplies, and in some pigments and electronic components (WHO, 2018).

Nickel's nutritional importance in humans has not been acknowledged, even though it is an essential nutrient for several plants, microbes, and animals (Song et al., 2017). Nickel is essential for morphological and physiological processes, including seed germination and productivity, and aids in the growth and development of plants (Desguin et al., 2018). The metabolic processes of plants are altered by excessive nickel concentrations, which block enzyme activity, chlorophyll production, and photosynthetic electron transport (Sreekanth et al., 2013).

Numerous things, such as the usage of solid and liquid fuels in industry, municipal garbage, and industrial waste, can lead to nickel contamination. Several health issues, including kidney disease,

allergies, lung fibrosis, heart disease, and nasal cancer, can be brought on by nickel exposure. Despite the lack of knowledge of the molecular mechanisms underlying nickel-induced toxicity, oxidative stress and mitochondrial dysfunction are thought to be important contributors to the metal's toxicity (Genchi et al., 2020). In an effort to determine if nickel has the potential to cause cancer, researchers have revealed that epigenetic alterations brought on by exposure to nickel can disrupt the DNA (Genchi et al., 2020). Because nickel, like all other heavy metals, cannot be broken down by microbes, it builds up in the environment (soil, water, and air) and contaminates the food chain, endangering human health (Doamekpor et al., 2018). According to the WHO (2018) and GSA (2017), the maximum Ni concentration is 0.02 mg/L.

Nickel concentrations in the Mokwé lagoon varied from 0.010 to 0.066 mg/L, with a mean of 0.024 mg/L (Addo et al., 2012). The lagoon sediment has an average nickel content of 97.9 mg/kg. The dry season was found to have higher nickel contents than the rainy season in the Chemu and Kpeshie lagoons (Doamekpor et al., 2018). The researchers concluded that human activities in the catchment areas were responsible for the elevation of nickel concentrations in sediments and water. The nickel concentrations were all higher than 0.02 mg/L. (WHO, 2018; GSA, 2017).

2.2.10 Selenium

In the earth's crust, selenium (Se) is typically found alongside minerals that contain sulfur. It is a metalloid with properties between metals and non-metals. In the periodic table, it comes after sulphur within the same group (chalcogen) as oxygen (Okonji et al., 2021). Selenium is used in electrical and electronic applications and as a chemical in making paint, glass, and ceramics (Mehdi et al., 2013).

Selenium contamination is a growing environmental problem around the world and has been attributed to a variety of human activities, including farming and industrialisation (Das et al., 2017). Leaching from seleniferous soils causes selenium pollution in agricultural drainage runoff. Selenium concentrations in drainage water have been linked in large part to the irrigation of seleniferous soil. Selenium is commonly found in shallow wells near an irrigated area with selenium-rich soil (Seiler, 2003).

Aquatic organisms are largely exposed to selenium build-up through their feed and water (Khamkhash et al., 2017). Selenium can accumulate over time in the top layer of sediment as a result of deposition or sedimentation (particulate settling), or if it is dissolved, it can stay in a free solution. Aquatic organisms are active by nature, and they are always looking for food in the sediment. Selenium can be transported and absorbed into biota from sediment and stored at high concentrations for lengthy periods. Aquatic species can acquire selenium even if selenium is no longer present in the water (bioaccumulation of selenium) (Okonji et al., 2021). This means that the potential of organic selenium to bioaccumulate in the food chain is not invalidated by the presence of low concentrations of selenium, making it undoubtedly a problem for the ecosystem.

High quantities of selenium above the typical beneficial limit can cause acute and chronic selenium toxicity. Acute exposure can cause neurotoxicity, whereas long-term exposure can alter endocrine activities such as thyroid hormone production (Vinceti et al., 2014). To a considerable degree, the toxicological effects of selenium are determined by its oxidation states and diverse chemical forms. In general, selenium is more harmful than the homeostatic need, resulting in health problems such as prostate cancer, hepatic cancer, neurological or dermatological illnesses, hair loss, faulty skin and nails, and genotoxicity (DNA mutilation) (Santos et al., 2015). According to Okonji et al.

(2021), selenium for human physiological processes is between 63–135 g/L, and it is hazardous when this level is exceeded. At a daily dose of more than 800 g/day, symptoms of selenium toxicity were observed, while chronic poisoning caused selenosis. Selenium in surface water should not exceed 0.04 mg/L, according to WHO (2018) and GSA (2017) guidelines.

2.2.11 Lead (Pb)

The crust of the earth contains lead, a heavy metal. Among the many uses for lead are alloys, acid batteries, cable, solder, sheathing, ammunition, pigments, plastic stabilisers, and glazes. Because of their widespread use as antiknock chemicals in gasoline, tetraethyl and tetramethyl lead are essential, but their use, for this reason, has nearly been phased out (WHO, 2018). Ingestion or inhalation of contaminated dust, air, or food also exposes people to the environment; however, broad prohibitions on leaded gasoline and paint, as well as better food safety, reduce these risks (Brown & Margolis, 2012).

Health problems such as kidney disease, cancer, cardiovascular disease, hypertension, and poor reproductive outcomes have all been related to lead exposure (Rauh & Margolis, 2016; Chowdhury, 2018). When swallowed, lead can breach the blood–brain barrier and has been linked to irreversible neurodevelopmental damage, which is particularly dangerous in children and developing foetuses (Rauh & Margolis, 2016). The WHO (2018) Pb in water guideline standard is 0.01 mg/L.

Pb levels in the Sakumo lagoon fluctuated between 0.12 and 0.15 mg/L and 0.13 to 0.55 mg/L throughout the wet and dry seasons, respectively (Doamekpor et al., 2018). They proposed that the enhanced detection and presence of lead in the Sakumo II lagoon may be due to the flocculation of lead-containing effluents that were discharged into watercourses and then washed down into the lagoons.

2.2.12 Zinc (Zn)

Almost all igneous rocks contain trace levels of zinc. Sulphides like sphalerite and wurzite are the most common zinc ores (WHO, 2018). In general, nearly half of the zinc consumed is used to galvanise steel and protect it from corrosion. Additionally, zinc is utilized for coatings and as an alloying component in a variety of alloys, including those made from bronze, brass, aluminium, and magnesium. Zinc is also utilized as an oxide in the pharmaceutical, chemical, paint, rubber, agricultural, and cosmetics industries (Pola et al., 2020). Some of them are employed in the building sector to create, among other things, roofing, downspouts, gutters, flashlight reflectors, and lamp parts (WHO, 2018).

Zinc is a necessary nutrient whose significance for health is becoming better acknowledged and whose deficiency may contribute to the development of disorders. As a catalyst, structural ion, and regulatory ion, zinc is one of the most important trace elements in the body. Since free zinc is mostly regulated at the single-cell level, many of the proteins encoded by the human genome contain zinc-binding motifs. Significant diseases of public health concern are linked to zinc deficiency because zinc is necessary for homeostasis, immune function, oxidative stress, apoptosis, and aging (Pola et al., 2020). Zinc deficiency may worsen the clinical aspects of many chronic conditions, including various neurological disorders, atherosclerosis, cancers, age-related autoimmune diseases, aging Wilson's disease, and degenerative diseases (Chasapis, 2012). Drinking water contaminated with zinc can lead to gastrointestinal disorders, changes in gastrointestinal soft tissue, early atrial strokes, and high blood pressure (Sankhla et al., 2019).

Furthermore, excessive zinc consumption resulted in neurotoxicity, which manifested as fatigue, dizziness, shock, difficulty writing properly, anxiety, sorrow, somnolence, and dragging (Nriagu, 2007). Zinc levels in surface water and groundwater, according to the WHO (2018), should not

exceed 3.0 mg/L. Cobbina (2015) found that zinc values in Nangodi water samples had an average of 0.0341 ± 0.001 mg/L, while that of Tinga was 0.003 ± 0.001 mg/L. Both mining communities had zinc concentrations less than the WHO (2018) permissible limit of 3.0 mg/L.

2.2.13 Mercury (Hg)

Mercury (Hg) occurs naturally in the Earth's crust with concentrations ranging from 0.021 to 0.056 mg kg1 (Wedepohl, 1995). According to Clarkson et al. (2003), Hg is widespread in the environment and exists in three major forms: elemental, organic, and inorganic, each with varying hazardous effects on mammals. Hg is released into the environment from both natural and anthropogenic sources, but the latter predominates, and as a result, Hg is currently prevalent at levels that exceed the environmental legislation thresholds in the atmosphere, soils, riverine, and ocean systems (Gworek et al., 2020). Mercury gets into the aquatic environment through dry and wet atmospheric depositions, erosion of contaminated soils, riverine runoff, and direct discharge (Acquavita et al., 2021).

Mercury in water can settle and sink in sediment to accumulate. Heavy metals in sediment can be remobilised to the upper water column (both in particulate and dissolved forms), especially in the case of resuspension due to natural (i.e., storm events, wind waves, tidal currents, and wave-current interaction) and anthropogenic (i.e., trawling, dredging, and fisheries activity) factors. At favourable conditions, mercury can be synthesised by specific microorganisms (e.g., sulphate and Fe(III)-reducing bacteria) to form methylmercury (MeHg), an organic species which, unlike the inorganic form, tends to bioaccumulate through the trophic chain and be biomagnified up to final consumers (Rice et al., 2014).

Mercury (Hg) is a toxic metal considered by the World Health Organization (WHO) as one of the top ten pollutants possessing health hazards (WHO, 2018). According to the International Agency for Research on Cancer (IARC), MeHg is a Group 2 B compound, possibly carcinogenic to humans (Skalny et al., 2022). The permissible WHO limit for mercury in water is 0.006 mg/L.

Elemental and methylmercury are both neurotoxins that affect both the central and peripheral nervous systems. Inhaling mercury vapour can affect the neurological, digestive, and immune systems, as well as the lungs and kidneys, and can be fatal. Inorganic mercury salts are corrosive to the skin, eyes, and gastrointestinal tract, and can cause kidney damage if consumed (Skalny et al., 2022).

2.3 Pesticides

Pesticide detection in surface water, like the Muni Lagoon and its tributaries, is essential since they can pose a significant health risk to human beings and aquatic organisms when their levels exceed recommended limits. In the Muni catchment area, vegetable farmers often use pesticides to control pests and weeds. These pesticides are likely to contaminate the water resources in the area, and so monitoring the level of pesticides in water, sediments, and fish is vital to protect human and environmental health.

2.3.1 Definition of pesticides

Chemical substances introduced to prevent, destroy, repel, or lessen the damage caused by pests are pesticides (Eldridge, 2008; USEPA, 2006). The pest which is usually targeted can be insects, weeds, plant pathogens, mammals, birds, nematodes, molluscs, fish, and microbiological organisms that strive to decrease plant yield, spread diseases, destroy properties, or cause nuisance. Pesticides are frequently employed in the medical and agricultural sectors (Yadav et al., 2015). Pesticides are used in agriculture to manage pests that affect crops, as well as in public health to

eliminate disease-carrying insects like mosquitoes. Non-target creatures may be poisoned by pesticides released into the environment. As a result, it's critical to use them carefully and dispose of them appropriately.

Pesticide application significantly impacts the efficiency of agricultural production in the world (Silva et al., 2019). Despite the economic benefits of pesticides on crop production, the release of these chemical substances raises serious environmental concerns because of their intensive and widespread use in the environment. According to the Food and Agriculture Organization (2017), approximately 3000 different types of pesticides have been used in the agricultural sector in Europe and other parts of the world. The main issue with pesticide use in agriculture is that only a small percentage of pesticides reach their intended plant pathogens, leaving the remainder as potential short- or long-term environmental toxins with a wide range of harmful consequences. Pesticides are only used to protect crops in less than 0.1 percent of cases, with the rest being deposited directly into the soil or transported off-site by wind or water (Stolte et al., 2016).

Any product or combination of substances intended for use in preventing, killing, or mitigating any pest that may infest or be harmful to vegetation, people, animals, or homes, or be present in any agricultural or non-agricultural environment, is referred to as a pesticide (California Department of Pesticide Regulation, 2015). As a plant regulator, defoliant, or desiccant, it is also a product intended to keep pests at a distance by avoiding, removing, repelling, or diminishing them (USEPA, 2006).

The United States Legal Service for Industry, which offers assistance and legal counsel, defines pesticides as "any substance or mixture of substances intended for preventing, destroying, repelling, attracting, or mitigating any rodents, nematodes, fungi, insects, weeds, or other forms of animal or plant life and/or viruses and bacteria, except bacteria or viruses on or in living man or

other animals, which are determined to be a pest." It may also refer to any medication or mixture of medications used as a desiccant, defoliant, or plant regulator (US Legal, 2014). The European Union's (EU) definition of a pesticide includes things like insecticides, herbicides, plant growth regulators, acaricides, biocides, fungicides, rodenticides, and veterinary medications. Pesticides are chemical substances that are employed to, in the words of the European Union, "Destroy, repel, or suppress pests to protect crops before and after harvest; Influence plant life processes; kill weeds or hinder their growth; and Preserve plant products."

Under Part II of the EPA Act, 1994, any pesticide that is distributed, sold, and used in Ghana is subject to regulation by the EPA (Act 490). In the Act, a pesticide is defined as:

(a) a chemical substance or combination of compounds used to eliminate, stop, repel, or lessen a pest's damaging effects, or

(b) a compound or combination of substances designed for use as a desiccant, regulator, or wood preservative for plants. In order to control diseases and pests, a pesticide can also comprise plant growth regulators, insecticides, herbicides, fungicides, biopesticides, rodenticides, and other chemicals.

The definition of pesticides by the EPA Ghana is in line with that of the USEPA definition. Other state institutions like the Ghana Food and Drugs Authority and the Ghana Standard Authority have adopted this definition. A close analysis of this definition and others stated in the literature identifies some common keywords used in defining pesticides. Important terms in the definition of pesticides include chemicals intended for use as a defoliant, plant regulator, or desiccant, as well as chemical substances or mixtures made to prevent, eliminate, repel, or reduce any insect. The term offered by Eldridge (2008) was chosen for this study because it is relatively concise and

effectively summarises the numerous meanings in light of the aforementioned assessment of pesticide definitions. He defines pesticides as "chemicals or combinations of substances designed to control, prevent, eliminate, repel, or attract any biological entity considered to be a nuisance."

Pesticides are chemical substances that are used to eradicate undesired animals and plants, such as insects, rodents, fungi, and weeds (Akashe et al., 2018). They said that the main purposes of pesticides are to safeguard crops, preserve food, and guard against diseases spread by insects. The food industry, forestry, aquaculture, agriculture, shipping, and storage of wood and other biological products are only a few of the businesses that use pesticides. It is important to keep in mind that excessive pesticide use may jeopardize numerous ecosystems as well as human health.

2.3.2 Classification of Pesticides

The main purposes of pesticides are to safeguard crops, preserve food, and guard against diseases spread by insects. In addition to forestry, agriculture, the food industry, aquaculture, and the processing, transporting, and storage of wood and other biological products, pesticides are used in a wide range of other industries as well. It is significant to remember that excessive pesticide use may endanger both human health and the existence of many ecosystems. These three methods of pesticide classes include:

(i) Classification focusing on the mode of entry,

(ii) The classification that focuses on pest organisms they kill, as well as the pesticide function

(iii) Classification focusing on the composition of the pesticide.

To prioritize public health, the Globally Harmonized System (GHS) and World Health Organization (WHO) categorised pesticides based on their harmful effects or toxicity. Two factors, dose and time, have the most effect on pesticide toxicity. Accordingly, chronic and acute toxicity

are two distinct types of toxicity, based on the amount of the chemical involved (dose) and how often the drug is exposed (time).

2.3.3 Pesticides Classification Based on Toxicity

The dose and time are two factors that influence a pesticide's toxicity. Therefore, chronic and acute toxicity are two distinct types of toxicity, depending on the amount of the chemical involved (dose) and how frequently it is exposed (time) (Yadav et al., 2015).

Acute Toxicity: Acute toxicity is the term used to describe how harmful a pesticide is to people, plants, or animals after a single brief exposure. Pesticides with high toxicity can be fatal even in small doses. There are three ways to measure acute toxicity: through the skin, through the lungs, and through the mouth (Yadav et al., 2015).

Chronic toxicity- Chronic toxicity refers to the hazardous effects of pesticide exposure that are delayed. The general population, as well as those who work directly with pesticides, are concerned about the chronic toxicity of pesticides due to the likelihood of exposure to pesticides on or in food products, water, and air. The World Health Organisation has only recognised acute toxicity when classifying pesticides (WHO). The estimated relative lethal dose (LD50), which is the quantity of pesticide required to kill half of the tested animals when taken orally or topically, is used by the WHO to classify pesticides according to their acute oral and acute dermal toxicity (Damalas & Koutroubas, 2016).

2.3.4 Classification of Pesticides Based on Chemical Composition

One of the most popular and useful methods of categorizing pesticides is based on their chemical makeup (Abubakar et al., 2020). According to their chemical compositions, pesticides such as fungicides, insecticides, herbicides, and rodenticides are categorized in the following ways:

Insecticides: Insecticides are categorized according to their chemical composition as Organochlorine (Endosulfan), Pyrethroids (Permethrin), Organophosphorus (Monocrotophos), Carbamates (Carbaryl), Neonicotinoids (Imidacloprid), miscellaneous pesticides such as Benzolureas (diflubenzuron), Antibiotics (abamectin), Spinosyns (Spinosad), etc.

Fungicides: Aliphatic nitrogen fungicides are a subclass of fungicides. They include: dinitrophenol fungicides (dinocap), dicarboximide fungicides (famoxadone), amide fungicides (carpropamid), aromatic fungicides (chlorothalonil), etc.

Herbicides- The herbicides are anilide herbicides (flufenacet), chlorotriazine herbicides (atrazine), sulfonylurea herbicides (chlorimuron), phenoxy acetic herbicides (2, 4-D), quaternary ammonium herbicides (Paraquat), etc.

Rodenticides – They have been categorized as coumarin rodenticides (organic) (bromadiolone, coumatetralyl) and inorganic rodenticides (Zinc phosphide, Aluminium Phosphide),

2.3.5 Natural Organic Pesticides

These are phytochemicals produced by plants. Phenolic chemicals, alkaloids, and terpenes have all shown evidence of pesticidal efficacy. These are only a few examples of the phytochemicals found in plants that fall under the category of natural organic pesticides. The remaining oilseed cakes, plant extracts, and essential oils obtained from plants are effective against many pests (Pavela, 2016). These are particularly desirable due to their short environmental duration, low mammalian toxicity, and complex chemistry that precludes pest resistance (George et al., 2014).

2.3.6 Inorganic Pesticides

Compared to organic pesticides, the compounds in inorganic pesticides are typically simpler and more soluble in water. Many of them work by poisoning insects' stomachs (Kim et al., 2017). Copper sulphate, ferrous sulphate, and sulphur are examples of pesticides (Gunnell et al., 2007).

2.3.7 Synthetic Pesticides

Organophosphates, carbamates, pyrethroids, and organochlorines are the four main groups of synthetic pesticides.

2.3.8 Organochlorine Pesticides (OCPs)

Organochlorines are substances with at least one covalently linked chlorine atom (Maruf et al., 2021). Organochlorines have a wide range of chemical characteristics and structural variations. Because chlorine has a large atomic weight, it has been found that organochlorine compounds are denser than water. These substances can be made using hydrogen chloride, chlorine, and other chlorinating chemicals. The majority of organochlorine insecticides, commonly known as chlorinated hydrocarbons, are composed of five or more chlorine atoms bonded to organic molecules. They are utilised in agriculture and represent one of the earliest subcategories of pesticides ever created. The bulk of them are commonly applied to control a range of insects as pesticides, and they have long-lasting effects on the environment. These pesticides may interfere with an insect's nervous system's normal operation, causing convulsions and other neurological diseases that eventually result in death (Zacharia, 2011). Endosulfan, DDT, lindane, aldrin, heptachlor, dieldrin, chlordane, and toxaphene are typical examples of these pesticides. Even though it has long been banned in the majority of industrialized countries, including the United States, DDT is still produced and used in the majority of tropical developing countries to control vectors.

Organochlorines are divided structurally into five categories (Henny et al., 2008). The classes are: 1. Dichlorodiphenyltrichloroethane (DDT) and its analogues, such as Hexachlorocyclohexane (HCH), such as lindane, 2. DDT and dichlorodiphenyldichloroethylene (DDE) 3. Cyclodienes, such as endrin, dieldrin, and aldrin, heptachlor, endosulfan, and chlordane; 4. mirex and 5. toxaphene.

2.3.8.1 Dichlorodiphenyltrichloroethane (DDT)

A common pesticide known as DDT is an organochlorine that has been used to prevent malaria and control pests in agriculture. Substances in this investigation include DDT and its metabolites (p,p′DDE, p,p′DDD, p,p′DDT, and o,p′DDT), HCHs (HCH), chlordane (CHLs), heptachlor (HPTs), and HCB.

DDT was created for the first time in 1874 by Othmar Zeidler, and Swiss chemist Paul Muller identified its insecticidal characteristics in 1939. Technical DDT products typically contain less than 5% additional substances and around 15% o,p'-DDT, 75% p,p'-DDT, 5% p,p'-DDE (Yang et al., 2020). In the natural environment, DDT degrades into DDE and DDD, respectively, through anaerobic reductive dechlorination and oxidative dehydrochlorination (Hitch & Day, 1992). DDE is a symptom of repeated exposure to DDT and can break down in the body into DDD, which is less damaging to health. DDE, DDT, and DDD are easily deposited in human fatty tissue. Levels in fatty tissues may either remain about the same over time or even increase with prolonged exposure (ATSDR, 2002).

In addition to these, DDTs are harmful to humans, animals, and insects. It has been established that they alter the endocrine system and may cause human cancers like breast cancer. They are commonly known to cause infertility and thinned eggshells in bird species (UNEP, 2003; Stokstad,

2007). The renowned book "Silent Spring" by Rachel Carlson, which detailed several detrimental impacts on the environment and wildlife as a result of pesticide use, sparked concern about the use of DDT in the 1960s (Carlson, 1962). The US Environmental Protection Agency (EPA) has classified DDT, DDE, and DDD as class B2 "probable" carcinogens. The Stockholm Convention restricts the production and application of DDT to eliminate disease-carrying mosquitoes like those that spread malaria. Until there are locally acceptable and affordable alternatives for a sustainable transition away from DDT, the WHO advises utilizing it for indoor residual spraying (IRS) (WHO, 2018).

2.3.8.2 Environmental fates of DDT, DDE, and DDD

DDT decomposes into two metabolites, DDD and DDE. DDD was still created, albeit on a much smaller scale and with far less extensive use as a pesticide than DDT. DDT is not commercially produced, but it can be turned into DDE by dehydrochlorinating it in an alkaline solution. DDE is commonly detected in the environment in quantities that are frequently higher than those recorded for DDT. DDT, DDE, and DDD isomers are present in the environment in different arrangements. The six most common isomers found or used in research that may be seen throughout this profile are technical or commercial DDT, o,p'-DDT, o,p'-DDE, p,p'-DDT, p,p'-DDE, and technical DDD and o,p'-DDD. In both human and animal studies, many of these isomers are described.

When DDT is absorbed into soil, water, or the atmosphere, it is widely disseminated over the globe, even into far-off places like the Arctic or Antarctic regions. DDT and its metabolites have a sluggish rate of biodegradation and can bioaccumulate (raise a chemical concentration within an organism above that in its surroundings) in fatty tissues. The use of DDT was banned in the United States and most of the rest of the globe in the 1970s, which led to a decrease in the levels of these chemicals in the environment. Except for areas where production and usage are still ongoing,

public exposure to DDT, DDE, DDD, and their isomers has also been declining. DDT, DDE, and DDD are still present in some products in detectable amounts. In US food sample investigations, p,p'-DDE was the isomer that was most frequently discovered (FDA 2006). Carrots, summer squash, celery, American cheese, butter, catfish, and salmon are a few examples of foods with detectable levels of DDT and its metabolites (FDA 2006; Hassaan & El Nemr, 2020).

2.3.8.3 Hexachlorocyclohexane (HCH)

Hexachlorocyclohexane (HCH) is the cyclic saturated chlorinated hydrocarbon pesticide with the broadest application. Standing crops have been protected from a variety of agricultural pests using HCH. It has become recognised as a major global environmental pollutant because of its persistent nature, bio-accumulative characteristics, and toxicity to unintended creatures (Kumar & Mukherji, 2018). Although using HCH has unquestionably been extremely beneficial, it has also seriously contaminated the ecosystem. By photo-chlorinating benzene in the presence of ultraviolet light, HCH is produced (UV). The creation of this saturated cyclic compound results in the production of numerous isomers with different chlorine atom arrangements around cyclohexane rings.

It was known as "Ganarnexane" back then. Van der Linden isolated it around the start of the 20th century, and it was later renamed "Lindane" in his honor. It is largely responsible for the outstanding insecticidal properties of HCH (part of just 10-15 percent of the technical HCH). For the treatment of the flea beetle, this new substance took the role of derris, which was then scarce. In addition, it was discovered to be quite effective in tests against a variety of agricultural and horticultural pests, including locusts, industrial insects like cockroaches, crickets, bed bugs, flies, etc. (Wacławek et al., 2019). People who were exposed to HCH displayed symptoms of CNS (central nervous system) abnormalities, including dysarthria, seizures, blindness, and mental

confusion. Chronic HCH exposure can cause liver and kidney failure. Numerous studies are now examining the toxicity of HCH to humans, including evidence of their carcinogenicity (Bradley et al., 2016).

One of the most pervasive and easily identifiable pesticides in the environment is the organochlorine lindane and its isomers (HCH). In contrast to HCH, which was dumped as garbage in uncontrolled landfills, lindane is widely distributed since it is used as an insecticide and is persistent and bioaccumulative. Unfortunately, some HCH is toxic to the reproductive, endocrine, and central neurological systems (particularly the most reactive ones: - and -HCH) (Waclawek et al., 2019).

2.3.8.4 Cyclodienes

Despite having the same generic name, only a small number of these compounds are dienes or cyclic compounds with two double bonds. They all have a completely chlorinated ring structure with a chlorinated "endomethylene bridge" connecting the ends of the ring. Another ring of this type is present in some of the compounds (shown on their right), although it's Toxaphene is a combination created by chlorinating camphene until it contains 69 percent chlorine, not a true cyclodiene; rather, it is a chlorinated terpene.

Cyclodienes are poisonous organochlorine insecticides (OC) that affect the GABAA receptor and Ca^{2+}-Mg^{2+} ATPase in the target organism's central nervous system. These compounds have the potential to be harmful to both the environment and human health (Abdulhamid, 2012). As a result, their production, usage, and disposal have been restricted or even outlawed in the majority of developed nations.

2.3.8.5 Toxaphene

Polychlorinated bornanes (CHBs) and other camphenes make up the compound toxaphene, also known as camphechlor (Clark et al., 2005). In the past, it was among the widely used chlorinated pesticides in the world, with total consumption estimated in megatonnes, similar to how much polychlorinated biphenyls were used (PCBs). Toxaphene (chlorinated camphene) was used as a stomach pesticide and a broad-spectrum, nonsystemic contact pesticide with some acaricidal effects. It was frequently used in conjunction with additional pesticides. The majority of the crops it was used on were cotton, but it was also used on corn, fruit, vegetables, and small grains. To control armyworms, bollworms, boll weevils, cotton flea hoppers, cotton aphids, grasshoppers, cotton leafworms, and other insects, it has been used as an insecticide. Additionally, it was used to manage ectoparasites that affect animals, such as mange and scab mites, ticks, flies, and lice.

Toxaphene is proven to be a pervasive environmental pollutant and is capable of long-distance transfer. It has the same potential for bioaccumulation in aquatic species as other organochlorine insecticides. Toxaphene in animal feed is related to fish and shellfish products; however, there is little information on it. Toxaphene is a known endocrine disruptor and a potential carcinogen, notwithstanding the paucity of toxicological data. The pesticide mixes originally used may not exactly match the residue composition in an animal feed product due to weathering and biotransformation. Small creatures that come into direct contact with sediment can absorb toxaphene from it, which can then move up the food chain. Phytoplankton, Zooplankton, Mysis, Bythotrephes, Sculpin, and Lake Trout were among the biota whose log of the bioaccumulation factor (organism concentration/water concentration) ranged from 5.8 to 7.0 (Swackhamer et al., 1998). Therefore, by 1990, all authorised applications of toxaphene were prohibited in the US (ATSDR, 2012). Toxaphene exposure can occur when someone consumes infected fish, shellfish,

or wild game, breathes polluted air, drinks contaminated water, or comes into direct contact with contaminated soil. Toxaphene might potentially induce liver cancer in mammals and damage the kidneys and liver.

2.3.8.6 Mirex and Chlordecone

It is unknown whether mirex (fig. 2.6) is a naturally occurring substance in the environment (IARC, 1979). Despite being created in 1946, mirex wasn't made available for purchase in the United States until 1958 under the name GC-1283 (IARC, 1979). Mirex has been manufactured in a variety of formulations in the past for a variety of purposes, including the first-ever suppression of imported fire ant populations in 1961.

Chlordecone was primarily applied to food goods as a wettable powder (Fig. 2.7). The only registered food use of chlordecone in the US was for the control of the banana root borer (in the US territory of Puerto Rico) up until 1976. In addition, registered formulations for tobacco and potato wireworm management, as well as non-food use on non-fruit-bearing citrus plants, were registered (Faroon et al., 1995). Additionally, roach and ant traps were placed outside of homes and businesses using chlordecone. Hexachlorocyclopendiene is used to make mirex and chlordecone. Both substances are extremely persistent in the environment and lipophilic. Mirex and chlordecone are mostly degraded by photolysis in water or on soil surfaces (Coat et al., 2006).

2.3.8.7 Organochlorine Pesticides Health Effects on the Environment

Pesticides with organochlorines have a high level of environmental persistence, are chemically stable, and can build up in adipose tissue. Organochlorines are capable of entering an organism's body through the lungs, skin, or gut wall. While dicofol, mirex, DDT, toxaphene, and methoxychlor are less absorbed via the skin than cyclodienes, hexachlorocyclohexane, endosulfan,

and lindane. Although storable lipophilic chemicals may be removed from breast milk, these volatile compounds are primarily stored in fat tissue and excreted through the biliary and urine systems. They have an impact on the central nervous system, resulting in ataxia, tremors, convulsions, hyperreflexia, and a hyperexcitable condition in the brain. In comparison to DDT and methoxychlor, cyclodienes, lindane, and mirex have the potential to have more negative consequences. DDT has undergone thorough testing on a variety of animal models to determine any potentially harmful effects (de Perre et al., 2014).

More hepatic microsomal drug metabolising enzymes are produced by the tissues when organochlorine concentrations are higher. On prolonged and intense exposure, effects can be detected in people. Organochlorines may also affect the oestrogen and androgen receptors found in the body. Their poisoning may result in a variety of symptoms, including headaches, dizziness, nausea, vomiting, tremors, a lack of coordination, and mental confusion (Singh et al., 2016). By using gas-liquid chromatographic techniques, organochlorine compounds (OCCs) can be found in the blood. Early stages of exposure can be handled with effective techniques to prevent negative effects. Organochlorine poisoning is treated with medications such as diazepam, lorazepam, and cholestyramine resin (Singh et al., 2016).

The build-up of DDT in animals has led to a variety of issues with reproduction, such as the thinned eggshells of several bird species (Tubbs, 2016). The baby bird would die since the egg would hatch before it was fully developed, and as a result, the progeny of birds would not be able to develop normally throughout their early embryonic life. Due to this, several bird species are in danger of going extinct. Overall, even though organochlorine compounds have fewer advantages, these substances should still be utilised carefully because they can be hazardous and damaging to many animal species to varying degrees.

The persistent nature of OCPs makes them common environmental pollutants in a variety of environmental matrices. These compounds' stability in the environment is a result of the Cl atoms on the organic moiety in OCPs. This persistence makes OCPs effective in battling pests like termites. However, because OCPs don't biodegrade and are highly lipid soluble, there are issues with the chemicals building up in animal tissue (Sangwan et al., 2014). According to Malhat et al. (2018), the "bioconcentration" process results in fish tissues having a significantly greater concentration of chlordane than the water in which the fish are residing. Acute and chronic diseases may result from human exposure to OCPs. Tremors, headaches, cutaneous irritation, respiratory issues, nausea, disorientation, and seizures are all signs of acute poisoning. OCPs are linked to a variety of chronic illnesses. OCP exposure has been associated with numerous cancer kinds, respiratory disorders, brain damage (neurotoxicity), birth defects, Parkinson's disease, and abnormal immune system function (Arcury et al., 2002). Recent research has shown that even extremely low levels of exposure to OCP during pregnancy can irreparably harm the reproductive system. Many OCPs are recognized or suspected to be hormone disruptors. Along the food chain, these chemicals also build up and biomagnify, reaching larger amounts in top carnivores (Malhat et al., 2018).

Singh et al. (2016) investigated the toxicological effects of organochlorine compounds (OCCs) utilizing a range of animal models. Tests on animal species, such as the Mean Probable Effect Concentration Quotient (PEC-Q), DNA repair assays, and histological examinations, were used to demonstrate the toxicity of organochlorine pesticides. The findings were seen using a variety of animals, including fish, furseals, frogs, rats, bats, and humans. Fish were shown to be acutely harmful by endosulfan. Additionally, the harmful impacts of synthetic pyrethroids,

microbiological insecticides, and organophosphorus compounds were found. The next most lethal compounds to fish were lambda-cyhalothrin, fenvalerate, deltamethrin, and cypermethrin.

According to research on the genotoxic effects of OCCs on mouse germ cells, a fatal mutation can appear in just one mating cycle after exposure. Following OCC exposure, more micronucleated cells have been seen. Studies on the neurobehavioral behaviour of rats revealed the existence of tremors brought on by p,p'DDT and chlordecone. Tumorigenicity brought on by organochlorine pesticides is discovered to be an epigenetic mechanism in a DNA repair experiment. The liver, kidney, and testicles of the albino rat had acute poisoning from the toxic effects of Dursban and DDT. OCC poisoning in many animal species has been linked to significant population losses. To lessen the potential health risks, exposure to these substances should be reduced both directly and indirectly (Singh et al., 2016).

The most popular insecticide in many developing countries is still dichloro diphenyl trichloroethane (DDT), an OCP derivative. OCPs constitute a continuous and ongoing threat to the biosphere because they are readily soluble in fats and saturated oils, insoluble in water, and have a very long shelf life. Farmers and other workers may unintentionally be exposed to OCP through food, air, touch, or drinking water during spraying (Masih et al., 2014). OCP dosages of approximately 280 mg/kg cause acute toxicity, which manifests as vomiting, nausea, exhaustion, seizures, and flu-like symptoms. Chronic exposures, however, affect numerous organ systems, including the nerves, kidneys, liver, and immunity. By influencing these organ systems, chronic exposures can cause malignancies, neurologic symptoms, infertility, and other disorders (Awasthi & Awasthi, 2019).

Exposure to organochlorine pesticides causes cancer in those who live and work in areas where these chemicals are often used. People who reside in locations where OCP is often used as a

pesticide in agriculture die from cancer and suffer from it, claim Masih et al. (2014). Hodgkin's is a type of cancer that affects both children and adults and has a proven connection to OCP (Qu et al., 2010). OCPs have also been linked to an increase in the prevalence of pancreatic and liver cancer, and those who work in farms and manufacturing facilities that produce OCPs have a four- to five-fold higher risk of developing these diseases. OCP is also linked to powerful neural responses (Eskenazi et al., 2009).

OCP poisoning is more likely to occur in individuals with higher body fat percentages, particularly females, and strong lipophilic properties of OCP compounds (Eskenazi et al, 2009). Research in China found significant amounts of OCP in women's umbilical cords as well as maternal milk and blood (Qu et al., 2010). Similar to South Africa, mothers in the Kwazulu region, where OCPs were used to combat malaria, had greater OCP levels in their breast milk (15.83mg/kg) than the non-exposed population (0.69mg/kg). However, research conducted in Kenya in the late 1990s found OCP in samples of breast milk taken from moms who did not farm, explaining the likelihood of its indirect dissemination (Nweke & Sanders III, 2009). The presence of OCP residues in mothers will have an immediate impact on all children, including those who are still developing or breastfeeding. Premature births may occur as a result of OCPs ability to cause an imbalance in the mother's estrogen-progesterone levels during pregnancy. OCPs ability to cross the placenta further supports how it may interfere with the baby's capacity for growth and development (Sharma et al., 2012; Nweke & Sanders III, 2009).

2.3.11 Organophosphorus Pesticides

Organophosphates (OP) are phosphoric acid esters that have electrophilic characteristics and the ability to phosphorylate esterase. They are artificial phosphoric, phosphonic, phosphonothionic,

and phosphorothionic acid esters, amides, or thiol derivatives that are widely employed to control pests in agriculture or homes (Kumar et al., 2015). High levels of OP exposure can have genotoxic effects as well as symptoms such as nausea, headaches, shortness of breath, lack of coordination, paralysis, and muscular spasms (Baconi et al., 2013).

Insecticides with organophosphates are the most widely used pesticides in agriculture. This kind of pesticide works by inhibiting acetylcholinesterase, an enzyme that stops nerve impulses from acting persistently, particularly those destined for muscles and those moving through cholinergic fibres of the autonomic nervous system. The clinical signs of poisoning in both people and animals are caused by the accumulation of acetylcholine, which is caused by the inhibition of this enzyme (Joshi & Sharma, 2011). They can be categorised as direct or indirect acetylcholinesterase (AchE) inhibitors and are often highly fat-soluble. Nevertheless, they typically do not linger in the environment (Cheng et al., 2017).

2.3.11.1 Health Impacts of Organophosphorus Pesticides

Organophosphorus compounds are phosphoric acid-derived insecticides that are thought to have a wide chemical spectrum and control a variety of pests, weeds, and plant diseases due to their multifaceted actions (Gámiz-Gracia et al., 2005). They interfere with neurotransmitters across a synapse as acetylcholine cholinesterase inhibitors (Bora et al., 2012). Voluntary muscles twitch swiftly due to the inability of nerve impulses to pass the synapse, which causes paralysis, which is associated with mortality. Some of the most widely used organophosphorus pesticides include parathion, diazinon, glyphosate, and malathion . This group of compounds is characterised by the covalent substitution of the carbon-phosphate (C-P) bond for one of the phosphate ester's four carbon-oxygen-phosphorus linkages.

Organophosphates are a class of pesticides that cause the most pesticide poisonings because of their widespread use and frequently high acute toxicity. (Sapahin et al., 2019). Cholinesterase activity is hindered by the organophosphates (Seebunrueng et al., 2014). The constant "messages" that the body's nerves send to the muscles result in twitching and weakening of the muscles when the cholinesterase enzyme is unable to function normally. The person may experience fits or convulsions if the poisoning is severe, and they could pass away (Musarurwa et al., 2019).

In many animal species, exposure to pesticides increases the growth of tumours and greatly lowers resistance to bacterial, viral, and parasitic illnesses. People who are exposed to pesticides are more likely to develop several tumours that are known to be immunosuppressive. In conclusion, a range of cancers may be affected by pesticides through an immune mechanism (Pirsaheb et al., 2013).

Chronic toxicity refers to a substance's ability to have long-lasting or delayed negative health effects. Numerous studies on numerous test species showed that atrazine is harmful over the long term. A dose of 20 mg/kg/day of atrazine was given orally to rats for six months, and 40% of the rats died after exhibiting symptoms of respiratory distress and limb paralysis. Organophosphate poisons affect body organs such as the brain, liver, kidneys, ovaries, and others, causing structural and chemical alterations as well as growth retardation (Mansour, 2004).

Organophosphates are irreversible cholinesterase inhibitors (Pirsaheb et al., 2013). It will take a few days, weeks, or even months without medical help for the level of enzyme activity to return to normal. The cumulative effects of small repeated doses over time, such as over a spraying season, may finally cause poisoning. Moderate poisoning in humans causes drowsiness, headaches, and lightheadedness (Zhao et al., 2007). Moderate poisoning causes weakness, chest

pain, and the inability to move. Muscle twitching, acute pupil constriction, and unconsciousness, all of which result in death, are signs of a serious scenario (Sapahin et al., 2014).

2.3.11.2 Environmental Fates of Organophosphorus Pesticides (Ops)

The main sources of organophosphate pesticides in soils, groundwater, surface waterways (rivers, lakes, and seas), and the atmosphere are the spraying of crops and animals, as well as the application of cow and sheep dip on fields. OPs have been found in sediments, the atmosphere, groundwater, river water, and estuary water (Plimmer, 1992). It is crucial to quantify the destiny and transit processes of OPs because they are transported over long distances by air and water. This will help us better understand how OPs behave in the environment. Although the speed at which these events happen is generally recognised, transport, chemical, and biological processes all have an impact on OP destiny in the environment (Dowling & Lemley, 1995).

Organophosphate pesticides (OPs) are widely accepted as safe for use on plants and animals due to their comparatively short rates of degradation. The type of microorganisms present, the temperature, the pH, and the presence of sunlight all affect how quickly they decompose. In the laboratory (25 °C and pH 7), biodegradation is about an order of magnitude faster than chemical hydrolysis, which is then about ten times faster than photolysis. Microbial biomass frequently requires a protracted adaptation time for soil bacteria to evolve and have the ability to metabolize OPs. Therefore, in soils that have received many applications of OPs, biodegradation is often an order of magnitude faster than it is in control soils that have never received OP treatments. Due to their greater solubility, OPs frequently enter surface and groundwaters (Ragnarsdottir, 2000). The main technique used to degrade OPs is chemical hydrolysis, which depends on pH. An OP pesticide's hydrolysis half-life increases from 10 days to one year in a lab setting with pH 6 and

5°C, demonstrating that OPs can persist in the environment for a very long time. OPs are still present in soil years after treatment. The OPs' sorption to soil particles, which rendered them inaccessible to microbial digestion, may be connected to this environmental persistence, even though its exact source is unknown. Calculations utilizing real-world examples and information from the literature show that soil conditions can occur where OPs are stored and transferred to people through food. A review of the literature suggests that since OPs are extremely dangerous, human exposure to them is not desired. According to the available data, OPs are mutagenic and teratogenic pesticides that may be to blame for a large number of existing mammalian immune and neurological problems (Ragnarsdottir, 2000).

2.3.12 Carbamates

Organic pesticides called carbamates are made from carbamic acid (H_2NCOOH) (Nantia et al., 2017). These include aminocarb, carbaryl, and carbofuran (Tano, 2011). They and organophosphates are structurally related. But they are distinct from where they started. Organophosphates are phosphoric acid derivatives, whereas carbamates are produced from carbamic acid. Carbamate insecticides function similarly to organophosphate pesticides by interfering with nerve signal transmission, which makes the pest toxic and ultimately kills it (Yadav et al, 2015). They are occasionally used as stomach poisons, contact poisons, and fumigants. This herbicide is easily biodegradable in a natural setting with no environmental harm.

2.3.12.1 Environmental and Health Effects of Carbamates

Because both carbamates and organophosphates block cholinesterase, which affects the transmission of nerve impulses, their effects are comparable (Zhou et al., 2020). They are commonly utilised in agriculture, gardens, and domestic settings. The hydrolysis reaction that carbamates go through causes them to break down into simple, non-toxic compounds means that

they don't last long in the environment (Rahman et al., 2017). Thus, even though carbamates have the potential to poison people severely, they rarely do so. Following cutaneous exposure, inhalation, or ingestion, they can cause severe cholinergic poisoning, which can have negative effects on humans such as headaches, nausea, cramps in the stomach, uncontrollable urination or faeces, and even a comatose state (Nantia et al., 2017).

2.3.12.2 Environmental Fates of Carbamate Pesticides

Carbamate insecticides are destroyed in the environment by a variety of physical, chemical, and biological mechanisms. Solar radiation (photolysis), warmth (evaporation), moisture (hydrolysis), and oxygen are the main factors in their disintegration (oxidation). Through field applications, carbamate insecticides frequently find their way into soil and water. Since it is soluble in water, most water bodies are contaminated when runoff picks it up. Pesticides can move through the soil in two different ways: diffusion or water flow. Water can contaminate groundwater and surface water in addition to acting as a transport medium in a soil body. Generally speaking, under ideal circumstances, the rate of degradation is mostly governed by their physicochemical characteristics, while environmental factors take center stage when environmental conditions reach extremes. The majority of research concurs that humus content and quality, or soil texture, play a major role in the sorption and/or desorption of pesticides in soil (Bekbolet et al., 1999). The soil's capacity to absorb water rises as the pH decreases. In an aqueous solution, a pesticide dissociates and primarily takes the form of anions. The negatively charged surfaces of soil particles and colloids repel one another, and a pesticide moves around in the soil environment as a result (Hiller et al., 2006). High levels of carbamates in the environment are detrimental to plants, animals, and humans.

2.3.13 Pyrethroids

The naturally occurring flowers of pyrethrums (*Chrysanthemum Coccineum and Chrysanthemum cinerariaefolium*) contain chemical substances called pyrethroids (Tano, 2011; Farajzadeh et al., 2014). Pyrethric acids are what give pyrethrins their insecticidal effects. Pyrethroids cause the organism to become paralysed by affecting the sodium channels. Pyrethroids are currently manufactured to suit the rising demand for pesticides in the agriculture sector (Noori et al., 2017). Permethrin, cypermethrin, deltamethrin, allethrin, furethrin, fenevelerate, and alphacypermethrin are the most popular synthetic pyrethroids. This class of pesticides, which can be created by mimicking the structure of naturally occurring pyrethrins, also includes synthetic pyrethroids. They are more stable and effective than natural pyrethrins, relatively speaking. Pyrethrins I and II, together with lesser levels of the related cinerins and jasmolins, are the main active ingredients. Synthetic pyrethroid insecticides have low neurotoxicity for humans and birds but significant neurotoxicity for insects and fish. The majority of synthetic pesticides are light-sensitive and readily break down when exposed to light. They are thought to be the most secure insecticides to use on food (Hu et al., 2015). Modern pyrethroids differ from the original natural compounds in their method of action and only marginally resemble their pyrethrin I (progenitor). Cypermethrin, fenvalerate, fluvalinate, deltamethrin, lethrin, furethrin, and permethrin are some of the synthetic pyrethroid insecticides that are often employed.

2.3.13.1 Health Effects of Synthetic Pyrethroids

Pyrethroids metabolism is rapid, and although they have acute neurotoxicity in humans, it was believed that their high turnover would prevent negative impacts on biodiversity and human health (Ye & Liu, 2019). Different animal studies have demonstrated the detrimental effects of both urban (bifenthrin, cyfluthrin, and permethrin) and agricultural (cypermethrin, fenvalerate, and

deltamethrin) pyrethroids, but there is a dearth of epidemiological information on the general population over time (Gabler et al., 2016).

Pyrethroid metabolites can enter the body through food, drink, inhalation, or ingestion as a result of their use in homes and other residential places. Additionally, due to slower rates of breakdown indoors, pyrethroid residues build up in floor dust, which is a significant source of exposure for young children (Saillenfait et al., 2015). The possibility that several pyrethroids may operate as endocrine-disrupting compounds capable of imitating, blocking, or synergizing is a major cause for concern, according to experimental and epidemiological research.

Pyrethroids have high lipid solubility and can enter the body through contact with the skin, digestive tract, and respiratory system (Holynska-Iwan et al., 2018; Chrustek et al., 2018). How much penetration takes place depends on how permeable the barrier is. It has been shown that contact with intact rabbit skin and deltamethrin for 15 seconds is enough to cause a depolarization reaction brought on by the influx of sodium ions into the cells (Holynska-Iwan et al., 2018). Children and pregnant women are more at risk for rapid pyrethroid body contamination. It has been established that human milk contains pyrethroids and their metabolites, which puts neonates in danger (Glorennec et al., 2017).

Pyrethroids were divided into two classes based on the kind of intoxication symptoms that emerged in a vertebrate organism after pyrethroid ingestion. Permethrin is one of the type I pyrethroids that can cause tremor type syndrome (T), which is characterized by physical tremors, hypersensitivity, aggressive behavior, and ataxia. Salivation and muscular dysfunction are linked to the choreoathetosis-salivation syndrome, which is caused by type II pyrethroids such as deltamethrin and cypermethrin (Bradberry et al., 2005).

2.3.13.2 Environmental Fates of Pyrethroid Pesticides

Applications in agriculture and non-agriculture both release pyrethroids into the environment. Pyrethroid pesticides are introduced into the numerous environmental sinks through direct spraying or application on crops, soil, and water. Runoff from treated farms, lawns, parking lots, etc., introduces pyrethroid insecticides into aquatic systems. The great propensity of these compounds to adsorb to organic materials and soils, however, means that, except for those particles that are moved by wind or water, they are unlikely to suffer significant migration from areas of direct application. Pyrethroid half-lives in aerobic soil conditions vary greatly, from 11.5 days for cyfluthrin to 96.3 days for bifenthrin (Oros & Werner, 2005). However, factors unique to a given field that affect breakdown rates include temperature, canopy cover, and persistence on the soil surface. Additionally, it has been suggested that the transportation of aqueous-phase pyrethroids via urban and suburban areas' concrete drainage systems may result in higher concentrations of pyrethroids than the transmission of particulate-rich agricultural runoff through earthen ditches (Weston & Lydy, 2010).

In the soil, pyrethroids are mostly degraded by photolysis, which is influenced by the soil's properties. As an illustration, the half-life of esfenvalerate in various soil systems was much longer in the dark, with half-lives of 7.8 to 100.0 days under continuous irradiation versus 150.0 to 553.4 days in the dark (Katagi, 1991). Thus, it is likely that in highly organic soils, the photolytic breakdown of pyrethroids will proceed more slowly. A key breakdown route also seems to involve microbial degradation. Pyrethroid insecticides were shown to degrade more quickly in natural soils than in soil that had been sterilized, demonstrating the contribution of biological processes to breakdown in soil (Palmquist et al., 2012). The authors concluded that the faster pace of soil degradation in natural soils was mostly caused by soil microorganisms. There is some evidence to

suggest that the parent chemicals of pyrethroids are not as mobile in soils as their metabolites are (Kaufman et al., 1981). These substances, however, are probably much less hazardous than the parent pesticide. Pyrethroid concentrations in the soil may be decreased as a result of plant canopy interception. For instance, it was discovered that the cypermethrin residues in agricultural field soils with crop cover were roughly one-tenth of those in bare soil after a spray.

The movement of pyrethroid-absorbed tiny particles causes pyrethroid transport in aquatic systems (Gan et al., 2005). Most pyrethroid insecticides have half-lives in the range of days to weeks in the water column; however, pyrethroids adsorbed on particulates have documented half-lives on sediments of 150 to 200 days (Amweg et al., 2005). The majority of the time, suspended particles and particulates were linked with pyrethroids in stream water (Palmquist et al., 2012).

2.4. Socio-economic development

Every day, people try to advance their social, cultural, or economic selves. Development is defined as a planned, comprehensive economic, social, cultural, and political activity in a specified geographic area that is focused on human rights and the environment and aims to consistently increase the welfare of the entire population and all of its members (Fritz, 2010). The people would take an active part in development and the fair distribution of rewards. Three elements make up this comprehensive definition: economic development, social development, and environmental protection.

The definition of socioeconomic development used in this study places an emphasis on how well social and economic factors are progressing within a geographic area. Economic development is the process of raising wealth through a rise in the production, consumption, and distribution of

goods and services. The complexity of social dynamics, on the other hand, is referred to as social development (the interaction of social structures, processes, and relationships) and is concerned with two things: (1) the social concerns of the people as development objectives; and (2) people-centered, participatory approaches to development.

The three pillars of social progress are inclusion, social fairness, and the common good. Indicators of social development offer comparative data on issues including poverty, employment, income, education, health, job security, civic engagement, and crime. Occasionally, lists of social development indicators have incorporated environmental data. Richard Estes, a co-author of the 2000 Social Report for Hong Kong, pointed out that the document had an environmental quality subindex with rankings for recycling of solid waste, beaches, public open space, and freshwater use (Fritz, 2010).

2.4.1 Impact of Socioeconomic Activities on the Ecosystem Services

Socioeconomic processes like urbanization, industrialisation, and agriculture can have a variety of harmful effects on stream ecosystems (Sanchez et al., 2015). These occurrences have the potential to seriously damage stream ecosystems. According to Anthony et al. (2009), lagoons and the drainage areas that flow into them are intricate ecosystems that are especially susceptible to anthropogenic stressors such as inappropriate resource extraction, intensive agricultural land use and management, and improper water use and management. For the sustainable management of river ecosystems, identifying the sources of deterioration is a crucial effort.

According to Kim et al. (2021) and Zahran (2008), mining, population density, major industries, land use and land cover (LULC), and policies about streams are socioeconomic variables that mostly harm water bodies. Similar findings indicate that urbanization has a detrimental effect on stream ecosystems (Sabater et al., 2016). According to Sabater et al. (2016), human settlement

activities in watersheds result in pollution from both land development, such as constructing infrastructure, and living sewage.

Environmental degradation remains a serious threat and concern throughout nations, notwithstanding the institutions and policies that are in place (Mathe & Phiri, 2016; Mensah et al., 2015). In Ghana, it was discovered in research by Mensah et al. (2015) that illicit small-scale miners have significantly contaminated the country's major rivers, leaving the surrounding land barren and vulnerable to increased erosion and a decline in agricultural viability. Again, the study found that greater clearance of vegetation for mining sites had a detrimental effect on Ghana's western region's hydrological regimes and patterns, and reports of the death of significant soil organisms and disruption of stable soil aggregates were made. As a result, mining operations had stripped away a larger amount of the landmass, and extensive stretches of land had lost their vegetation. In a different study, Mathe and Phiri (2016) discovered that Banket Mine's open-pit mining in Zimbabwe had an impact on the topography of the land, the vegetation, and the water, which contributed to the decline in biodiversity in the region around the mine. According to the same study, removing trees and other plants with large machinery causes land degradation. Additionally, removing nutrients from the soil changes its biological systems, making it more susceptible to erosional forces.

One of the most significant negative effects of human activity on the environment is water pollution (Owa, 2014). Water pollution happens when undesirable items enter water sources, alter the water's quality, and make it dangerous for the environment and people's health. Water contamination has been acknowledged as a problem since the 1970s and is an environmental issue

that many countries around the world find to be extremely concerning (Halder & Islam, 2015). Human actions such as defecating, dumping trash, producing industrial waste, and washing clothes have an impact on the quality of the water (Owa, 2014). The well-being and survival of aquatic species are seriously threatened by the ensuing water pollution.

One of the most significant forces transforming the environment has been agriculture (Skinner et al., 1997). The same authors discovered that soil erosion, pesticides, nitrogen compounds, and pollution from farm animals are the main environmental effects of agriculture in the United Kingdom. In a study, Matsvange et al. (2016) discovered that crop management practices in the Zimbabwean districts of Nyanga, Zvimba, and Guruve frequently included the use of organic resources like manure and compost. It was discovered that farming practices supported in Zimbabwe's Zvimba, Nyanga, and Guruve regions had a substantial impact on the quality of the soil and future cropping. Pesticide use is mostly popular in gardens. In a different empirical study carried out in Botswana by Markus (2011), overgrazing resulted in desertification in the central Boteti region, and it has caused a decrease in the productivity of the land and the availability of natural resources, which has had a detrimental effect on the ecosystem.

The quality and usefulness of the Ethiopian River were evaluated in a study by Okumagba and Ozabor (2014) to determine how socioeconomic activities impact it. The results show that socioeconomic activities like washing clothes, processing cassava, and disposing of sewage waste on the river by different resort facilities had a significant impact on the river's quality. It was also noted that the sources of river pollution are the same in both urban and rural areas.

In addition to seeing a notable drop in water pH, Antonelli et al. (2021) found a significant silt concentration. They explained the variations in river silt and quality as being caused by the significant flow of untreated municipal garbage from underdeveloped areas. The intensification of agriculture and urban sprawl, which have changed land use in areas adjacent to the river course that are permanently protected areas, includes other reasonable causes that contributed to these detrimental effects on the water quality of the River Das Antas. In addition, farmers are cropping and residents are building their homes too close to the course of the river.

According to Masere et al. (2012), the primary human activities in the study area were agriculture, light and heavy manufacturing, and some mining. In Zimbabwe, it has been determined that these practices, along with untreated and just partially treated sewage effluent, are to blame for contaminating the Manyame River and its tributaries. These activities were comparable to those discovered by Mudozori and Kusangaya (2005), who discovered that intense urban and commercial agriculture along the long profile of Manyame and its tributaries adds to pesticide pollution. Along the Nyatsime and Mukuvisi Rivers, it was discovered that agriculture, both in its commercial and unregulated subsistence forms, was the primary type of human activity.

In addition, the impacts of dumping untreated sewage in aquatic systems deplete DO because organic matter is oxidized, and nutrients like nitrogen and phosphorus, which cause algal blooms in rivers and lagoons to increase. This suggests that wastewater that enters Muni Lagoon and its tributaries elevates the organic matter of the water bodies and increases microbial activities, thereby decreasing DO in the water. Decreased DO in water can result in the death of many fish species. Additionally, abundant nutrients encourage alien invasive organisms like the water

hyacinth, which can lower water's DO and light levels (Masundire & Mackay, 2002). The water hyacinth weed reduces fish catches in water bodies and increases evaporative water losses from reservoirs and water bodies by up to 3.5 times (Davies & Day, 1998), which represents a significant economic loss in terms of water available for economic production, such as irrigation.

Sedimentation continues to be one of the biggest risks to river ecosystems worldwide (Tundu et al., 2018). In this study, agricultural activities and encroachment in the Muni catchment area can destroy the vegetative cover of the place and make the land bare, thereby enhancing soil erosion. The increased erosion can increase water turbidity and elevate sedimentation in water resources. Sediment accumulation in rivers decreases their reservoir storage capacity (Eroglu et al., 2010) and destroys invertebrates, which are the primary source of food for fish. Excessive sedimentation of river and lagoon beds can dramatically modify and degrade the water ecosystem.

CHAPTER THREE
METHODOLOGY

3.1 Study area

The study was conducted on Muni Lagoon and its tributaries in the Effutu Municipality of the Central Region of Ghana. The Effutu Municipality has a population of 107,798 (GSS, 2021), with most of them being fishermen and farmers. In the municipality, Muni Lagoon and its tributaries (Pratu and Ntakofa Rivers) provide a source of livelihood for some residents. A sand bar that occasionally breaches separates Muni Lagoon, a shallow saltwater body, from the ocean. When it rains in the Muni catchment area, the two main tributaries of Muni Lagoon receive the majority of the runoff in the area. These water bodies subsequently empty their content into the Muni Lagoon. The natural flora in the region is divided into four primary categories: terrestrial vegetation on high terrain, riverine vegetation, floodplain vegetation (including wetland and mangrove vegetation), and dune vegetation. The terrestrial vegetation is made up of plantations of eucalyptus, meadows, and thickets. The natural vegetation occupies 53% of the catchment area, while 32.5% and 12.5% are classified as agricultural land and residential area for some communities, respectively.

Most of the people in the catchment area engage in either farming or fishing. Land and forest within the catchment area of the two rivers (Pratu and Ntakofa) and the Muni Lagoon are extensively used for bush meat hunting, vegetable cultivation, and as hunting grounds for the Effutu people. Aside from the Muni-Pomadze site's importance for biodiversity on a worldwide scale, management of the site is justified by its potential to develop into an educational and financially lucrative nature reserve with an eco-cultural focus. Local communities, government, and non-governmental conservation organisations work together to manage the Muni Lagoon. Figure 3.1 shows the map of the study area.

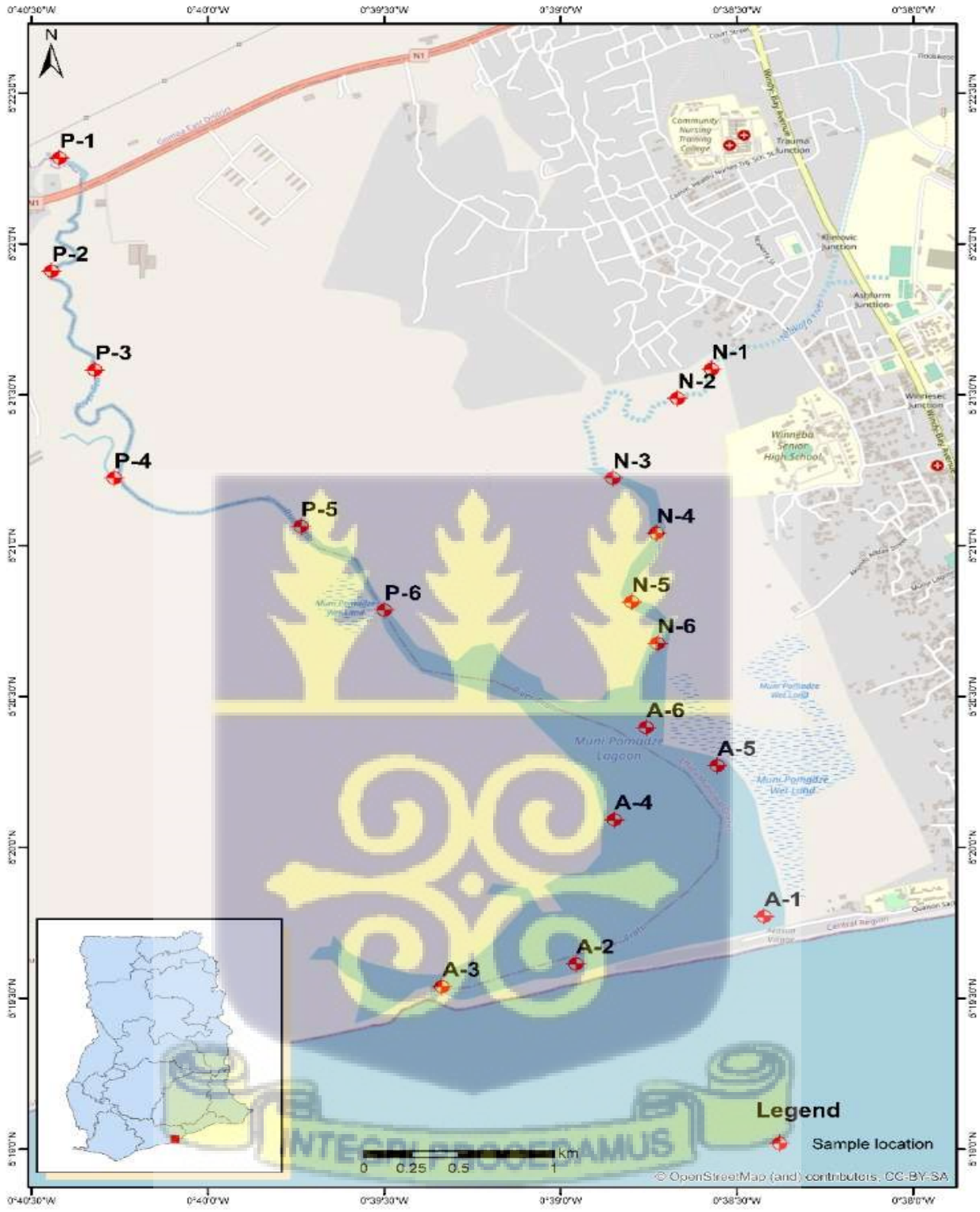


Figure 3. 1: Map of the study area with sampling locations

3.2 Research Approach

The research approach adopted for this study was a mixed method. This research approach combines qualitative and quantitative research approaches in a single study (Molina-Azorin, 2016). Molina-Azorin and López-Gamero (2016) stated that a mixed method design enables researchers to compare qualitative and quantitative findings to better comprehend the study challenge. In effect, a combination of qualitative and quantitative methodologies results in a deeper comprehension of study issues than any approach used separately (Creswell, 2009).

3.3 Water, sediment, and fish samples collection

The fieldwork was conducted from July 2021 to April 2022. Water, sediment, and fish samples were collected from Muni Lagoon, River Pratu, and River Ntakofa. Some staff of the Effutu Municipal Wildlife Division of the Forestry Commission, who were in charge of the Muni Ramsar site, assisted during the sampling period. They acted as my guides during sample collection, and I was able to sample from isolated areas of the forests.

Water and sediment samples in Muni Lagoon, Pratu, and Ntakofa Rivers were collected for analysis. Seasonality was not considered because the rainfall pattern shifted, and as a result, rainfalls were experienced during the dry season, with few rains occurring during the wet season. Samples were taken from six locations on each of the three water bodies. These locations were chosen based on the closeness of land use activities likely to influence the river or lagoon quality. In all, 36 water samples were collected for the analysis of physicochemical parameters using a previously washed 1.5L plastic bottles, 36 water samples were collectd for heavy metal analyses using 0.75L plastic bottles, 36 sediment samples were collected into ziplock plastic bags for heavy metal analysis using an auger, 36 water samples were collected for pesticide residual analysis using 0.75L plastic bottles and 36 sediment samples from the bottom of the water bodies were collected into ziplock plastic bags for pesticides analysis using an auger. In accordance with the

recommended procedure (APHA, 1998), water samples collected for heavy metal analysis were acidified with 10 percent concentrated nitric acid and maintained in a cold box to keep them below 4 °C during transport from the field to the laboratory.

At the same area where water samples were taken, sediment samples were collected at a depth that ranged from 5 cm to 10 cm. A depth between 5 cm to 10 cm is the zone where contaminants and chemical signatures are more stable and historically integrated (Batley & Simpson, 2016). They added that this zone is less influenced by short-term fluctuations (like a single storm event) and more reflective of long-term accumulation of particles like metals and organic matter. As soon as a sample was taken, the auger was cleansed to prevent cross-contamination, which could affect the results. The sediment from the bottom of the water was carefully transferred into a zip plastic bag, which was labelled and placed in a cold box.

In addition, 120 fish samples each were collected from Muni Lagoon for heavy metal and pesticide analysis. The fish species collected were mostly black chin tilapia (*Sarotherodon melanotheron*) with a few *Tilapia guineensis*. The fish length was between 3-5 cm, and they were kept in zip plastic bags, labelled, and transported to the laboratory in a cold box for analysis. The fish were obtained with the help of some local fishermen who fish from the Muni Lagoon using hand nets and drag nets. All samples collected in this study were labelled and transported to the laboratory. In this study, samples for physicochemical and heavy metal analysis were analysed at UCC Chemistry Laboratory, while samples for pesticide residues were sent to Ghana Standards Authority (GSA) Pesticide Residues Laboratory for analysis.

Table 3. 1 GPS locations for the various sampling points

Pratu river	Latitude	Longitude
P-1	5.3666520	-0.6706506
P-2	5.3618617	-0.6730767
P-3	5.3607867	-0.6728200
P-4	5.3537300	-0.6710900
P-5	5.3524667	-0.6699533
P-6	5.3559033	-0.6702317
Ntakofa		
N-1	5.3597450	-0.6428700
N-2	5.3592283	-0.5054810
N-3	5.3582350	-0.6433433
N-4	5.3437633	-0.6463483
N-5	5.3545930	-0.6332860
N-6	5.3611583	-0.6731667
Muni Lagoon		
A-1	5.3540750	-0.6470550
A-2	5.3267333	-0.6484600
A-3	5.3267367	-0.6484550
A-4	5.3593767	-0.6430533
A-5	5.326500	-0.6505800
A-6	5.339970	-0.6466100

Figure 3. 2: Images of sample collection

3.4 Determination of Physicochemical Parameters of Water Samples

3.4.1 pH

To determine the pH of the water sample, a digital pH meter (HANNA model 209) that provided a direct pH measurement was calibrated using common pH 9.0, 4.0, and 7.0 buffer solutions. A 100 ml volume of water sample was measured and transferred into a cleaned 250 ml beaker. The pH meter electrode was placed in the water sample, and the button selection was turned on to read the pH. The displayed pH value was noted, and the process was repeated to ensure consistency.

3.4.2 Electrical Conductivity (EC)

Water samples were measured for conductivity in the lab using a HANNA model HI 9032 conductivity meter. A standard sodium chloride solution with a concentration of 12880 S/cm was used to calibrate the apparatus. The conductivity meter was operating in the measuring mode. The conductivity metre electrode was inserted into a 120 ml water sample placed in a clean 250 ml glass beaker. After five (5) minutes, the value that was displayed was recorded in S/cm. For each of the water samples, the process was replicated three times.

3.4.3 Total Suspended Solid (TSS)

In an oven, evaporating crucibles designated A, B, and C were heated and then cooled in a desiccator. An analytical balance was used to weigh the thoroughly cleaned crucibles. A measuring cylinder was used to measure 20 ml of each water sample, which was added to each crucible and placed in the water bath to dry out. The crucibles were taken out after drying, put in a 105°C oven for an hour, cooled for 20 minutes in a desiccator, and then reweighed using an analytical balance. The weights after drying were recorded. Total solids were estimated from the weight differences between the weights before and after.

$$\text{TSS (mg/l)} = \frac{\text{Weight of Sample in Dish before} - \text{Weight of sample in Dish after}}{\text{Volume of Sample}}$$

3.4.4 Total Dissolved Solids (TDS) in water samples

To calculate the total dissolved solids in water samples, a calibrated HANNA multifunctional metre (model HI 9032) was utilised. A 50 mL water sample was transferred into a washed glass beaker. For measurement, the instrument's electrode was placed in the water sample. The value on the monitor was noted and recorded in mg/L.

3.4.5 Turbidity

After calibration, the HACH 2100 AN turbidimeter was used to measure turbidity. Before adding a water sample, the cuvette was rinsed in distilled water. The blank sample and the remaining water samples underwent the same procedure. The light shield was placed over the cuvette before it was placed within the cuvette chamber. The turbidity value that was displayed was read and recorded.

3.4.6 Determination of Nitrite-Nitrogen

After the instrument was calibrated, nitrite-nitrogen was measured using the comparator method using the Lovibond Nessleriser (model 2150). Griess-Ilosvays Nos. 1 and 2 were added to a clean Erlenmeyer flask after a 50 mL water sample was measured out into it. After stirring the mixture, it was allowed to stand for fifteen (15) minutes. After the mixture's colour had changed to pink, it was put into a Nessler's tube and introduced into the chamber of the comparator. By matching colours with the aid of a nitrite disc and comparator, the value was determined by using the formula:

$$N\ (mg/L) = \frac{\text{Disc Reading} \times 0.5}{\text{Sample Volume (ml)}}$$

NO_2 (mg/L) = N (mg/L) × 3.284 (American Public Health Association, 1998).

NB. The markings on the disc indicate how much nitrogen (N) is present as nitrite.

3.4.7 Nitrate-Nitrogen in water samples

Nitrate-nitrogen was determined with a Palintest photometer (model 5000). A Nitratest tube was filled with 20 ml of the sample using a measuring cylinder. The tube was then sealed and rapidly shaken for one minute to ensure a homogenous mixture of its ingredients before adding a teaspoon of Nitratest powder and one Nitratest tablet. The tube was then left to stand for another minute, flocculated by repeatedly inverting it, and allowed to stand for an additional two minutes for complete settlement. A 10 ml portion of the decanted solution was put into an already-cleaned test tube. One crushed Nitricol tablet was added, mixed to dissolve, and then left to stand for an additional 10 minutes to allow the colour to develop. The test tube containing the water sample was inserted into the photometer chamber, read at 570 nm wavelength, and the results were read and recorded. The nitrate-nitrogen was calculated using the Nitratest calibration table, and the concentration of the nitrate was multiplied by 4.4 to mg/L of NO_3.

3.4.8 Sulphate in water sample

The sulphate concentration was measured using the colorimetric method using the Palintest photometer (model 5000) after the meter had been calibrated. The reagent for sulphate determination in the Palintest photometer is a single tablet that is mostly made of barium chloride and has a mildly acidic composition. A pipette was used to transfer a 10ml water sample into a clean test tube. To dissolve and blend the sulphate turb, it was crushed and placed into the water sample. The development of a cloudy solution indicated that sulphate was present. To ensure homogeneous mixing, the mixture was left to stand for five minutes before being blended. At a wavelength of 520 nm, the transmittance (percent T) was computed when the cell was placed within the chamber. The required concentration in mg/L was determined using the sulphate calibration chart.

3.4.9 Chloride

Chloride concentrations in water samples were determined using the argentometric technique. The potassium chromate indicator solution was created by mixing 50g of K_2CrO_4 with a little bit of distilled water, then gradually adding 1.0M $AgNO_3$ solution until a discernible precipitate was formed. The solution was filtered and diluted to a volume of 1000 millilitres after leaving it for 12 hours to settle. To create the silver nitrate titrant solution, 2.395g of silver nitrate was dissolved in 1000 mL of distilled water (0.0141M).

A clean conical flask was used to hold 50 ml of the water sample that had been pipetted. Then 1 ml of a K_2CrO_4 indicator at 5% was added. This was titrated against a 0.0141M $AgNO_3$ solution with gentle swirling, and the colour was watched until it changed from yellow to brick red. The titre value was measured and read in millilitres. The chloride level was determined as shown below:

$$Cl^- \text{ (mg/L)} = \frac{(A - 0.2) \times 0.5 \times 1000}{\text{Sample Volume (ml)}}$$

Where A = Titre value (American Public Health Association, 1998).

3.4.10 Phosphate

Following standardization, the phosphate concentration in water samples was measured using the Palintest photometer (model 5000).

A 10 ml water sample was measured and put in a washed test tube. The water sample was added to the crushed phosphorus No. 1 LR and No. 2 LR tablets to dissolve them. Ten minutes were allowed for the mixture to stand to complete the colour development process. The test tube was positioned inside the chamber, a wavelength of 640 nm was chosen, and the sample transmittance

(percent T) was then calculated. Using the phosphate LR calibration chart, the corresponding mg/L concentration was determined.

3.4.11 Determination of Total Alkalinity

Using the titrimetric approach, the total alkalinity of water samples was determined. The titration was performed using 0.02M H_2SO_4 as the titrant and phenolphthalein and methyl orange as indicators.

Two drops of the phenolphthalein indicator were added to a 50 ml water sample, which had been pipetted into a cleaned conical flask. After adding the phenolphthalein indicator, the sample solution turned pink and was titrated against 0.02M H_2SO_4, gently swirled until the pink colour almost completely vanished. At the equivalence point, the titre value was noted. At the phenolphthalein indicator's end point, three drops of the methyl orange indicator were added. The yellow sample was then titrated with 0.02M H_2SO_4, gently stirred until the colour changed to orange, and the titre value was noted and used to calculate the total alkalinity using the formula:

$$\text{Total Alkalinity as CaCO3 (mg/L)} = \frac{A \times T \times 1000}{\text{Sample volume (ml)}}$$

Where A = Titre of standard acid at phenolphthalein endpoint

T = Titre of standard acid at methyl orange endpoint

(American Public Health Association, 1998).

3.4.12 Calcium

EDTA Titrimetric Method

EDTA has a stronger affinity for calcium ions than magnesium ions. As a result, EDTA combines first with calcium ions when it is added to water containing these two ions. When the pH of the

water sample is sufficiently high and the right indicator is added, calcium can be determined directly with the precipitation of magnesium largely as hydroxides.

A pipette was used to measure 50 ml of the water sample into a 250 ml conical flask, and 2.0 ml of NaOH solution was added to estimate the amount of calcium. After giving the flask a gentle shake to combine, 0.1–0.2g of murexide indicator was added. After adding the indicator, it was promptly titrated. The addition of EDTA titrant was done slowly while swirling the conical flask till the colour changed from salmon to orchid purple. To ensure that no additional color change occurred, one or two drops of extra titrant were injected into the terminal point. It was ensured that the 15 ml EDTA solution volume limit was not exceeded throughout the titration. The calcium concentration was calculated as follows:

$$\text{Ca (mg/l)} = \frac{\text{A x B x 400.8}}{\text{Volume of sample}}$$

Where A = ml of EDTA titrant used

B = ml of standard calcium solution ml of EDTA titrant

Three significant figures were used to express the data in mg/l Ca (APHA, 1998).

3.4.13 Magnesium Ions

To measure calcium and total hardness in water, an EDTA titration method was utilized. When both hardnesses are stated in the same units, the value for magnesium hardness is the difference between the two.

Keeping track of the calcium and total hardness results, the following methods were used to determine Magnesium ion concentration:

Calcium hardness as mg $CaCO_3$/l = A x B x 1000 ml sample

Where;

A= mL titrant for the sample

A = mg $CaCO_3$, equivalent to 1.00 ml EDTA titrant at the calcium indicator endpoint.

Then, calcium hardness as mg $CaCO_3$/l = $\frac{\text{concentration of Ca}}{0.4}$

Where, $0.4 = \frac{\text{Atomic weight of Ca}}{\text{The molecular weight of } CaCO_3}$

The total hardness concentration was recorded as mg/l $CaCO_3$.

Magnesium hardness as mg/l $CaCO_3$ = total hardness – calcium hardness.

Mg^{2+} / mg/l = (total hardness – calcium hardness) x 0.243

Where 0.243 = atomic weight of Mg / molecular weight of CaCO3.

(American Public Health Association (APHA), 1998).

3.4.14 Total Iron (Fe)

For the iron measurement, a 50 ml aliquot of the water sample was digested with strong nitric acid, diluted accordingly, and aspirated. This was done to detect the absorbance at 248.3 nm using an Agilent 240 FS Atomic Absorption Spectrophotometer. The absorbance was then compared using an air-acetylene oxidizing flame to identically prepared standards and blank solutions (APHA, 2012).

3.5 Heavy Metal Analysis in Water, Sediment, and Fish

3.5.1 Heavy metals detection in water by the Acid digestion method

The Milestone Acid digestion method was used to dissolve the metals. The water sample was pipetted five milliliters at a time into a 20 milliliter Teflon tube. After that, 3ml of concentrated hydrochloric acid (HCl, 37%), 6ml of concentrated nitric acid (HNO3, 65%), and 0.25ml of concentrated hydrogen peroxide were added (H_2O_2). A blank was made using 6ml of HNO_3 (65

percent), 3ml of HCl (37 percent), and 0.25ml of H_2O_2. The materials were digested in an ETHOS 900 microwave digester for thirty minutes. The samples were digested, and the solutions were then diluted with distilled water to make 20 ml after cooling to room temperature. The Nexion 2000 ICP-MS equipped with micro mist nebulizer and spray chamber was used to analyze the liquid extract for the presence of Arsenic(As), barium (Ba), boron (B), cobalt (Co), cadmium (Cd), copper (Cu), chromium (Cr), manganese (Mn), mercury (Hg), lead (Pb), nickel (Ni), selenium (Se), and Zinc (Zn). The individual heavy metals had dwell times set at 50,25,20,20,25,15,25,22,50,25,25,25, and 25 for As, Ba, B, Co, Cd, Cu, Cr, Mn, Hg, Pb, Ni, Se, and Zn, respectively. All the samples relative standard deviations were under 20%. The concentration of each metal was calculated using the formula below:

Final concentration (mg/l) = concentration of metal x dilution factor x Sample volume (ml).

3.5.2 Heavy metals detection in sediment by the Acid digestion method

The sediment samples were sieved and put through a digestion process after being air-dried for three days and ground into smaller particles. Two grammes (2 g) of the sieved sediment sample was weighed using an electronic balance and then transferred into a beaker. Each sediment sample was weighed into a 20 ml Teflon tube before concentrated acids of 6 ml nitric acid (HNO_3, 65%), 3 ml hydrochloric acid (HCl, 37%), and 0.25 ml hydrogen peroxide (H_2O_2) were added. The samples were taken out of the ETHOS 900 microwave digester after 30 minutes, and the solution was allowed to cool to room temperature. Each sample was mixed with about 5 ml of distilled water before being filtered into a 20 ml Teflon tube using a funnel and Whatman No. 41 filter paper. The solution was then diluted to 20 ml with distilled water. The liquid extract was then used for the determination of heavy metals as described in section 3.5.1.

3.5.3 Heavy metals detection in fish by the acid digestion method

Because fish muscles and gills are the primary target tissues for metal accumulation, they were used for heavy metal detection. A 100 ml glass beaker containing two grammes of fish sample (gills and muscle) was treated with 2 ml of concentrated hydrogen peroxide (H_2O_2) and 20 ml of concentrated nitric acid (HNO_3) in a fume chamber. Afterward, a cling film was used to cover the beaker, which was then placed on a hot plate and digested for three hours at a temperature of 45°. The sample was then placed in a 50 ml measuring cylinder, and additional distilled water was added until the 30 ml threshold was reached. The entire contents were then put into a test tube for analysis using the Nexion 2000 ICP-MS equipped with a micro-mist nebulizer and spray chamber. The concentrations of heavy metals in sediment extracts were determined as described in section 3.5.1.

Heavy metal concentration calculations were made as follows:

Final conc. (mg/L or mg/kg) = Conc. (analytical measurement) ×Nominal volume/ Sample weight in grammes, where conc. = instrumental measurement

Nominal volume = final volume of digested sample solution

Conc. (mg/kg) = concentration of metals in soil

3.5.4 Quality Control and Quality Assurance

The analysis was conducted using the following quality assurance and control methods. Blanks: During sample processing, they were to check for contamination. Duplicates: These were made to examine the method's ability to be replicated. Standards: To evaluate the effectiveness of the instruments in use. Blanks and duplicate samples were digested under the same conditions as the samples, as were reference standards utilised for the constituents of interest. These acted as internal good checks. Reference standards were from the Swiss company Sigma-Aldrich Chemie GmbH's

and Fluka Analytical's line of products. The right standards were used to calibrate the equipment before the analysis.

3.5.5 Calibration of the Instrument

Calibration was done using standard solutions of known and rising concentration for each target analyte element to ascertain the ICP-MS instrument signal sensitivity to changes in concentration. In this work, the Garcia and Baez equation was used to determine the actual metal concentration in sampled materials (2014).

$$Actual\ conc.\ (mgkg) = \frac{Digested\ Concentration \times Nominal\ volume}{Sample\ dry\ weight\ (kg)}$$

Where the amount of any substance that was measured into a container is the nominal volume. It is used to symbolize the accepted situation, which approximates the genuine value that is always present. The values recorded were changed to kilograms.

3.6 Pesticides Analysis

3.6.1 Instrumentation and Reagents

Instrumentation and reagents for pesticide analysis are presented in Tables 3.2 and 3.3

Table 3. 2: Laboratory reagents and materials used for analysis

REAGENT	GRADE
Acetone	Pesticides grades
Hexane	Pesticides grades
Acetonitrile	Pesticides grades
Toluene	Pesticides grades
Sodium sulphate	AnalaR
Sodium hydroxide	AnalaR
Sodium chloride	AnalaR
Potassium dihydrogen	AnalaR
Dipotassium hydrogen phosphate	AnalaR
Ethyl acetate	AnalaR
Bond elute C18 SPE cartridges.	-
ENVI-Car LC-NH2 500mg. 500mg.6ml	
Filter paper	

Table 3. 3: Description of Equipment Used for sample analysis

EQUIPMENT	TYPE
Gas chromatograph	Shimadzu GC – 2010 with AOC 20 Autoinjector and AOC 20S Autosampler and Electron Capture Detector
Analytical column	30m x 0.25mm internal diameter fused silica capillary column coated with VF-5ms (0.25µm film).
Centrifuge	Sanyo (MSE) Harrier 18 / 80
Glass vials	2 mL
Vacuum manifold	209 x 200 – Aldrich TM round bottom flask
Horizontal shaker	Ika-Werke HS 501 Digital
Macerator	IKA Ultra Turrrax Homogenizer
General laboratory glassware	Round-bottomed flasks, volumetric flasks, centrifuge tubes, separating funnels, funnels, measuring cylinders
Rotary film evaporator	Buchi Rotary evaporator (India)
Ultrasonic bath	Clifton SW 3H and Grant XUB 18 UK
Vortex mixer	Thermolyne (Mai Max-Plus)
Recirculating chiller	Buchi, B-740

3.6.2 Determination of Pesticide Residue

The organochlorine and pyrethroid pesticide residues were examined using a Shimadzu gas chromatograph, model GC-2010, which features a 63Ni electron capture detector (GC-ECD), while those of organophosphates were examined using a Shimadzu gas chromatograph, model GC-2010, with a flame photometric detector (GC-FPD). The GC conditions and detector response were changed to match the relative retention time and reaction. ZB-5 (30 mm x 0.25 mm, 0.1 m film thickness) was coated on the capillary column used for the analysis. For sample preparation, extraction, cleanup, and analysis, QuEChERS (Quick Easy Cheap Effective Rugged Safe) (Anastassides et al., 2003) was employed.

A Shimadzu gas chromatograph (GC-MS QP 2010 Ultra, Japan) equipped with Restek (Bellefonte, PA) Rxi-5MS with fused silica (30 m long x 0.25 mm internal diameter x 1.0 µm film thickness), analytical column setup, and mass selective detector was used for analysis. The operating conditions of pyrethroid and organophosphate pesticides were splitless injection mode, helium gas as a carrier with flow rate of 0.75 mL/min, injector and interface temperature of 250 ^{o}C, a sampling

time of 1 min, 14 mL/ min total flow rate, linear velocity in flow control mode, 37 cm/s linear velocity, 71.2 KPa pressure, 3 mL/min purge flow, 1 mL/min column flow, and injection volume of 1 µL. The temperature was programmed for organophosphate pesticide from an initial value of 90 ºC, ramped to 180 ºC at 25ºC/min, and then to 270 ºC at 3ºC/min, and was increased to 300 ºC at 20 ºC for 3 min, and the total run time was 40 min. Likewise, the operating condition of organochlorine pesticide was split mode, split ratio 10, 250 ºC injection port temperature, 1 min sampling time, linear velocity flow of control mode, helium gas as carrier with flow rate 0.75 mL/min, 19.5 mL/min of total flow, 1.5 mL/min of column flow, 124.6 KPa pressure, 46 cm/s of linear velocity 3 mL/min of purge flow and injection volume was 1µL. The initial value of 120 ºC, ramped up to 200 ºC at 45 ºC for 3 min, and then to 240 ºC at 5 ºC for 10 min, and finally raised to 310 ºC at 10 ºC for 3 min, and the total run time was 34 min. Analysis was carried out in selected ion monitoring (SIM) mode for the identification of all analytes and each pesticide. In Chapter 4, the quantified pesticide parameters are reported.

3.6.3 Experimental Procedures

Before the samples were subjected to the analysis process, all relevant glassware was carefully cleaned with distilled water, rinsed with acetone, and dried in an oven at 150 ºC for around five hours. The pesticide was extracted and cleaned from the sediment, water, and fish samples using the QuEChERS (Quick Easy Cheap Effective Rugged Safe) method (Anastassides et al., 2003). The final injection solvent was ethyl acetate, and synthetic pyrethroid insecticides, organochlorines, and organophosphates were identified using GC with an electron capture detector (ECD).

3.6.3.1 Preparation of standard solutions

The standard solutions of each pesticide were prepared by dissolving the appropriate mass in distilled water and were prepared using an ultrasonic bath after being adjusted for purity, equal to 1000 g/mL. For each pesticide standard, such as Heptachlor and HEPT 1, this was designated as a Parent Standard Reference. These Parent Standard References were diluted to be used as fortification standards throughout the procedural recovery process and as calibration standards for device calibration. A sufficient quantity of the stock solutions was diluted with ethyl acetate to serve as working standards in instrument calibration and as fortification standards in the procedural recovery process. All aqueous solutions were made with distilled water. The Whatman paper was utilised to filter every gas chromatography (GC) solution. Repeated analyses of the samples were conducted against internationally standardised reference material to verify the analytical process. Additionally, the examination of procedural matrix blanks, solvent blanks, and duplicate samples was used to guarantee the quality of pesticide residues. All reagents used in the analysis were subjected to the same extraction techniques before being tested for interference-causing compounds. No pesticide was found in any of the extraction procedures' blanks. Duplicate samples from each series were examined. Until quantification was accomplished, all extracts were kept frozen.

Before analysis, the technique was strengthened and spiked with a reference mixture to assess the recovery of compounds. For the majority of the pesticides analysed, the recoveries of internal standards were between 70% and 95%.

$$\text{Recovery (\%)} = \frac{\text{Conc of pesticide residues recovered from fortified samples}}{\text{Concentration of pesticide added to the sample}} \times 100$$

3.6.3.2 Preparation of 0.5 mol/l phosphate buffer (pH 7.0)

An electronic balance was used to properly weigh 52.7 g dipotassium hydrogen phosphate and 30.2 g potassium dihydrogen phosphate, and placed in a 250 mL beaker**.** In order to lower the pH of the solution to 7, 1.0 M HCl and 1.0 M NaOH solutions were used. The completed mixture was poured into a one-litre volumetric flask. Distilled water was added until the solution was on the mark.

3.6.3.3 Extraction of sediment samples

Sediment samples weighing 10 g each were quantitatively placed into 250 mL separating flasks. Each of the sediment samples in the flasks received 10 mL of hexane before being ultrasonically processed for 5 min. Hexane was added in an additional 10 mL, and the flasks were then tightly sealed. The samples were put on a mechanical shaker that had a 30-minute timer set to shake continuously at a speed of 300 m/min. The phases or layers were then properly separated by allowing the mixture to stand for 10 minutes. Afterward, 10 mL of the supernatant was carefully pipetted into a 50 mL round-bottom flask and dried over 2 g of anhydrous magnesium sulphate. The concentrations were then prepared for silica to clean up by being reduced to roughly 2 mL with the help of a rotary film evaporator at 35 °C.

3.6.3.4 Clean-up of sediment extract

There was a requirement for a clean-up to get rid of the matrix chemicals that can obstruct the GC analysis. Using polypropylene cartridge columns with 1 g of silica gel that had been activated for 10 hours at 130 °C, a centimetre-thick layer of anhydrous $MgSO_4$, and a conditioning step with 6 mL acetonitrile, extracts were cleaned up. The columns or cartridges were then loaded with the concentrated extracts, and 50 mL conical flasks were positioned beneath various columns to collect

the eluates. 10 mL of hexane was then used to elute the columns. Using a rotary evaporator, the entire filtrates were concentrated until dry at 40 °C. The leftovers were pipetted back into 1 mL of ethyl acetate and then transferred into a 2 mL standard tube using gas chromatography (GC). Until analysis was required, every extract was kept frozen.

3.6.4 Extraction of water samples

The water samples were filtered using Whatman filter paper to get rid of particles and suspended matter. Portions of each filtered water sample, totaling 1000 mL, were then added to two-litre separating flasks. Thirty (30) mL of a saturated sodium chloride solution was added to trigger salt-out and raise the pH to 7. Following five minutes of manual agitation, a two-litre separating funnel containing one litre of filtered water and fifty millilitres of hexane was left to settle. The organic phase was completely separated and transferred to a 250 mL conical flask, followed by two extractions with 50 mL of hexane of the aqueous phase. The organic solutions collected separately were combined and dried by passing through a glass funnel containing anhydrous sodium sulphate. The organic portion was cleaned of silica and then concentrated using a rotary evaporator.

3.6.5 Clean-up of water Extract

Two grams of anhydrous sodium sulphate, one gram of silica gel, and six milliliters of hexane were used to condition the silica gel in polypropylene cartridge columns. The silica gel was activated for ten hours at 130 °C in the oven. The cartridges were then filled with the concentrated extracts, and the eluates were collected in 100 mL conical flasks positioned beneath the columns. Following the elution of the columns or cartridges with 20 mL of hexane, a rotary evaporator set to 40 °C was used to concentrate the recovered total eluents until they were dry. In order to analyze the sample using a gas chromatograph (GC) fitted with an electron capture detector, it was once

again dissolved in 2 mL of ethyl acetate. Until quantification was accomplished, all extracts were kept frozen.

3.6.6 Fish sample preparation and analysis of pesticides

The fish was taken out of the refrigerator and left to thaw at room temperature. To create a homogenous composite, the gill, liver, and muscle were cleaned, diced, and blended with an electric blender. The materials were examined by the organochlorine (OC), organophosphate (OP), and pyrethroid groups. The QuEChERS sample preparation method for pesticides was used to guide the extraction and cleanup procedures (Anastassiades et al., 2003). Pesticide detection and quantification were carried out using GC-MS analysis. For the quantification of pesticide residues, Cunha et al. (2007) state that the QuEChERS approach employs both gas chromatography-mass spectrometry (GC-MS) and liquid chromatography-tandem mass spectrometry (LC-MS/MS).

3.6.7 Extraction of fish samples

With the use of a blender, the fish samples were combined before being put into a large beaker. A 50 mL centrifuge tube was filled with 2g of the homogenised fish sample (0.05g), 12 mL of distilled water, and vortexed for one minute. In addition, the centrifuge tube's contents received 15 ml of acetonitrile, which was added after a minute of vortexing. Four grammes of magnesium sulphate anhydrous, one gramme of sodium chloride, one gramme of trisodium citrate dihydrate, and 0.5 grammes of disodium hydrogen citrate sesquihydrate (Tamponed method EN 15662) were added to the centrifuge tube. The mixture was vortexed for one minute and then centrifuged at 4000 rpm for five minutes (Q-sep. QuEChERS, dSPE, RESTEK, France) (TidianeDione et al., 2022).

3.6.8 Clean-up of fish extract

A 6 ml aliquot of the acetonitrile (ANC) reagent was placed into a clean 15 mL centrifuge tube containing 150 mg PSA, 150 mg C18, and 900 mg magnesium sulphate using a tiny measuring cylinder (Anastassides et al., 2003). The tube was tightly closed, shaken for 30 seconds, and then centrifuged for 5 minutes at 4000 rpm. After that, 40 µL of a 5 percent formic acid solution in acetonitrile (v/v) was added to 4 mL of the cleaned extract in a round-bottom flask to bring the pH to 5. The filtrate of the resultant mixture was dried to dryness on a rotary evaporator below 40 ^{o}C. Afterward, it was redissolved in 1 mL of ethyl acetate. The extract was transferred into a 2 ml standard opening vial for quantitation by GC-ECD and GC-PFPD. The QuEChERS method for pesticide analysis employed in this study was also adopted by Rahman et al. (2021)

3.6.9 Quantification of Pesticide Residues

Pesticide residue levels (OCPs, OPs, and Pyrethroids) were quantified using reference standards and residence duration projections. The residual levels were determined using the traditional external approach by comparing the peak heights of the samples with the corresponding peak heights of the reference standards at different concentrations. The calculation was carried out within the linear dynamic range of the detector. The concentration was determined by extrapolating from the peak regions whose retention times correlated with the standards to the relevant calibration curves. In this investigation, the LOD for pesticides was estimated using the lowest analyte level that could reliably recover 70% or more from the enriched samples, as recommended by Koranteng (2015). Serial dilutions of common pesticide mix solutions were used. Five different concentrations were evaluated, and the one with the lowest signal-to-noise ratio (1:3) and the highest recovery from fortified samples (more than 70%) passed the test. The signals' standard deviation was determined. The LOD was calculated by multiplying the standard

deviation (SD) by three (i.e., SD x 3 = LOD). The limit of quantification (LOQ) was calculated by multiplying the standard deviation for the LOD result by 10 (i.e., SD x 10 = LOQ). The LOD of pesticides in water, sediment, and fish were set at 0.01 µg/kg, 0.13 µg/kg, and 0.11 µg/kg, respectively. Similarly, the LOQ established for water, sediment, and fish were 0.082 µg/kg, 0.298 µg/kg, and 0.312 µg/kg, respectively.

3.7 Social survey

3.7.1 Research design

The study employed a descriptive survey design. A survey research design, according to Creswell and Creswell (2017), is a quantitative process in which researchers distribute a survey to a sample or the entire population to characterise the attitude, opinions, behaviours, or features of the population. Aggarwal and Ranganathan (2019) defined descriptive research as the process of acquiring data to describe and interpret current circumstances or settings. The research approach known as a "descriptive survey study" is one that only focuses on the current situation in terms of conditions, beliefs, behaviours, processes, relationships, or trends (Salaria, 2012). Information was gathered as part of this study about the effects that human activity has had on the ecosystem in the Muni catchment area.

3.7.2 Study Population for Social Survey

People who reside in the catchment areas of Muni Lagoon and its two tributaries made up the research target populations. Only residents who were over the age of 18 years and above were involved. This age restriction complies with a clause in Ghana's constitution that specifies that such individuals make decisions that will benefit their communities. High levels of human activity have a negative influence on the Muni Lagoon and its tributaries. When this occurs, the local population will not have access to the ecosystem services the lagoon and the rivers offer.

Therefore, understanding the impact levels and their sources is essential to the mitigation and repair action. The accessible population included farmers, fishermen, opinion leaders (including assemblymen, chiefs, and family leaders), and leaders of government agencies such as municipal wildlife division officers, forestry division officers, EPA, and agricultural extension officers. These persons gave information on various human activities that had an impact on the Muni Lagoon, its tributaries, and the resources in the research region because of their roles or jobs in the communities.

3.7.3 Sample and sampling procedure

Sampling is the process of selecting a subset of the study's intended audience (Turner, 2020). Using Kothari's (2004) sample size calculation formula, the necessary sample size for this investigation was determined.

$$n = \frac{pqZ^2}{E^2} \quad \ldots\ldots\ldots(1)$$

Where n= sample size; Z=1.96 (confidence level is 95 % and value obtained from the table); P= proportion of the population containing the main characteristics of interest; q=1-p and E= allowable error. Since the proportion containing the major characteristics of interest was unknown, P= 0.5, q=0.5, Z=1.96, and E= 0.05. Approximately 384 people were included in the sample as a result of this. The respondents were farmers, fishermen, and other people whose activities are affected by the degradation of Muni lagoon and its tributaries. They were selected from four communities, namely, Akosua village, Ntakofam, Onynadze, and Mankoadze, which are very close to the Muni catchment area in Effutu municipality. The locations were purposively selected, while the respondents were conveniently sampled. The four communities were selected because of their nearness to the water and forest resources in the Muni catchment area. Also, most of the people in these communities depend on the forest and water resources in the study area for their

livelihood, and so can account for how ecosystem services have been impacted in the Muni catchment area. The sample size of 384 comprised 100 respondents each from Akosua village, Ntakofam, and Onyadze, with 84 of them from Mankoadze. Purposive sampling, according to Seetharaman (2016), encourages individuals who can provide the best information about the experience under study.

3.7.4 Instrument for data collection

Both primary and secondary sources were used to create the data for this study. A questionnaire was the main instrument used for data collection, and it was supplemented with an unstructured interview. To ensure generalisation, dependability, and objectivity, questionnaires were used to collect quantitative data (Barnham, 2015). It was used to assess the impact of human activities on ecosystem services provided by the environment in the Muni catchment area. The questionnaire consisted of closed-ended questions, which were 5-point Likert-scaled as well as open-ended questions. The scale range was strongly agree (5), agree (4), undecided (3), disagree (2), and strongly disagree (1). Information that the questionnaire was unable to elicit was obtained through an unstructured interview.

3.7.5 Pilot study

The questionnaire was administered to fifty (50) residents who farm along the Ayensu River in Effutu municipality. Their responses were used to improve the reliability of the measuring instrument.

3.7.6 Validity

According to Drost (2011), an instrument's validity refers to how well it reflects the fundamental construct that it is intended to measure. The ability, knowledge, attribute, or attitude that the researcher is looking at is referred to as a construct. In this study, the questionnaire was given to a

senior lecturer at the Institute for Environment and Sanitation Studies to evaluate whether the topics were pertinent to the study's goals and to ensure the validity of the questionnaire (content validity). In addition, the questionnaire items were scored by some lecturers and some of my colleagues. A strong correlation greater than 0.8 was an indication of valid items.

3.7.7 Reliability

The reliability of a measure refers to its internal consistency, stability, and equivalence (Polit & Beck, 2016). In effect, reliability is the instrument's ability to consistently and repeatedly measure something (Drost, 2011). Following the pilot study, the internal consistency of the questionnaire was evaluated using Cronbach's alpha test to establish its reliability. To eliminate uncertainty in comprehension and response to questions, poorly formed elements were omitted, and some were redefined. The indicated items were consistent with one another and could collectively reflect the construct being studied, and the Cronbach coefficient alpha for the items was satisfactory (above 0.68). Items relating to how human activity affects ecosystem services had a 0.72 reliability coefficient. According to Bretz and McClary (2014), reliability is considered to be satisfactory when the Cronbach alpha coefficient is 0.7 or higher. As a general rule, reliability levels between 0.6 and 0.7 are considered to be satisfactory, whereas those between 0.8 and greater are considered to be extremely good (Ursachi et al., 2015).

3.7.8 Secondary data

Secondary data was gathered from the examination of documents from published and unpublished sources, including books, journals, reports, theses, and photographs, as well as from relevant offices (districts, local, traditional, NGOs/CBOs). It was also gleaned from literature reviews and printed and electronic media.

Nevertheless, it is significant to mention that mixed approach data collection techniques are advised for good quality data. As a result, this study incorporated unstructured interviews, questionnaires, observations, and secondary data. The materials were then triangulated to improve data reliability and convergent validation for use in analysis and result interpretation. Triangulation, according to Cohen et al. (2017), improves the validity and reliability of research findings. Triangulation is based on the idea that procedures that yield the same outcomes increase the credibility of study findings (Given, 2008).

3.8 Data Analysis

3.8.1 Quantitative data

Data were analysed using SPSS (version 25.0) for both descriptive and inferential statistics. In this study, descriptive statistics like mean and standard deviation were determined to analyse the collected data. To determine the variations in physicochemical, heavy metal, and pesticide residual levels in water, sediments, and fish at a 95% confidence level, inferential statistics, including principal component analysis (PCA), linear regression, one-way analysis of variance (ANOVA), and Pearson correlation coefficient, were used. Tukey HSD multiple comparisons were used in the post hoc test to identify the variables that contributed to the difference in the ANOVA study. Using the principal component analysis, components that cause changes in physicochemical, heavy metal, and pesticide variations were extracted by taking into account Eigenvalues greater than 1. The factorability of the data was assessed using the Kaiser-Meyer-Olkin (KMO) and Bartlett's test of sphericity. Regression analysis was used to analyse data obtained from the questionnaire.

3.8.2 Qualitative data

Qualitative descriptions were used in the data analysis process. Using descriptive statistics like mean and standard deviation, the information gathered using a questionnaire was examined. It

described the degree to which human activities have impacted water and other resources (Muni Lagoon and its tributaries) in the research area. Unstructured interviews and observations were used to support the quantitative data in the analysis.

3.9 Ethical Issues

The University of Ghana, Legon's Ethics Committee was consulted for permission to proceed ethically. This committee is responsible for making sure graduate students adhere to moral standards to protect respondents' privacy and safety. The committee also considers the procedures for gathering data and any other problems associated with the study. When the researcher (student) satisfies the criteria and the committee's satisfaction, clearance is granted, and a letter of clearance (Appendix H) is issued. Participants were introduced to the researcher, who then went over the research's goals, time requirements, and protocol. Each participant received a guarantee of confidentiality and anonymity regarding the disclosure of the data they gave for the study. The rules governing the use of human beings in the research were also scrupulously followed. The research did not record the names of the respondents. There were no prejudices towards any race, religion, or culture. Participants' consent was requested before including them in the study. Without the participants' consent, no group of individuals may be studied. This falls under the category of ethical issues in social research. In this regard, before collecting information from respondents, the researcher secured their permission and agreement. This was accomplished through the researcher's introduction, which included information on the study goals, intended applications, and anticipated benefits for the communities being studied. They were also given the assurance that the information they provided would be held in strict confidence and that their identities would not be revealed anywhere. Finally, approval from the Wildlife Division of the Ghana Forestry Commission was requested to conduct this investigation at the Muni Ramsar site. The approval letter has been presented in Appendix I.

3.10 Human Health Risk Assessment of Heavy Metals in Fish

The USEPA (2012) risk assessment model and associated threshold values were used to predict the potential negative health effects on humans from exposure to heavy metals in fish (Kamunda et al., 2016). The various exposure assessments conducted in this study include daily exposure assessment, non-carcinogenic and carcinogenic risk assessments. Because adults differ physiologically from children, the human health risk assessment was conducted for each category of people

3.10.1 Exposure Assessment

To determine the health risks associated with the consumption of fish, we need to estimate the maximum daily intake (EDI) mg/kg/day of these metals as expressed based on USEPA methods (1992). The estimated daily intake (EDI) of heavy metals was determined separately for children and adults using Equation 5.

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad \ldots\ldots\ldots (2)$$

Where EDI (mg/kg/day) is the estimated daily intake, IR is the intake rate (kg/day), C is the dietary metal concentration (mg/kg), EF is the exposure frequency, BW (kg) is normal body weight, ED is the exposure duration, and AT is human exposure time. Table 3.4 shows the parameters used for calculating EDI Values in this study.

Table 3. 4: Parameters for assessment of estimated daily intake

Parameter	Value	Reference
IR	0.2g/day for children and 0.1g/day for adults	USEPA, 2012
EF	180 days/year	USEPA, 2012
ED	6 years for children and 24 years for adults	USEPA, 2012
BW	70kg for adults and 15kg for children	USEPA, 2012
AT	365 *ED	

According to USEPA (2002), the intake rate (IR) is the amount of a contaminated medium to which a person is exposed during a specified period, the exposure frequency (EF) is how frequently exposure occurs, often measured in days per week and weeks per year, the exposure duration (ED) is the length of time a population has been exposed to site contaminants and an averaging time (AT) is the amount of time over which exposure is averaged and is equal to ED for assessing non-cancer risks.

3.10.2 Noncarcinogenic health risk

Identifying the possibility that a chemical may have harmful health consequences over a particular time in a given amount is known as assessing noncarcinogenic health risks. Using the Hazard quotient and Hazard index, it was possible to assess the noncarcinogenic health risk.

3.10.2.1 Hazard quotient

Each heavy metal's Hazard Quotient (HQ) was computed by dividing the estimated daily intake (EDI) by the appropriate reference dosage (USEPA, 1989) (i.e., the level at which metal concentrations do not pose adverse effects). The individual reference dose (RD) for the various

heavy metals (HMs) and their cancer slope factors (CSF) are presented in Table 3.2 (USEPA, 2012).

$$HQ = \frac{EDI}{\text{RD}} \qquad \ldots\ldots (3)$$

Where RfD is the reference dose (mg kg^{-1} day^{-1}) and HQ is the hazard quotient. HQ values of < 1 signify unlikely adverse health effects, while HQ values > 1 indicate a likely adverse health effect.

Table 3. 5: Reference dose and cancer slope factor (CSF) for HMs

Parameter	RF dose (mg/kg/day)	CSF (mg/kg/day)
As	0.0003	1.5
Cd	0.001	0.0061
Co	0.0003	0
Cr	1.5	0.041
Cu	0.04	0
Mn	0.14	0
Hg	0.0001	0
Ni	0.02	0.00084
Pb	0.0035	0.0085
Se	0.005	0
Zn	0.3	0

Source: (USEPA, 2012)

3.10.2.2 Hazard Index (HI)

The non-carcinogenic toxic risk of hazardous substances in environmental media is the sum of individual hazard quotients and is equal to the hazard index (HI) (Ayantobo et al., 2014; Naveedullah et al., 2014; Amirah et al., 2013). Therefore, the overall potential for non-carcinogenic effects posed by the various heavy metals detected in fish samples was computed as the sum of the HQs for each element as a hazard index (HI) as defined by Eqn 7: The equation is similar to that described by USEPA (1989).

$$HI = \sum HQ \quad \ldots. (4)$$

If the HI value is less than 1, the exposed population is unlikely to experience any appreciable adverse health effects. HI, values greater than 1 may result in adverse health effects (USEPA, 1989).

3.10.3 Carcinogenic risk assessment

According to USEPA (2012), lifetime exposure to a probable carcinogen is considered when determining a person's risk of developing cancer. To calculate this, a cancer slope factor was used to convert the lifetime exposure dose index (EDI) of heavy metals and pesticide residues to the likelihood of a person developing cancer (USEPA, 2012).

$$\text{Cancer Risk} = \sum n, I = EDI \times CSF \quad \ldots\ldots\ldots\ldots\ldots. (5)$$

Where CSF = Cancer Slope Factor

A cancer risk value less than 1×10^{-6} is considered insignificant and cancer risk can be neglected; a CR value above 1×10^{-4} is considered significant and there is a cancer risk (USEPA, 2012). Cu, Mn, Co, Fe, and Zn do not have any carcinogenic effects, according to USEPA (2012), as the carcinogenic potency slope, oral (CPSo) (mg/kg/day1) has not yet been established. As, Cd, Cr, Ni, and Pb were among the heavy metals evaluated for potential carcinogenic effects.

3.11 Water Quality Index

Water Quality Indices (WQIs) are a set of information on several aspects of water quality that are combined to provide a single figure for the water quality, reducing a large amount of data to a manageable amount (Aljanabi et al., 2021). In order to assess the quality of surface water, many people use the water quality index (WQI) model (Uddin et al., 2021). The data on water quality are aggregated to create a single number or index. The WQI model has been applied internationally to assess the quality of surface and groundwater using regional water quality standards. Since its creation in the 1960s, it has grown in popularity because of its universal structure and ease of use. The four processes that WQI models commonly follow are the selection of the water quality parameters, computation of the parameter weighting values, development of sub-indices for each parameter, and aggregation of sub-indices to generate the overall water quality index (Sun et al., 2016).

Several researchers have evaluated the water quality of lakes, rivers, and estuaries using a range of WQI model applications. In Ghana, Darko et al. (2013) used WQI to assess the quality of river basins in Ghana. In this study, using the Weighted Arithmetic WQI Method (WAWQI), which was created by Brown et al. (1972) and later used by Wu et al. (2018), Tian et al. (2019), and Zotou et al. (2019), the water quality of the Pratu River, Muni lagoon, and Ntakofa River was evaluated in this study. The general quality of the surface water bodies was assessed using both the Heavy Metal Pollution Index (HPI) and the Water Quality Indices (WQI).

$$WQI = \frac{\sum Qi\, Wi}{\sum Wi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where Qi=quality rating (sub-index) of the ith water quality parameter

Wi unit weight of ith water quality parameter; = 1

Also, Qi, which relates the value of the parameter in polluted water to the standard permissible value, is obtained as follows:

$$Qi = \left(\frac{Vi - Vio}{Si - Vio}\right) x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where *Vi* is the estimated concentration of the ith parameter in the analysed water
Vio is the ideal value of this parameter in pure water
Vio = 0 (except pH =7.0 and DO = 14.6 mg/l)
Si is the recommended standard value of the ith parameter (see Appendix E)

The unit weight (Wi), which is inversely proportional to the values of the recommended standards, is obtained as:

$$Wi = \frac{K}{Si} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Where K = proportionality constant, and can also be calculated by using the following equation:

Where: $$k = \frac{1}{\frac{1}{\sum(Si)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The Si values were from the WHO/GSA (2017) specifications. The water characteristics were taken into consideration when performing the calculations: Among them are pH, chemical oxygen demand, biological oxygen demand, concentrations of nitrates, sulphates, chlorides, alkalinity, total dissolved solids, and electrical conductivity. Water status is classified as excellent (WQI ≤ 25), good (25 < WQI ≤ 50), poor (50 < WQI ≤ 75), very poor (75 < WQI ≤ 100), and unfit for drinking (WQI > 100) depending on WQI (Wu et al., 2018).

3.12 Heavy Metal Pollution Index (HPI)

In addition, the presence of heavy metals in the examined water samples was considered while evaluating water quality. You can find the calculation technique for the Heavy Metal Pollution Index (HPI) elsewhere (i.e., Tiwari et al., 2015; Giri & Singh, 2014; Prasad & Bose, 2001; Kone

et al., 2019; Chaturvedi et al., 2019; Kumar et al., 2019). In the current investigation, the weighted arithmetic value of the HPI was used instead of the WQI (Giri and Singh, 2014):

$$HPI = \frac{\sum Wi \,.\, Qi}{\sum Wi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where: Wi is the unit weight of the i-th parameter calculated as 1/Si, Si is the standard value of the i-th parameter, Qi is the sub-index of the i-th parameter, and n is the number of parameters included in the calculation. Qi was calculated in the same manner as for WQI, based on Eq. (2). Si values were taken from EU requirements (EU, 1975, 2008). The calculations were made taking into account the concentrations of trace elements – including twelve heavy metals: arsenic, boron, barium, cadmium, chromium, cobalt, manganese, copper, nickel, lead, zinc, and selenium.

A heavy metal pollution index of less than 100 indicates the presence of low levels of heavy metals and is probably not harmful to health. According to Prasad and Bose (2001), the critical pollution index value is 100. When the HPI score is 100, it means that there is a threshold risk and potential for negative health effects. When the HPI value exceeds 100, it means that the water is unfit for human consumption and should not be drunk (Saleh et al., 2019; Mativenga & Marnewick, 2018; Tiwari et al., 2015).

3.13 Geo-Accumulation Index (Igeo)

The geoaccumulation index was estimated using Müller's (1969) method to evaluate the various heavy metal accumulations in sediment samples. It gives reliable and comparable data and directly assesses heavy metal pollution in sediment samples while reflecting the concentration of external heavy metals (Müller, 1969; Audry et al., 2004). It is calculated as follows:

$$I_{geo} = log_2 \frac{C_{sample}}{1.5 C_{background}} \quad \ldots\ldots\ldots (11)$$

Where $C_{background}$ is the geochemical background concentration (mg kg^{-1}) of the heavy metal (Müller, 1979) and C_{sample} is the concentration of the heavy metal in the sediment sample. The $C_{background}$ concentration values were obtained by analysing uncontaminated soil samples from the river Ayensu in Winneba municipality (see Appendix E). This was done because of its closeness to the water bodies and the fact that the river Ayensu is used as drinking water in Winneba and its environment. A background matrix correction factor of 1.5 is adopted as a coefficient to compensate for the weathering and lithogenic effect. The Geo-accumulation index (Igeo) values were interpreted as Igeo ≤ 0 – uncontaminated; 0 ≤ Igeo ≤ 1—uncontaminated to moderately contaminated; 1 ≤ Igeo ≤ 2—moderately contaminated; 2 < Igeo ≤ 3—moderately to heavily contaminated; 3 ≤ Igeo ≤ 4— heavily contaminated; 4 ≤ Igeo ≤ 5—heavily to extremely contaminated; and 5 < Igeo—extremely contaminated (Chowdhury et al., 2015). Also, in this study, the various heavy metal accumulations in the sediment samples were determined using the formula described by Förstner and Müller (1981).

3.14 Bioaccumulation Factor (BAF)

The Bioaccumulation Factor (BAF) is the equilibrium ratio of the concentration of an element (or chemical) in the aquatic organism or tissue (fresh weight or dry weight) to the concentration of that element (or chemical) in the water (USEPA, 1994; Saxena, 2024). The bioaccumulation factor was used to evaluate the degree of fish contamination by heavy metals in the studied fish samples. Equation (15) was employed for BAF calculation (Ma et al., 2014).

$$BAF = \frac{C_{Fish}}{C_{water}} \quad \text{.....(12)}$$

Where C_{fish} is the mean concentration of heavy metals or pesticides in fish, and C_{water} is the mean concentration of heavy metals or pesticides in the water phase. A BAF value exceeding one indicates probable bioaccumulation of heavy metal from water, but not significant unless the BAF

exceeds 100 (Feng et al., 2020). According to the US Environmental Protection Agency (USEPA), the BioConcentration Factor (BCF) values for 'bioaccumulative' and 'very bioaccumulative' are 1000–5000 and 5000, respectively (Arnot and Gobas, 2006).

3.15 Pesticides Quality Index (PQI)

The pesticide quality index is a water assessment tool that summarises the overall pesticide contamination in one value (Liu et al., 2023).

$$PQI = \sum\left(\frac{C_i}{MPL_i}\right) \quad \ldots\ldots\ldots\ldots (13)$$

Where Ci is the measured concentration of pesticides in water and MPL is the maximum permissible limit for the ith pesticide from WHO or FAO. PQI <1 is excellent, PQI =1 is acceptable, PQI >1 is poor (above safe pesticide levels), and PQI >3 is severely polluted (Liu et al., 2023).

3.16 Principal Component Analysis (PCA)

One of the data reduction techniques used in data analysis is Principal Component Analysis (PCA). In accordance with Pallant (2020), the information in the original data is not lost when duplicate features of the data are found and reduced to primary components using factor analysis. Factor analysis (FA) is a technique that identifies the fundamental variables or dimensions that make up the majority of the variance in a large set of data. PCA was used in this study to break down a huge data set of physicochemical and heavy metal parameters into its constituent main components. The distinct number of factors to retain was calculated following this factor analysis. Before doing the factor analysis, the data set must adhere to several statistical hypotheses (Zeynivandnezhad et al., 2019). According to Pallant (2020), one of the presumptions used to assess a data set's suitability for factor analysis is that a sample size of 150 or more is required. Additionally, r = 0.3 or higher

correlation coefficients are typically required for factor analysis (Pallant, 2020). The test of sphericity by Bartlett and the Kaiser-Meyer-Olkin (KMO) can also be used to measure the factorability of data. Before computing component analysis, it must pass Bartlett's sphericity test to be meaningful ($p < 0.05$) (Pallant, 2020). According to Tabachnick and Fidell (2007), for factor analysis, the KMO test coefficient must be between 0 and 1, with a cutoff of 0.6. The data set used in this investigation met each of the aforementioned presumptions. Bartlett's test of sphericity yielded significant results ($p < 0.000$), and the KMO test's coefficient was also very significant (0.817).

CHAPTER FOUR

RESULTS

4.0 Overview

Results of the study are presented in this chapter and include physical and chemical parameters of Muni Lagoon and its tributaries. Also, it presents heavy metal concentrations in water, sediments, and fish from Muni Lagoon, Pratu, and Ntakofa Rivers. Again, the chapter presents the results on pesticide residual levels in water, sediment, and fish samples collected from the Muni catchment area, as well as the health risk assessment related to the consumption of fish contaminated with heavy metals and pesticides. Finally, results on how provisioning ecosystem services have been influenced by human activities in the Muni catchment area have been presented in this chapter.

4.1 Physicochemical parameters of water bodies in the Muni catchment area

Tables 4.1 to 4.9 present the results of the physicochemical parameters measured for the Ntakofa River, Pratu River, and Muni Lagoon.

Table 4. 1: Physical parameters of Ntakofa River

Parameter	Unit	Mean	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
pH		7.35	0.45	6.94	7.99	6.5 – 8.5
EC	µS/cm	1372.33	282.75	902.00	2550.00	1000
Turbidity	NTU	43.44	27.76	5.43	75.70	5
TSS	mg/L	67.78	11.53	22.60	99.00	
TDS	mg/L	1002.00	131.33	590.00	1576.00	1000

In Table 4.1, Ntakofa River recorded a mean pH of 7.35 ± 0.45. The pH values measured for the rivers ranged from 6.94 to 7.99. The pH values obtained were all within the WHO (2018) and GSA (2017) guideline values. Again, the electrical conductivity of water samples varied between 902 µS/cm and 2550 µS/cm. The mean value of electrical conductivity was 1372.33 ± 282.75 µS/cm. Higher conductivity values were obtained for samples collected near where the river joins the

lagoon and places where the growing of vegetables was intensive. The mean value for electrical conductivity was above the WHO (2018) and GSA (2017) permissible value of 1000 µS/cm. Also, the minimum and maximum turbidity values were 5.43 to 75.7 NTU, respectively. The mean turbidity value was 43.44 ± 27.76 NTU. The turbidity values measured exceeded their GSA (2017) guideline value of 5 NTU. In addition, the TSS and TDS concentrations of water samples from Ntakofa River ranged from 22.60 to 99.0 mg/L and 590 to 1576 mg/L, respectively. The mean TSS value was 67.78 ± 11.53 mg/L, while that of TDS was 1002.00 ± 131.33 mg/L. WHO (2018) and GSA (2017) TDS guideline value is 1000 mg/L, while that of TSS has no permissible value. The obtained mean TDS value exceeded 1000 mg/L.

Table 4.2 shows that the mean pH of water in the Pratu River is 7.37 ± 0.101. The pH levels for the Pratu River ranged from 7.03 to 7.64, respectively. The pH readings all fell within the range of 6.5 to 8.5 recommended by the WHO (2018) and GSA (2017). Once more, water samples from the Pratu River had electrical conductivities that ranged from 2900 µS/cm to 15710 µS/cm. The mean electrical conductivity value for the Pratu River was 9597.17 ± 2098.27 µS/cm. The electrical conductivity values obtained for all the samples collected were above the WHO (2018) and GSA (2017) guideline values of 1000 µS/cm.

Table 4. 2: Physical parameters of Pratu River

Parameter	Unit	Mean	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
pH		7.37	0.10	7.03	7.64	6.5 – 8.5
EC	µS/cm	9597.17	2098.27	2900	15710	1000
Turbidity	NTU	157.55	69.15	10.43	444.8	5
TSS	mg/L	834.57	536.69	28.2	3438.0	
TDS	mg/L	6471.83	1136.30	2536.00	9676.00	1000

From Table 4.2, the minimum and maximum turbidity values were 10.43 NTU and 444.8 NTU, respectively. The mean turbidity value was 157.55 ± 69.15 NTU. Every turbidity value measured was more than the GSA (2017) guideline value of 5 NTU. Additionally, water samples from the Pratu river had TSS and TDS concentrations that varied from 28.2 to 3438.0 mg/L and 2536.0 to 9676 mg/L, respectively. The mean TSS value was 834.57±536.69 mg/L, while that of TDS was 6471.83 ± 1136.30 mg/L. WHO (2018) and GSA (2017) TDS guideline value is 1000 mg/L, while that of TSS has no permissible value. The obtained mean TDS value in the Pratu River was above the permissible value of 1000 mg/L.

From Table 4.3, the minimum and maximum pH values of water samples collected from Muni Lagoon were 7.71 and 8.10, respectively. The mean pH of Muni Lagoon was 7.93 ± 0.07. The pH values measured in the lagoon were all within the USEPA (2017) guideline values. The electrical conductivity of Muni Lagoon ranged from 17820.00 µS/cm to 23200 µS/cm.

Table 4. 3: Physical parameters of Muni Lagoon

Parameter	Unit	Mean	Stand. Dev	Min	Max	USEPA (2017)
pH		7.93	0.07	7.71	8.10	6.5 – 9
EC	µS/cm	20227.33	1069.10	17820.00	23200.00	1500
Turbidity	NTU	6.03	0.75	3.35	9.00	0.2
TSS	mg/L	98.77	4.40	86.60	114.80	-
TDS	mg/L	13264.00	902.89	10987	16021	1000

The mean electrical conductivity value for the Muni Lagoon was 20227 ± 1069.10 µS/cm. Electrical conductivity values for all the samples collected were above the USEPA (2017) permissible value of 1000 µS/cm. Also, the minimum and maximum turbidity values in Muni Lagoon were 3.35 NTU and 9.00 NTU, respectively. The mean turbidity value was 6.03 ± 0.75 NTU. The mean turbidity is greater than the USEPA (2017) guideline value of 0.2 NTU. In addition, the TSS and TDS concentrations of water samples in Muni Lagoon ranged from 86.60 to

114.80 mg/L and 10987 to 16021 mg/L, respectively. The mean TSS was 98.77 ± 4.40 mg/L, while that of TDS was 13264 ± 902.89 mg/L. USEPA (2017) TDS guideline value is 1000 mg/L, while that of TSS has no permissible value. The obtained mean TDS value in Muni Lagoon was above the permissible value of 1000 mg/L.

The variations in mean pH and Turbidity values in Muni Lagoon, Ntakofa River, and Pratu River have been presented in Figure 4.1 for comparison.

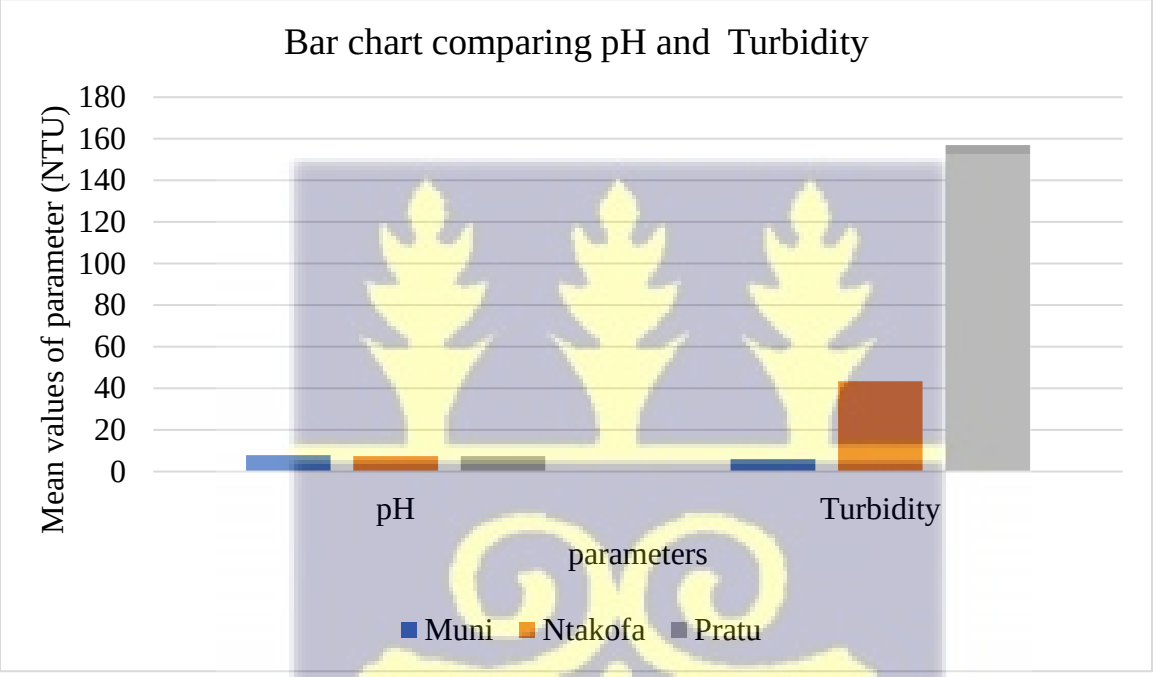


Figure 4. 1: pH and Turbidity variations among Muni Lagoon, Ntakofa River, and Pratu River

In comparison to the Ntakofa (7.35) and Pratu (7.37) Rivers, Muni Lagoon had a mean pH of 7.93, which was higher. The ANOVA analysis shows that the mean pH values of the three water bodies differ significantly from one another (P = 0.008) (Appendix A). The pH values of the water samples taken from Muni Lagoon and Pratu River, as well as Muni Lagoon and Ntakofa River, differ significantly from one another, but not from Pratu and Ntakofa Rivers, according to a pair-wise comparison using Tukey's HSD.

The mean turbidity value of Pratu River was 157.50 NTU, which was higher than that of Muni Lagoon (6.00 NTU) and Ntakofa River (43.50). The measured turbidity levels varied significantly from one another (P = 0.046). The Pratu River had higher turbidity values than the other water bodies, as shown by Tukey's HSD, which explains the turbidity difference. The variations in mean electrical conductivity, TSS, and TDS values in Muni Lagoon, Ntakofa River, and Pratu River have been presented in Figure 4.2 for comparison.

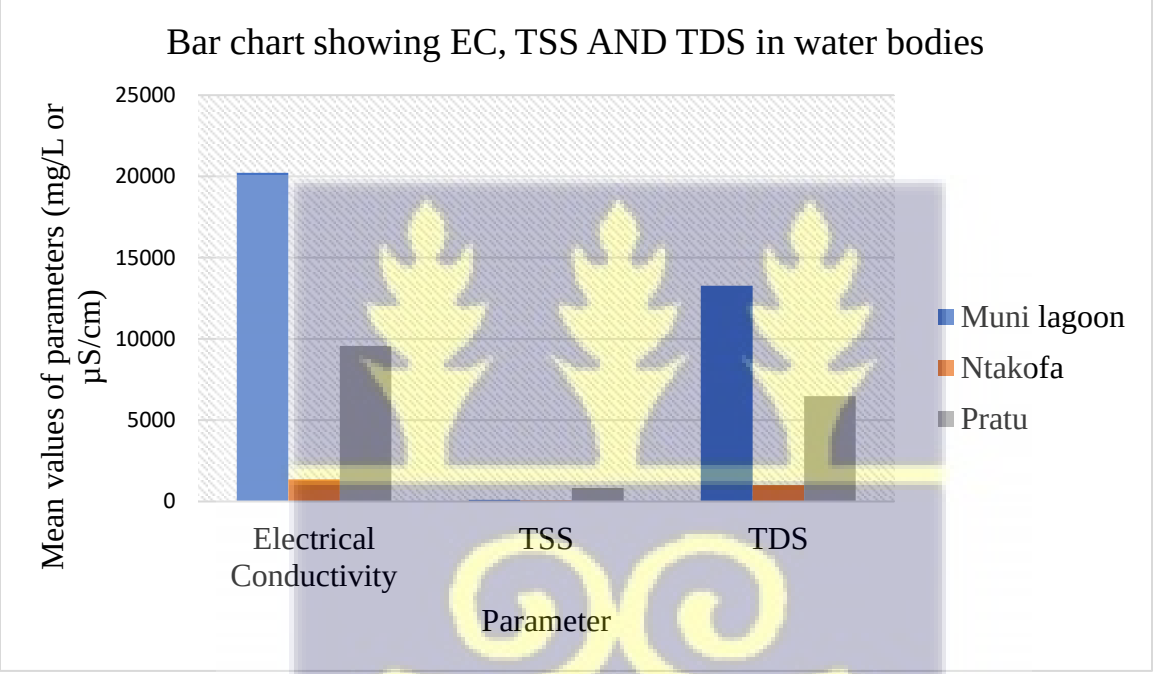


Figure 4. 2: Variations of EC, TSS, and TDS among Muni Lagoon, Ntakofa, and Pratu Rivers

The electrical conductivity (EC) mean value of Muni Lagoon was 20227 ± 1069.10 µS/cm, while that of Ntakofa and Pratu Rivers was 1372.33 ± 692.6 µS/cm and 9597.17 ± 2098.27 µS/cm, respectively. Analysis of variance shows a statistically significant difference (P = 0.000) between the EC values. The TSS mean values for Muni, Ntakofa, and Pratu water bodies were 98.77 ± 4.40 mg/L, 67.78 ± 28.25 mg/L, and 834.57 ± 536.69 mg/L, respectively. Analysis of variance shows

no statistically significant (P = 0.175) difference in TSS values of samples analysed from the different water bodies. The TDS mean values for Muni Lagoon, Ntakofa, and Pratu Rivers were 13264 ± 902.89 mg/L, 1002 ± 131.33 mg/L, and 6471.83 ± 1136.30 mg/L, respectively. Analysis of variance shows a statistically significant difference (P = 0.000) (Appendix A) between the TDS mean values. Tukey's HSD test shows that the highest mean TDS value measured in Muni Lagoon is significantly different from that measured in Ntakofa and Pratu Rivers. Also, TDS values in the Ntakofa River and Muni Lagoon were significantly different from each other (Appendix B).

As shown in Table 4.4, the alkalinity levels in the water samples taken from the Ntakofa River ranged from 82.6 mg/L to 182.95 mg/L. The Ntakofa River's mean alkalinity value was 126.92 ± 19.12 mg/L. The WHO (2018) and GSA (2017) recommended levels of 500 mg/L for alkalinity were not met by any of the alkalinity values.

Table 4. 4: Chemical parameters of Ntakofa River

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
ALK	126.92	19.12	82.6	182.95	500
COD	41.62	3.61	36.89	48.70	250
BOD	12.27	1.64	10.20	15.50	50
SO_4^{2-}	70.09	6.67	58.86	96.13	500
Cl^-	274.41	47.25	195.93	453.29	250
NO_3^-	2.17	0.55	0.65	3.8	50
NO_2^-	0.00	0.01	0.00	0.01	3
PO_4^{3-}	1.20	0.30	0.89	1.63	0.5

According to Table 4.4, Ntakofa River COD values ranged from 36.89 mg/L to 48.70 mg/L, with a mean value of 41.62 ± 3.61 mg/L. All of the measured COD concentrations fell within the 250 mg/L acceptable range set by the WHO (2018) and GSA (2017). Additionally, BOD had a range of 10.20 mg/L and 15.50 mg/L, respectively. The mean BOD Value of the Ntakofa River was

12.27±1.64 mg/L. All the BOD measured in the river were below the WHO (2018) and GSA (2017) guideline values of 50 mg/L.

The Ntakofa River had sulphate ions (SO_4^{2-}) ranging from 70.09 mg/L to 96.13 mg/L, with a mean value of 70.09 ± 6.67 mg/L. (Table 4.4). All of the sulphate ion concentrations that were detected fell below the 500 mg/L acceptable range set by the WHO (2018) and GSA (2017). Additionally, the mean concentration of chloride ions was 274.41 ± 47.25 mg/L, with the lowest and maximum values of 195.93 mg/L and 453.29 mg/L, respectively. Some of the samples that recorded higher Chloride concentrations greater than the GSA (2017) permissible value of 250 mg/L were close to a health facility situated near the river.

The Ntakofa River observed nitrate concentration had a mean value of 2.17 ± 0.55 mg/L and a range of 0.65 mg/L to 3.8 mg/L (Table 4.4). All samples had nitrate levels that were less than the 50 mg/L guidelines established by the WHO (2018) and GSA (2017). With a mean value of 0.005 ± 0.0086 mg/L, nitrite concentrations in the Ntakofa River (Table 4.4) ranged from 0.00 mg/L to 0.01 mg/L. All the nitrite values recorded were below the GSA (2017) guideline value of 3 mg/L.

With a mean value of 1.20 ± 0.302 mg/L, the phosphate ion (PO_4^{3-}) concentration in the Ntakofa River ranged from 0.89 mg/L to 1.63 mg/L. All PO_4^{3-} concentrations were above the 0.5 mg/L acceptable range established by GSA (2017). The fact that there are agricultural activities taking place alongside the water body may be the cause of the Ntakofa River elevated phosphate levels.

In Table 4.5, the minimum and maximum alkalinity readings for the water samples from Pratu River were 20.5 mg/L and 368.93 mg/L, respectively. The Pratu River had an average alkalinity of 152.64 ± 61.91 mg/L. The WHO (2018) and GSA (2017) recommendation values of 500 mg/L were not met by any of the alkalinity readings.

Table 4. 5: Chemical parameters of Pratu River

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
ALK	152.64	61.91	20.5	368.93	500
COD	82.17	39.56	9.93	146.24	250
BOD	40.13	22.72	1.55	80.2	50
SO_4^{2-}	265.25	125.46	6.15	659.74	500
Cl^-	2878.13	773.15	747.48	5309.20	250
NO_3^-	0.05	0.11	0.00	0.46	50
NO_2^-	0.002	0.01	0.012	0.004	3
PO_4^{3-}	0.41	0.32	0.05	1.00	0.5

The COD levels in the Pratu River were 9.93 mg/L to 146.24 mg/L, with a mean value of 82.17 ± 39.56 mg/L. The COD measurements were all below the permitted value of 250 mg/L set by the WHO (2018) and GSA (2017). Furthermore, BOD had a range of 1.55 mg/L and 80.2 mg/L, respectively. The Pratu River had a mean BOD Value of 40.13 ± 22.72 mg/L. The WHO (2018) and GSA (2017) recommended guideline levels of 50 mg/L were not met by any of the BOD samples found in the river.

The Pratu River had sulphate ions (SO_4^{2-}) ranging from 6.15 mg/L to 659.74 mg/L, with a mean value of 265.25 ± 125.46 mg/L. (Table 4.5). The WHO (2018) and GSA (2017) acceptable threshold of 500 mg/L was not met by all of the sulfate ion concentrations. Additionally, the concentration of chloride ions ranged from 747.48 mg/L to 5309.20 mg/L, with a mean value of 274.41 ± 47.25 mg/L. Some of the samples that had chloride concentrations greater than the GSA (2017) permitted limit of 250 mg/L were close to a health facility situated close to the river.

A mean value of 0.05 ± 0.11 mg/L of nitrate was found in the Pratu River, with a range of 0.00 mg/L to 0.46 mg/L (Table 4.5). All samples had nitrate levels that were less than the 50 mg/L guidelines established by the WHO (2018) and GSA (2017). According to Table 4.5, nitrite concentrations in the Prtatu River ranged from 0.01 mg/L to 0.004 mg/L, with a mean value of 0.002 ± 0.006 mg/L. The GSA (2017) recommendation value for nitrite, 3 mg/L, was not reached for any of the measured values.

The Pratu River phosphate ion (PO_4^{3-}) content ranged from 0.05 mg/L to 1.00 mg/L, with a mean value of 0.41 ± 0.32 mg/L. Some of the samples that were gathered had PO_4^{3-} readings that were higher than the 0.5 mg/L acceptable range set by GSA (2017). The agricultural activities that take place alongside the water body may be the cause of the Pratu River's elevated phosphate levels.

Table 4. 6: Chemical parameters of Muni Lagoon

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	USEPA (2017)
ALK	174.37	16.17	139.36	225.4	-
COD	49.57	0.69	48.48	50.85	100
BOD	20.23	0.41	19.60	21.00	50-200
SO_4^{2-}	875.46	103.27	751.23	988.81	250
Cl^-	6737.66	453.96	5406.71	7944.21	250
NO_3^-	0.004	0.003	0.00	0.01	10
NO_2^-	0.18	0.06	0.004	0.39	1.0
PO_4^{3-}	0.13	0.03	0.05	0.27	0.5

From Table 4.6, the alkalinity values of Muni Lagoon samples ranged from 139.36 mg/L to 225.4 mg/L, respectively. The Muni Lagoon had a mean alkalinity value of 174.37 ± 16.17 mg/L. USEPA (2017) has no alkalinity guideline values.

From Table 4.6, COD values in Muni Lagoon ranged from 48.48 mg/L to 50.85 mg/L and had a mean value of 49.57 ± 0.69 mg/L. The measured COD values were all below the USEPA (2017) permissible value of 100 mg/L. Additionally, BOD levels ranged from 19.60 mg/L and 21.00

mg/L. The average BOD value for the Muni Lagoon was 20.23 ± 0.41 mg/L. Every measured BOD sample from the lagoon was below the 50 mg/L minimum guideline value established by the USEPA (2017).

In Muni Lagoon, sulphate ions (SO_4^{2-}) ranged from 751.23 mg/L to 988.81 mg/L, with a mean value of 875.46 ± 103.27 mg/L (Table 4.6). Sulphate ion concentrations were all above the acceptable range of 250 mg/L set by the USEPA (2017). Also, chloride ions measured ranged from 5406.71 mg/L and 7944.21 mg/L and had a mean concentration of 6737.66 ± 453.96 mg/L. All the samples had Chloride concentrations higher than the USEPA (2017) permissible value of 250 mg/L. The high chloride value may be due to the presence of salt (NaCl) in the lagoon.

Muni Lagoon had a mean nitrate concentration of 0.004 ± 0.003 mg/L, with a range of 0.00 mg/L to 0.01 mg/L (Table 4.6). The nitrate samples measured were below the 10 mg/L guidelines established by the USEPA (2017). In Muni Lagoon, nitrite concentrations ranged from 0.004 mg/L to 0.392 mg/L, with a mean value of 0.187 ± 0.063 mg/L (Table 4.6). All nitrite measurements were below the 1 mg/L USEPA (2017) recommendation threshold.

The concentration of phosphate ions (PO_4^{3-}) in Muni Lagoon was examined, and the range was 0.05 mg/L to 0.27 mg/L, with a mean value of 0.125 ± 0.033 mg/L. PO_4^{3-} values measured in Muni Lagoon were all below the USEPA (2017) permissible value of 0.5 mg/L. Figure 3 compares the alkalinity, COD, and BOD of Muni Lagoon and its tributaries.

The variations in mean Alkalinity, COD, and BOD values in Muni Lagoon, Ntakofa River, and Pratu River have been presented in Figure 4.3 for comparison.

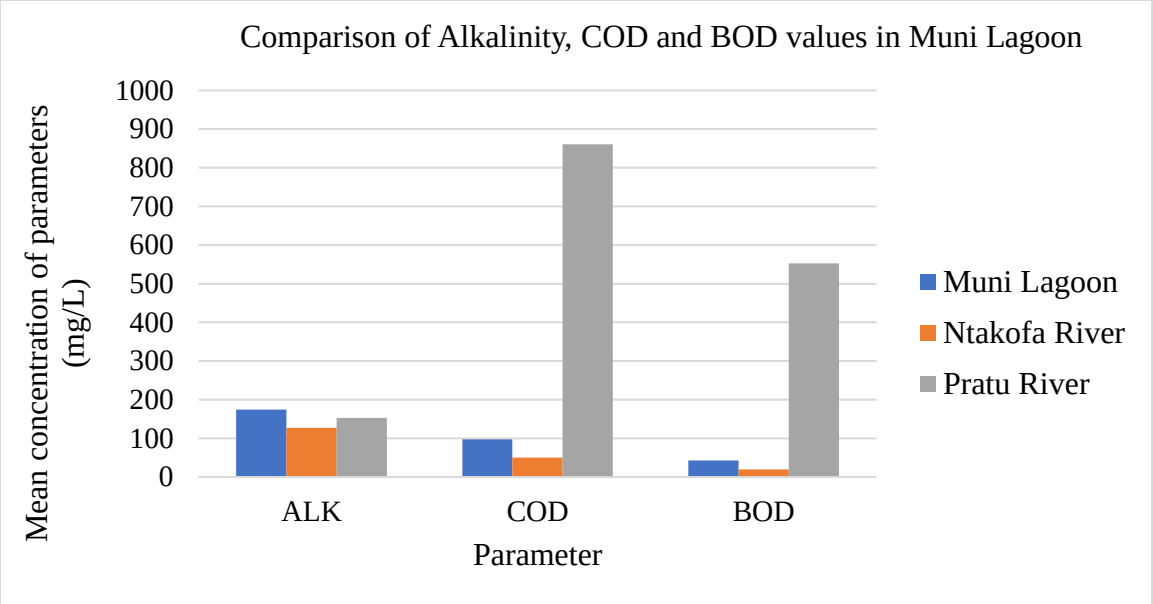


Figure 4.3: Variation of Alkalinity, COD, and BOD among Muni Lagoon, Ntakofa, and Pratu Rivers

The average alkalinity values recorded for Muni Lagoon, Ntakofa River, and Pratu River were 174.37 ± 16.17 mg/L, 126 ± 46.83 mg/L, and 152.64 ± 61.62 mg/L, respectively. The results of the analysis of variance show that there is no statistically significant difference between the mean alkalinity levels of the water bodies (P = 0.691). The mean COD value for Muni Lagoon was 97.42 ± 53.48 mg/L, Ntakofa River was 50.51 ± 14.31 mg/L, and Pratu River was 860.40 ± 364.03 mg/L. A statistically significant difference was discovered by analysis of variance (P = 0.027). (Appendix A). Tukey's test revealed that the difference was a result of the higher COD values recorded for water samples analysed from the Pratu River (Appendix B). Muni Lagoon and Pratu River COD measurements did not differ significantly; however, Ntakofa and Pratu River COD measurements did differ significantly (P = 0.040). Muni Lagoon had a mean BOD value of 42.45 ± 25.14 mg/L, Ntakofa River had a mean BOD value of 19.33 ± 11.12 mg/L, and Pratu River had a mean BOD value of 552.70 ± 244 mg/L. A statistically significant difference (P = 0.029) between the BOD values recorded for the water bodies was found by analysis of variance. According to the results

of the Tukey test, there is no statistically significant difference between the BOD levels obtained from Muni Lagoon and the Pratu River (P = 0.99) and the Ntakofa River (P = 0.055) (Appendix B). There was, however, a significant difference between mean BOD values for Pratu and Ntakofa Rivers (P = 0.044) (Appendix B). Figure 4.4 compares the mean values of Sulphate and Chloride Ions.

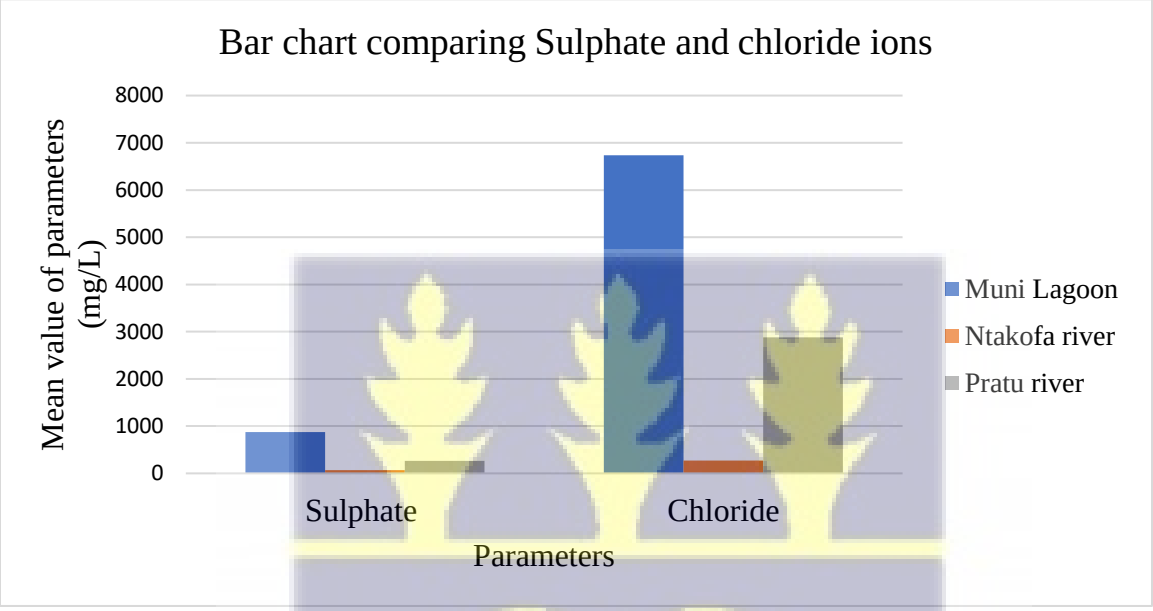


Figure 4.4: Variation of sulphate and chloride ions among Muni Lagoon, Ntakofa, and Pratu Rivers

From Figure 4.4, the mean sulphate ions in Muni Lagoon was 875.46 ± 103.27 mg/L, Ntakofa River was 70.09 ± 16.33 mg/L, and Pratu River was 267.30 ± 305.16 mg/L. Analysis of the variance conducted revealed a statistically significant difference (P = 0.000) between the sulphate ions recorded for Muni Lagoon, Ntakofa River, and Pratu River. Tukey's test revealed that the difference was due to the high sulphate concentration in water samples collected from Muni Lagoon, since no significant difference (P = 0.192) between the recorded means for Pratu and Ntakofa Rivers (Appendix B).

The mean chloride value for Muni Lagoon was 6737.66 ± 1111.97 mg/L, Ntakofa River was 274.41 ± 115.74 mg/L, and Pratu River was 2878.13 ± 1893.83 mg/L. Analysis of variance revealed a statistically significant difference (P = 0.000) between the chloride ions recorded for Muni Lagoon, Ntakofa, and Pratu Rivers. Figure 4.5 compares the mean values of Nitrate, Nitrite, and Phosphate ions of the three water bodies.

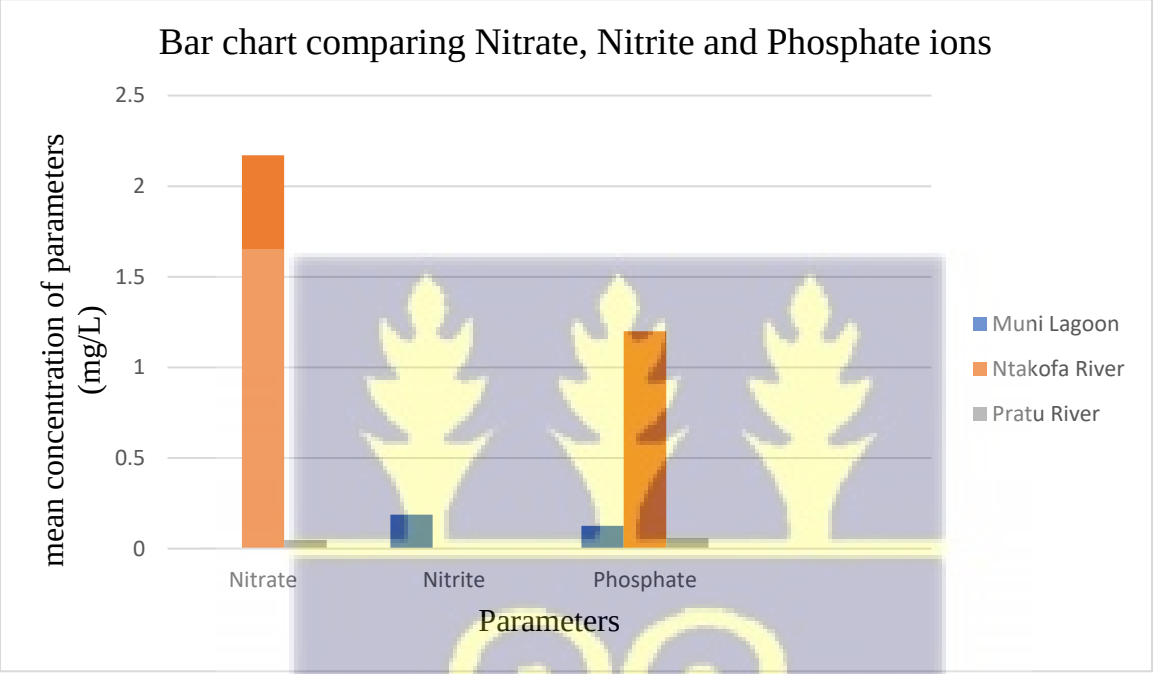


Figure 4.5: Variation of Nitrate, Nitrite, and Phosphate ions among Muni Lagoon, Ntakofa and Pratu Rivers

Figure 4.5 shows that the mean nitrate value in Muni Lagoon was 0.004 ± 0.003 mg/L, Ntakofa River was 2.17 ± 0.55 mg/ L, and Pratu River was 0.048 ± 0.55 mg/ L. The results of the analysis of variance showed that the nitrate amounts recorded for the three water bodies differed statistically significantly (P = 0.000). The mean nitrate measurements made for the Muni Lagoon and Pratu River did not differ significantly (P = 0.992), according to the Tukey test. Contrary, the Tukey test revealed a statistically significant difference (P = 0.001) between the mean nitrate values of Muni Lagoon and Ntakofa River, as well as between Pratu and Ntakofa Rivers.

Muni Lagoon had a mean nitrite value of 0.187 ± 0.063 mg/L, Ntakofa 0.0045 ± 0.0086 mg/L, and Pratu 0.0022 ± 0.006 mg/L. The findings of the analysis of variance showed a significant difference (P = 0.003) between the mean nitrite measurements made for the three water bodies. Muni Lagoon and the Ntakofa and Pratu Rivers differ significantly, according to Tukey's test results (Appendix B). The Ntakofa and Pratu Rivers did not show any statistically significant difference (P = 0.991), either.

The mean Phosphate value in Muni Lagoon was 0.125 ± 0.08 mg/L, Ntakofa River was 1.20 ± 0.12 mg/L, and Pratu River was 0.405 ± 0.316 mg/L. The findings of the analysis of variance showed a significant difference (P = 0.000) between the mean phosphate measurements made for the three water bodies. Tukey's test revealed a significant difference between Ntakofa and both Muni Lagoon and Pratu River (Appendix B). Additionally, it showed no statistically significant difference between Muni Lagoon and Pratu River (P = 0.177).

Table 4.7 shows that the Ntakofa River's aluminium ion (Al^{3+}) concentration ranged from 0.053 mg/L to 1.625 mg/L, with a mean of 0.659 ± 0.247 mg/L. The average Al^{3+} concentration is above the allowed value of 0.2 mg/L. (WHO, 2O18; GSA, 2017). Additionally, the calcium ion concentrations were 37.592 mg/L at the minimum and 68.065 mg/L at the maximum levels. The mean Ca^{2+} value was 51.571 ± 5.40 mg/L. All the Ca^{2+} values in the Ntakofa River were below the permissible value of 200 mg/L (GSA, 2017). Once more, 0.197 mg/L and 1.71 mg/L were the minimum and maximum values for Fe^{2+} in the Ntakofa River. The mean Fe^{2+} value was 0.849 ± 0.228 mg/L, and it was less than the 0.3 mg/L recommended value by the GSA (2017).

Table 4. 7: Major cations in Ntakofa River

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
Al^{3+}	0.659	0.247	0.053	1.625	0.2
Ca^{2+}	51.571	5.40	37.592	68.065	200
Fe^{2+}	0.849	0.228	0.197	1.71	0.3
K^{+}	9.455	0.675	7.43	11.25	30
Mg^{2+}	38.134	7.166	21.652	65.259	200
Na^{+}	162.55	34.68	82.99	285.54	200

Potassium ion concentration ranged from 7.43 mg/L to 11.25 mg/L in Table 4.7, with a mean value of 9.455 ± 0.675 mg/L. Every K^{+} measurement was lower than the GSA (2017) threshold of 30 mg/L. The Ntakofa River has magnesium (Mg^{2+}) concentrations that range from 21.652 mg/L to 65.2529 mg/L, with a mean value of 38.134 ± 7.166 mg/L. Mg^{2+} measurements were all below the 200 mg/L acceptable GSA (2017) guideline threshold. Additionally, the measurements of the highest and minimum sodium ion concentrations were 82.99 mg/L and 285.54 mg/L, respectively. The sodium ion concentration was 162.55 ± 34.68 mg/L, which is less than the 200 mg/L threshold recommended by GSA (2017).

According to Table 4.8, the concentration of aluminium ions (Al^{3+}) in the Pratu River ranged from 0.146 mg/L to 30.31 mg/L, with a mean of 10.23 ± 6.08 mg/L. The average concentration of Al^{3+} is greater than the permitted value of 0.2 mg/L. (WHO, 2018; GSA, 2017).

Additionally, the calcium ion concentrations were 122.23 mg/L at the minimum and 1715.80 mg/L at the maximum values. The average Ca^{2+} concentration was 742.30 ± 311.13 mg/L. The Pratu River's mean Ca^{2+} concentration was higher than the allowed level of 200 mg/L (GSA, 2017). This might be due to runoff from agricultural fields and industrial effluent close to the water body. Again, 0.15 mg/L and 43.61 mg/L were the minimum and maximum values for Fe^{2+} in the Pratu

River. The mean Fe^{2+} value was 14.52 ± 8.68 mg/L, exceeding the 0.3 mg/L recommended threshold set by the GSA (2017).

Table 4. 8 : Major cations in Pratu River

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
Al^{3+}	10.23	6.08	0.146	30.31	0.2
Ca^{2+}	742.30	311.13	122.23	1715.80	200
Fe^{2+}	14.52	8.68	0.150	43.61	0.3
K^{+}	77.15	15.70	1.65	105.13	30
Mg^{2+}	234.60	33.13	116.44	325.90	200
Na^{+}	1405.02	385.61	248.27	2529.99	200

In Table 4.8, the concentration of the potassium ion (K^{+}) ranged from 1.65 mg/L to 105.13 mg/L, with a mean value of 77.15 15.70 mg/L. The mean K^{+} value was higher than the 30 mg/L value reported by GSA (2017). Magnesium (Mg^{2+}) measurements in the Pratu river ranged from 116.44 mg/L to 325.90 mg/L, with a mean value of 234.60 ± 33.13 mg/L. The measured mean concentration of Mg^{2+} was above the accepted GSA (2017) guideline value of 200 mg/L. Additionally, the sodium ion concentrations ranged from 248.27 mg/L to 2529.99 mg/L with a mean concentration of 1405.02 ± 385.61 mg/L, exceeding the 200 mg/L acceptable value by GSA (2017).

In Muni Lagoon, the concentration of aluminium ions (Al^{3+}) ranged from 0.106 mg/L to 3.61 mg/L, with a mean of 1.30 ± 0.67 mg/L, according to Table 4.9. The mean Al^{3+} concentration was above the allowed value of 0.2 mg/L (WHO, 2O18; GSA, 2017). The calcium ion concentration ranged from 140.48 mg/L to 165.65 mg/L, with 140.48 being the minimum and 165.65 being the maximum value. In Muni Lagoon, the mean Ca^{2+} value of 150.74 ± 4.41 mg/L was less than the permitted level of 200 mg/L. (GSA, 2017). Again, in Muni Lagoon, Fe^{2+} concentrations ranged from 0.045 mg/L to 0.256 mg/L. The mean Fe^{2+} value was 0.115 ± 0.032 mg/L, which was below

the 0.3 mg/L recommended threshold set by the GSA (2017). The potassium ion (K^+) concentration ranged from 124.27 mg/L to 134.72 mg/L, with a mean value of 128.01 ± 1.636 mg/L, as shown in Table 4.9. The average K^+ value was higher than the 30 mg/L value reported by GSA (2017).

Table 4.9: Major cations in Muni Lagoon

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
Al^{3+}	1.30	0.67	0.106	3.61	0.2
Ca^{2+}	150.74	4.41	140.48	165.65	200
Fe^{2+}	0.115	0.032	0.045	0.256	0.3
K^+	128.01	1.636	124.27	134.72	30
Mg^{2+}	389.91	8.00	371.42	425.05	200
Na^+	3157.36	125.85	2620.02	3493.16	200

The Muni Lagoon had magnesium (Mg^{2+}) concentrations to range from 371.42 mg/L to 425.05 mg/L, with a mean value of 389.91 ± 8 mg/L. The recorded mean value of Mg^{2+} was higher than the acceptable GSA (2017) guideline value of 200 mg/L. Additionally, the sodium ion concentrations were measured at maximum and minimum levels of 2620.02 mg/L and 23493.16 mg/L, respectively. The average concentration of sodium ions was 3157.36 ± 125.85 mg/L, which was greater than the value of 200 mg/L recommended by GSA (2017). Figure 4.6 compares calcium and potassium ions in Muni Lagoon, Ntakofa, and Pratu Rivers.

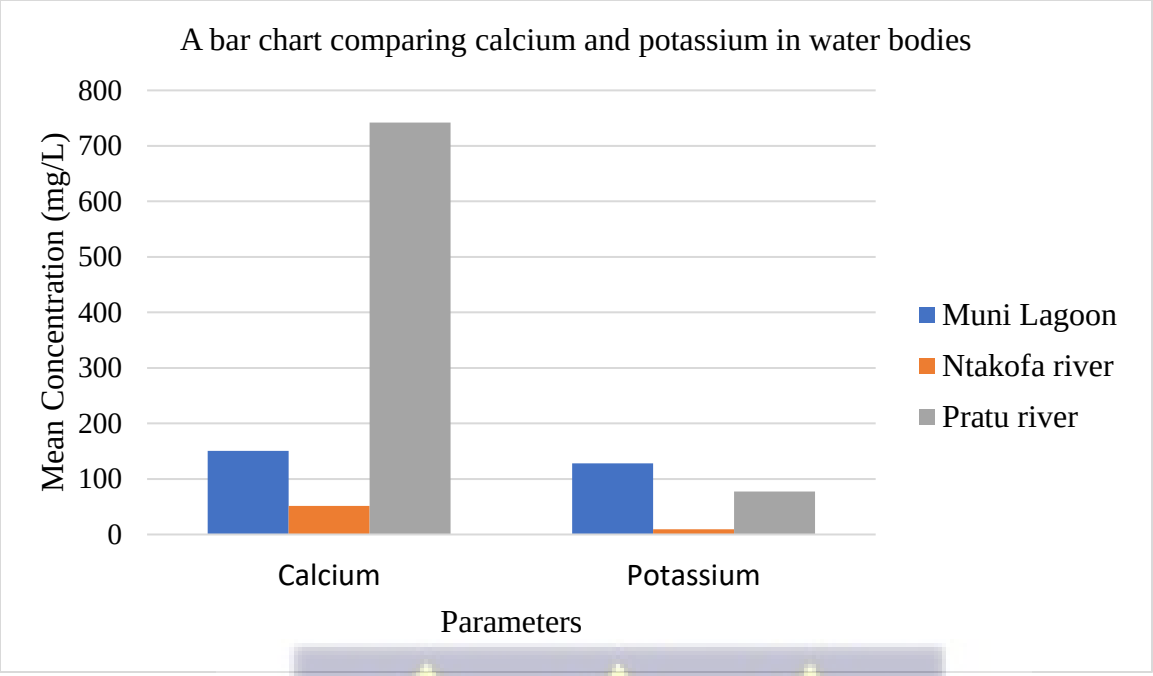


Figure 4. 6: Variation of calcium and potassium ions among Muni Lagoon, Ntakofa, and Pratu Rivers

Figure 4. 6 shows that the mean calcium concentrations in Muni Lagoon, Ntakofa, and Pratu Rivers were 150 ± 10.81 mg/L, 51.57 ± 13.2 mg/L, and 742.30 ± 311.13 mg/L, respectively. A statistically significant difference between the mean calcium values measured from the water bodies was found by analysis of variance (P = 0.033) (Appendix A). Tukey's test of multiple comparisons (Appendix B) revealed a significant difference (P = 0.04) between mean calcium concentrations measured in water samples from Ntakofa River and Muni Lagoon, but not Ntakofa and Pratu River.

Again, Figure 4.6 shows that the mean potassium concentration in Muni Lagoon was 128.01 ± 4.01 mg/L, Ntakofa River was 9.45 ± 1.65 mg/L, and Pratu River was 77.15 ± 38.46 mg/L. The ANOVA results revealed a statistically significant difference (P = 0.000) in mean potassium values measured from the water bodies (Appendix A). Tukey's test of multiple comparisons showed that there is a significant difference between mean potassium values for Ntakofa River, Muni Lagoon,

and Pratu River (Appendix B). Figure 4.7 Compares Fe and Al ions in Muni Lagoon, Ntakofa, and Pratu Rivers.

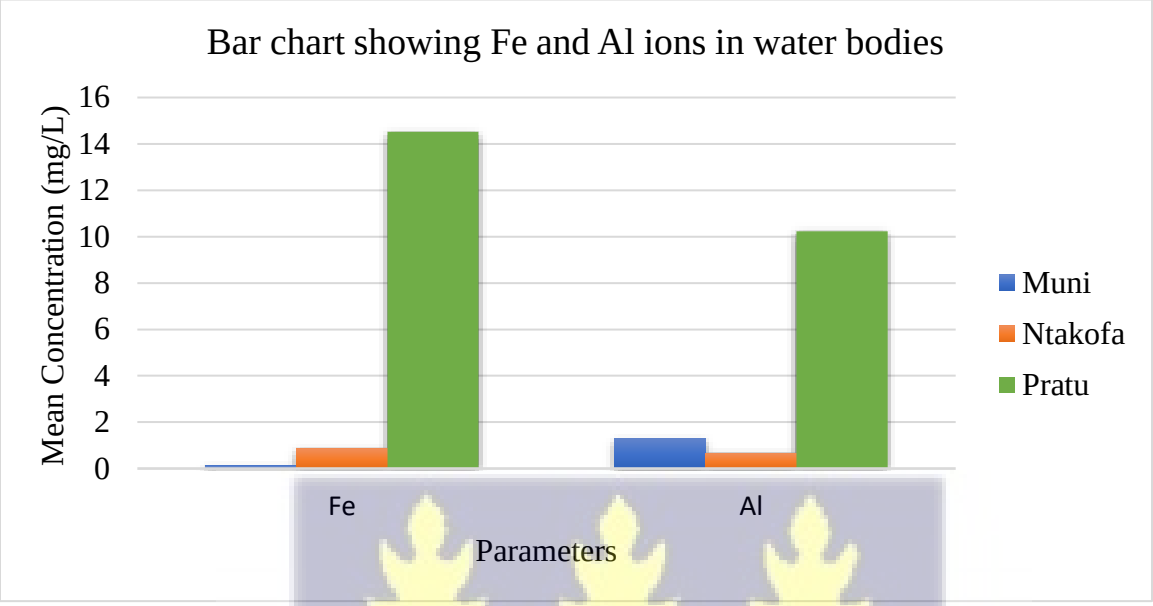


Figure 4.7: Variation of Fe and Al ions among Muni Lagoon, Ntakofa, and Pratu Rivers

Figure 4.7 shows that the mean Fe concentration in Muni Lagoon was 0.115 ± 0.08 mg/L, Ntakofa River was 0.85 ± 0.56 mg/L, and Pratu River was 14.52 ± 21.27 mg/L. The results of ANOVA showed no statistically significant difference (P = 0.106) between the mean Fe values obtained from the water bodies (Appendix A).

Figure 4.7 shows that the mean Al concentrations in Muni Lagoon, Ntakofa, and Pratu rivers were 1.30 ± 1.64 mg/L, 0.659 ± 0.604 mg/L, and 10.23 ± 14.90 mg/L, respectively. The ANOVA results revealed no statistically significant difference (P = 0.135) between the mean Aluminium values measured from the Muni Lagoon, Ntakofa, and Pratu Rivers (Appendix A). Figure 4.8 Compares Mg and Na ions in Muni Lagoon, Ntakofa, and Pratu Rivers

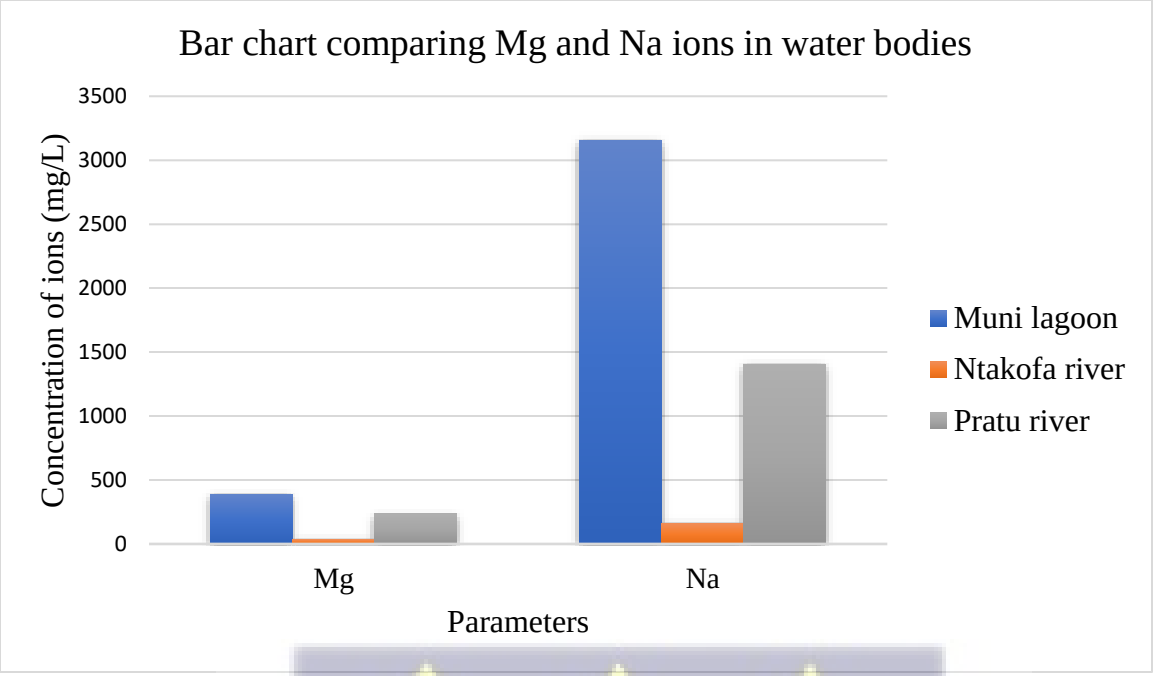


Figure 4.8: Variation of Magnesium and Sodium ions among Muni Lagoon, Ntakofa, and Pratu Rivers

Figure 4.8 shows that the mean Mg concentrations in Muni Lagoon, Ntakofa, and Pratu Rivers were 389.91 ± 19.60 mg/L, 38.13 ± 17.56 mg/L, and 234.60 ± 81.15 mg/L, respectively. A statistically significant difference (P = 0.000) in the mean magnesium values measured from the Muni Lagoon, Ntakofa River, and Pratu River was found by ANOVA analysis (Appendix A). Tukey's multiple comparison tests revealed that the mean magnesium values are significantly different from each other (Appendix B).

In Figure 8, the mean Na concentration in Muni Lagoon was 3157.35 ± 308.28 mg/L, Ntakofa River was 162.55 ± 84.94 mg/L, and Pratu River was 1405.02 ± 944.54 mg/L. Analysis of variance revealed that there is a statistically significant difference (P = 0.000) between the mean Na values measured from the water bodies (Appendix A). Tukey's multiple comparison tests revealed that the mean Na values are significantly different (Appendix B).

4.2 Water Quality Index

The water quality index is crucial for assessing the water's quality using the physicochemical parameters of the examined water samples. The various water quality indices for the Ntakofa River, Pratu River, and Muni Lagoon are shown in Table 4.10.

In Table 4.10, the Pratu River's weighted arithmetic water quality index was 249.98. The Pratu River's WQI was higher than 100 (WQI > 100), which indicates that the water is unfit for human consumption. In Table 4.10, Muni Lagoon and Ntakofa River had water quality indices of 71.612 and 66.05, respectively. The WQIs were within the class, which indicates poor water quality (50 < WQI ≤ 75).

4.3 Heavy Metal Pollution Index (HPI)

The heavy metal pollution indices for the Ntakofa River, Pratu River, and Muni Lagoon are shown in Table 4.11. From Table 4.11, the heavy metal pollution indices for Ntakofa River, Pratu River, and Muni Lagoon were 6.89, 348.43, and 51.85, respectively. HPI values for Ntakofa River and Muni Lagoon were below the critical value of 100, indicating low-level heavy metal pollution in the water bodies. HPI of Pratu River was higher than the critical value of 100.

Table 4. 10: Water quality indices (WQI) of surface water from Ntakofa River, Pratu River, and Muni Lagoon

Parameters	stand (Sn)	1/Sn	∑1/Sn	K=1/∑1/Sn	Wn=K/Sn	Ntakofa Qn=Vn/Sn*100	Pratu Qn= Vn/Sn*100	Muni Qn=Vn/Sn*100	Ntakofa WnQn	Pratu WnQn	Muni WnQn
pH	8.5	0.1176	0.80331	1.2448	0.146452	23.3	24.67	93.29412	0.9778	1.0353	3.9152
EC	1000	0.001	0.80331	1.2448	0.001245	137.233	959.717	2022.733	0.0489	0.3423	0.7215
Turbidity	5	0.2	0.80331	1.2448	0.248969	868.8	3151	120.6	61.983	224.805	8.6041
TDS	1000	0.001	0.80331	1.2448	0.001245	100.2	647.183	1326.4	0.0357	0.23086	0.4731
ALK	500	0.002	0.80331	1.2448	0.00249	25.384	30.528	34.874	0.01811	0.02177	0.0248
COD	250	0.004	0.80331	1.2448	0.004979	16.648	32.868	19.828	0.0237	0.04689	0.0282
BOD	50	0.02	0.80331	1.2448	0.024897	24.54	80.26	40.46	0.1750	0.57260	0.2886
SO_4^{2-}	500	0.002	0.80331	1.2448	0.00249	14.018	53.05	175.092	0.0100	0.03784	0.1249
Cl-	250	0.004	0.80331	1.2448	0.004979	109.764	1151.252	2695.064	0.156	1.64271	3.8455
NO_3^-	50	0.02	0.80331	1.2448	0.024897	4.34	0.096	0.008	0.0309	0.00068	5.71E-05
NO_2^-	3	0.33333	0.80331	1.2448	0.414948	0.15	0.073333	6.233333	0.0178	0.00871	0.7411
Ca^{2+}	200	0.005	0.80331	1.2448	0.006224	25.7855	371.15	75.37	0.0459	0.66198	0.1344
K^+	30	0.0833	0.80331	1.2448	0.103737	78.7916667	642.9167	1066.75	2.3422	19.1118	31.710
Mg^{2+}	200	0.005	0.80331	1.2448	0.006224	19.067	117.3	194.955	0.0340	0.20921	0.3477
Na^+	200	0.005	0.80331	1.2448	0.006224	81.275	702.51	1578.68	0.1449	1.25299	2.8157
		∑1/Sn= 0.80331			∑ Wn=1				∑ WnQn =66.04586	∑ WnQn =249.98116	∑ WnQn = 53.776

Table 4. 11: Heavy metal pollution indices (HPI) of surface water from Ntakofa River, Pratu River, and Muni Lagoon

Metal	stand (Sn)	1/Sn	K=1/∑1/Sn	Wn=K/Sn	Ntakofa Qn=Vn/Sn*100	Pratu Qn=Vn/Sn*100	Muni Qn=Vn/Sn*100	Ntakofa WnQn	Pratu WnQn	Muni WnQn
As	0.01	100	0.00153	0.15298	15	192	268	2.294706	29.37223	40.99874
B	2.4	0.416667	0.00153	0.000637	1.495833	152.9792	45.1625	0.000953	0.097512	0.028787
Ba	0.7	1.428571	0.00153	0.002185	8.757143	104.1714	6.5	0.019138	0.22766	0.014205
Cd	0.003	333.3333	0.00153	0.509935	0	143.3333	3.333333	0	73.09063	1.699782
Co	0.05	20	0.00153	0.030596	2.7	45.8	2	0.082609	1.4013	0.061192
Cr	0.05	20	0.00153	0.030596	13.2	120.6	21.8	0.403868	3.689887	0.666994
Cu	2	0.5	0.00153	0.000765	0.405	4.135	2.57	0.00031	0.003163	0.001966
Mn	0.4	2.5	0.00153	0.003825	32.475	481	24.425	0.124201	1.839589	0.093414
Ni	0.02	50	0.00153	0.07649	19.85	369.6	27	1.51833	28.27078	2.065235
Pb	0.01	100	0.00153	0.15298	7.1	1354	0	1.086161	207.1354	0
Se	0.04	25	0.00153	0.038245	35.75	85.5	162.25	1.367262	3.269956	6.205267
Sr	4	0.25	0.00153	0.000382	5.345	53.3325	37.245	0.002044	0.020397	0.014244
Zn	4	0.25	0.00153	0.000382	0.14275	27.1475	0.035	5.46E-05	0.010383	1.34E-05
		∑1/Sn = 653.678		∑ Wn=1				∑ WnQn =6.899638	∑ WnQn =348.4289	∑ WnQn =51.84984

4.4 Heavy metal concentrations in water

Table 4.12 shows that Arsenic (As) values measured for water samples collected from river Ntakofa were from no detection to 0.0032mg/L with a mean value of 0.0015 ± 0.0013 mg/L. This mean value was less than 0.01 mg/L acceptable as the recommended value (GSA, 2017; WHO, 2018). Additionally, the Ntakofa River had boron and barium concentrations that varied from 0.0048 mg/L to 0.1118 mg/L and 0.0010 mg/L to 0.1831 mg/L, respectively. Boron and barium mean levels were 0.0359 ± 0.0475 mg/L and 0.0613 ± 0.0911 mg/L, respectively. The GSA (2017) permitted values for B and Ba were 2.4 mg/L and 0.7 mg/L, respectively, and these mean readings were all below those values.

Table 4.12: Heavy metal concentrations in water samples from Ntakofa River

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
As	0.0015	0.0013	ND	0.0032	0.01
B	0.0359	0.0475	0.0048	0.1118	2.4
Ba	0.0613	0.0911	0.0010	0.1831	0.7
Cd	ND	ND	ND	ND	0.003
Co	0.0014	0.0017	0.0002	0.0039	0.05
Cr	0.0066	0.0063	0.0021	0.0159	0.05
Cu	0.0081	0.0158	ND	0.0316	2.0
Mn	0.1299	0.1467	0.0297	0.3732	0.4
Hg	ND	ND	ND	ND	0.006
Ni	0.0039	0.0056	0.0002	0.0124	0.02
Pb	0.0007	0.0019	ND	0.0035	0.01
Se	0.0143	0.0092	0.0024	0.0258	0.04
Zn	0.0057	0.0116	ND	0.0249	4.0

***ND=not detected**

Cadmium and mercury levels in the river Ntakofa were below the detection threshold. Cobalt (Co) concentrations ranged from 0.0002 to 0.0039 mg/L, chromium (Cr) values from 0.0021 to 0.0159 mg/L, and copper (Cu) concentrations from not detected to 0.0316 mg/L. The respective mean concentrations of Co, Cr, and Cu were 0.0014 ± 0.0017 mg/L, 0.0066 ± 0.0063mg/L, and 0.0081 ± 0.0158 mg/L. The average readings for Co, Cr, and Cu were less than the recommended levels

set by the GSA (2017) and WHO (2018), which are 0.05 mg/L, 0.05 mg/L, and 2.0 mg/L, respectively.

Ni and Mn values were 0.0002 mg/L to 0.0124 mg/L and 0.0297 mg/L to 0.3732 mg/L, respectively. Mean values for Mn and Ni were 0.1299 ± 0.1467 and 0.00397 ± 0.0056 mg/L, respectively. The Ntakofa River's mean values for Mn and Ni were lower than those allowed by the GSA (2017) and WHO (2018) for surface water. Once more, the concentrations of Pb and Se were not detected to 0.0035 mg/L for Pb and 0.0024 to 0.0258 mg/L for Se, respectively. The mean Pb and Se readings were 0.00071 ± 0.0018 mg/L and 0.0143 ± 0.0092 mg/L, respectively. Pb and Se readings were all below the acceptable GSA (2017) and WHO (2018) guideline values of 0.01 mg/L, 0.04 mg/L, and 4.0 mg/L, respectively. Additionally, the Zn content ranged from not detected to 0.0249 mg/L. The average Zn concentration was 0.00571 ± 0.0116 mg/L, which was below the 4.0 mg/L threshold set by the GSA and WHO in 2018.

From Table 4.13, the concentrations of arsenic (As) in water samples taken from the Pratu River ranged from 0.0005 to 0.0388 mg/L, with a mean value of 0.0192 ± 0.0190 mg/L. The average concentration of As detected is greater than the allowed amount of 0.01 mg/L (GSA, 2017; WHO, 2018). Additionally, the levels of boron (B) and barium (Ba) ranged from 0.0061 mg/L to 8.5626 mg/L and from no detection to 2.0029 mg/L, respectively. The mean concentrations of B and Ba were 3.6715 ± 4.1733 mg/L and 0.7292 ± 0.9339 mg/L, respectively. These mean B and Ba readings were all greater than the GSA (2017) permitted limits of 2.4 mg/L and 0.7 mg/L, respectively. Cadmium levels in the river Pratu ranged from 0.0001 to 0.0128 mg/L. The mean Cd value was 0.0048 ± 0.005 mg/L, which is somewhat higher than the allowed value of 0.003 mg/L. Once more, the concentrations of cobalt (Co), chromium (Cr), and copper (Cu) varied from 0.0010 to 0.0647 mg/L, 0.0019 mg/L to 0.1599 mg/L, and not detected to 0.2114 mg/L, respectively.

Mercury level was below the detection limit in the Pratu River. Co, Cr, and Cu had mean values of 0.0229 ± 0.0324 mg/L, 0.0603 ± 0.0779 mg/L, and 0.0827 ± 0.1017 mg/L, respectively. The average results for Co and Cu were less than the recommended levels set by the GSA (2017) and WHO (2018), which are 0.05 mg/L and 2.0 mg/L, respectively. However, the mean Cr value exceeded the 0.05 mg/L guideline value established by the GSA (2017) and the WHO (2018).

Table 4.13: Concentration of heavy metals in water samples from Pratu River

Parameter	Mean (mg/ L)	Stand. Dev	Min	Max	WHO (2018, 2011)/ GSA (2017)
As	0.0192	0.0190	0.0005	0.0388	0.01
B	3.6715	4.1733	0.0061	8.5626	2.4
Ba	0.7292	0.9339	ND	2.0029	0.7
Cd	0.0043	0.0061	0.0001	0.0128	0.003
Co	0.0229	0.0324	0.0010	0.0647	0.05
Cr	0.0603	0.0779	0.0019	0.1599	0.05
Cu	0.0827	0.1017	ND	0.2114	2.0
Mn	1.9240	2.5604	0.0513	5.2547	0.4
Hg	ND	ND	ND	ND	0.006
Ni	0.0739	0.0983	0.0004	0.2002	0.02
Pb	0.1354	0.2004	ND	0.3954	0.01
Se	0.0342	0.0143	0.0169	0.0527	0.04
Zn	1.0859	1.5937	ND	3.2665	4.0

***ND=not detected**

Also, in the Pratu River, Mn and Ni concentrations varied from 0.0513 mg/L to 5.2547 mg/L, and from 0.0004 mg/L to 0.2002 mg/L, respectively. Mean concentrations of Mn and Ni were 1.924 ± 2.5604 mg/L and 0.07392 ± 0.983 mg/L, respectively. The mean concentrations of Mn and Ni in the Pratu River were higher than the levels permitted for surface water by the GSA (2017) and WHO (2018). In addition, Pb and Se concentrations varied from not detected to 0.3954 mg/L and 0.0169 mg/L to 0.0527 mg/L, respectively. The mean Pb (0.1354 ± 0.2004mg/L) and Se (0.0342 ± 0.0143 mg/L) concentrations were higher than their acceptable levels of 0.01 mg/L and 0.04 mg/L, respectively (GSA, 2017; WHO, 2018). With a mean value of 1.0859 ±1.5937 mg/L, the

Zn content ranged from not detected to 3.2665 mg/L. The Zn mean value was below the 4.0 mg/L recommended limit set by the GSA (2017) and WHO (2018).

Arsenic (As) measurements for water samples taken from Muni Lagoon ranged from 0.0014 mg/L to 0.0981 mg/L, with a mean value of 0.0268 ± 0.0390 mg/L, as shown in Table 4.14. The average concentration of As detected is greater than the allowed amount of 0.01 mg/L (GSA, 2017; WHO, 2018). Additionally, the levels of boron (B) and barium (Ba) ranged from no detection to 0.1571 mg/L and 0.0966 mg/L to 3.6256 mg/L, respectively. Mean Ba and B measured were 0.0455 ± 0.0757 mg/L and 1.0839 ± 1.557 mg/L, respectively. The GSA (2017) permitted values for B and Ba were 2.4 mg/L and 0.7 mg/L, respectively, and these mean readings were all below those values. Muni Lagoon had cadmium levels ranging from not detectable to 0.0001 mg/L. The mean Cd level was 0.0001 ± 0.00001 mg/L, which is less than the allowed level of 0.003 mg/L (GSA, 2017; WHO, 2018).

Table 4.14: Heavy metal levels in water samples from Muni Lagoon

Parameter	Mean (mg/L)	Stand. Dev	Min	Max	WHO (2018) / GSA (2017)
As	0.0268	0.0390	0.0014	0.0891	0.01
B	1.0839	1.557	0.0966	3.6256	2.4
Ba	0.0455	0.0757	ND	0.1571	0.7
Cd	0.0001	0.00001	ND	0.0001	0.003
Co	0.0010	0.0013	0.0001	0.0031	0.05
Cr	0.0109	0.0132	0.0024	0.0327	0.05
Cu	0.0514	0.0765	0.0019	0.1670	2.0
Mn	0.0977	0.1601	0.0038	0.3933	0.4
Hg	ND	ND	ND	ND	0.006
Ni	0.0054	0.0071	0.0008	0.0171	0.02
Pb	ND	ND	ND	ND	0.01
Se	0.0649	0.0602	0.0257	0.1641	0.04
Zn	0.0014	0.0039	ND	0.0080	4.0

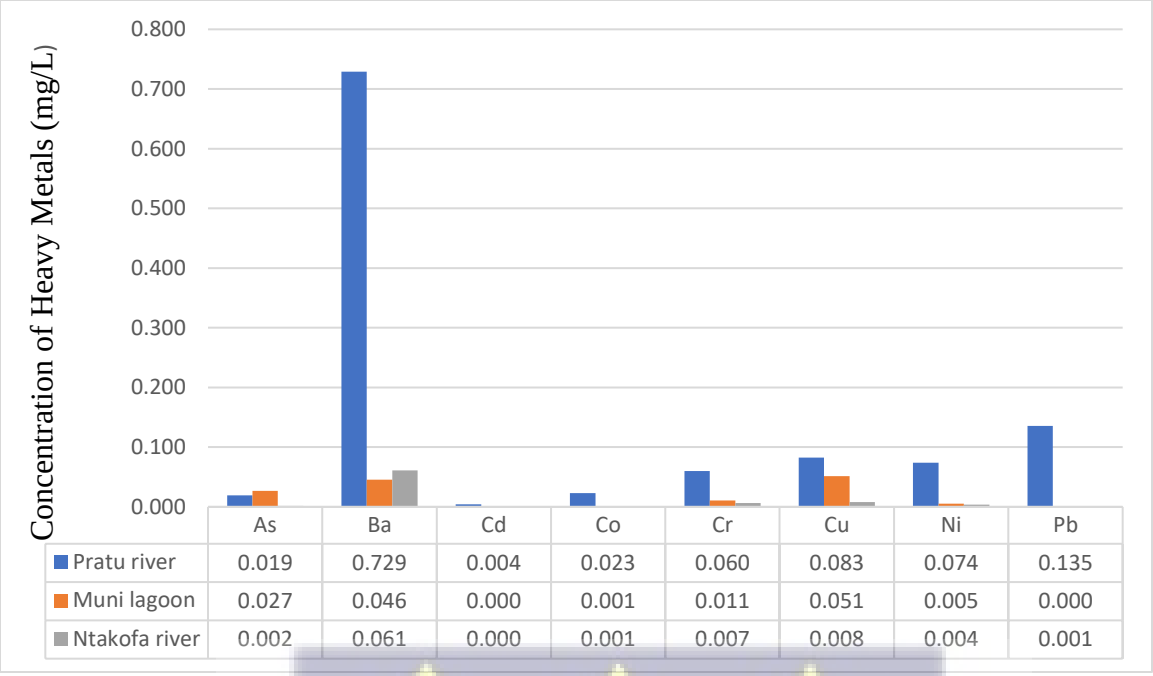
***ND=not detected**

Again, the concentrations of cobalt (Co), chromium (Cr), and copper (Cu) varied from 0.0001 to 0.0031 mg/L, 0.0024 mg/L to 0.0327 mg/L, and 0.0019 mg/L to 0.1670 mg/L, respectively. The

average concentrations of Co, Cr, and Cu were 0.0010 ± 0.0013 mg/L, 0.0109 ± 0.0132 mg/L, and 0.05143 ± 0.0765 mg/L, respectively. The average levels of Co, Cr, and Cu were under the suggested GSA (2017) and WHO (2018) guideline levels of 0.05 mg/L, 0.05 mg/L, and 2.0 mg/L, respectively.

Ni and Mn concentrations varied from 0.0008 mg/L to 0.0171 mg/L and 0.0038 mg/L to 0.3933 mg/L, respectively. Mean values for Mn and Ni were 0.0977 ± 0.1601mg/L and 0.0054 ± 0.0071 mg/L, respectively. Mn and Ni mean values in Muni Lagoon were below the GSA (2017) and WHO (2018) permissible values in surface water. Lead (Pb) and Hg were not detected in Muni Lagoon. Muni Lagoon had Se values ranging from 0.0257 mg/L to 0.1641 mg/L, with a mean value of 0.0649 ± 0.0602 mg/L. The mean value recorded for Se was above its acceptable level of 0.04 mg/L (GSA, 2017; WHO, 2018). A mean value of 0.0014 ± 0.0039 mg/L was found for the concentration of Zn, which again ranged from not detectable to 0.0080 mg/L. The mean reported for zinc was lower than the 4.0 mg/L recommendation threshold set by the GSA (2017) and WHO (2018).

Figure 9 compares some heavy metal levels in Water samples of Muni Lagoon, Pratu, and Ntakofa Rivers.



	As	Ba	Cd	Co	Cr	Cu	Ni	Pb
Pratu river	0.019	0.729	0.004	0.023	0.060	0.083	0.074	0.135
Muni lagoon	0.027	0.046	0.000	0.001	0.011	0.051	0.005	0.000
Ntakofa river	0.002	0.061	0.000	0.001	0.007	0.008	0.004	0.001

Figure 4.9: Variation of heavy metals in water samples from Muni Lagoon, Ntakofa, and Pratu Rivers

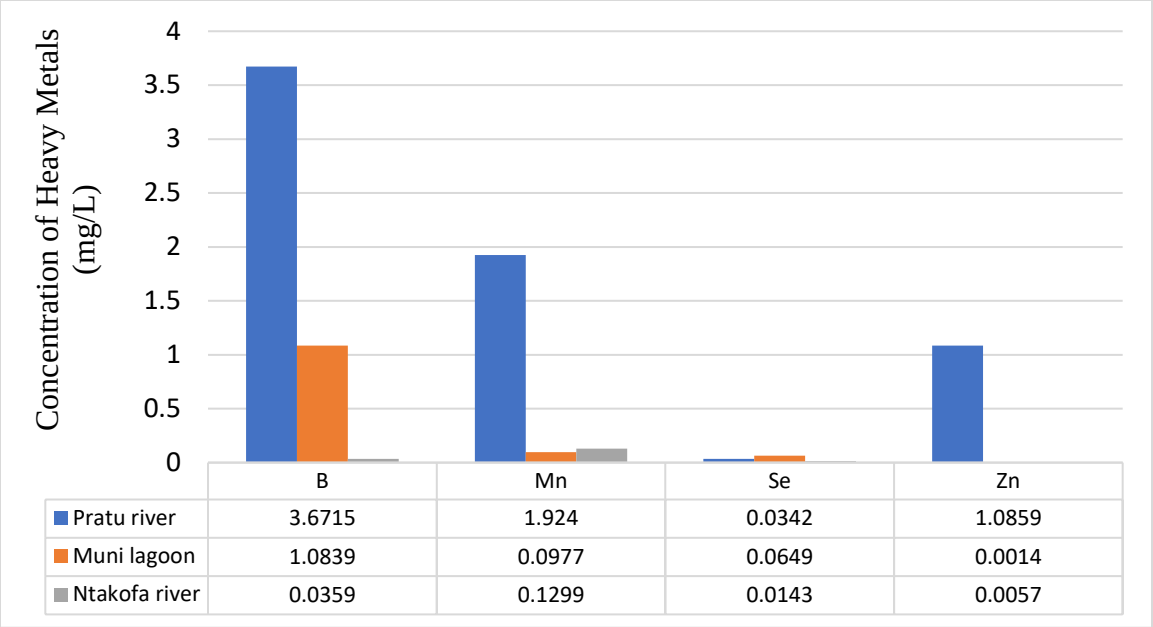
According to Figure 4.9, the mean As concentrations in the Pratu River, Muni Lagoon, and Ntakofa River were, respectively, 0.019 ± 0.019 mg/L, 0.027 ± 0.039 mg/L, and 0.0015 ± 0.0013 mg/L. The mean As levels measured from the Muni Lagoon, Ntakofa, and Pratu Rivers did not differ significantly (P = 0.233) (Appendix C). In the Pratu River, Muni Lagoon, and Ntakofa River, the mean Ba concentrations were 0.7292 ± 0.9339 mg/L, 0.0455 ± 0.0757 mg/L, and 0.0613 ± 0.0911 mg/L, respectively. The mean Ba levels observed in the water bodies did not significantly differ (P = 0.075) from one another (Appendix C). The Cd recorded for Pratu River was 0.0043 ± 0.0061mg/L. The mean Cd values for Muni Lagoon and Ntakofa River were below the detection limit. The mean Co concentrations in Pratu River, Muni Lagoon, and Ntakofa River were 0.0229 ± 0.0324 mg/L, 0.0010 ± 0.0013 mg/L, and 0.001135 ± 0.0017 mg/L, respectively.

The mean Co values observed in the water bodies were not significantly different (P = 0.101) from one another (Appendix C). The mean Cr value for water samples from Pratu River was 0.0603 ±

0.0779 mg/L, Muni Lagoon was 0.0109 ± 0.0132 mg/L, and Ntakofa River was 0.0066 ± 0.0063 mg/L. ANOVA results revealed no significant difference between the Cr values in water samples collected from the three water bodies. Again, the mean Cu value for water samples from Pratu River was 0.0827 ± 0.1017 mg/L, Muni Lagoon was 0.0514 ± 0.07652 mg/L, and Ntakofa River was 0.0081 ± 0.0158 mg/L. There was no significant difference between the Cu values in water samples from the three water bodies.

The mean Ni value for water samples from Pratu River was 0.07392 ± 0.0983 mg/L, Muni Lagoon was 0.0054 ± 0.0071 mg/L, and Ntakofa River was 0.0039 ± 0.0056 mg/L. The Ni levels in water samples taken from the three water bodies did not significantly differ from one another.

The mean Pb value for water samples from Pratu River was 0.1354 ± 0.2004 mg/L, Muni Lagoon was below the detection limit mg/L, and Ntakofa River was 0.0007 ± 0.00187 mg/L. The Pb levels in the water samples taken from the three water bodies did not significantly differ ($P = 0.855$). Figure 4.10 compares a few heavy metals in water samples from the Pratu River, Ntakofa River, and Muni Lagoons.



	B	Mn	Se	Zn
Pratu river	3.6715	1.924	0.0342	1.0859
Muni lagoon	1.0839	0.0977	0.0649	0.0014
Ntakofa river	0.0359	0.1299	0.0143	0.0057

Figure 4. 10: Variation of heavy metals in water samples from Muni Lagoon, Ntakofa, and Pratu Rivers

The mean B value for water samples from Pratu River was 3.6715 ± 4.1733mg/L, Muni Lagoon was 1.0839 ± 1.557 mg/L, and Ntakofa River was 0.0359 ± 0.0475 mg/L. The B values in the water samples taken from the three water bodies did not differ significantly. Again, the mean Mn value for water samples from Pratu River was 1.924 ± 2.5604 mg/L, Muni Lagoon was 0.0977 ± 0.1601 mg/L, and Ntakofa River was 0.1299 ± 0.1467 mg/L. There was no significant difference in the Mn values in the water samples from the three water bodies.

The mean Se for water samples from Pratu River was 0.0342 ± 0.0143 mg/L, Muni Lagoon was 0.0649 ± 0.0602 mg/L, and Ntakofa River was 0.0143 ± 0.0092 mg/L. There was no significant difference between the Se values in water samples from the three water bodies. The mean Zn value for water samples from Pratu River was 1.0859 ± 1.594 mg/L, Muni Lagoon was 0.0014 ± 0.0039 mg/L, and Ntakofa River was 0.00571 ± 0.0116 mg/L. There was no significant difference between the Zn values in water samples from the three water bodies.

4.5 Heavy metal concentrations in sediments

The results of heavy metal levels in sediment samples have been presented in this section.

4.5.1 Concentration of heavy metals in sediment samples from the Pratu River

Table 4.15 shows that Arsenic (As), Boron (B), and Barium (Ba) values measured for sediment samples collected from Pratu river ranged from 1.896 to 20.818 mg/Kg,0.385 to 5.987 mg/Kg, and 96.350 to 281.340 mg/Kg, respectively. The means for As, B, and Ba were 7.964 ± 7.410 mg/Kg, 2.922 ± 2.451 mg/Kg, and 163.733 ± 69.247 mg/Kg, respectively.

Table 4. 15: Concentration of heavy metals in sediment samples from Pratu River

Parameter	Mean (mg/Kg)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
As	7.964	7.410	1.896	20.818	20
B	2.922	2.451	0.385	5.987	300
Ba	163.733	69.247	96.350	281.340	300
Cd	0.0244	0.0203	0.0035	0.0536	3
Co	24.951	14.886	0.634	43.860	50
Cr	101.397	73.004	1.453	191.061	100
Cu	33.326	10.020	23.696	49.793	100
Mn	669.136	371.043	57.847	1047.323	200
Hg	0.0196	0.0079	0.0106	0.0335	2
Ni	29.477	11.363	16.873	47.604	50
Pb	8.365	4.010	4.365	14.773	50
Se	0.481	0.317	0.103	0.971	10
Zn	34.930	18.284	2.855	54.041	300

The concentrations of Cd, Co, Cr, and Cu ranged were 0.0035 to 0.0536 mg/ Kg, 0.634 to 43.860 mg/ Kg, 1.453 to 191.061 mg/ Kg, and 23.696 to 49.793 mg/ Kg, respectively. The mean of Cd was 0.0244 ± 0.0203 mg/Kg, while that of Co, Cr, and Cu were 24.951 ± 14.886 mg/ Kg, 101.397

± 73.004 mg/ Kg, and 33.326 ± 10.020 mg/ Kg, respectively. Again, the concentration ranges for heavy metals detected in the river Pratu sediment were 57 to 1047.323 mg/ Kg for Mn, 16.873 to 47.604 mg/ Kg for Ni, 4.365 to 14.773 mg/ Kg for Pb, 0.103 to 0.971 mg/ Kg for Se, and 2.855 to 54.041 mg/ Kg for Zn. Also, Hg concentration in River Pratu sediment ranged from 0.0106 to 0.0335 mg/Kg with a mean of 0.0196 ± 0.008 mg/Kg. The mean of the various heavy metals concentrations was 669.136 ± 371.043 mg/ Kg for Mn, 29.477 ± 11.363 mg/ Kg for Ni, 8.365 ± 4.010 mg/ Kg for Pb, 0.481 ± 0.31 mg/ Kg for Se, and 34.930 ± 18.284 mg/ Kg for Zn.

4.5.2 Concentration of heavy metals in sediment samples from Muni Lagoon

Table 4.16 shows that Arsenic (As), Boron (B), and Barium (Ba) mean values measured for sediment samples collected from Muni Lagoon ranged from 0.317 to 1.318 mg/Kg, 2.120 to 13.650 mg/Kg, and 3.777 to 78.593 mg/Kg, respectively. Their means were 0.886 ± 0.409 mg/Kg for As, 7.832 ± 4.250 mg/Kg for B, and 41.132 ± 28.682 mg/Kg for Ba. The concentrations of Cd, Co, Cr, and Cu ranges were 0.00006 to 0.0022 mg/ Kg, 0.373 to 4.946 mg/ Kg, 2.819 to 27.779 mg/ Kg, and 1.570 to 8.744 mg/ Kg, respectively. The mean concentrations measured were 0.0008±0.001 mg/Kg for Cd, 3.225 ± 1.546 mg/ Kg for Co, 14.262 ± 9.509 mg/ Kg for Cr, and 5.170 ± 2.633 mg/ Kg for Cu. The ranges of heavy metal concentrations found in the sediment samples from Muni Lagoon were once more 9.534 to 77.685 mg/ Kg for Mn, 0.0002 to 0.0077 mg/Kg for Hg, 0.537 to 8.696 mg/ Kg for Ni, 1.311 to 5.031 mg/ Kg for Pb, 0.0198 to 0.175 mg/ Kg for Se, and 3.697 to 12.672 mg/ Kg for Zn. The mean of the various heavy metals concentrations was 42.703 ± 24.557 mg/ Kg for Mn, 0.0033 ± 0.003 mg/ Kg for Hg, 5.051± 3.530 mg/ Kg for Ni, 3.343 ± 1.427 mg/ Kg for Pb, 0.0913 ± 0.0757 mg/ Kg for Se, and 6.968 ± 3.434 mg/ Kg for Zn.

Table 4.16: Concentration of heavy metals in sediment samples from Muni Lagoon

Parameter	Mean (mg/Kg)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
As	0.886	0.409	0.317	1.318	20
B	7.832	4.250	2.120	13.650	300
Ba	41.132	28.682	3.777	78.593	300
Cd	0.0008	0.001	0.00006	0.0022	3
Co	3.225	1.546	0.373	4.946	50
Cr	14.262	9.509	2.819	27.779	100
Cu	5.170	2.633	1.570	8.744	100
Mn	42.703	24.557	9.534	77.685	200
Hg	0.0033	0.0031	0.0002	0.0077	2
Ni	5.051	3.530	0.537	8.696	50
Pb	3.343	1.427	1.311	5.031	50
Se	0.0913	0.0757	0.0198	0.175	10
Zn	6.968	3.434	3.697	12.672	300

4.5.3 Concentration of heavy metals in sediment samples from Ntakofa River

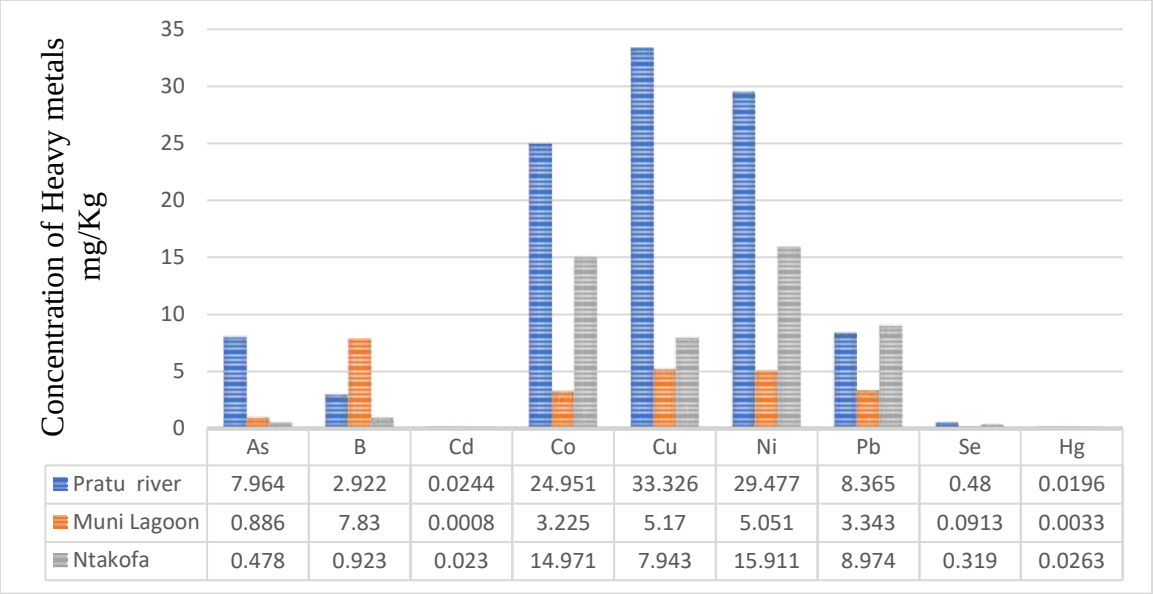
Table 4.17 shows that Arsenic (As), Boron (B), and Barium (Ba) values measured for sediment samples collected from Ntakofa river ranged from 0.3572 to 0.6550 mg/Kg, 0.3631to 2.0855 mg/Kg, and 79.1019 to 197.5315 mg/Kg, respectively. Their means were 0.4783 ± 0.1038 mg/Kg for As, 0.9226 ± 0.6926 mg/Kg for B, and 129.0076 ± 42.2560 mg/Kg for Ba. The concentrations of Cd, Co, Cr, and Cu ranges were 0.0029 to 0.0644 mg/ Kg, 7.1089 to 23.9710 mg/ Kg, 11.2868 to 46.7046 mg/ Kg, and 3.0969 to 16.0212 mg/ Kg, respectively. The mean concentrations measured were 0.0227 ± 0.0246 mg/Kg for Cd, 14.9710 ± 6.1719 mg/ Kg for Co, 25.7690 ± 13.022 mg/Kg for Cr, and 7.9430±5.4367 mg/ Kg for Cu. Again, the concentration ranges for heavy metals

detected in Ntakofa river sediment were 307.573 to 1094.727 mg/ Kg for Mn, 0.0065 to 0.0404 mg/Kg for Hg, 6.3353 to 22.6317 mg/ Kg for Ni, 5.7864 to 14.8499 mg/ Kg for Pb, 0.0805 to 0.5091 mg/ Kg for Se, and 7.8118 to 28.2430 mg/ Kg for Zn. The mean of the various heavy metals concentrations was 662.586 ± 324.396 mg/ Kg for Mn, 0.0263 ± 0.0151 mg/ Kg for Hg, 15.9109 ± 6.1933 mg/ Kg for Ni, 8.9736 ± 3.628 mg/ Kg for Pb, 0.3193 ± 0.1644 mg/ Kg for Se, and 16.493 ± 9.1034 mg/ Kg for Zn.

Table 4.17: Concentration of heavy metals in sediment samples from Ntakofa River

Parameter	Mean (mg/Kg)	Stand. Dev	Min	Max	WHO (2018)/ GSA (2017)
As	0.4783	0.1038	0.3572	0.6550	20
B	0.9226	0.6926	0.3631	2.0855	300
Ba	129.0076	42.2560	79.1019	197.5315	300
Cd	0.0227	0.0246	0.0029	0.0644	3
Co	14.9710	6.1719	7.1089	23.9710	50
Cr	25.7690	13.022	11.2868	46.7046	100
Cu	7.9430	5.4367	3.0969	16.0212	100
Mn	662.586	324.396	307.537	1094.727	200
Hg	0.0263	0.0151	0.0065	0.0404	2
Ni	15.9109	6.1933	6.3353	22.6317	50
Pb	8.9736	3.628	5.7864	14.8499	50
Se	0.3193	0.1644	0.0805	0.5091	10
Zn	16.4934	9.1034	7.8118	28.2430	300

Figure 4.11 compares heavy metal levels in sediment samples of Muni Lagoon, Pratu, and Ntakofa Rivers.



	As	B	Cd	Co	Cu	Ni	Pb	Se	Hg
Pratu river	7.964	2.922	0.0244	24.951	33.326	29.477	8.365	0.48	0.0196
Muni Lagoon	0.886	7.83	0.0008	3.225	5.17	5.051	3.343	0.0913	0.0033
Ntakofa	0.478	0.923	0.023	14.971	7.943	15.911	8.974	0.319	0.0263

Figure 4. 11: Variation of heavy metals in sediment samples from Muni Lagoon, Ntakofa and Pratu Rivers

The mean As value for sediment samples from Pratu River was 7.964 ± 7.41mg/ Kg, Muni Lagoon was 0.886 ± 0.409 mg/ Kg, and Ntakofa River was 0.478 ± 0.104 mg/ Kg. ANOVA results indicated a statistically significant difference (P = 0.014) between the As values in sediment samples collected from the different water bodies. Tukey's test shows no significant difference between mean As values measured for Muni Lagoon and Ntakofa River (P = 0.985). There is, however, a significant difference between As values in sediment samples for Pratu River and Muni Lagoon (P = 0.03) as well as Pratu River and Ntakofa River (P = 0.02) (Appendix D).

The mean boron (B) concentrations in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 2.922 ± 2.451 mg/Kg, 7.83 ± 4.250 mg/ Kg, and 0.923 ± 0.693 mg/ Kg, respectively. Analysis of variance revealed a significant difference (P = 0.002) among the B concentrations. Tukey's multiple comparisons revealed a significant difference between mean boron concentrations measured for Pratu River and Muni Lagoon (P = 0.024) sediment samples, as well as Ntakofa River and Muni Lagoon (P = 0.002) sediment samples.

The mean Cd concentrations in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 0.0244 ± 0.02 mg/Kg, 0.0008 ± 0.0004 mg/Kg, and 0.0227 ± 0.025 mg/ Kg, respectively. ANOVA results did not indicate a statistically significant difference (P = 0.077) in measured Cd values (Appendix D).

The mean Co concentrations in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 24.951 ± 14.89 mg/Kg, 3.225 ± 1.55 mg/Kg, and 14.97 ± 6.172 mg/Kg, respectively. ANOVA results showed a significant difference (P = 0.004) among the Co values. Tukey's multiple comparisons revealed a significant difference between mean Co concentrations measured for Pratu River and Muni Lagoon (P = 0.003) sediment samples. There is no difference between Co concentrations measured for Pratu and Ntakofa Rivers (P = 0.188) (Appendix D).

The mean Cu concentrations in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 33.326 ± 10.02 mg/Kg, 5.170 ± 2.634 mg/Kg, and 7.943 ± 5.437mg/Kg, respectively. ANOVA results showed significant differences (P = 0.000) among the Cu values (Appendix D). Tukey's test revealed a significant difference (appendix D) between Cu concentrations measured in sediment samples from Muni Lagoon and Pratu River, but not Muni Lagoon and Ntakofa River.

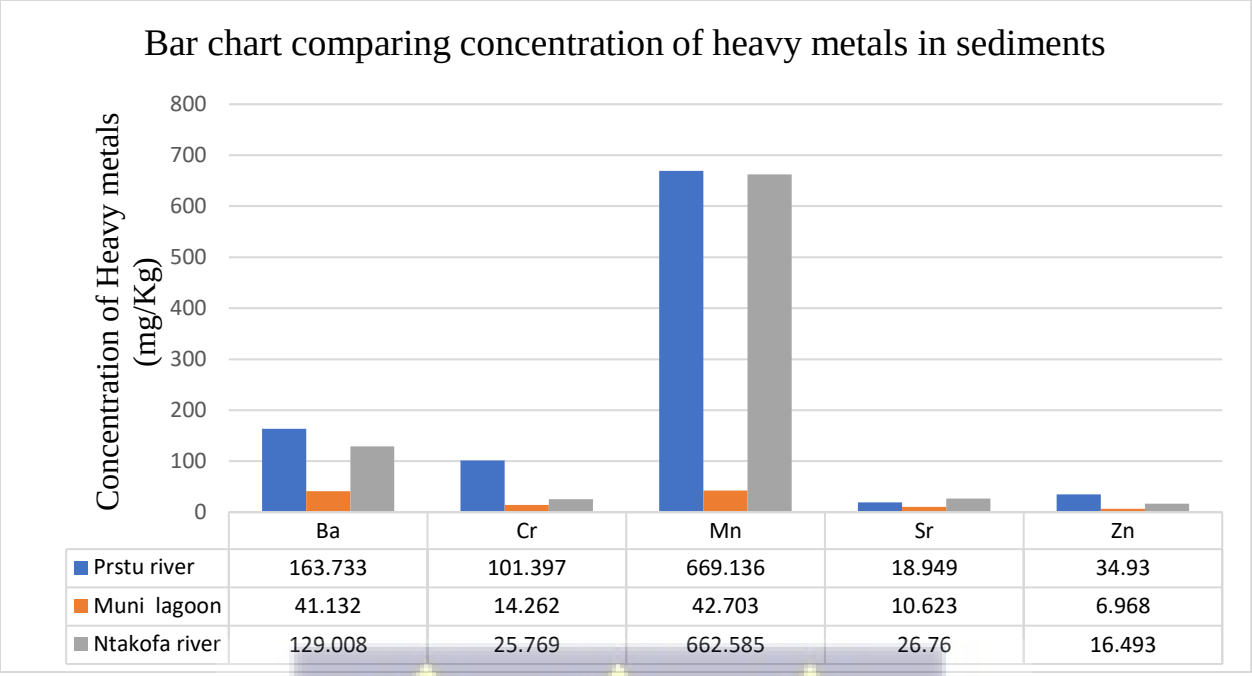
The mean Ni concentrations in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 29.477 ± 11.363 mg/Kg, 5.051 ± 3.530 mg/Kg, and 15.911 ± 6.193mg/Kg, respectively. ANOVA test revealed a significant difference (P = 0.000) among the Ni values (Appendix D). Tukey's multiple comparison tests indicated a significant difference between Cu concentrations measured in sediment samples from Muni Lagoon and Pratu River (P = 0.000) as well as Pratu River and Ntakofa (P = 0.022), but not between those of Muni Lagoon and Ntakofa River (P = 0.069) (Appendix D).

The mean Pb concentrations in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 8.365 ± 4.005 mg/Kg, 3.343 ± 1.427mg/Kg, and 8.974 ± 3.629 mg/Kg, respectively. ANOVA results indicated a significant difference (P = 0.016) among the Pb values (Appendix D). Tukey's test revealed a significant difference (appendix D) between Pb concentrations measured in sediment samples from Muni Lagoon and Pratu River (P = 0.042) as well as Muni Lagoon and Ntakofa River (P = 0.022).

The mean Se in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 0.480 ± 0.317 mg/Kg, 0.091 ± 0.076 mg/Kg, and 0.319 ± 0.164 mg/Kg, respectively. ANOVA results indicated a significant difference (P = 0.020) among the Se values (Appendix D). Tukey's multiple comparison tests showed a significant difference between Se concentrations measured in sediment samples from Muni Lagoon and Pratu River (P = 0.016) but not between those of Muni Lagoon and Ntakofa River (Appendix D).

The mean Hg in sediment samples from Pratu River, Muni Lagoon, and Ntakofa River were 0.0196 ± 0.0079 mg/Kg, 0.0033 ± 0.0031 mg/Kg, and 0.0263 ± 0.0151 mg/Kg, respectively. ANOVA results indicated a significant difference between them. Tukey's test showed a significant difference in mean Hg levels between Muni Lagoon and Pratu River, as well as Muni Lagoon and Ntakofa River, but not between those obtained for Ntakofa and Pratu Rivers.

Figure 14.2 presents the comparison of some heavy metals that were detected in sediment samples from the Ntakofa River, Muni Lagoon, and Pratu River.



	Ba	Cr	Mn	Sr	Zn
Prstu river	163.733	101.397	669.136	18.949	34.93
Muni lagoon	41.132	14.262	42.703	10.623	6.968
Ntakofa river	129.008	25.769	662.585	26.76	16.493

Figure 4.12: Variation of heavy metals in sediment samples from Muni lagoon, Ntakofa, and Pratu Rivers

The mean Ba value for sediment samples from Pratu River was 163.733 ± 69.247mg/ Kg, Muni Lagoon was 28.682 ± 11.709 mg/ Kg, and Ntakofa River was 129.008 ± 42.256 mg/ Kg. There is a significant difference (P = 0.002) between the Ba values in sediment samples collected from the different water bodies. Tukey's multiple tests showed a significant difference between mean Ba values measured for Muni Lagoon and Ntakofa River (P = 0.020) as well as between Muni Lagoon and Pratu River (P = 0.002) (Appendix D).

The mean Cr in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 101.397 ± 73.00mg/Kg, 14.262 ± 9.509 mg/Kg, and 25.769 ± 13.022 mg/Kg, respectively. Analysis of variance revealed a significant difference (P = 0.006) among the Cr values (Appendix D). Tukey's test revealed a significant difference between Cr concentrations measured in sediment samples from Muni Lagoon and Pratu River (P = 0.009) as well as that of Muni Lagoon and Ntakofa River (P = 0.0210) (Appendix D).

The mean Mn in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 669.135 ± 371.043 mg/Kg, 42.703.262 ± 24.557 mg/Kg, and 324.396 ± 13.022 mg/Kg, respectively. ANOVA results showed a significant difference (P = 0.002) among Mn values (Appendix D). Tukey's multiple tests showed a significant difference among Mn concentrations measured in sediment samples from Muni Lagoon and Pratu River (P = 0.005) as well as that of Muni Lagoon and Ntakofa River (P = 0.005) (Appendix D).

The mean Zn in sediment samples collected from Pratu River, Muni Lagoon, and Ntakofa River were 34.930 ± 18.283 mg/Kg, 6.968 ± 3.434 mg/Kg, and 16.493 ± 9.103 mg/Kg, respectively. ANOVA results indicated a significant difference (P = 0.003) in Zn values (Appendix D). Tukey's multiple comparison tests revealed a significant difference between Zn concentrations measured in sediment samples from Pratu River and Muni Lagoon (P = 0.003) as well as that of Pratu River and Ntakofa River (P = 0.044) (Appendix D).

4.6 Geo-Accumulation Index (I_{geo})

The geo-accumulation index of heavy metals in sediment samples taken from the Pratu River, Muni Lagoon, and Ntakofa River is shown in Table 4.18.

Table 4. 18: Heavy metal geo-accumulation index in sediment samples

Parameter	Pratu River	Muni Lagoon	Ntakofa River
As	4.7435	1.5754	0.6860
B	0.5561	1.9785	-1.1071
Ba	5.5311	3.5381	5.1873
Cd	4.1131	-0.8176	4.0089
Co	6.1558	3.2041	5.4189
Cr	5.2617	2.4319	3.2854
Cu	4.5007	1.8123	2.4318
Mn	6.2262	2.2563	6.2120
Hg	0.4269	-2.1435	0.8511
Ni	5.0715	2.5266	4.1820
Pb	1.9986	0.6754	2.0999
Se	4.6927	2.2953	4.1015
Zn	3.2979	0.9723	2.2154
Mean	**4.0443**	**1.5619**	**3.0441**
SD	**1.9383**	**0.4431**	**2.1061**
MIN	**0.4269**	**-2.1435**	**-1.1071**
MAX	**6.2262**	**3.5381**	**6.212**

Source: Field data, Twumasi (2022)

According to Table 4.18, the geo-accumulation index (Igeo) of heavy metals in the Pratu River ranged from 0.4269 to 6.2262, with a mean value of 4.0443 (SD = 1.9383). In addition, the mean Igeo values for the Ntakofa River and Muni Lagoon were 3.0441 (SD = 2.1061) and 1.5619 (SD

= 0.443), respectively. In the Ntakofa River and Muni Lagoon, respectively, the Igeo values of heavy metals ranged from -1.1071 to 6.2120 and -2.1435 to 3.5381. Among the three water bodies, Pratu River had the highest mean I geo value (Igeo = 4.0443), followed by Ntakofa River (Igeo = 3.0441). The lowest Igeo value was recorded in Muni Lagoon (Igeo = 1.5619).

The Igeo values determine the sediment sample's amount of heavy metal contamination as well as the pollution index class. The Igeo value (4.0443) of Pratu River was in class five (5) range ($4 \leq$ Igeo ≤ 5), indicating heavy to extreme contamination. The Igeo values of Ntakofa River and Muni Lagoon were within the index classes of four ($3 \leq$ Igeo ≤ 4), indicating heavy sediment contamination, and two ($1 \leq$ Igeo ≤ 2), indicating moderate sediment contamination, respectively.

4.7 Factor Analysis of physical parameters and heavy metals

From Table 4.19 and Figure 13 (scree plot), the number of components that were extracted was forty-four (44), and out of this, the first six (6) components cumulatively explained 93.89% of the total variations among physiochemical and heavy metal parameters. These six components were therefore retained in the model.

Table 4.19: Component Matrix of Physicochemical and Heavy Metal Parameters in Water and Sediment

Parameters	Components						Commonalities
	1	2	3	4	5	6	
As	0.343	0.347			0.859		0.991
B	0.883				0.333		0.996
Ba	0.976						0.998
Cd	0.986						0.992
Co	0.991						0.996
Cr	0.979						0.998

Cu	0.788			0.561		0.990
Mn	0.988					0.996
Ni	0.985					0.997
Pb	0.988					0.991
Se		0.404		0.894		0.978
Sr	0.741			0.607		0.996
Zn	0.987					0.993
Sulphate	-0.386	0.803			-0.351	0.963
Chloride		0.867				0.956
Nitrate		-0.827				0.808
Nitrite		0.586	-0.314	0.326	-0.544	0.903
Phosphate		-0.895				0.945
TSS	0.792					0.736
TDS		0.888				0.948
pH		0.509		0.618		0.710
Turbidity		0.896				0.958
Conductivity		0.891		0.303		0.955
Alkalinity	0.645			0.58	0.334	0.896
Ca				-0.878		0.917
Fe				-0.906		0.884
K		0.932				0.925
Mg		0.938				0.957
Na		0.881		0.354		0.948
Al				-0.911		0.893
COD	0.664				0.636	0.962
BOD	0.63				0.671	0.957
As		-0.938				0.979
B		-0.884				0.929

Ba	0.339	0.335	0.76				0.868
Cd	0.874						0.914
Co	0.354		0.862				0.972
Cr	0.469	-0.308	0.634				0.888
Cu		-0.906					0.929
Mn	0.346		0.882				0.990
Hg		0.302					
Ni		-0.866					0.884
Pb		-0.9					0.935
Se		-0.91					0.956
Sr		0.582	0.651				0.913
Zn	0.359		0.85			0.354	0.982
Eigenvalue	17.283	12.386	6.099	2.310	1.933	1.301	
% Variance	39.28	28.150	13.862	5.249	4.392	2.957	
% cumulative	39.28	67.43	81.29	86.54	90.93	93.89	

*Empty spaces are suppressed eigenvalues less than 0.3

Also, As was moderated and weakly loaded, respectively. The only physicochemical parameter that was strongly loaded for PC-1 was TSS. The other physicochemical variables that were moderately loaded for PC-1 were alkalinity, COD, and BOD. Cadmium (Cd) was the only heavy metal that was strongly loaded in PC-1 for sediment samples. In addition, Ba, Co, Cr, Mn, and Zn were all weakly loaded for sediment heavy metals analysed.

The second principal component (PC-2) contributed to 28.15% of the total variation, and the physicochemical parameters that were strongly loaded include sulphates, chlorides, Nitrates, phosphates, TDS, Conductivity, K, Mg, and Na. There was no strong loading for heavy metals in

water for PC-2. Arsenic, B, Cu, Ni, and Se were strongly loaded for heavy metals in sediment samples analysed. pH and was moderately loaded in water samples for PC-2.

Heavy metals Ba, Co, Cr, Mn, and Zn were heavily loaded in the third main component (PC-3), which contributed 13.86 percent of the overall variance. Ca, Fe, and Al were substantially loaded onto the fourth main component (PC-4) in water samples, which contributed 5.25 percent to the overall variance. pH and alkalinity were moderately loaded for PC-4.

The fifth main component (PC-5) was heavily loaded by As and Se in water samples, contributing 4.39 percent of the overall variance. Copper and Nitrite were moderately loaded in water samples. The sixth principal component (PC-6) contributed to 2.96% and was moderately loaded by COD and BOD. In addition, Zn in sediment samples and sulphate in water samples were weakly loaded for PC-6. Additionally, the commonalities shown in Table 4.19 demonstrate that each parameter (whether physicochemical or heavy metal) contributed more than 70% of the overall variance. The scree plot presented in Figure 13 shows six components that had eigenvalues greater than 1.

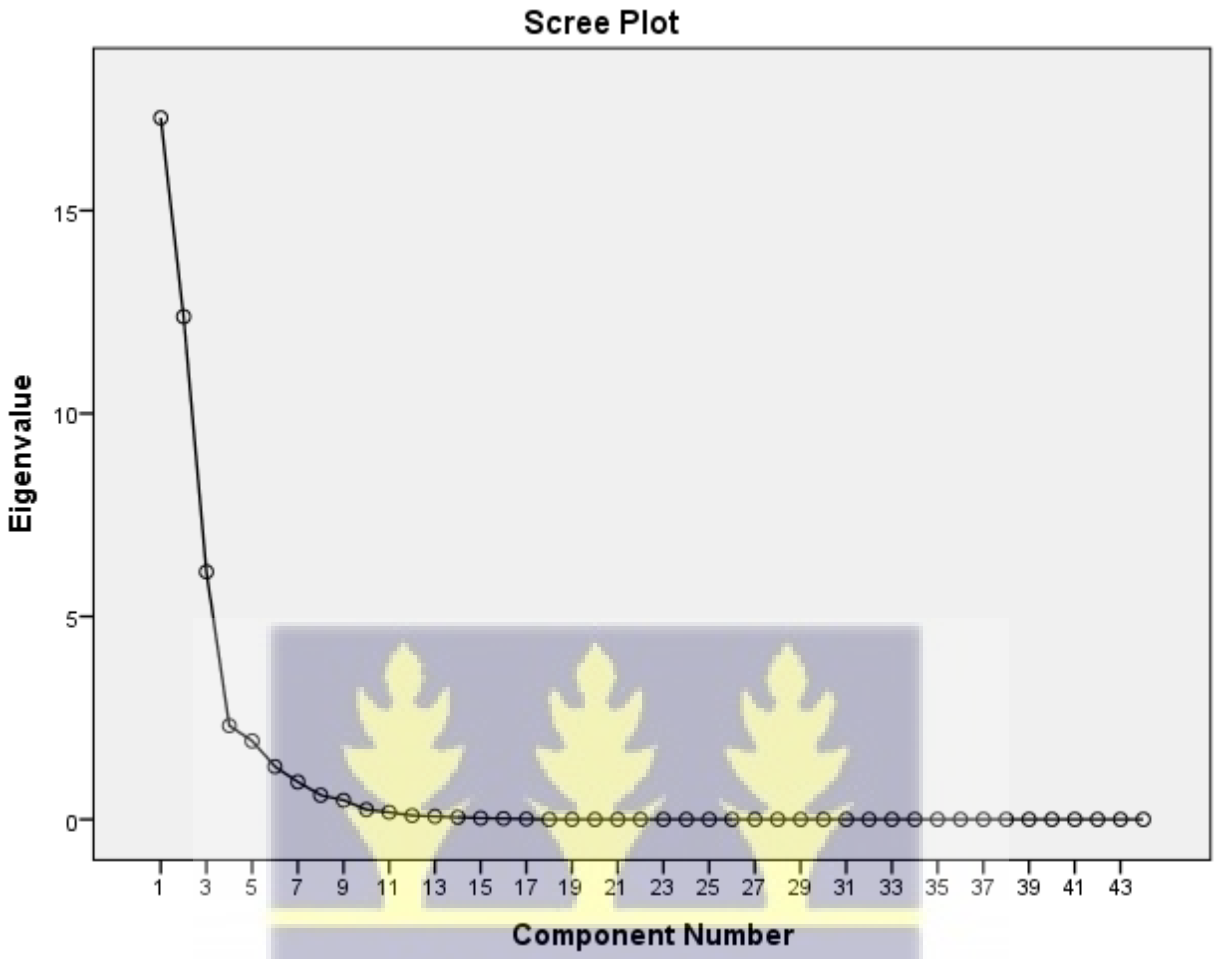


Figure 4. 13: Scree plot of physicochemical and heavy metal among water bodies and Sediment

4.7.2 Correlation of Physicochemical Parameters of Water Bodies

Table 4.20 presents Pearson's correlation matrix of physicochemical parameters between water samples collected from the Muni lagoon and its tributaries. The correlation analysis revealed a significant positive correlation (where all the coefficients were greater than 0.5 (r> 0.5)) between the following variables; Chlorine and sulphate, nitrite and sulphate, nitrite and chlorine, phosphate and nitrate, TDS and Sulphate, TDS and chloride, TDS and nitrite, pH and sulphate, pH and chlorine, pH and nitrite, pH and TDS, EC and sulphate, EC and chlorine, EC and nitrite, EC and TDS, EC and pH, alkalinity and TSS, alkalinity and pH, Fe and Ca, K and sulphate, K and

chlorine, K and nitrite, Mg and sulphate, Mg and chlorine, Mg and nitrate, Mg and TDS, Mg and pH, Mg and EC, Mg and K, Na and sulphate, Na and chlorine, Na and nitrite, Na and EC, Na and K, Na and Mg, Na and pH, Na and TDS, Al and Ca, Al and Fe, COD and TSS, COD and alkalinity, BOD and TSS, BOD and alkalinity, as well as BOD and COD. The analysis also revealed a strong negative correlation ($r \geq -0.5$) between nitrate and sulphate, nitrate and chlorine, phosphate and sulphate, phosphate and chlorine, TDS and nitrate, TDS and phosphate, EC and nitrate, EC and phosphate, Ca and alkalinity, Fe and alkalinity, nitrate and K, K and phosphate, K and TDS, K and pH, K and EC, Mg and nitrate, Mg and phosphate as well as Na and nitrate.

Table 4.21 illustrates Pearson's correlation matrix between heavy metals found in water samples collected from the Muni lagoon and its tributaries. The correlation analysis revealed a significant positive correlation between the following variables; B and As (r = 0.655), Ba and B (r = 0.941), Cd and B (r = 0.0.889), Cd and Ba (r = 0.981), Co and B (r = 0.988), Co and Cd (r = 0.997), Cr and As (r = 0.478), Cr and B (r = 0.952), Cr and Ba(r = 0.992), Cr and Cd (r = 0.980), Cr and Co (r = 0.990), Cu and As (r = 0.842), Cu and B (r = 0.933), Cu and Ba (r = 0.826),Cu and Cd (r = 0.772), Cu and Co (r = 0.799), Cu and Cr (r = 0.871), Mn and B (r = 0.923),Mn and Ba (r = 0.993), Mn and Cd (r = 0.993),Mn and Co (r = 0.998), Mn and Cr (r = 0.993), Mn and Cu (r = 0.810), Ni and B (r = 0.934), Ni and Ba (r = 0.996), Ni and Cd (r = 0.992), Ni and Co (r = 0.997), Ni and Cr (r = 0.996), Ni and Cu (r = 0.823), Ni and Mn (r = 0.999), Pb and B (r = 0.890), Pb and Ba (r = 0.980), Pb and Cd (r = 0.999), Pb and Co (r = 0.998),Pb and Cr (r = 0.982), Pb and Cu(r = 0.774), Pb and Mn (r = 0.995), Pb and Ni (r = 0.993), Se and As(r = 0.947), Se and Cu (r = 0.648), Sr and As (r = 0.880), Sr and Cu (r = 0.923), Sr and Ba (r = 0.788),Sr and Cd (r = 0.728), Sr and Co (r = 0.756), Sr and Cr (r = 0.836), Sr and Cu (r = 0.995), Sr and Mn (r = 0.770), Sr and Ni (r

= 0.784), Sr and Pb (r = 0.730), Sr and Se (r = 0.705), Zn and B (r = 0.892), Zn and Ba (r = 0.983), Zn and Cd(r = 1.0)), Zn and Co (r = 0.997), Zn and Cr (r = 0.982), Zn and Cu (r = 0.775), Zn and Mn (r = 0.994),Zn and Ni (r = 0.992), Zn and Pb (r = 0.999) as well as Zn and Sr (r = 0.731).

Table 4.20: Pearson's product-moment correlation coefficient between physicochemical parameters in water samples

	SO_4^{2}	Cl^-	NO_3^-	NO_2^-	PO_4^{3-}	TSS	TDS	pH	EC	ALK	Ca	Fe	K	Mg	Na	Al	COD	BOD
SO_4^{2-}	1																	
Cl^-	.97**	1																
NO_3^-	-.52*	-.626**	1															
NO_2^-	.56*	.511*	-0.308	1														
PO_4^{3-}	-98**	-.746**	.856**	-0.413	1													
TSS	-0.31	-0.142	-0.224	-0.186	-0.102	1												
TDS	.945**	.992**	-.653**	.503*	-.780**	-0.083	1											
pH	.480*	.503*	-0.045	.595**	-0.248	0.063	.518*	1										
EC	.808**	.884**	-.648**	.509*	-.709**	0.157	.899**	.626**	1									
ALK	-0.068	0.096	-0.011	-0.02	-0.011	.690**	0.173	.475*	0.394	1								
Ca	0.089	0.074	-0.282	-0.174	-0.342	-0.114	0.051	-0.403	-0.065	-.554*	1							
Fe	-0.007	-0.035	-0.181	-0.196	-0.238	-0.137	-0.06	-0.45	-0.162	-.549*	.975**	1						
K	.798**	.855**	-.722**	.517*	-.759**	0.131	.856**	.520*	.954**	0.191	0.167	0.054	1					
Mg	.792**	.87**	-.713**	.526*	-.770**	0.179	.890**	.599**	.982**	0.331	0.043	-0.073	.978**	1				
Na	.784**	.85**	-.642**	.525*	-.688**	0.174	.869**	.649**	.993**	0.4	-0.114	-0.213	.951**	.979**	1			
Al	0.055	0.028	-0.212	-0.214	-0.285	-0.154	0.004	-0.434	-0.101	-.530*	.972**	.994**	0.104	-0.021	-0.157	1		
COD	-0.35	-0.134	-0.266	-0.243	-0.005	.583*	-0.049	0.034	0.089	.610**	-0.138	-0.162	0.023	0.133	0.095	-0.181	1	
BOD	-0.355	-0.142	-0.259	-0.24	0.011	.545*	-0.059	0.024	0.078	.582*	-0.132	-0.155	0.015	0.122	0.084	0.174	.99	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Source: Field data, Twumasi (2022)

Table 4.21: Pearson's product-moment correlation between heavy metals in water samples

	As	B	Ba	Cd	Co	Cr	Cu	Mn	Ni	Pb	Se	Zn
As	1											
B	.655**	1										
Ba	0.403	.941**	1									
Cd	0.324	.889**	.981**	1								
Co	0.359	.907**	.988**	.997**	1							
Cr	.478*	.952**	.992**	.980**	.990**	1						
Cu	.842**	.933**	.826**	.772**	.799**	.871**	1					
Mn	0.378	.923**	.993**	.993**	.998**	.993**	.810**	1				
Ni	0.398	.934**	.996**	.992**	.997**	.996**	.823**	.999**	1			
Pb	0.326	.890**	.980**	.999**	.998**	.982**	.774**	.995**	.993**	1		
Se	.947**	0.423	0.133	0.07	0.097	0.218	.648**	0.115	0.135	0.071	1	
Sr	.880**	.923**	.788**	.728**	.756**	.836**	.995**	.770**	.784**	.730**	.705**	
Zn	0.328	.892**	.983**	1.000**	.997**	.982**	.775**	.994**	.992**	.999**	0.072	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Source: Field data, Twumasi (2022)

Table 4.22 presents Pearson's correlation matrix between heavy metal parameters of sediment samples collected from the Muni Lagoon and its tributaries. The correlation analysis revealed a significant positive correlation between the following variables; B and As (r = 0.971), Co and Ba (r = 0.870), Co and Cd (r = 0.573),Cr and Ba (r = 0.508), Cr and Cd (r = 0.581), Cr and Co (r = 0.759), Cu and As (0.958), Cu and B (r = 0.944), Mn and Ba (r = 0.904), Mn and Cd (r = 0.568), Mn and Co (r = 0.990), Mn and Cr (r = 0.728), Ni and As (r = 0.943), Ni and B (r = 0.973), Ni and Cu (r = 0.871), Pb and As (r = 0.938),Pb and B (r = 0.931), Pb and Cu (r = 0.913), Pb and Ni (r = 0.916), Se and As (r = 0.964), Se and B (r = 0.947), Se and Cu (r = 0.944), Se and Ni (r = 0.936), Se and Pb (r = 0.917), Zn and Ba (r = 0.765), Zn and Cd (r = 0.631), Zn and Co (r = 0.870), Zn and Cr (r = 0.621), Zn and Mn (r = 0.900). In addition, Cd and Ba were moderately positively correlated. Also, there was a significant negative correlation between the following variables; Ba and B (r = - 0.540), Cu and Ba (r = - 0.541), Ni and Ba (r = - 0.503), Pb and Ba (r = - 0.511), Se and Ba (r = - 0.565), Ba and As (r = - 0.483), as well as Sr and Se (r = - 0.708).

Except for As and Se, all the heavy metals are significantly positively correlated with TDS in Table 22 (r > 0.5). Additionally, As, B, Ba, Cd, Co, Cr, Cu, Mn, Ni, Pb, and Zn all showed a substantial positive connection with alkalinity. Once more, all of the heavy metals, except for As and Se, had a strong positive association between COD and BOD of larger than 0.5. The correlations between chlorine and selenium (r = 0.550), EC and As (r = 0.527), EC and selenium (r = 0.592), and Na and As (r = 0.485) were all positive.

Table 4. 22: Correlation between Heavy metal parameters in sediment samples

	As	B	Ba	Cd	Co	Cr	Cu	Mn	Ni	Pb	Se	Zn
As	1											
B	.971**	1										
Ba	-.483*	-.540*	1									
Cd	-0.233	-0.276	.470*	1								
Co	-0.315	-0.416	.870**	.573*	1							
Cr	0.18	0.038	.508*	.581*	.759**	1						
Cu	.958**	.944**	-.541*	-0.282	-0.406	0.106	1					
Mn	-0.318	-0.418	.904**	.568*	.990**	.728**	-0.405	1				
Hg	0.15	0.051	0.412	0.061	0.254	0.137	0.201	1				
Ni	.943**	.973**	-.503*	-0.255	-0.379	0.044	.871**	-0.381	1			
Pb	.938**	.931**	-.511*	-0.267	-0.373	0.024	.913**	-0.377	.916**	1		
Se	.964**	.947**	-.565*	-0.271	-0.43	0.089	.944**	-0.429	.936**	.917**	1	
Sr	-.642**	-.669**	.792**	0.163	.661**	0.136	-.682**	.709**	-.641**	-.665**	-.708**	
Zn	-0.232	-0.311	.765**	.631**	.870**	.621**	-0.306	.900**	-0.275	-0.282	-0.322	1

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

Source: Field data, Twumasi (2022)

Table 4. 23: Correlation between physicochemical and heavy metal parameters in water samples

	As	B	Ba	Cd	Co	Cr	Cu	Mn	Ni	Pb	Zn
Sulphate	0.294	-0.218	-0.385	-0.354	-0.364	-0.32	-0.038	-0.37	-0.358	-0.357	-0.358
Chloride	0.43	-0.003	-0.193	-0.183	-0.189	-0.133	0.149	-0.189	-0.173	-0.187	-0.186
Nitrate	-0.338	-0.3	-0.216	-0.175	-0.183	-0.223	-0.326	-0.193	-0.206	-0.172	-0.177
Nitrite	-0.282	-0.296	-0.267	-0.208	-0.234	-0.268	-0.325	-0.249	-0.246	-0.212	-0.213
Phosphate	-0.362	-0.211	-0.127	-0.162	-0.155	-0.18	-0.305	-0.149	-0.157	-0.162	-0.16
TSS	0.294	.763**	.843**	.826**	.805**	.803**	.655**	.801**	.813**	.804**	.827**
TDS	.488*	0.097	-0.098	-0.09	-0.093	-0.034	0.238	-0.092	-0.075	-0.092	-0.093
pH	0.163	0.091	0.008	0.035	0.015	0.029	0.095	0.008	0.023	0.027	0.03
Conductivity	.527*	0.202	0.003	-0.026	-0.036	0.035	0.305	-0.031	-0.004	-0.04	-0.028
Alkalinity	.597**	.777**	.696**	.651**	.653**	.704**	.753**	.661**	.680**	.641**	.652**
Ca	-0.164	-0.174	-0.161	-0.122	-0.142	-0.167	-0.207	-0.14	-0.148	-0.125	-0.124
Fe	-0.204	-0.204	-0.173	-0.137	-0.153	-0.181	-0.233	-0.153	-0.163	-0.139	-0.139
K	0.374	0.088	-0.08	-0.1	-0.119	-0.064	0.158	-0.115	-0.089	-0.117	-0.102
Mg	0.461	0.218	0.037	0.019	0.003	0.062	0.28	0.009	0.035	0.005	0.017
Na	.485*	0.19	0.003	-0.027	-0.039	0.028	0.278	-0.034	-0.006	-0.042	-0.028
Al	-0.114	-0.19	-0.187	-0.157	-0.17	-0.185	-0.184	-0.168	-0.176	-0.159	-0.159
COD	0.379	.841**	.779**	.680**	.703**	.740**	.643**	.736**	.749**	.684**	.684**
BOD	0.361	.815**	.748**	.645**	.669**	.707**	.613**	.704**	.717**	.649**	.649**

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

Source: Field data, Twumasi (2022)

4.8 Concentration of heavy metals in Fish samples from Muni Lagoon

Table 4.24 presents heavy metal concentrations in fish samples collected from the Muni Lagoon.

Table 4. 24: Concentration of heavy metals in fish samples from Muni Lagoon

Metal	Mean (mg/Kg)	Stand. Dev	Min	Max	limits	Reference
As	0.2314	0.5047	0.028	0.8	0.1	(FAO/WHO, 2002)
B	0.8740	0.3618	0.4851	1.5243	-	
Ba	2.4948	1.4813	0.2162	3.9501	-	
Cd	0.0028	0.0010	0.0022	0.0036	0.5	(FAO/WHO, 2002)
Co	0.0718	0.0348	0.0111	0.1011	1.0	(FAO/WHO, 2002)
Cr	0.4381	0.1899	0.2158	0.7762	0.15	(WHO, 2008)
Cu	0.5830	0.2372	0.2992	0.8412	30	(FAO/WHO, 2002)
Mn	9.8071	14.3321	0.2633	36.1139	2.5	(FAO/WHO, 2002)
Hg	ND	ND	ND	ND	0.5	(FAO/WHO, 2002)
Ni	0.1848	0.0661	0.1073	0.2635	0.4	(FAO/WHO, 2009)
Pb	0.0428	0.0117	0.0258	0.0592	0.5	(FAO/WHO, 2009)
Se	0.5134	0.5568	0.1728	1.6439	-	
Zn	4.3402	3.2862	9.5892	17.707	40	(FAO/WHO, 2009)

Source: Field data, Twumasi (2022)

Table 4.24 shows that the mean Arsenic (As), Boron (B), and Barium (Ba) values measured in fish samples collected from Muni Lagoon ranged from 0.028 to 0.8 mg/Kg, 0.4851 to 1.5243 mg/Kg, and 0.2162 to 3.9501 mg/Kg, respectively. Their means were 0.2314 ± 0.5047 mg/Kg for As, 0.8740 ± 0.3618 mg/Kg for B, and 2.4948 ± 1.4813 mg/Kg for Ba. The concentrations of Cd, Co, Cr, and Cu ranges were 0.0022 to 0.0036 mg/ Kg, 0.0111 to 0.1011 mg/ Kg, 0.2158 to 0.7762 mg/ Kg, and 0.2992 to 0.8412 mg/ Kg, respectively. The mean concentrations measured were 0.0028 ±0.0010 mg/Kg for Cd, 0.0718± 0.0348 mg/ Kg for Co, 0.4381 ± 0.1899 mg/Kg for Cr, and 0.5830 ± 0.2372 mg/ Kg for Cu. Again, the concentration ranges for heavy metals detected in fishes from Muni

Lagoon were 0.2633 to 36.1139 mg/ Kg for Mn, 0.1073 to 0.2635 mg/ Kg for Ni, 0.0258 to 0.0592 mg/ Kg for Pb, 0.17285 to 1.6439 mg/ Kg for Se, 7.2094 to 16.0012 mg/ Kg for Ti, and 9.5892 to 17.707 mg/ Kg for Zn. The means of the various heavy metals concentrations were 9.8071 ± 14.3321 mg/ Kg for Mn, 0.1848 ± 0.0661mg/ Kg for Ni, 0.0428 ± 0.0117mg/ Kg for Pb, 0.5134 ± 0.5568 mg/Kg for Se, 12.1846 ± 3.1735 mg/ Kg for Ti, and 4.3102± 3.2862 mg/ Kg for Zn. Among the heavy metals detected in fish samples from Muni lagoon, As, Mn, and Cr levels exceeded the permissible values described by FAO and WHO.

4.9 Bioaccumulation Factor (BAF) of heavy metals in Fish samples

The Bioaccumulation Factors were calculated after the examination of fish samples from Muni Lagoon. In Table 4.25, the results of such computations are presented.

Table 4. 25: Bioaccumulation Factor of heavy metals in fishes

Metal	C_{fish}	C_{water}	BAF
As	0.231	0.027	8.556
B	0.874	1.084	0.806
Ba	0.495	0.046	10.760
Cd	0.003	0.0001	30.00
Co	0.072	0.001	72.00
Cr	0.238	0.018	13.222
Cu	0.283	0.051	5.549
Mn	9.807	0.198	49.530
Ni	0.185	0.015	12.333
Se	0.513	0.065	7.892
Zn	4.340	0.281	15.445

Table 4.25 shows that the bioaccumulation factors of As, B, Ba, Cd, Co, Cr, and Cu were 8.556, 0.806, 10.760, 30.00, 72.00, 13.222, and 5.549, respectively. Also, the BAFs of Mn, Ni, Se, and Zn were 49.530, 12.333, 7.892, and 15.445, respectively. The element with the highest accumulation factor was Co, followed by Mn and then Cd. The decreasing order of heavy metal accumulation in fish is Co>Mn>Cd>Zn>Cr>Ni>Ba>As>Se>Cu>B.

4.10 Health risk assessment of heavy metals in fish

Health risk assessment of heavy metals through fish consumption was done using the estimations presented in Tables 4.26 and 4.27.

Table 4. 26: Estimated daily intake (EDI) of heavy metals through fish consumption

Parameter	Adult EDI	Child EDI	UTDI	Reference
As	0.000163	0.001522	0.13	FAO/WHO, 2009
Cd	1.97E-06	1.84E-05	0.06	FAO/WHO, 2009
Co	5.06E-05	0.000472	-	
Cr	0.000309	0.002881	0.2	FAO/WHO, 2009
Cu	0.000411	0.003833	10	FAO/WHO, 2009
Mn	0.012545	0.117088	11	FAO/WHO, 2009
Ni	0.00013	0.001215	1	FAO/WHO 2009
Pb	3.02E-05	0.000281	0.21	FDA, 2001
Se	0.000362	0.003376	-	
Zn	0.010103	0.094292	40	FDA, 2001

*UTDI=Upper Tolerable Daily Intake (mg/kg body weight/day)

Table 4.26 shows that the adult EDI values of As, Cd, Co, Cr, and Cu were 0.000163, 1.97E-06, 5.06E-05, 0.000309, and 0.000411 mg/kg body weight/day, respectively. Also, adult EDI values of Mn, Ni, Pb, Se, and Zn were 0.012545, 0.00013, 3.02E-05, 0.000362, and 0.010103 mg/kg body weight/day, respectively. Again, Table 4.26 shows that the children's EDI concentrations of As, Cd, Co, Cr, Cu, and Mn were 0.001522, 1.84E-05, 0.000472, 0.002881, 0.003833, and 0.117088 mg/kg body weight/day, respectively. Furthermore, children's EDI values of Ni, Pb, Se, and Zn were 0.001215, 0.000281, 0.003376, and 0.094292 mg/kg body weight/day, respectively. All the EDI values of heavy metals for adults and children were below their upper tolerable intake levels described by FAO and WHO.

Table 4. 27: Hazard quotient (HQ), Hazard Index (HI), and Cancer risk index (CRI) of heavy metals through fish consumption

Parameter	ADULT HQ	ADULT CRI	ADULT HI	CHILD HQ	CHILD CRI	CHILD HI
As	0.5434	0.000245		5.0717	0.00228	
Cd	0.0019	1.2E-08		0.0184	1.12E-07	
Co	0.1686	0		1.5736	0	
Cr	0.00021	1.27E-05	0.9352	0.0019	0.000118	8.7286
Cu	0.0102	0		0.0958	0	
Mn	0.0896	0		0.8363	0	
Ni	0.0065	1.09E-07		0.0607	1.02E-06	
Pb	0.0086	2.56E-07		0.0804	2.39E-06	
Se	0.0723	0		0.6751	0	
Zn	0.0336	0		0.3143	0	

Table 4.27 shows that the adult HQ values of As, Cd, Co, Cr, Cu, and Mn were 0.5434, 0.0019, 0.1686, 0.00021, 0.0102, and 0.0896, respectively. Also, HQ values of Ni, Pb, Se, and Zn were 0.0065, 0.0086, 0.0723, and 0.0336, respectively. In Table 4.27, the children HQ for As, Cd, Co, Cr, Cu, and Mn were 5.0717, 0.0184, 1.5736, 0.0019, 0.0958, and 0.8363, respectively. Also, the adult HQ of Ni, Pb, Se, and Zn were 0.0607, 0.0804, 0.6751, and 0.3143, respectively. Again, children HQ of As, Cd, Co, Cr, Cu, and Mn were 5.0717, 0.0184, 1.5736, 0.0019, 0.0958, and 0.8363, respectively. Furthermore, children's HQ values of Ni, Pb, Se, and Zn were 0.0607, 0.0804, 0.6751, and 0.3143, respectively. All the adult HQ values of heavy metals analysed were less than 1. Except for children's HQ values of As and Co, all the other children's HQ values for the rest of the heavy metals analysed were less than 1.

The hazard indices for adults and children, as shown in Table 4.27, were 0.9352 and 8.7286, respectively. Among these two values, the HI for adults was below 1, while that of children was above 1.

Table 4.27 shows that the adult CRI of As, Cd, Cr, Ni, and Pb were 0.000245, 1.2E-08, 1.27E-05, 1.09E-07 and 2.56E-07 respectively. Also, children's CRI of As, Cd, Cr, Ni, and Pb were 0.00228, 1.12E-07, 0.000118, 1.02E-06, and 2.39E-06. The CRI values were analysed for only heavy metals, which have cancer slope factors.

4.11 Concentration of pesticides in water, sediment, and fish samples from Muni Lagoon, Pratu and Ntakofa Rivers

The organochlorine pesticide concentrations in water, sediment, and fish samples from Muni Lagoon, Pratu, and Ntakofa Rivers were not detected. Also, organophosphate pesticide concentrations in water, sediment, and fish samples from Muni Lagoon and its tributaries were not detected. Among

the organophosphate parameters analysed, only Chlorpyrifos was detected in sediment samples collected from Ntakofa River and had a concentration of 0.002 ± 0.05 µg/L. In addition, pyrethroid pesticide residues were not detected in water, sediment, and fish samples taken from Muni Lagoon, Ntakofa River, and Pratu River.

4.12 Results of Social Survey

The results obtained from the social survey using a questionnaire (see Appendix G) have been presented in Table 4.34 and Table 4.35. The sociodemographic details of the respondents are shown in Table 4.34.

Table 4. 28: Demographic characteristics of respondents

Item	Frequency	Percentage (%)
Gender		
Male	235	61.2
Female	149	38.8
Age		
20-29	32	8.3
30-39	117	30.5
40-49	192	50
50-59	43	11.2
Education		
No formal education	29	7.6
JHS	84	21.9
SHS	145	37.8
Tertiary(HND/BA/BSc)	126	32.8

Table 4.34 shows that 235 (61.2%) respondents were males, while 149 (38.8%) respondents were females. The respondents, 32(8.3%), 117(30.5%), 192 (50.0%) were aged between 20-29, 30-39, 40-49, and 50-59, respectively. From Table 4.21, 29 (7.6%) of respondents did not receive a formal education, 84 (21.9%) had received Junior High School education, 145(37.8%) were SHS graduates, and 126(32.8%) were graduates from the tertiary institutions holding Higher National Diploma (HND) or first degree.

Table 4.35 presents the ecosystem services that are impacted by human activities in the Muni catchment area.

Table 4. 29: Ecosystem services that are influenced by human activities at Muni catchment area.

s/n	Statement	Mean	SD
E1	Rivers in the Muni catchment area are not used for drinking due to pollution.	4.54	0.73
E2	Wood fuel is scarce to get from the Muni catchment area.	4.49	0.76
E3	Most herbal plants are destroyed due to farming and deforestation.	4.66	0.88
E4	Deforestation is high and has resulted in timber loss in the Muni catchment area.	4.50	0.72
E5	Recreational and Tourism to the Ramsar site have reduced due to pollution	4.68	0.53
E6	Hunters hardly get bush meat from the forest in the Muni catchment area due to habitat loss	4.52	0.66
E7	Polluted water bodies are not used for irrigation	4.45	0.57

In Table 4.35, the respondents scored a mean of 4.54 (SD=0.73) to agree that rivers in the Muni catchment area are not used for drinking by residents due to pollution. They agreed that fuel wood is scarce (mean=4.49; SD=0.76) and that most herbal plants have been destroyed due to farming and deforestation (mean=4.50; SD=0.88). The respondents scored a mean of 4.50 (SD=0.72) and 4.68

(SD=0.53) to agree that high deforestation in the Muni catchment area has resulted in habitat loss and reduced recreational and tourism activities, respectively. Again, they scored a mean of 4.52(SD=0.66) and 4.45 (SD=0.57) to agree that hunters hardly get bush meat from the forest in the Muni catchment area and that polluted water bodies in the area were not used for irrigation.

The various human activities that impacted ecosystem services in the Muni catchment area are presented in Table 4.36

Table 4.30: Human Activities that Impact Ecosystem Services at the Muni catchment area

Strongly agree =5 Agree =4, undecided =3, Disagree = 2, strongly disagree =1

s/n	Statement	Mean	SD
	Wood collection /Burning charcoal		
W1	Firewood collected from the Muni catchment area degrades forest resources.	4.61	0.64
W2	Firewood is the main energy source for the cooking and smoking of fish by inhabitants near the Muni catchment area.	4.57	0.61
W3	Charcoal is a source of energy for cooking by the inhabitants in the catchment area	4.68	0.47
W4	Charcoal production occurs in the Muni catchment area	4.50	0.94
W5	Mangrove along the Muni lagoon has been depleted due to firewood collection	4.51	0.58
W6	Burning of charcoal has increased deforestation in the Muni catchment area	4.84	0.48
	Mean of means	4.62	0.62
	Agriculture activities		
A1	Fertilizer use is negatively affecting water and land resources.	4.64	0.48
A2	Pesticides used in farms contaminate water bodies in the area	4.84	0.41
A3	Poultry farms along the water bodies contaminate the rivers.	4.81	0.43
A4	Farmers in the area use excessive pesticides to control pests on their farms.	4.59	0.55

A5	Soil erosion has increased due to the destruction of vegetation cover	4.75	0.44
A6	Some fishermen in the Muni area are involved in bad fishing methods.	4.69	0.50
A7	Some farmers wash spraying machines at the banks of rivers	4.58	0.49
	Mean of means	4.70	0.47
	Industrial Activities		
I 1	Hospital waste is not discharged into any of the tributaries.	4.55	0.66
I2	Industrial waste discharged pollutes water bodies in the Muni catchment area	4.82	0.46
13	Salt mining pollutes Muni Lagoon	4.68	0.57
I4	Workshops built near water banks contaminate rivers	4.50	0.53
I5	Industrial wastewater is discharged into water bodies in the Muni Lagoon catchment area	4.68	0.50
I6	Industrial pollution of Muni Lagoon and its tributaries is increasing the heavy metal load in them.	4.59	0.49
	Mean of means	4.64	0.54
	Building and Encroachment		
B1	Encroachment has degraded part of the forest in the Muni catchment area.	4.67	0.50
B2	Building close to the lagoon has increased sand winning at the beach.	4.48	0.53
B3	Many animals have lost their habitat due to encroachment.	4.39	0.60
B4	Building close to river banks has enhanced flooding in my community	4.37	0.55
B5	Residents near rivers dump waste into them	4.49	0.66
B6	Domestic wastewater pollutes rivers in the area	4.37	0.64
	Mean of means	4.46	0.58

In Table 4.36 the respondents scored means of 4.61 (SD = 0.64), 4.57(SD = 0.61) and 4.68(SD = 0.47) to agree that firewood collection in the Muni catchment area has contributed to the degradation of forest resources, firewood is the main source of energy for cooking and smoking fish by inhabitants near Muni catchment area and charcoal is another source of energy used by inhabitants for cooking respectively. Again, they scored a mean of 4.50 (SD = 0.94) to agree that charcoal production occurs at the Muni catchment area. The respondents agreed that (mean = 4.51; SD = 0.58) mangrove along the Muni lagoon area has been depleted due to firewood collection. In addition, respondents agreed (mean =4.84; SD=0.58) that the burning of firewood has increased deforestation in the Muni catchment area.

In Table 4.36, respondents agreed (mean = 4.64; SD = 0.48) that fertilizer use is negatively affecting water and land resources in the study area. They scored means of 4.84 (SD = 0.41) and 4.81 (SD = 0.43) to agree that pesticides used in farms contaminate water bodies in the Muni catchment area, and poultry farms near the catchment area contaminate rivers in the area, respectively. Also, they agreed (mean = 4.59; SD = 0.55) that farmers in the Muni catchment area are assisted by agriculture extension officers on their farms. The respondents agreed (mean = 4.75; SD = 0.44) that soil erosion has increased in the area due to the destruction of vegetation cover, and also agreed (mean = 4.69; SD=0.50) that some fishermen in the study area engage in the bad fishing method. Some farmers wash spraying machines at the banks of rivers in the study area.

From Table 4.36, the respondents agreed (mean = 4.55; SD = 0.66) that some hospital discharges their waste into rivers and also agreed (mean = 4.82; SD = 0.46) that some industries discharge their waste effluent into rivers in the Muni catchment area. The respondents agreed (mean = 4.68; SD = 0.57) that salt mining pollutes the Muni lagoon. Also, they scored a mean of 4.59 (SD = 4.93) to agree that some factories have been sited near the tributaries of the Muni lagoon.

In Table 4.36, respondents agreed (mean = 4.68; SD = 0.57) that encroachment has degraded part of the forest in the muni catchment area and also agreed (mean = 4.48; SD = 0.53) that building close to the lagoon has increased sand-winning at the beach. They scored means of 4.38 (SD = 0.60), 4.37(SD = 0.55), and 4.85(SD = 0.66) to agree that many animals have lost their habitat due to encroachment, building close to river banks has enhanced flooding in my community, and that residents near rivers dump waste into rivers respectively. Again, the respondent agreed (mean = 4.37; SD = 0.64) that domestic wastewater pollutes rivers in the area.

4.12.1 Multiple Regression Analysis

Table 4.37 presents the model summary of the regression analysis conducted.

Table 4.31: Model Summary of the Regression Analysis

Model	R	R Squared	Adjusted R-squared	Std. error of the Estimate
1	0.362	0.131	0.127	0.29959
2	0.408	0.166	0.158	0.29419
3	0.468	0.219	0.207	0.28541

Table 4.37 shows that three models have been predicted to explain how the variations in the dependent variable can be explained by the independent variables. It shows that the R square for model one, model two, and model three were 0.131, 0.166, and 0.219, respectively. R-squared is the coefficient of determination. The highest R-squared was obtained for model three, and it suggests that model three is the best, followed by model two and model one. Also, it means that in model three, the variations in the dependent variable can be explained by 21.9 % of the independent variables. The coefficients of regression analysis for model three have been presented in Table 4.38.

Table 4.32: Coefficients of regression analysis

Model	Unstandardized Coefficients(B)	Standardized Coefficients (Beta)	t	Sig
3. Constant	0.286		0.476	0.634
Building/Encroachment	0.323	0.263	3.942	0.000
Firewood	0.282	0.256	3.778	0.000
Agriculture	0.323	0.239	3.647	0.000

Table 4.38 shows that the independent variables that significantly (P = 0.0000) contributed to the best model were building/encroachment, firewood collection, and agriculture activities. The standardized coefficient in Table 4.38 shows that the variable, building/encroachment (beta = 0.263), contributed highly to the model, followed by firewood collection (beta = 0.256) and agriculture activities (beta = 0.263).

CHAPTER FIVE
DISCUSSION

5.1 Physicochemical quality of Muni Lagoon and its tributaries

5.1.1 pH

Muni Lagoon recorded the highest mean pH value, followed by Pratu River, with Ntakofa River recording the lowest value. All the mean pH values recorded for Muni Lagoon and its tributaries were greater than a pH of 7 and hence were all alkaline during the period of study. The mean pH values for all the water bodies were within the GSA and WHO guideline range of 6.5 – 8.5. The results of the Tukey HDS test showed that there was no significant difference between the pH readings for the Ntakofa and Pratu Rivers. However, comparing the pH values of Muni against the two rivers, a significant difference was noted in both situations. It, therefore, indicates that Pratu and Ntakofa Rivers contribute to modifying the pH of Muni Lagoon when they empty their content into it since the communality for pH was 71%. The tolerance pH range for most aquatic organisms is between 6.5 –8.5 (WHO, 2018), suggesting that aquatic organisms are not affected by the pH of the three water bodies. The finding supports that of Ami and Tadi (2018), who also had the pH of Lake water to fall between 6.5 and 8.5. A pH below 4 or beyond 10 provides unfavourable living circumstances in aquatic systems (Ami & Tadi, 2018).

Among the two tributaries, the Pratu River is close to a paper mill factory, which discharges its waste effluent to contaminate the river with chemicals such as caustic soda (NaOH) and soap used when pulping waste. This might be the reason why a strong correlation was established between pH and sodium ions (r = 0.65) as well as magnesium ions (r = 0.60), since hydroxides of both ions are basic. According to a related study by Shokunbi and Omenka (2022), the sixth-largest industry polluting the environment and aquatic bodies is the pulp and paper industry, which is considered to be energy,

water, and resource demanding. In their study, they reported that waste effluent from the paper industry made the receiving water look like a black liquor, and the pH was alkaline, as was the case with the Pratu River in this study. However, Ntakofa River and Muni Lagoon were not dark. In addition, the pH of Muni Lagoon, Pratu, and Ntakofa Rivers might be influenced by waste discharge from the domestic area containing soap, as well as runoff that flows into the waterbodies and is alkaline.

5.1.2 Turbidity

The mean turbidity of the Pratu River was the highest among the three water bodies, followed by the Ntakofa River, with Muni Lagoon having the lowest value. The mean turbidity values of all three water bodies were higher than the WHO guideline value of 5 NTU (GSA, 2017; WHO, 2018). The study is in consonance with the findings of Shankar et al. (2021), who noted that the turbidity of industrial effluents was higher than the WHO (2018) standard limits of 5 NTU. It, therefore, indicates that light penetration through the Ntakofa River and Pratu River is very poor compared to Muni Lagoon. Poor light penetration means that most photosynthetic organisms in water will be deprived of light due to the presence of silt and suspended materials. Onyegeme-Okerenta et al. (2016) claimed in a study that increased turbidity hinders light penetration in water, limiting photosynthesis and the production of dissolved oxygen. Reduction in dissolved oxygen is likely to threaten fish and other aquatic life. According to Oboh and Agbala (2017), sediment, particularly silt and clay, coloured organic compounds, fine organic and inorganic materials, microscopic organisms, and algae are examples of particulate matter that increase water turbidity. The effluent discharge of the Nixin Paper Mill, which is located closer to the Pratu River, is the cause of the high turbidity of the river. The various stages of paper making (including raw material processing, pulping, pulp washing, washing, bleaching, and coating operations) release particulate materials and coloured compounds, which

largely constitute paper mill waste effluent (ShankarSingh & Tripathi, 2020). Another factor that might be influencing the turbidity of the Pratu River is the Casa de Ropa sweet potato factory, which discharges its wastewater into the Pratu River. Also, high turbidity in the Ntakofa River might be due to wastewater discharged from domestic areas and runoff from agricultural lands. A high turbidity value is an indication of poor water quality (Olumuyiwa et al., 2012).

5.1.3 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

The mean EC and TDS values obtained in this study were high in Muni Lagoon, followed by Pratu River, with Ntakofa River recording the lowest values. Apart from the Ntakofa River, EC values of Muni Lagoon and Pratu River were above the WHO (2018) permissible value of 1500 μS/cm. The TDS values of the three water bodies were higher than the WHO (2018) recommended value of 1000 mg/L. The high EC and TDS values of Muni Lagoon indicate the presence of more ions that have dissolved in water. The dissolutions of organic and inorganic salts containing sodium, potassium, calcium, magnesium, chloride, bicarbonates, and sulphates increase the EC and TDS values of water bodies. In a similar study, Jain and Agarwal (2012) asserted that the presence of high ionisable salts in water leads to higher electrical conductivity and TDS. In the Muni Lagoon, high EC and TDS might be due to its saline nature.

In addition, the two contaminated tributaries empty their ionic content into the lagoon and increase the conductivity and TDS of the Muni Lagoon. The high EC and TDS values of the Pratu River compared to the Ntakofa River might be due to the contamination of the river by industrial waste effluent from a paper mill. The Nixin paper mill situated close to the Pratu River uses a lot of water and discharges its waste effluent containing dissolved ions produced during the pulping and bleaching stages of production. Similarly, Salami and Sulemana (2021) and Zubaida (2021) reported on how

carelessly the Nixin Paper Mill discharges chemical waste into the adjoining rivers of Muni Lagoon. Again, runoff from agricultural lands and domestic areas dissolves a lot of ionic substances that end up in the water bodies in the Muni catchment area. The finding agrees with that conducted in Ethiopia, in which high values of electrical conductivity in water were detected and were attributed to soil type and geology of the study area, as well as waste effluents entering surrounding water sources (Gebresilasie et al., 2021). Principal component analysis conducted in this study revealed that EC had a strong, significant correlation ($p < 0.01$) with Magnesium ($r = 0.982$), sodium ($r = 0.993$), potassium ($r = 0.954$), sulphate (0.808), and chloride ($r = 0.884$) ions. It was also noted that TDS was strongly correlated with the conductivity of water bodies. The strong correlation and loadings indicate that ions have a common source of pollution. The three water bodies' electrical conductivity has generally increased as a result of human disturbances that have increased the amount of dissolved solids entering rivers. EC is important in water quality and helps to display the presence of dissolved ions and monitor salinity, which has a significant impact on water flavour. Rivers that have high EC values are not suitable for irrigation since the water can inhibit seed germination in plants and decrease agricultural yields (Kumar & Kumar, 2013). In terms of conductivity, the Ntakofa River is suitable for irrigation, but the Pratu River at the lower part of the Paper mill is not suitable for irrigation.

Weber-Scannell and Duffey (2007) attributed high TDS and EC values to human activities such as mining or agricultural activities. The salts that dissolve in the water bodies might include both inorganic salts and organic matter. Banunle et al. (2018) attributed high TDS to illegal mining and weathering of rocks. Similarly, Rameshkumar et al. (2019) recorded mean TDS values ranging from 230 ± 7.56 to 275.42 ± 12.77 mg/L and stated that urbanization, fertilization runoff (agricultural), and

domestic effluents influenced the EC and TDS of the water bodies. Rivers used for drinking may be unpleasant when TDS values are high. Also, High TDS may affect the aquatic organisms and influence water pH. In this study, TDS was strongly correlated with electrical conductivity ($r = 0.899$), potassium (0.856), Magnesium ($r = 0.890$), and sodium ($r = 0.869$). They were all significant at $p < 0.01$. The strong correlations between these variables indicate that they all work together to contribute to the high TDS of the water bodies in the research area. Increases in salinity, modifications to the water's ionic composition, and the toxicity of certain ions are all effects of total dissolved solids toxicity. It has been demonstrated that changes in biotic communities, biodiversity restrictions, the exclusion of less resistant species, and acute or chronic consequences at particular life stages are all caused by salt increases (Weber-Scannell et al., 2007).

5.1.4 Total Suspended Solids (TSS)

Total suspended solids are undissolved matter, including fibres, inorganic and organic fillers, pigments, and other particles that are present in water (Singh et al., 2020). In this study, the mean TSS value of River Pratu was higher than that of Muni Lagoon and River Ntakofa. Muni Lagoon recorded the lowest mean TSS value in the water. The high TSS value of the Pratu River might be due to the presence of charcoal particles, which have changed the colour of the Pratu River to black due to the discharge of black wastewater that contaminates the river, which finally ends up in the Muni lagoon to contaminate it. TSS of water bodies were influenced by runoff from farms and industrial areas, which carry pigments, fibres, clay, and sand particles that remain undissolved in water. TSS measures all suspended solids, which are either organic or inorganic materials (Rügner et al., 2013). Reduced photosynthesis by aquatic vegetation is caused by high TSS levels, which also harm benthic organisms and impede the biological treatment of water. The amount of oxygen is likely to be reduced if most of the suspended particles are organic. This agrees with the findings of

Naveedullah et al. (2016), who indicated that high TSS depletes dissolved oxygen (DO) by raising surface water temperature due to greater solar energy absorption by particulates. Pearson correlation revealed a moderate correlation between TSS and BOD (r=0.545) as well as TSS and COD (r=0.583) in this study. It means that both inorganic and organic particles influence the high TSS values in water. The high correlation is an indication that heavy metals were from a common source. Higher TSS levels in rivers and lagoons can negatively impact invertebrates and fish reproduction (Naveedullah et al., 2016). TSS values were directly related to turbidity. Contrary, a study conducted by Magadum et al. (2017) reported on lower TSS values for a river in India. The mean TSS values for Muni Lagoon and Ntakofa River were lower than 100 mg/L, but that of Pratu River exceeded 100 mg/L. In a similar study conducted in Ghana, Bessah et al. (2021) recorded TSS values of the river Pra to be more than 2000 mg/L (>2,000 mg/L). Although WHO and GSA have no guideline value for TSS, it is recommended to keep TSS values low (WHO 2006).

5.1.5 Alkalinity

The highest mean alkalinity value was recorded in Muni Lagoon (174.37 ± 16.17 mg/L), followed by Pratu River (152.64 ± 61.62 mg/L), with Ntakofa River (126 ± 46.83 mg/L) having the least mean value. The three water bodies mean alkalinity values recorded were below the WHO (2018) and GSA (2017) guideline values of 500 mg/L and therefore do not pose any challenge to fish species. Alkalinity measures a solution's ability to neutralise acids to the carbonate or bicarbonate equivalence point (Boyd, 2016). In other words, alkalinity gauges how well a body of water can balance out acids and bases to keep the pH somewhat steady. In this study, the Muni Lagoon has a higher capacity to neutralize any added acid or base than Pratu and Ntakofa Rivers. Omer (2019) asserts that water with strong buffering properties shields fish and other aquatic creatures from abrupt pH shifts and makes water less susceptible to acid rain. In a related investigation, the mean alkalinity value was 1057.14

± 499.52 mg/L, with ranges between 400 and 2000 mg/L (Apau et al., 2012). They added that Na^+ dominance is required for significant HCO_3^- alkalinity to occur. The presence of alkalinity in significant amounts impacts water quality by giving a bitter taste to water and can cause eye and skin irritation in humans (Buridi & Gedala, 2014). The Pearson correlation revealed a significant moderate correlation between BOD and COD. This means that high alkalinity in water is related to BOD and COD, and they are likely to have a common source of origin.

5.1.6 COD and BOD

Among the three water bodies, Pratu River recorded the highest COD and BOD values, followed by Muni Lagoon, with Ntakofa River being the least. Apart from the Pratu River, the COD of Muni Lagoon and Ntakofa River were below the WHO and GSA permissible value of 250 mg/L. It, therefore, suggests that the mean COD values of Muni Lagoon and Ntakofa River do not pose a risk to aquatic organisms since oxygen depletion in water might not be significant. The mean COD value of the Pratu River was higher than the WHO (2018) value of 250 mg/L.

The amount of dissolved oxygen required by aerobic living organisms in a given water sample at a particular temperature over a certain period is known as the biological oxygen demand (BOD) (Li & Liu, 2018). The BOD values of Ntakofa River and Muni Lagoon do not pose a threat to aquatic organisms since their mean BOD was less than the WHO (2018) guideline value of 50 mg/L. In the Pratu River, the high mean BOD is an indication that the water has been polluted with more organic pollutants (produced from pulping) and that a lot of aerobic activities are taking place in the river than in the two other water bodies.

The high COD and BOD of the Pratu River might be due to contamination from industrial effluent from the Nixin paper mill industry. In a similar study, it was found that Nixin Paper Mill carelessly discharges chemical waste into adjoining rivers of Muni Lagoon, which includes the Pratu River

(Zubaida, 2021). Also, Pokhrel and Viraraghavan (2004) asserted that effluent from a paper mill is characterized by a dark colour, foul odour, high organic content, and extreme levels of COD, BOD, and pH. Similarly, Singh and Tripathi (2020) asserted that high organic matter and suspended solid contents are major pollutants of pulp and paper industry effluents. Again, runoff from agricultural fields and domestic areas might increase pollution in water bodies in the Muni catchment area. COD is strongly correlated with alkalinity, TSS, and BOD. In addition, COD is correlated with most heavy metals like B, Ba, Cd, Co, Cr, Cu, Mn, Pb, and Zn. The finding revealed that both organic and inorganic pollutants have contributed to the high COD in the Pratu River and have a common source. COD determines the amount of oxidizer organic and inorganic matter in water (Alam, 2015). In a similar study, common interferences for COD, which cause it to be higher than BOD, were sulphides, sulphites, thiosulphates, and chlorides (Russell, 2019). High COD indicates that oxygen is much more depleted in the Pratu River than in the Muni Lagoon and Ntakofa River.

High BOD has been attributed to faecal contamination or increases in particulate and dissolved organic carbon from non-human and animal sources. High COD and BOD can restrict water use and development, necessitate expensive treatment of water, and impair ecosystem health. Aquatic organisms are likely to die in the Pratu River due to high depletion of oxygen in the river. BOD is strongly correlated with COD and TSS. This suggests that most of the organic pollutants in the Pratu River are in suspension. According to Ansah et al. (2011), the release of excessive amounts of organic matter into surface waters may cause a considerable reduction in oxygen levels, which will cause fish and other oxygen-dependent aquatic or marine creatures to perish.

5.1.7 Sulphates

The mean concentration of sulphate in Muni Lagoon was the highest among the three water bodies analysed. This was followed by the mean concentration of sulphate in the Pratu River, with the

Ntakofa River recording the lowest mean sulphate concentration. The high sulphate concentration in Muni Lagoon might be due to the intrusion of seawater into the lagoon. According to Prascal et al. (2006), magnesium sulphate ($MgSO_4$) is high in seawater, and this might be due to the dissolution of sulphate salts in water naturally. In addition, the discharge of domestic and Industrial waste also influenced the sulphate concentration in Muni Lagoon. In a similar study, Apau et al. (2012) found that the sulphate concentration of Kpeshi Lagoon ranged from 7820 to 16598 mg/L and attributed the cause of pollution to domestic wastewater that gets into the lagoon. The presence of high concentrations of sulphate in water can be attributed to detergents and soap water discharged into water bodies from nearby communities (Njoku et al., 2015). The Pearson product-moment correlation revealed that sulphate is strongly correlated with EC (r = 0.808), Chloride (r = 0.970), potassium (r = 0.798), magnesium(r = 0.792), and sodium(r = 0.784). In PC-2, sulphate is strongly correlated, and this indicates the fact that sulphate concentration in Pratu River, Ntakofa River, and Muni Lagoon is from a common source that can be attributed to human activities such as domestic waste discharges and industrial activities. In human beings, a small amount of sulphate causes a temporary laxative effect. Additionally, drinking water with a lot of sulphates may cause diarrhoea and other gastrointestinal issues (Agoro et al., 2018).

5.1.8 Chloride ions

The mean concentration of chloride ions in Muni Lagoon was the highest among the three water bodies, followed by Pratu River, with Ntakofa River recording the lowest value. All of the chloride ions found in the three water bodies exceeded the 250 mg/L WHO guideline limit. Muni Lagoon's increased chloride ion concentration can be ascribed to the lagoon's salinity because of the presence of sodium chloride. In addition, industrial effluents from the Nixin paper mill (bleaches used in paper

processing), runoff from agricultural fields as well as domestic areas (bleaches used in homes for cleaning) have contributed to the high chloride ion concentration of Muni Lagoon, Pratu, and Ntakofa Rivers. According to Shankar Singh and Tripathi (2020), bleaches used in paper mill industries increase the chloride ions in rivers and nearby water bodies. The result confirms what Afzal et al. reported (2008). They claimed that the direct release of effluents comprising bleach and black liquor into water bodies by the paper and pulp mill sectors is a major source of environmental problems.

Once more, there are numerous ways that chlorides can get into surface water, including through wastewater, agricultural runoff, and rocks that contain chlorides (Omer, 2019). Water will start to taste salty at concentrations above 250 mg/L, and if the level rises further, it will become objectionable and may be unsuitable for agricultural irrigation (Chigor et al., 2013). The potability of water would be severely harmed if the chloride concentrations were greater than 600 mg/L (Hosseinifard & Aminiyan, 2015). In this study, the potability of the Pratu River is severely harmed. Chloride (r = 0.867) was strongly correlated in principal component 2 (PC-2), which contributes to 28.15% of the variability in the analysis. It is strongly correlated with TDS(r = 0.992), EC(r = 0.884) potassium (r = 0.855), magnesium(r = 0.872), and sodium(r = 0.855).The high correlation of these values suggests that they have a common source of contamination. Human activities have elevated the values of all these parameters in water.

5.1.9 Nitrate and Nitrite

The nitrate and nitrite values were all below the WHO recommended limits of 50 mg/L and 3mg/L, respectively. Among the three water bodies, the Ntakofa River recorded the highest nitrate value, followed by the Pratu River, with Muni Lagoon being the least. The high nitrate value of the Ntakofa River might be due to intense agricultural activities that occur along the river. It was noted that vegetable farmers along the Ntakofa River use a lot of fertilizers. However, the concentration of

nitrate below the WHO guideline value suggests no potential risk of nitrate to the environment and the public. Although Muni Lagoon recorded the highest nitrite value, it was below the WHO guideline value and likely not to pose harm to the environment. In another study conducted in rural and agricultural areas, excessive nitrate in the soil and water bodies was attributed to fertilizer application (Sahoo et al., 2016). Also, agricultural activities and waste discharges from industries contribute to nitrate and nitrite levels in water bodies (Health Canada, 2021). The Pearson moment correlation revealed that Nitrate is strongly correlated to phosphate (r = 0.856) in the water bodies. It also suggests that both parameters have their source to be from agricultural activities (fertilizer application). High nitrates and phosphate values can cause an algal bloom in water bodies.

5.1.10 Phosphate

The mean phosphate concentration for the Ntakofa River was the highest among the three water bodies, followed by that of Muni Lagoon. The Pratu River recorded the lowest mean phosphate concentration. Apart from the Ntakofa River, the mean phosphate levels in Muni lagoon and Pratu River were below the permissible WHO limit of 0.5 mg/L. The higher phosphate concentration of the Ntakofa River might be due to intensive agricultural activities that occur along the river, as compared to the Pratu River and Muni Lagoon. In addition, Ntakofa passes through some of the communities in the Effutu municipality, so domestic waste discharge might have influenced the level of phosphate. Runoff from agricultural land (cropland and animal farms) and domestic areas carries varying amounts of phosphates into water bodies (Kumar & Puri, 2012) to influence water quality. Although phosphorus in the form of phosphate (PO_4^{-3}) is an important mineral for plants and makes up a large portion of most fertilizers, a large amount of phosphate in surface water can lead to eutrophication (Braga et al., 2022). In this study, Muni Lagoon and Pratu River may not experience

algal bloom due to low levels of phosphorus and Nitrates. However, the Ntakofa River is likely to experience an algal bloom. In this case, too much phosphate in the Ntakofa River will cause algae and aquatic plants to grow out of control, clog the canal, and use a lot of oxygen. Similarly, Braga et al. (2022) recorded phosphate concentrations that ranged from 1.26 to 4.85 mg/L and were above the WHO (2017) permissible value. Eutrophication is likely to occur in such water bodies. Except at extremely high concentrations or volumes, phosphorus in the environment, food, or water is not hazardous to humans or animals (Oladeji et al., 2016).

5.1.11 Calcium and Magnesium ions

The highest mean calcium concentration was recorded in the Pratu River, followed by Muni Lagoon, with River Ntakofa being the lowest. The high mean value of calcium in the Pratu River than the other water bodies can be attributed to the effluent from the Nixin paper recycling industry. According to Erkan and Engin's (2019), paper recycling process uses high amounts of calcium carbonate and so discharges water that contains high calcium ions. Hammes et al. (2003) reported that in the paper recycling industry, calcium carbonate ($CaCO_3$) is used to improve paper surface properties such as high whiteness and opacity.

Magnesium, just like calcium, is an important element that occurs naturally in rivers and lagoons (Kožíšek, 2003). In this study, magnesium concentration in Muni Lagoon was the highest, followed by Pratu River, with Ntakofa River recording the lowest value. Except for the Ntakofa River, the magnesium concentration exceeded the WHO guideline values of 200 mg/L. The use of magnesium sulphate in treating wastewater of paper mills, as well as domestic wastewater, might have contributed to the high magnesium ions in water (Shankar Singh & Tripathi, 2020). Similarly, Rapant (2017) asserted that anthropogenic contamination has increased the contents of Ca and Mg in water.

There is no health-based quantity for the consumption of Magnesium since scientists have not recorded any hazard related to magnesium toxicity (WHO, 2018).

The Muni Lagoon and Ntakofa Rivers also get contaminated by Ca and Mg ions because of runoff from the domestic areas and agricultural fields. Except for the Pratu River, all the calcium concentrations recorded were below the WHO guideline value of 200 mg/L. Calcium and magnesium are both essential elements for human health. However, at high levels in the water bodies, they cause water hardness. Magnesium also helps to protect against metabolic syndrome, stroke, diabetes, insulin resistance, hypertension, preeclampsia, and other chronic disorders (Tamboli et al., 2011).

5.1.12 Aluminium ions

The Pratu River had the highest level of aluminium ions, followed by Muni Lagoon and then the Ntakofa River. All the aluminium ion concentrations recorded in the three water bodies were above the WHO guideline value of 0.2 mg/L. In the case of the Pratu River, effluent discharge from the Nixin paper mill might have increased the aluminium level in the water body. Muni Lagoon and Ntakofa River are also polluted by runoff from agricultural land and sewage discharges. In a similar study, ShankarSingh and Tripathi (2020) asserted that the use of chemicals containing alum used in treating effluent from paper mills before discharging might have contributed to high aluminium discharge into water bodies. Also, wastewater from domestic areas containing dissolved aluminium compounds might have increased aluminium levels in the water. Alzheimer's disease, Parkinson's dementia, and amyotrophic lateral sclerosis are serious nervous system disorders that are linked to chronic aluminium poisoning in drinking water (Health Canada, 2008).

5.1.13 Iron

The highest mean iron concentration was recorded in the Pratu River, followed by the Ntakofa River, with Muni Lagoon recording the least. The high mean concentration of iron in the Pratu River might be due to the release of iron-containing wastewater into the river. It might also be due to the dissolution of iron-containing mineral rocks in the earth crust. In a similar study, Shankar Singh and Tripathi (2020) indicated that the use of chemicals like ferrous sulphate and ferric chloride, used in treating effluents from paper mills before discharging, contributes to high iron levels in water bodies like rivers and lakes. In addition, wastewater from domestic areas in the nearby communities has contributed to the high level of iron in water bodies in the Muni catchment area. Iron is required for the formation of myoglobin, haemoglobin, and a variety of enzymes, and its absence causes anaemia and a loss of well-being. However, in humans, it causes serious health problems such as diabetes, liver cancer, heart disease, liver cirrhosis, and infertility (Kumar et al., 2017).

5.1.14 Sodium and Potassium

Sodium and potassium ions are alkali metals that are essential to living organisms. At high levels, they can be detrimental to health. Both sodium and potassium ions were present in large quantities in the Muni Lagoon. The lowest sodium and potassium ion concentrations were recorded in the Ntakofa River. The potassium and sodium values in Muni Lagoon and Pratu River were higher than the WHO guideline values of 12 mg/L and 200 mg/L, respectively. In a similar study conducted in Kpeshi Lagoon, sodium and potassium ions were among the dominant ions in water (Apau et al., 2012). In this study, the high levels of potassium and sodium in water bodies can be attributed to runoff from agricultural fields and effluents from industrial activities. For instance, runoff from a commercial farm (Casa de Ropa Limited) situated close to the Pratu River increases potassium levels as well as other nutrients like nitrates and phosphorus. Also, the intrusion of seawater into the Muni Lagoon has contributed to the increased levels of sodium and potassium ions.

According to Atiqah et al. (2017), water becomes contaminated with sodium ions through the dissolution of mineral deposits, sewage effluents, saline intrusion, and salt used in road de-icing. In addition, effluent from the Nixin paper factory introduces a lot of sodium ions into the water body because of the high use of caustic soda in their operations. This study validates the conclusions of Salami and Sulemana (2021) and Zubaida (2021), who discovered that Nixin Paper Mill irresponsibly discharged chemical waste into the adjoining rivers of Muni Lagoon, which resulted in pollution of the lagoon and its tributaries. Similarly, Okyere et al. (2023) asserted that the use of agrochemicals by farmers around the Muni Lagoon catchment area has decreased the quality of water bodies in the area. The Pearson moment correlation coefficient revealed that sodium is strongly correlated with potassium (r = 0.951), Magnesium (0.979), iron (0.994), and calcium (0.972). This suggests that the various ions involved all have a common origin or source of pollution.

Potassium aids in the proper functioning of the human body by protecting the heart, regulating blood pressure, protein dissolution, muscle contraction, and nerve stimulus, among other things. Increased potassium exposure, on the other hand, can have serious health consequences in those who have renal illness or other disorders, including coronary artery disease, heart disease, diabetes, and hypertension, or who are taking medications that interfere with the body's normal potassium management (Arega, 2020). Also, excess intake of sodium leads to heart disease, high blood pressure, and stroke (Thompson et al., 2022).

5.1.15 Water Quality Indices

The water quality index of the Pratu River in Table 4.10 was 249.98. WQI of Pratu River was greater than 100 (WQI >100) and which suggests the water is unfit for drinking and requires treatment before use. The major parameters that influenced the high water quality index at the time of the study were noted to be turbidity, chloride ions, potassium ions, and sodium ions. Again, in Table 4.10, Muni

Lagoon and Ntakofa River had water quality indices of 71.612 and 66.05, respectively. The WQIs were within the class, which indicates poor water quality ($50 < WQI \leq 75$), and they can only be used for irrigation, but not for drinking. In these two water bodies, turbidity, potassium, and sodium were noted to influence the poor quality of water. In a similar study, WQI indicated poor water quality of the Oti River in Ghana (Duncan et al., 2019) and was attributed to anthropogenic activities like farming and illegal mining. In this study, anthropogenic activities like farming, domestic effluent, and industrial effluent discharges into water bodies have contributed to the poor water quality.

The findings suggest that the physicochemical quality of water bodies in the Muni catchment area has been impaired by anthropogenic activities, and conditions have departed from natural or desirable levels. Also, the quality of water bodies in these WQI classes may not be suitable for domestic use and sustainably support aquatic organisms (Miyittah et al., 2020). Similar to Muni Lagoon and rivers in the catchment area, Aby Lagoon was noted to be poor in quality, and Miyittah et al. (2020) concluded that lagoon pollution was largely due to anthropogenic inputs of domestic waste and sediments transported from upstream in the Tano River.

5.2 Heavy metals in water samples from Muni lagoon and its tributaries

The highest mean concentration of arsenic (As) was recorded in Muni Lagoon, followed by Pratu River, with Ntakofa recording the lowest value. Except for the Ntakofa River, the other two water bodies (Muni Lagoon and Pratu River) in the Muni catchment area recorded As values that were greater than the WHO (2018) permissible value of 0.01 mg/L, which suggests that As can cause potential health effects to people. In the Muni Lagoon, high As concentration is likely to make fish unsafe for consumption. Similarly, Shanker (2019) reported that drinking water with high levels of arsenic has a negative impact on public health. The study also supports the findings of Kone et al.

(2019), who reported high As concentrations in surface water samples and which ranged from 0.009 to 53.508 mg/L. They noted that some of the water samples had As values more than the WHO permissible limit. According to Yunus et al. (2011), high As levels in water may lead to heart failure, chromosomal abnormalities, diabetes mellitus, cirrhosis, goitre, hypertension (high blood pressure), peripheral neuropathy, gangrene, myocardial degeneration, liver enlargement, and skin malignancies are some of the health effects of arsenic intake. Furthermore, places where water has been contaminated with arsenic have been linked to increased foetal loss and neonatal fatalities (Sohel et al., 2010).

Arsenic (As) is a naturally occurring element in the crust of the earth and can be found in water, soil, air, and rocks (Singh et al., 2015). The detection of arsenic in water is of environmental concern because of the detrimental effect it can have on humans, plants, and animals (Ahmad & Bhattacharya, 2019). In this study, high levels of arsenic in water might be due to the release of waste effluent from the Nixin paper mill industry, effluents from nearby damp sites in some of the communities (like Akosua village), as well as runoff from agricultural lands close to the Pratu River. Also noted sources of arsenic release into the environment include mining, smelting iron ores, cement manufacture, pulp and paper production, fuel burning, and waste disposal (Adeloju et al., 2021).

The mean barium (Ba) concentrations recorded for Muni Lagoon and Ntakofa River were below the WHO (2018) guideline value. It, therefore, suggests that Ba concentrations in these water bodies are not causing any adverse health effects to people. On the other hand, the mean Ba concentration in the Pratu River exceeded the WHO (2018) limit of 0.7 mg/L. The high level of barium in the Pratu River might be due to the discharge of waste effluent from the paper industry. According to Verbruggen et al. (2020), barium is used as a pigment and as a loader for paper, soap, and rubber. Also, compounds such as barium carbonate, barium chloride, and barium hydroxide are useful raw materials in paper

manufacturing and sugar refining (USEPA, 2005). Barium can be introduced into the Pratu River because of domestic waste effluents as well as agricultural runoff. Similarly, Anim et al. (2011) stated that heavy metals are introduced into water bodies by anthropogenic activities, primarily from industrial and domestic wastewater emissions. High levels of Ba in water can pose health effects to consumers. Oral exposure to soluble barium salts has been reported to cause gastroenteritis, hypokalemia, severe hypertension, cardiac arrhythmia, skeletal muscular paralysis, and death (USEPA, 2005).

Cadmium (Cd) ions were not detected in water samples of the Ntakofa River, but were detected in Muni Lagoon and Pratu River. The mean Cd concentration in Muni Lagoon was below the WHO permissible value of 0.003mg/L, while that of Pratu River exceeded this value. It, therefore, suggests that Cd will not pose a health threat to people using water from the Muni Lagoon and Ntakofa River. Contrary, Cd in the Pratu River can pose a health threat to people. The release of waste effluent from the Nixin paper mill industry is responsible for the elevated Cd levels. Also, runoff from agricultural land like Casa de Ropa situated close to the river can influence the Cd levels. In a related study, Tripathy et al. (2022) reported that industrial discharges from the paper mill industry and agricultural lands were the cause of heavy metal pollution. Sharma et al. (2021) further stated that to ensure the safety of human and animal health, pulp paper industry sludge has to be properly treated and heavy metals removed before being released into the environment. When food crops are irrigated with contaminated water, metals can build up in the plants, which can then bioaccumulate and biomagnify in the food chain, posing a threat to human health. The results of the study are consistent with those of Cobbina et al. (2015), who found greater cadmium concentrations in water samples from the Nangodi River, ranging from 0.001 to 2.227 mg/L with a mean of 0.534 ± 0.088 mg/L. The kidney appears to be the most vulnerable organ to persistent oral exposure to cadmium. Cadmium interferes

with the proximal tubules' resorption function, causing tubular proteinuria, or an increase in the urine excretion of low-molecular-weight proteins. Long-term exposure to cadmium-contaminated drinking water can result in chronic anaemia. The accumulation of Cd in the kidney occurs under these conditions, leading to cancer and cardiovascular disease (Burke et al., 2016).

Cobalt (Co) and copper (Cu) were detected in water samples of Muni Lagoon and its two tributaries, but were all detected below their respective WHO (2018) values. This is an indication that Co and Cu do not pose any adverse health effects to consumers. Similar results were found by Ansah et al. (2018) in the Weija reservoir in Accra, where Cu readings ranged from non-detection to 0.32 mg/L with a mean value of 0.02 mg/L, which was lower than the WHO (2018) allowed value of 2 mg/L.

At the time of the study, the levels of Cr, Ni, and Pb in water samples from the Ntakofa River and Muni Lagoon were below their respective WHO values and did not constitute a serious threat to human health. Contrarily, the Pratu River recorded greater Cr, Ni, and Pb values that exceeded their permissible levels. Chromium, Nickel, and Lead are very toxic metals, and their presence in water bodies is a health concern. Cr (VI) has been identified by the International Agency for Research on Cancer as being human carcinogenic (IARC, 2012). According to Tumolo et al. (2020), Cr is extremely toxic and can harm the liver and kidneys as well as induce internal bleeding and respiratory issues. Ni exposure can also cause allergies, cardiovascular and kidney disease, lung fibrosis, and nose cancer, among other health issues (Genchi et al., 2020).

Again, Pb exposure causes a variety of health issues, including kidney disease, hypertension, cancer, cardiovascular disease, and poor reproductive consequences (Rauh & Margolis, 2016; Chowdhury, 2018). In this study, the presence of high levels of Cr, Ni, and Pb concentration in Pratu River can be

attributed to the release of waste effluent from the Nixin paper mill industry during chemical pulping and bleaching stages of production, as well as runoff from agricultural land like Casa de Ropa, a commercial farm situated close to the river. In a similar study, Sharma et al. (2021) and Chandra et al. (2012) reported that effluent from Pulp paper mills contains high content of chlorinated compounds, chlorolignins, chlorinated hydrocarbons, acids, phenolics, surfactants, biocides, plasticizers, waxes, fatty acids, heavy metals, and other complex organic and inorganic compounds. Also, effluent from waste disposal sites in nearby communities is a possible source of these metals in water. In a similar study, sources of Ni pollution, like other heavy metals, came from industrial and municipal waste effluent discharges into water bodies as well as agricultural activities due to excessive use of fertilizers and pesticides (Genchi et al., 2020).

The mean concentrations of Se, Sr, and Zn in water samples from Ntakofa River, Muni Lagoon, and Pratu River were below their respective permissible WHO (2018) values except for the mean Se value in Muni Lagoon. The high value of Se in Muni Lagoon poses a threat to public health. Even the fact that metals such as Cr, Ni, Pb, Sr, and Zn are in low concentrations does not invalidate their tendency to bioaccumulate in the food web. Selenium in high quantities exceeding the typical permissible limit can cause acute and chronic selenium toxicity. Acute exposure can of Se causes neurotoxicity, whereas long-term exposure can alter endocrine activities such as thyroid hormone production (Vinceti et al., 2014). Also, selenium can cause health problems such as prostate cancer, hepatic cancer, neurological or dermatological illnesses, hair loss, faulty skin and nails, and genotoxicity (DNA mutilation) (Santos et al., 2015).

Selenium, just like most metal elements in the earth, can dissolve in water bodies when conditions are favourable. The presence of Se, Sr, and Zn in Muni Lagoon and its tributaries can be attributed to effluent discharge from waste disposal sites near the lagoon in the nearby communities, runoff

from agricultural fields and domestic areas, as well as industrial activities. In a similar study, selenium contamination, like other heavy metals, has been attributed to a variety of human activities, including farming and industrialisation (Das et al., 2017).

Boron (B) and Manganese (Mn) were detected in the Muni Lagoon and its tributaries. The levels of B and Mn in the Pratu River were greater than their respective WHO (2018) and GSA (2017) guideline values. In contrast, the concentrations of B and Mn in Muni Lagoon and Ntakofa River were less than their recommended values. The high values of B and Mn in the Pratu River pose a threat to people who depend on the water. These metals are toxic and can be absorbed by plants when the water is used for irrigation, and so they can enter the food chain, which can affect human beings. High values of B and Mn might be due to the release of waste effluent from a paper mill industry, as well as from runoff from agricultural fields due to excessive use of fertilizers in nearby farms. In a similar study, the value of Mn was 53.17 ± 0.28 mg/L and was due to the direct release of wastewater from the paper mill industry (Sharma et al., 2022). Also, manganese compounds can be found in fertilisers and ceramic glazes (ATSDR, 2012). Again, pesticides and agricultural fertilisers have all used boric acid, borates, and perborates (Kabu & Akosman, 2013).

Mercury in water was below the detection limit in Muni Lagoon, Ntakofa, and Pratu Rivers. This suggests that Hg is likely not to cause any adverse health effects among the people in the Muni catchment area. When ingested, inorganic mercury salts can harm the kidneys and are damaging to the skin, eyes, and digestive system (Skalny et al., 2022).

Boron is a trace element found in minute levels in the human body, but is essential for its correct functioning. Dried fruits, avocados, nuts, and legumes are the finest sources of boron (1.0–4.5 mg/100 g) (Parks & Edwards, 2005). Pesticides and agricultural fertilisers have used boric acid, borates, and

perborates (Kabu & Akosman, 2013) that contaminate rivers and lagoons with B. Similarly to this, a study by Asante et al. (2007) found significant levels of manganese and arsenic in surface water and groundwater resources in the Tarkwa Nsuaem Municipality.

5.2.1 Heavy metal pollution index (HPI)

The heavy metal pollution index is a method used to assess the level of heavy metal content in water. Based on several factors, the term "indexing" refers to the general quality of water (Prasad & Bose, 2001). In this study, the HPI for Ntakofa River was 6.899, while that of Muni Lagoon was noted to be 51.85. These two values are below the critical value of 100, suggesting that Ntakofa River and Muni Lagoon have low levels of heavy metals and pose no adverse health effects. Contrary, the HPI value of Pratu River was more than 100, indicating that the river is unsuitable for consumption and cannot be used for drinking (Saleh et al., 2019; Mativenga & Marnewick, 2018; Tiwari et al., 2015). The high concentration of heavy metals in the Pratu River, which is above the recommended limit, confirms the effects of nearby human activities like the Nixin paper mill factory. According to Sharma et al. (2022), effluents from pulp and paper mill sectors contain a lot of heavy metals that are often seen in black liquor.

5.3 Heavy Metals in Sediments

Arsenic (As) and Cadmium (Cd) concentrations in sediment samples were higher in the Pratu River than those recorded in Muni Lagoon and Ntakofa River. Arsenic and Cadmium levels in all sediment samples from the three water bodies were below the WHO (2011) guideline values of 20 mg/ Kg and 3 mg/Kg, respectively. The high levels of As and Cd in sediment samples from the Pratu River can be attributed to effluent discharges from the paper industry, runoff from domestic areas (including those from waste disposal sites), and agricultural fields. Among the most carcinogenic metals with no nutritional value for plants or animals are As and Cd (Amadi et al., 2012). Since high levels of

As and Cd can contaminate plants and phytoplankton eaten by fish, which can enter the food chain and bioaccumulate even in small amounts, they constitute a health risk to humans. Additionally, metal buildup in grazers' feed has the potential to cause bioaccumulation and biomagnification of metals in the food chain, which can negatively impact human health (Tripathy et al., 2022).

Boron (B) concentration in sediment samples of Muni Lagoon was the highest among the three water bodies. Boron concentrations in sediment samples from Pratu River, Muni Lagoon, and Ntakofa River were below the WHO guideline value of 300 mg/Kg. In this study, the low levels of boron in sediment samples indicate the natural occurrence of boron in the earth crust. In addition, B in Muni Lagoon can be influenced by the intrusion of seawater into the lagoon. According to Kabay et al. (2010), boron is widely distributed in rocks, soil, and water, so a low boron concentration in soil indicates its natural occurrence. However, anthropogenic activities are increasing the amounts of numerous heavy metals, including boron, in aquatic environments (Xu et al., 2022; Okey-Wokeh et al., 2023). The main way that humans are exposed to boron is through oral consumption of food and water. In this study, the low boron concentrations of sediment samples might not cause significant adverse health effects to consumers.

The Co, Cu, Ni, and Se levels in sediment samples were much higher in the Pratu River than in both Muni Lagoon and Ntakofa River. The sediment samples from Muni Lagoon recorded the lowest concentrations of Co, Cu, Ni, and Se. The higher values of all these heavy metals in the Pratu River than in the other rivers might be due to the release of industrial effluent discharge (Paper mill wastewater) and runoff from agricultural fields, which carry soil particles contaminated with fertilizers and pesticides. However, all the copper values measured in the current study were found below the WHO guideline value of 100 mg/Kg. In a similar study conducted in the Sakumo II lagoon, levels of copper in sediment samples varied significantly from 28.29 mg/Kg – 101.27 mg/ Kg

(Doamekpor et al., 2018). They attributed high Cu values in some of the locations to intense domestic and industrial influences. Furthermore, in research by Huang et al. (2020), Ni and Co contents in river silt were 36.29 mg kg1 and 16.97 mg kg1, respectively. They explained the presence of heavy metals in river sediment as the result of mine effluent being released.

In flowing rivers, pollutants, including heavy metals, are adsorbed by suspended sediments, which get deposited onto the river bed. Such pollutants that accumulate in river bed silt have long-lasting effects on the biocommunity through the food chain (Afum & Owusu, 2016). Since sediments have been defined as a sink for pollutants in water, the high amounts of heavy metals found in the river sediment relative to those in the water are therefore not surprising (Afum & Owusu, 2016). For instance, selenium can collect in the top layer of sediment over time due to deposition or sedimentation (particulate settling), or it can remain in a free solution if dissolved. Organisms in the aquatic system are dynamic by nature, and they are continually searching for nourishment in the sediment. Selenium can be transported and absorbed into biota from sediment and stored at high concentrations for lengthy periods. Aquatic species can acquire selenium even if selenium is no longer present in the water (bioaccumulation of selenium) (Okonji et al., 2021). This implies that the existence of low-concentration selenium does not invalidate organic selenium's tendency to bioaccumulate in the food web; it is thus unquestionably an environmental concern.

Sediment samples from the Ntakofa River recorded the highest lead (Pb) concentration, followed by those from the Pratu River. Muni Lagoon recorded the lowest sediment concentration. All the Pb values recorded in the three water bodies were below the WHO permissible limit of 10 mg/Kg. Lead is carcinogenic, and when present in the food chain, even in small quantities is deleterious to human beings since it can bioaccumulate. In this study, surface runoff from urban and rural regions, river

bank runoff, and wastewater discharge from home sources could all contribute to lead pollution. Heavy metals such as As, Cd, Ni, Pb, and Zn are present in large concentrations in fertilizers used in agricultural activities (Tang et al., 2010). Lead exposure has been linked to a variety of health issues, including cancer, cardiovascular disease, hypertension, kidney disease, and poor reproductive consequences (Rauh & Margolis, 2016; Chowdhury et al., 2018).

Sediment samples from the Pratu River had higher quantities of Ba, Cr, Mn, and Zn than those from the Ntakofa River and the Muni Lagoon. The sediment concentrations of Ba and Zn were below their WHO guideline value of 300 mg/Kg. This indicates that Ba and Zn are less likely to cause adverse health effects to consumers. Except for the Pratu River, Cr and Mn concentrations in sediment samples from Muni Lagoon and Ntakofa River were below the WHO guideline values of 100 mg/Kg and 200 mg/Kg, respectively. However, concentrations of Cr and Mn in the Pratu River exceeded their WHO values. The low values of these metals in Muni Lagoon and Ntakofa River suggest that anthropogenic activities releasing heavy metals into the environment are minimal. On the other hand, the presence of the paper mill industry, which directly discharges waste effluent into the Pratu River, has increased its heavy metal levels. In another study, Sharma et al. (2021) found that waste effluent from paper mills contains heavy metals like Mn, Pb, Zn, Cu, Cr, Ni, and As, which were all noted to be above their prescribed environmentally acceptable parameters. In addition, heavy metals in sediment samples can be attributed to runoff from agricultural fields due to the heavy use of fertilizers and pesticides by farmers in the area and discharge of wastewater from domestic areas, since major drainages from the nearby communities empty their content into the tributaries of Muni Lagoon.

When metals are very high in the sediments of rivers, they can dissolve in surface water and increase their levels. Heavy metals in sediments can contaminate phytoplankton and other aquatic foods.

When this happens, metals, therefore, enter the food chain and bioaccumulate to pose a health threat to human beings.

Sediment samples from Ntakofa recorded the highest Hg values, followed by Pratu River, with Muni lagoon obtaining the lowest value. Although Hg in sediment from all three waterbodies was below the WHO limit of 2 mg/Kg, it can bioaccumulate in the food chain and cause harm. Hg enters the aquatic environment through dry and wet atmospheric depositions, riverine runoff, erosion of contaminated soils, and direct discharge (Acquavita et al., 2021).

Similarly, Sharma et al. (2021) argued that numerous heavy metals build up in water and sediments, thereby causing carcinogenicity and oxidative stress in human and fish health through the food chain. Manoj et al. (2020) opined that cadmium (Cd), Copper (Cu), zinc (Zn), chromium (Cr), and lead (Pb) are some of the hazardous heavy metals that are considered priority contaminants. Similarly, Doamekpor et al. (2018) attributed the higher levels of heavy metals in Chemu Lagoon to intense domestic and industrial influence may be attributed to urbanization.

In general, it was noted that heavy metal levels in sediment and water samples from the Pratu River were relatively higher than those of Muni Lagoon and Ntakofa River. High levels of pollutants like heavy metals in sediment samples indicate significant anthropogenic metal loadings. Polluted sediments may act as a metal puddle, releasing metals into the water below and posing a serious threat to riverine ecosystems (Reda & Ayu, 2016). In this study, it was noted that sediment samples from the Muni lagoon had lower levels of heavy metals than Pratu River and the Ntakofa River. It is important to monitor and regulate human activities along these water bodies to reduce pollution to the barest minimum.

5.3.1 Geo-accumulation Index of Heavy Metal

The average Igeo value for heavy metal contamination in sediment samples from the Pratu River was in the index class of 5 ($4 \leq Igeo \leq 5$), which denotes moderately to severely polluted. The increasing order of heavy metals that greatly influenced the mean Igeo value of sediment from Pratu River was: Hg<B<Pb<Zn< Cd<Cu<Se<As<Cr<Ni<Ba<Co<Mn. The individual Igeo values of heavy metals in sediment from Pratu River show that boron was within the uncontaminated to moderately contaminated class ($0 \leq Igeo \leq 1$) while Pb was moderately polluted ($1 \leq Igeo \leq 2$). The rest of the metals (Zn, Cd, Cu, Se, As, Cr, Ni, Ba, Co, Mn) were all heavily contaminated in the River Pratu sediment.

Also, the mean Igeo value of heavy metals in sediment samples from Ntakofa River was within index class 4 ($3 \leq Igeo \leq 4$), indicating heavily contaminated or polluted. The increasing order of heavy metals pollution in sediment samples from Ntakofa River based on their Igeo values was: B<As<Hg<Pb<Zn<Cu<Cr<Cd<Se<Ni<Ba<Co<Mn. From Table 4.16, Igeo values of B were below zero (negative value) and were uncontaminated. As was uncontaminated to moderately contaminated, Pb, Zn, Cu were moderately contaminated, Cr was heavily contaminated, with Cd, Se, Ni, Ba, Co, and Mn being either heavily polluted or extremely polluted.

Once more, the average Igeo value for heavy metals in sediment samples from Muni Lagoon fell into index class 2 ($1 \leq Igeo \leq 2$), indicating moderately contaminated sediment samples. The increasing order of heavy metals pollution in sediment samples from Muni Lagoon based on their Igeo values was: Hg<Cd<Pb<Zn<As<Cu<B<Mn<Se<Cr<Ni<Co<Ba. From Table 4.16, Cd was below zero (negative value) and was uncontaminated, Pb and Zn were uncontaminated to moderately contaminated, As, Cu, and B were moderately contaminated, Mn, Se, Ni, and Cr were moderate to heavily contaminated ($2 < Igeo \leq 3$), with Co and Ba being heavily contaminated. In a related study,

Jiao et al. (2018) found that the sediments of the Pearl River have moderate levels of Cr, Co, Ni, Pb, and Cu contamination and strong levels of Zn and Cd contamination. Again, Radomirovic et al. (2020) reported that soil samples under study had moderate levels of Cr, Cd, Ni, and Hg pollution, while As contamination ranged from mild to severe. The I-geo value for Cd in Awodua, Heman, and Ankobra in a related study carried out in Ghana was within the moderately to extremely polluted range, indicating anthropogenic influences (Asare et al., 2019). According to Asare et al. (2019), human activities like mining and agriculture were the cause of the elevated amounts of heavy metals in the Ankobra River, which was consistent with Mwashote's study (2003).

In this study, the high contamination of sediment with heavy metals suggests that human activities such as agriculture (due to fertilizer and pesticide application) and industrial activities have greatly introduced toxic heavy metals into the Muni Lagoon and its tributaries. In addition, the tributaries were also influenced by domestic wastewater since both rivers pass through places inhabited by people. However, the buildup of pollutants in the river bed silt can have long-lasting effects on the bio-community via the food chain.

5.4 Variations of physicochemical and heavy metals in water and sediment samples from Muni Lagoon and its tributaries

The variations in physicochemical and heavy metal parameters were collectively explained by the first six (6) principal components (PC), accounting for 93.89 percent of the variance. The variabilities of PC-1, PC-2, PC-3, PC-4, PC-5 and PC-6 were 39.28%, 28.15%, 13.86%, 5.25%, 4.39% and 2.96% respectively. The heavy metals that were strongly loaded for PC-1 were Ba, B, Co, Cd, Cu, Cr, Mn, Pb, Ni, and Zn. The physicochemical parameter that was loaded for PC-1 was TSS. Also, alkalinity, BOD, and COD were moderately loaded for PC-1. Among the heavy metals analysed in sediment samples, only Cd was strongly loaded, and those that were weakly loaded include Ba, Co, Cr, Mn,

and Zn. The high loadings of heavy metals and physicochemical parameters indicated that they have a common source of origin. In this study, domestic and industrial waste discharge and agricultural activities (such as the application of fertilizer and pesticides) were the sources of pollution in water bodies. Probably, effluent discharge from a paper mill is the dominating source of heavy metal pollution of water and sediment samples in PC-1. The metals are the source of pollution, and this is confirmed by the strong correlation between heavy metal parameters. In a similar study, Asare et al. (2019) asserted that high correlations between soil heavy metals are an indication of a common source of contamination. In Pearson's correlation analysis in Tables 18 and 19, the heavy metals reported in this study were significantly positively correlated and supporting that they have the same origin (Huang et al., 2020).

In PC-2, nitrate, phosphate, As, B, Cu, Ni, Pb, and Se had strong negative loadings in sediment samples. Mercury was, however, weakly loaded in sediment. Also, parameters such as sulphates, chlorides, TDS, conductivity, K, Mg, and Na had strong positive loadings. In PC-2, most of the parameters that had strong positive loadings were physicochemical parameters, with a few sediment heavy metals having strong negative loadings. The negative and positive loadings reflect the mixed sources (Anthropogenic and natural sources) of pollution that influence both the physicochemical and heavy metals quality of Muni Lagoon and its tributaries. However, the influence of anthropogenic sources is far greater than natural sources. In this study, industrial effluent from the Nixin paper mill, runoff from agricultural fields, domestic waste discharges, as well as leachates from nearby dump sites along the rivers were noted to contaminate water bodies in the Muni Lagoon catchment area. This finding is in line with that reported by Okyere et al. (2023). In addition, natural sources, due to the weathering of rocks, might have contributed to the levels of heavy metals in sediment samples recorded in this study. The low level of Hg in sediment samples from all three water bodies below

the WHO permissible limit of 2.0 mg/Kg might be from natural sources due to weathering of rocks. It also suggests that mining activities are absent in the Muni catchment area. This hypothesis is supported by Huang et al. (2020), Chen et al. (2018), and Apau et al. (2022).

In PC-3, PC-4, and PC-6, there were no loadings for heavy metals in water. PC-5 had strong positive loadings for As and Se, and weak loadings for alkalinity, as well as moderate negative loadings for nitrite. The strong loadings suggest that As and Se have a common origin of pollution in water, which is from anthropogenic sources. Industrial waste discharge from the Nixin paper mill industry and agricultural activities due to the use of fertilizers and pesticides are the major causes of heavy metal pollution in the current study. Nitrite had weak and moderate loadings for PC-3 and PC-5, respectively, and this suggests that nitrite had mixed sources of pollution, which might be from agricultural activities and natural sources. Chazelas et al. (2022) asserted that apart from agricultural and industrial sources, nitrates and nitrites are present naturally in soil and water. PC-4 and PC-6 had strongly positive loadings for pH, COD, and BOD. It had moderate loadings for conductivity and alkalinity. The source of pollution of these metals is anthropogenic sources. Again, PC-4 had strong negative loadings for Ca, Fe, and Al. It, therefore, suggests that apart from anthropogenic sources of pollution, some parameters, such as Ca, Fe, and Al, had natural sources of contamination since they are present in the earth's crust. The principal component analysis conducted in this study has verified significant anthropogenic and natural contributions to the levels of physicochemical and heavy metals sources in water bodies in the Muni Lagoon and its tributaries. The finding is similar to that reported by Chen et al. (2018) and Apau et al. (2022). In another study, Yang et al. (2020) asserted that potential sources of heavy metals in water and sediments were anthropogenic activities due to domestic sewage and industrial wastewater discharged.

The Pearson product-moment correlation was conducted to assess whether the physicochemical and heavy metal pollution within the water bodies were from the same origin. In Tables 4.20, 4.21, 4.22, and 4.23, most of the physicochemical parameters and heavy metals were strongly correlated. Some of them were either significant at $p < 0.01$ or $p < 0.05$. The high positive correlation confirms that heavy metal contamination in this study was from the same source. It also suggests that since the pollutants are from the same origin increase in one parameter increases the level of the other parameter in the water bodies. The main source of pollution is due to anthropogenic activities like waste effluent from the paper mill industry near the Pratu River, runoff from agricultural fields due to the use of fertilizer and pesticides, as well as wastewater discharged from domestic areas. Similarly, parameters that were negatively correlated indicate that they have a different source of origin. In this study, the alternative source of origin is natural sources due to weathering of rocks and other minerals in the earth crust. It can also be attributed to the deposition of these substances from the atmosphere. Similarly, Dey et al. (2021) reported on the deposition of nitrates and lead compounds into rivers from the atmosphere.

Mixed sources of pollution are confirmed by the existence of both positive and negative correlation values in the Pearson correlation matrix of Principal Component Analysis (PCA) in this study. For example, nitrate contamination of river and lagoon water can occur directly due to the discharge of nitrate-containing fertilizers, weathering of nitrate-containing rocks, and atmospheric deposition of nitrogen-containing chemicals originating from automobiles. This finding supports the study conducted by Dey et al. (2021) and Apau et al. (2022). Similarly, Akter et al. (2019) reported that the sources of soil contamination were both natural and anthropogenic origins.

5.5 Pesticide residues in the Muni lagoon and its tributaries

Organochlorine pesticides in water and sediment samples from Muni Lagoon, Pratu River, and Ntakofa Rivers were not detected. Also, Organophosphorus and Pyrethroid pesticides in water and sediment samples were not detected. In addition, pesticides were not detected in fish samples. The only organophosphorus that was detected in Ntakofa River sediment samples was chlorpyrifos, and the concentration was less than the US/EU and WHO (2018) minimum residual level. The non-detection of chlorpyrifos in water and the detection in the sediment below an acceptable level indicate that chlorpyrifos is likely not to cause adverse health effects to people. In contrast to this study, Ávila-Díaz et al. (2021) found that Chlorpyrifos concentrations in water and sediment surpassed quality criteria, representing a hazard to environmental and human health. According to Johanif et al. (2021), chlorpyrifos in river sediment can bioaccumulate in fish and other aquatic species.

In this study, pesticides were below detection levels, suggesting that farmers in the Muni Lagoon catchment area use pesticides in their right proportion. Also, farmers in the Muni catchment area do not use organochlorine pesticides since they were not detected, although they are persistent in the environment. However, the presence of chlorpyrifos in sediment samples can be attributed to soil particles carried into the Ntakofa River due to agricultural activities. In another study, Akoto et al. (2016) attributed the presence of pesticide residues in the Tono reservoir to high farming activities with increased volumes of runoff from the agricultural activities along the river banks.

5.6 Heavy metals and pesticide residual levels in fish in Muni lagoon.

Pesticide residues in fish collected from Muni Lagoon for analysis were below the detection limit. However, heavy metals were detected in fish sampled from Muni Lagoon. Only boron had a BAF value less than one (BAF<1), and it indicated low boron accumulation in fish. All the BAF values of the other heavy metals exceeded one and indicated possible accumulation of these heavy metals in

the fish collected from Muni Lagoon. Accumulation of Co, Mn, Cd, Zn, Cr, Ni, and Ba in fish is likely to pose a significant health risk to consumers. According to Feng et al. (2020), a BAF value exceeding one indicates probable bioaccumulation of heavy metals from water, but not significant unless the BAF exceeds 100. Also, Arnot and Gobas (2006) asserted that the BioConcentration Factor (BCF) values for 'bioaccumulative' and 'very bioaccumulative' are 1000–5000 and 5000, respectively. It therefore suggests that residence in the study area can consume fish from the Muni Lagoon. However, the BAF values of heavy metals suggest that the various heavy metals can reach levels that can cause serious health risks to consumers if measures are not put in place to protect the lagoon from pollution.

The presence of heavy metals like Mn in fish found in Muni Lagoon can be attributed to their consumption of food particles that have been contaminated with heavy metals in the water and sediments. Anthropogenic sources such as industrial discharges and runoff from agricultural fields are the source of Mn and other heavy metals in water bodies (ATSDR, 2012). In a similar study, a high level of Mn was attributed to natural geochemical processes such as weathering of Mn bearing minerals and rocks (Momade &Tay, 2006). In addition, wastewater discharged from refuse dump sites and wastewater from domestic areas that get into the lagoon might have increased the Mn levels. Another source might be the inflow of Pratu and Ntakofa Rivers into the lagoon, since they recorded high levels of Mn in both water and sediment samples. This finding is in line with that reported by Okyere et al. (2023). They mentioned that the manganese level in Muni Lagoon is influenced by the feed rivers (Ntakofa and Pratu Rivers). The consumption of water and food contaminated with Mn by fish has elevated Mn levels in them.

Human exposure to high Mn levels can lead to its accumulation in the pancreas, liver, kidneys, bones, and brain. Mitochondrial dysfunction, Oxidative stress, endoplasmic reticulum stress (ER), misfolded protein, autophagy dysregulation, and other metal homeostasis disorders are some of the molecular pathways of Mn toxicity (Kim et al., 2002). Manganism is a sickness that occurs when Mn accumulates in the brain's basal ganglia area and causes symptoms similar to Parkinson's disease (Shakoor et al., 2018). Nerve damage in the cortex and subcortical brain, particularly the basal ganglia, causes manganism (Rawson et al., 2017; Agustina et al., 2020).

The high levels of As and Cr in fish samples might be due to the high levels of the metals in Muni Lagoon. The As and Cr levels in Muni lagoon exceeded the FAO/WHO (2002) guideline value of 0.1 mg/Kg and the WHO (2008) 0.15 mg/kg, respectively. Both As and Cr are introduced into the environment through natural and man-made processes (Saha & Rahman, 2020). Agriculture, livestock, and industrial activities are anthropogenic sources of As and Cr in water bodies. In a similar study, Adeloju et al.(2021) asserted that mining, smelting iron ores, pulp and paper production, fuel combustion, cement production, and waste disposal are all known sources of arsenic release into the environment (Adeloju et al., 2021).

Cancer risks are among the negative impacts of inorganic arsenic exposure on people. Again, human exposure to a high level of As causes skin illnesses such as melanosis (hyperpigmentation), hyperkeratosis, leuco-melanosis, and keratosis are among the typical side effects of drinking arsenic contaminated water (Tchounwou et al., 2019). In addition, chromosomal abnormalities, heart failure, cirrhosis, gangrene, diabetes mellitus, goitre, hypertension (high blood pressure), myocardial degeneration, liver enlargement, skin malignancies, and peripheral neuropathy are also health effects of arsenic intake (Yunus et al, 2011).

The presence of Cr, like other heavy metals, even at low concentrations in fish, can bioaccumulate in humans over prolonged and continuous exposure. Chromium exposure to humans can harm the eyes, immune system, respiratory system, skin, and blood (Zhang et al., 2014; Tumolo et al., 2020). On a cellular level, the genotoxic effects of chromium produce oxidative stress, DNA damage, and other damage that can result in the development of tumors (Wise et al., 2019). Cr (VI) is the most poisonous type, causing damage to the liver and kidneys, as well as internal bleeding and respiratory problems. It is considered to be human carcinogenic by the International Agency for Research on Cancer (IARC, 2012; Tumolo et al., 2020).

Furthermore, Cd, Cu, Co, Pb, and Zn were detected in *Sarotherodon melanotheron (*black chin tilapia) *and Tilapia guineensis*, the two main fish species in Muni lagoon. The concentrations of Cd, Cu, Co, Pb, and Zn were below their guideline values and so may not pose a significant health threat to consumers. However, these heavy metals are toxic and can enter the food chain through fish consumption, bioaccumulate in humans, and threaten public health. In a similar study, Okyere et al. (2023) noted that cadmium, manganese, lead, and zinc were below FAO/WHO guideline values in fish samples, but noted that the Mn level in water was higher than the WHO permissible value. The differences in Mn values and other heavy metals in fish samples between the two studies can be attributed to the fact that sediment chemistry is likely to vary due to differences in inundation periods (Dankwa et al., 2004).

In contrast to the findings of Okyere et al. (2023), in this study, manganese was higher above the FAO/WHO permitted level in fish samples. Okyere et al. (2023) did not assess levels of Cr and As in their study, but in this study, levels of Cr and As were higher in fish samples. The presence of all these heavy metals in water, sediment, and fish samples is due to anthropogenic activities like agricultural activities due to the use of fertilizers and pesticides in vegetable farming, industrial waste

discharge from the paper mill industry, and domestic waste discharged into water bodies. This research confirms the findings of Tay et al. (2009), who found that the central site in Muni lagoon had a higher concentration of heavy metals than the northern and southern sites. Heavy metals recorded in Muni Lagoon were lower than those reported in Fosu Lagoon (Eshun, 2011). Eshun (2011) also detected heavy metals in fish samples caught from the Fosu Lagoon located in the same ecological zone as the Muni Lagoon. Similar to this study, Momade and Tay (2006) attributed the presence of Mn and As in the Muni Lagoon to natural geochemical processes such as the weathering of Mn and Cr bearing minerals and rocks. In addition, Mn has been used as a fuel additive for motor vehicles, which are normally used along the coast for commercial or recreational activities, and this could contribute to its presence. Other sources, such as refuse dump sites and dust from the atmosphere, cannot be overlooked for their contribution to the Mn levels.

Mercury was not detected in fish samples from Muni Lagoon. This finding contrasts with that reported by Nyantakyi et al. (2021), who detected Hg in fish samples collected from the Tano River. In their study, Hg exceeded the FAO/WHO (2002) limits of 0.5 mg/kg in fish.

5.7 Human health risks associated with the dietary intake of fish in terms of heavy metals and pesticide pollution.

Health risks associated with pesticide residues were not calculated because they were not detected in fish samples. Therefore, the health risk assessment done in this study was for only heavy metals.

5.7.1 Estimated Dietary Intake (EDI) of heavy metals in fish samples from Muni Lagoon

The adults estimated dietary intake (EDI) of heavy metals presented in Table 4.26 was in the order Mn>Zn>Cu>Se>Cr>As >Ni>Co>Pb>Cd. Also, children's EDI of the heavy metals analysed were in the order Mn>Zn>Cu>Se>Cr>As>Ni>Co>Pb>Cd. All the EDI values of heavy metals were below their respective upper tolerable consumption intake described by FAO/WHO (2009). The ingestion

of heavy metals by fish through the intake of aquatic foods in Muni lagoon was the primary exposure path instead of inhalation and direct dermal contact. In a similar study, Hossain et al. (2022) reported that ingestion of heavy metals through fish consumption in the study area for adults and children was below the recommended daily allowance. Therefore, EDI values lower than the upper tolerable daily intake indicated no significant health effect for the targeted population (adults and children) in the Muni Lagoon catchment area.

5.7.2 Non-carcinogenic risk

In this study, all the adult HQ values of heavy metals were below 1 (HQ < 1), and this suggests that heavy metals in fish samples are unlikely to cause non-carcinogenic health effects in the adult population. Also, apart from the children's HQ values of As and Co, which were greater than 1, the other HQ values of heavy metals were less than 1. It, therefore, suggests that As and Co are likely to cause non-carcinogenic effects in children in the study area. The HQ values for both adult and children population decreases in the order: As>Co>Mn>Se>Zn>Cu>Pb>Ni>Cd>Cr.

The overall non-carcinogenic effect was predicted by the hazard index. The HI for the adult population was less than 1(HI = 0.93521<1), and this indicates no adverse non-carcinogenic health risk to the adult population through consumption of fish from Muni Lagoon. The HI for the children population was greater than 1 and which suggests a possible non-carcinogenic effect of fish in the children population. Non-carcinogenic effect in children was highly influenced by As and Co. The risk of non-carcinogenic effects was higher in children than in adults.

5.7.3 Carcinogenic risk (CRI)

The adult cancer risk index for Cd, Cr, Ni, and Pb was less than 1x 10^{-4}. Also, children's cancer risk for Cd, Ni, and Pb was noted to be less than 1x 10^{-4}. The only element likely to pose a carcinogenic risk to the adult population was As, while As and Cr were noted to pose carcinogenic effects in the

children population since their CRI values were greater than 1x 10^{-4}. This also suggests that children are more susceptible to cancer risk than adults. CRI value above 10^{-4} is unacceptable (USEPA, 2012; Baki et al., 2018). In a related study, Gyimah et al. (2018) discovered that people may have cancer risk effects by consuming Cr from any of the fish species from the Barekese reservoir, with adults being at a higher risk.

Pesticide pollution in this study was not detected in fish and water bodies. Only chlorpyrifos was detected in the sediment sample collected from the Ntakofa River, and its concentration was less than the WHO guideline value. In this study, pesticide residues do not pose a health threat to people through fish consumption.

5.8 Impact of anthropogenic activities on provisioning ecosystem services

The respondents agreed that wood collection/ burning of charcoal, agricultural activities, industrial activities, and building/encroachment were the main anthropogenic activities that have affected the provisioning of ecosystem services in the Muni Lagoon catchment area. The various services that have been negatively impacted include the inability of residents to use the Pratu and Ntakofa Rivers as a source of drinking water due to pollution from agricultural, domestic, and industrial areas. At the time of the study, the lower part of the Pratu River, after the Nixin paper mill, was not used for irrigation, while the upper part, before the paper mill, was used for irrigation. Analysis conducted revealed that the lower part of the Pratu River in Effutu Municipality was unsuitable for drinking and irrigation. The Ntakofa River was noted to be suitable for irrigation but not for drinking in the Effutu municipality. It is therefore important for appropriate regulatory bodies such Environmental Protection Agency (EPA) and the Water Resource Commission to ensure that industrial effluents do not pollute our water bodies. In a similar study, Sanchez et al. (2015) reported that industrialization and agriculture impacted negatively on stream and river environments. The findings of Sabater et al.

(2016) support the findings of this study. They reported that human settlement activities in watersheds result in pollution from land development, including the building of infrastructure, as well as contamination from human sewage. The use of contaminated rivers for irrigation can pose a health threat to the public and the environment.

Also, respondents indicated that polluted water bodies affected the ability of the water bodies to support aquatic life. Some of the residents in an interview mentioned cases where some fish were seen dead on the surface of the water, especially at the estuary of Muni Lagoon and the Pratu River. This can be attributed to the high pollution of the Pratu River. Fishes in heavy metal-polluted water are vulnerable and susceptible to toxicological problems due to their feeding habits and location in water environments (Morshdy et al., 2019). If measures are not taken by regulatory institutions to stop the pollution of water in the Muni catchment area, fish in the area will become unsuitable for human consumption.

The respondents indicated that the increased collection of firewood for cooking, smoking of fish, and burning charcoal in the Muni catchment area has depleted forest resources. The indiscriminate wood collection has also depleted Mangrove trees in Akosua Village and other parts of the lagoon. Carbon sequestration by Mangrove plants and trees has therefore been reduced due to forest loss. Other ecosystem services that have been influenced by human activities in the Muni Lagoon catchment area include the loss of herbal plants and a reduction in bush meat. The livelihood of residents who depend on herbal plants and those who are hunters has been affected, and this was confirmed by some residents in an interview. Some participants who usually collect medicinal plants indicated in an interview that they no longer get access to some herbal plants that were found in the Muni catchment area. This finding supports that of Amponsah-Tawiah and Dartey-Baah (2011), who opine that some

residents nowadays have to travel far distances to obtain herbal plants that were previously found in their village.

In addition, agricultural activities have resulted in water pollution and forest destruction. The respondents agreed that increased soil erosion in the study area was mainly due to vegetation and forest destruction. Vegetation destruction and soil erosion were also enhanced by encroachment and the building of houses close to the Muni Lagoon and its tributaries. Increased erosion has resulted in river and lagoon sedimentation in the study area. According to Tundu et al. (2018), sedimentation continues to be one of the most important threats to river ecosystems around the world. Sediment deposition reduces the storage capacity and life span of reservoirs as well as river flows (Eroglu et al., 2010). Excessive sedimentation of river and lagoon beds can significantly alter and degrade habitats by killing invertebrates, which are an important food source for fish. This finding is in line with that reported by Tundu et al. (2018). Also, forest destruction and habitat loss in the Muni catchment area can affect the hunting grounds where the people of Winneba go for deer hunts to celebrate the Aboakyere festival. Forest destruction has destroyed the beauty of the Muni Ramsar site and has caused a decline in tourism as well.

The regression analysis conducted revealed that Building/Encroachment, Firewood collection, and Agricultural activities were the main human activities that significantly impacted the provisioning of ecosystem services in the Muni Lagoon catchment area. It is therefore important for the Wildlife Division, EPA, Water Resource Commission, Municipal assembly, and chiefs to ensure that environmental regulations are properly implemented to enhance sustainable development.

CHAPTER SIX
CONCLUSION AND RECOMMENDATION

6.1 Conclusion

6.1.1 Physicochemical Quality of Muni Lagoon and Its Tributaries

Most of the physicochemical parameters were above the WHO (2018) and GSA (2017) permissible values in Muni Lagoon and its tributaries. The weighted arithmetic Water Quality Index (WQI) of Pratu River was 249.98. WQI of Pratu River was greater than 100 (WQI >100) and which suggests that the water is unfit for drinking and irrigation purposes. Muni Lagoon and Ntakofa River had water quality indices of 71.612 and 66.05, respectively. These WQIs were within the class, which indicates poor water quality ($50 < WQI \leq 75$). In the case of the Ntakofa River, although it is not good for drinking, it can, however, be used for irrigation purposes. The water quality index in Muni Lagoon and its tributaries was highly influenced by turbidity, chloride, potassium, sodium, and calcium. Principal component analysis shows strong loadings and correlations for most of the physicochemical parameters, and it indicates a common source of pollution. Anthropogenic activities such as agriculture, industrial effluent discharge, and waste discharges from domestic areas were the main sources of pollution for Muni Lagoon and its tributaries.

6.1.2 Heavy Metals in water samples from Muni lagoon and its Tributaries

Arsenic in water exceeded the WHO (2018) permissible value of 0.01 mg/L and can cause potential health effects to people and bioaccumulate in the food chain. Barium (Ba) in Muni Lagoon and Ntakofa River was below the WHO limit and likely not to pose a health risk. Cadmium levels in Muni Lagoon and Ntakofa River are low and likely not to pose a health threat to people using the water resources.

Cobalt (Co) and copper (Cu) were below their respective WHO (2018) values in Muni Lagoon and its two tributaries, and so they are likely not to pose any adverse health effects to consumers.

The concentrations of Cr, Ni, and Pb in water samples of Muni Lagoon and Ntakofa River at the time of the study were below their respective WHO values and do not pose a significant health risk to people who use the water bodies. On the other hand, the Pratu River recorded higher values of Cr, Ni, and Pb, which were above their recommended values. Chromium, Nickel, and Lead are very toxic metals, and their presence in water bodies is a health concern since they can contaminate fish and other aquatic organisms, thereby posing a health risk to consumers. The mean concentrations of Se, Sr, and Zn in water samples from Ntakofa River, Muni Lagoon, and Pratu River were below their respective permissible WHO (2018) values except for the mean Se value in Muni Lagoon. Hence, only Se can pose a public health risk, but not Sr and Zn. Heavy metal contamination of water bodies in the Muni catchment area can get worse if measures are not put in place to control pollution sources.

The Heavy metal pollution index (HPI) for Ntakofa River was 6.899, while that of Muni Lagoon was noted to be 51.85. These two values were below the critical value of 100, suggesting that the Ntakofa River and Muni Lagoon have low levels of heavy metals and pose no adverse health effects. Contrarily, the HPI value of the Pratu River was more than 100 and which indicates that the river is unsuitable for consumption and cannot be used for drinking due to heavy metal contamination.

6.1.3 Heavy metals in sediment samples from Muni lagoon and its tributaries

The sediment samples from Muni Lagoon recorded the lowest concentrations of Co, Cu, Ni, and Se. The higher values of all these heavy metals in the Pratu River than in the other sediment samples are due to the discharge of industrial waste effluent (Paper mill wastewater) and runoff from agricultural fields, which carry soil particles contaminated with heavy metals due to fertilizers and pesticide use. Among the three sediment samples, those collected from Pratu River were heavily to extremely contaminated or polluted with heavy metals ($4 \leq Igeo \leq 5$), followed by Ntakofa River (heavily

contaminated or polluted) and then Muni Lagoon (moderately contaminated). The ecological risk of heavy metal contamination in sediment samples is low. However, heavy metals in sediment can contaminate aquatic food particles or remobilize into surface water at low pH to pose a health risk to people.

The principal components analysis (PCA) showed high loadings for heavy metals in sediment samples. The high loading and high correlation of sediment heavy metals suggest a common source of origin. In this study, the source of pollution in water bodies was linked to anthropogenic activities such as industrial and agricultural activities (fertilizer and pesticide applications) as well as domestic waste discharge into water bodies. There were negative loadings for some heavy metal parameters also. The negative and positive loadings reflect the mixed sources of pollution that influence both the physicochemical and heavy metals quality of Muni Lagoon and its tributaries. It, therefore, suggests that apart from anthropogenic sources of heavy metal pollution, natural sources due to weathering of rocks might have contributed to the levels of heavy metals in sediment samples recorded in this study.

6.1.4 Pesticide residues in the muni lagoon and its tributaries

Organochlorine, Organophosphorus, and Pyrethroid pesticides do not pose any health risk to residents who depend on Muni Lagoon and its tributaries since they were not detected in water, sediment, and fish samples. In general, the non-detection of organophosphorus and pyrethroids suggests that farmers in the area use the right proportions of pesticides during their applications.

6.1.5 Human health risks associated with dietary intake of fish in terms of heavy metals and pesticide pollution.

Human health risk assessments done in this study were for only heavy metals since pesticides were not detected in fish samples. Fish in the Muni Lagoon have been contaminated with low amounts of heavy metals, and the EDI values of heavy metals were below their respective upper tolerable consumption intake described by FAO/WHO (2009). The ingestion of heavy metals by fish through the intake of aquatic foods in Muni Lagoon was the primary exposure path instead of inhalation and direct dermal contact.

The HQ and HI values indicate that heavy metals in fish are likely not to pose a non-carcinogenic health risk in the adult population in the study area. Contrary, the children population is at risk of non-carcinogenic effects through the consumption of fish from Muni Lagoon since the HI value was greater than one. Non-carcinogenic effect in children was highly influenced by As and Co. The risk of non-carcinogenic effects was higher in children than in adults. Also, among the adult population, only As was likely to pose carcinogenic effects, while both As and Cr were noted to pose carcinogenic effects in the children population.

6.1.6 Impact of anthropogenic activities on provisioning ecosystem services

Human activities have negatively impacted ecosystem services provisioning in the Muni catchment area. Mainly due to encroachment/building, wood collection, agricultural, and industrial activities.

6.2 Recommendation

- The Effutu Municipal EPA authorities should implement stricter regulations and monitoring of agricultural runoff, sewage discharge, and industrial effluents entering these water bodies.

- The Effutu Municipal EPA and Wildlife Division authorities should control point and non-point sources of heavy metal pollution, such as industrial discharge and improper waste disposal.
- The EPA authorities in Effutu Municipality should periodically monitor pesticide residues in water, sediment, and fish to detect emerging contamination trends early.
- EPA authorities should conduct regular biomonitoring of fish species to track heavy metal and pesticide accumulation over time. Also, heavy metal pollution sources can be mitigated through improved waste management.
- The Effutu Municipal Assembly and EPA officers should control pollution sources by strengthening environmental monitoring and regulation enforcement.
- The Effutu Municipal EPA and Wildlife Division authorities should enforce land-use regulations and zoning laws to prevent further encroachment and unauthorized construction in ecologically sensitive areas.
- Environmental protection agencies should include ICT technologies in tracking and protecting environmental resources within the Muni catchment area and in Ghana as a whole.

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APPENDICES

APPENDIX A

ANOVA RESULTS FOR PHYSICOCHEMICAL PARAMETERS

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Sulphate	Between Groups	2114723.566	2	1057361.783	30.484	.000
	Within Groups	520282.831	15	34685.522		
	Total	2635006.397	17			
Choride	Between Groups	126897679.104	2	63448839.552	39.356	.000
	Within Groups	24182365.261	15	1612157.684		
	Total	151080044.366	17			
Nitrate	Between Groups	18.541	2	9.270	14.787	.000
	Within Groups	9.404	15	.627		
	Total	27.944	17			
Nitrite	Between Groups	.138	2	.069	8.656	.003
	Within Groups	.119	15	.008		
	Total	.257	17			
Phosphate	Between Groups	3.695	2	1.847	27.967	.000
	Within Groups	.991	15	.066		
	Total	4.686	17			
TSS	Between Groups	2260636.574	2	1130318.287	1.961	.175
	Within Groups	8645975.255	15	576398.350		
	Total	10906611.829	17			
TDS	Between Groups	452818497.444	2	226409248.722	53.307	.000
	Within Groups	63708782.833	15	4247252.189		

	Total	516527280.278	17			
pH	Between Groups	1.300	2	.650	6.814	.008
	Within Groups	1.431	15	.095		
	Total	2.730	17			
Turbidity	Between Groups	74709.000	2	37354.500	3.800	.046
	Within Groups	147469.000	15	9831.267		
	Total	222178.000	17			
conductivity	Between Groups	1072493183.444	2	536246591.722	47.661	.000
	Within Groups	168768803.500	15	11251253.567		
	Total	1241261986.944	17			
Alkalinity	Between Groups	6771.056	2	3385.528	.380	.691
	Within Groups	133808.305	15	8920.554		
	Total	140579.360	17			
Ca	Between Groups	1673771.739	2	836885.870	4.320	.033
	Within Groups	2905610.131	15	193707.342		
	Total	4579381.870	17			
Fe	Between Groups	789.850	2	394.925	2.616	.106
	Within Groups	2264.084	15	150.939		
	Total	3053.934	17			
K	Between Groups	42449.283	2	21224.642	42.515	.000
	Within Groups	7488.382	15	499.225		
	Total	49937.665	17			
Mg	Between Groups	372940.771	2	186470.386	76.866	.000
	Within Groups	36388.793	15	2425.920		
	Total	409329.564	17			
Na	Between Groups	27166491.242	2	13583245.621	40.979	.000
	Within Groups	4971989.619	15	331465.975		

	Total	32138480.861	17			
Al	Between Groups	343.629	2	171.814	2.291	.135
	Within Groups	1125.095	15	75.006		
	Total	1468.724	17			
COD	Between Groups	2480513.569	2	1240256.784	4.661	.027
	Within Groups	3990965.821	15	266064.388		
	Total	6471479.389	17			
BOD	Between Groups	1090763.008	2	545381.504	4.540	.029
	Within Groups	1801757.070	15	120117.138		
	Total	2892520.077	17			

APPENDIX B

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Sample Id	(J) Sample Id	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Sulphate	Muni	Ntakofa	805.3666667*	107.5260001	.000	526.071080	1084.662253
		Pratu	608.1566667*	107.5260001	.000	328.861080	887.452253
	Ntakofa	Muni	-805.3666667*	107.5260001	.000	-1084.662253	-526.071080
		Pratu	-197.2100000	107.5260001	.192	-476.505587	82.085587
	Pratu	Muni	-608.1566667*	107.5260001	.000	-887.452253	-328.861080
		Ntakofa	197.2100000	107.5260001	.192	-82.085587	476.505587
Choride	Muni	Ntakofa	6463.24500*	733.06609	.000	4559.1276	8367.3624
		Pratu	3859.53000*	733.06609	.000	1955.4126	5763.6474
	Ntakofa	Muni	-6463.24500*	733.06609	.000	-8367.3624	-4559.1276
		Pratu	-2603.71500*	733.06609	.008	-4507.8324	-699.5976
	Pratu	Muni	-3859.53000*	733.06609	.000	-5763.6474	-1955.4126
		Ntakofa	2603.71500*	733.06609	.008	699.5976	4507.8324
Nitrate	Muni	Ntakofa	-2.1798333*	.4571303	.001	-3.367216	-.992451
		Pratu	-.0548333	.4571303	.992	-1.242216	1.132549
	Ntakofa	Muni	2.1798333*	.4571303	.001	.992451	3.367216
		Pratu	2.1250000*	.4571303	.001	.937618	3.312382
	Pratu	Muni	.0548333	.4571303	.992	-1.132549	1.242216
		Ntakofa	-2.1250000*	.4571303	.001	-3.312382	-.937618
Nitrite	Muni	Ntakofa	.1821667*	.0515053	.008	.048383	.315950
		Pratu	.1888333*	.0515053	.006	.055050	.322617
	Ntakofa	Muni	-.1821667*	.0515053	.008	-.315950	-.048383
		Pratu	.0066667	.0515053	.991	-.127117	.140450
	Pratu	Muni	-.1888333*	.0515053	.006	-.322617	-.055050

		Ntakofa	-.0066667	.0515053	.991	-.140450	.127117
	Muni	Ntakofa	-1.0700000*	.1483876	.000	-1.455432	-.684568
		Pratu	-.2800000	.1483876	.177	-.665432	.105432
Phosphate	Ntakofa	Muni	1.0700000*	.1483876	.000	.684568	1.455432
		Pratu	.7900000*	.1483876	.000	.404568	1.175432
	Pratu	Muni	.2800000	.1483876	.177	-.105432	.665432
		Ntakofa	-.7900000*	.1483876	.000	-1.175432	-.404568
	Muni	Ntakofa	30.9833	438.3295	.997	-1107.565	1169.531
		Pratu	-735.8000	438.3295	.245	-1874.348	402.748
TSS	Ntakofa	Muni	-30.9833	438.3295	.997	-1169.531	1107.565
		Pratu	-766.7833	438.3295	.220	-1905.331	371.765
	Pratu	Muni	735.8000	438.3295	.245	-402.748	1874.348
		Ntakofa	766.7833	438.3295	.220	-371.765	1905.331
	Muni	Ntakofa	12262.000*	1189.853	.000	9171.39	15352.61
		Pratu	6792.167*	1189.853	.000	3701.56	9882.78
TDS	Ntakofa	Muni	-12262.000*	1189.853	.000	-15352.61	-9171.39
		Pratu	-5469.833*	1189.853	.001	-8560.44	-2379.22
	Pratu	Muni	-6792.167*	1189.853	.000	-9882.78	-3701.56
		Ntakofa	5469.833*	1189.853	.001	2379.22	8560.44
	Muni	Ntakofa	.5771667*	.1783030	.014	.114030	1.040303
		Pratu	.5626667*	.1783030	.017	.099530	1.025803
pH	Ntakofa	Muni	-.5771667*	.1783030	.014	-1.040303	-.114030
		Pratu	-.0145000	.1783030	.996	-.477637	.448637
	Pratu	Muni	-.5626667*	.1783030	.017	-1.025803	-.099530
		Ntakofa	.0145000	.1783030	.996	-.448637	.477637
	Muni	Ntakofa	-37.500	57.246	.792	-186.19	111.19
		Pratu	-151.500*	57.246	.046	-300.19	-2.81
Turbidity	Ntakofa	Muni	37.500	57.246	.792	-111.19	186.19
		Pratu	-114.000	57.246	.149	-262.69	34.69
	Pratu	Muni	151.500*	57.246	.046	2.81	300.19
		Ntakofa	114.000	57.246	.149	-34.69	262.69
	Muni	Ntakofa	18855.000*	1936.600	.000	13824.74	23885.26
		Pratu	10648.167*	1936.600	.000	5617.91	15678.43
conductivity	Ntakofa	Muni	-18855.000*	1936.600	.000	-23885.26	-13824.74
		Pratu	-8206.833*	1936.600	.002	-13237.09	-3176.57
	Pratu	Muni	-10648.167*	1936.600	.000	-15678.43	-5617.91
		Ntakofa	8206.833*	1936.600	.002	3176.57	13237.09
Alkalinity	Muni	Ntakofa	47.4520000	54.5299723	.667	-94.187981	189.091981

		Pratu	21.7273333	54.5299723	.917	-119.911648	163.367314
	Ntakofa	Muni	-47.4520000	54.5299723	.667	-189.090981	94.187981
		Pratu	-25.7246667	54.5299723	.885	-167.364648	115.915314
	Pratu	Muni	-21.7273333	54.5299723	.917	-163.367314	119.911648
		Ntakofa	25.7246667	54.5299723	.885	-115.915314	167.364648
	Muni	Ntakofa	99.1681010	254.1045336	.920	-560.860866	759.197068
		Pratu	-591.5611753	254.1045336	.082	-1251.590143	68.467792
Ca	Ntakofa	Muni	-99.1681010	254.1045336	.920	-759.197068	560.860866
		Pratu	-690.7292764*	254.1045336	.040	-1350.758244	-30.700309
	Pratu	Muni	591.5611753	254.1045336	.082	-68.467792	1251.590143
		Ntakofa	690.7292764*	254.1045336	.040	30.700309	1350.758244
	Muni	Ntakofa	-.7348296	7.0931646	.994	-19.159114	17.689454
		Pratu	-14.4051344	7.0931646	.139	-32.829418	4.019150
Fe	Ntakofa	Muni	.7348296	7.0931646	.994	-17.689454	19.159114
		Pratu	-13.6703048	7.0931646	.165	-32.094589	4.753979
	Pratu	Muni	14.4051344	7.0931646	.139	-4.019150	32.829418
		Ntakofa	13.6703048	7.0931646	.165	-4.753979	32.094589
K	Muni	Ntakofa	118.5549672*	12.8999412	.000	85.047754	152.062181
		Pratu	50.8596092*	12.8999412	.004	17.352396	84.366823

	Ntakofa	Muni	-118.5549672*	12.8999412	.000	-152.062181	-85.047754
		Pratu	-67.6953580*	12.8999412	.000	-101.202572	-34.188144
	Pratu	Muni	-50.8596092*	12.8999412	.004	-84.366823	-17.352396
		Ntakofa	67.6953580*	12.8999412	.000	34.188144	101.202572
	Muni	Ntakofa	351.7799116*	28.4365932	.000	277.916707	425.643117
		Pratu	155.3141656*	28.4365932	.000	81.450961	229.177371
Mg	Ntakofa	Muni	-351.7799116*	28.4365932	.000	-425.643117	-277.916707
		Pratu	-196.4657459*	28.4365932	.000	-270.328951	-122.602541
	Pratu	Muni	-155.3141656*	28.4365932	.000	-229.177371	-81.450961
		Ntakofa	196.4657459*	28.4365932	.000	122.602541	270.328951
	Muni	Ntakofa	2994.8024729*	332.3983427	.000	2131.407666	3858.197280
		Pratu	1752.3353878*	332.3983427	.000	888.940581	2615.730195
	Ntakofa	Muni	-2994.8024729*	332.3983427	.000	-3858.197280	-2131.407666
		Pratu	-1242.4670851*	332.3983427	.005	-2105.861892	-379.072278
Na	Pratu	Muni	-1752.3353878*	332.3983427	.000	-2615.730195	-888.940581
		Ntakofa	1242.4670851*	332.3983427	.005	379.072278	2105.861892
Al	Muni	Ntakofa	.6382094	5.0002118	.991	-12.349692	13.626111

COD	Ntakofa	Pratu	-8.9330158	5.0002118	.208	-21.920917	4.054886
		Muni	-.6382094	5.0002118	.991	-13.626111	12.349692
	Pratu	Ntakofa	-9.5712252	5.0002118	.169	-22.559127	3.416676
		Muni	8.9330158	5.0002118	.208	-4.054886	21.920917
		Ntakofa	9.5712252	5.0002118	.169	-3.416676	22.559127
	Muni	Ntakofa	46.9122222	297.8055227	.986	-726.628764	820.453209
		Pratu	-762.9775000	297.8055227	.053	-1536.518486	10.563486
	Ntakofa	Muni	-46.9122222	297.8055227	.986	-820.453209	726.628764
		Pratu	-809.8897222*	297.8055227	.040	-1583.430709	-36.348736
	Pratu	Muni	762.9775000	297.8055227	.053	-10.563486	1536.518486
		Ntakofa	809.8897222*	297.8055227	.040	36.348736	1583.430709
BOD	Muni	Ntakofa	23.1150000	200.0975912	.993	-496.632541	542.862541
		Pratu	-510.2566667	200.0975912	.055	-1030.004207	9.490874
	Ntakofa	Muni	-23.1150000	200.0975912	.993	-542.862541	496.632541
		Pratu	-533.3716667*	200.0975912	.044	-1053.119207	-13.624126
	Pratu	Muni	510.2566667	200.0975912	.055	-9.490874	1030.004207
		Ntakofa	533.3716667*	200.0975912	.044	13.624126	1053.119207

*. The mean difference is significant at the 0.05 level.

APPENDIX C

ANOVA FOR WATER HEAVY METAL CONCENTRATIONS

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
As 75 (ppm)	Between Groups	.002	2	.001	1.607	.233
	Within Groups	.009	15	.001		
	Total	.011	17			
B 11 (ppm)	Between Groups	42.024	2	21.012	3.177	.071
	Within Groups	99.220	15	6.615		
	Total	141.244	17			
Ba 138 (ppm)	Between Groups	1.827	2	.914	3.093	.075
	Within Groups	4.431	15	.295		
	Total	6.259	17			
Cd 111 (ppm)	Between Groups	.000	2	.000	2.743	.097
	Within Groups	.000	15	.000		
	Total	.000	17			
Co 59 (ppm)	Between Groups	.002	2	.001	2.681	.101
	Within Groups	.005	15	.000		
	Total	.007	17			
Cr 52 (ppm)	Between Groups	.011	2	.005	2.549	.111
	Within Groups	.031	15	.002		
	Total	.042	17			
Cu 63 (ppm)	Between Groups	.017	2	.008	1.538	.247
	Within Groups	.082	15	.005		
	Total	.099	17			
Mn 55 (ppm)	Between Groups	13.115	2	6.557	2.979	.081
	Within Groups	33.015	15	2.201		
	Total	46.130	17			
Ni 60 (ppm)	Between Groups	.019	2	.010	2.954	.083

	Within Groups	.049	15	.003		
	Total	.068	17			
Pb 208 (ppm)	Between Groups	.073	2	.037	2.729	.098
	Within Groups	.201	15	.013		
	Total	.274	17			
Se 78 (ppm)	Between Groups	.008	2	.004	3.000	.080
	Within Groups	.020	15	.001		
	Total	.027	17			
Sr 88 (ppm)	Between Groups	11.454	2	5.727	1.768	.204
	Within Groups	48.599	15	3.240		
	Total	60.054	17			
Zn 66 (ppm)	Between Groups	4.686	2	2.343	2.767	.095
	Within Groups	12.702	15	.847		
	Total	17.388	17			

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Sample Id	(J) Sample Id	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
As 75 (ppm)	MUNI LAGOON	NTAKOFA RIVER	.0252822	.0144688	.221	-.012300	.062865
		PRATU RIVER	.0076051	.0144688	.860	-.029977	.045187
	NTAKOFA RIVER	MUNI LAGOON	-.0252822	.0144688	.221	-.062865	.012300
		PRATU RIVER	-.0176771	.0144688	.459	-.055259	.019905
	PRATU RIVER	MUNI LAGOON	-.0076051	.0144688	.860	-.045187	.029977

		NTAKOFA RIVER	.0176771	.0144688	.459	-.019905	.055259
	MUNI LAGOON	NTAKOFA RIVER	1.0480889	1.4848845	.764	-2.808854	4.905032
		PRATU RIVER	-2.5875723	1.4848845	.222	-6.444516	1.269371
B 11 (ppm)	NTAKOFA RIVER	MUNI LAGOON	-1.0480889	1.4848845	.764	-4.905032	2.808854
		PRATU RIVER	-3.6356612	1.4848845	.066	-7.492605	.221282
	PRATU RIVER	MUNI LAGOON	2.5875723	1.4848845	.222	-1.269371	6.444516
		NTAKOFA RIVER	3.6356612	1.4848845	.066	-.221282	7.492605
	MUNI LAGOON	NTAKOFA RIVER	-.0157872	.3138073	.999	-.830892	.799318
		PRATU RIVER	-.6836662	.3138073	.108	-1.498771	.131439
Ba 138 (ppm)	NTAKOFA RIVER	MUNI LAGOON	.0157872	.3138073	.999	-.799318	.830892
		PRATU RIVER	-.6678790	.3138073	.118	-1.482984	.147226
	PRATU RIVER	MUNI LAGOON	.6836662	.3138073	.108	-.131439	1.498771
		NTAKOFA RIVER	.6678790	.3138073	.118	-.147226	1.482984
	MUNI LAGOON	NTAKOFA RIVER	-.0000158	.0020651	1.000	-.005380	.005348
		PRATU RIVER	-.0041967	.0020651	.139	-.009561	.001167
Cd 111 (ppm)	NTAKOFA RIVER	MUNI LAGOON	.0000158	.0020651	1.000	-.005348	.005380
		PRATU RIVER	-.0041808	.0020651	.140	-.009545	.001183
	PRATU RIVER	MUNI LAGOON	.0041967	.0020651	.139	-.001167	.009561
		NTAKOFA RIVER	.0041808	.0020651	.140	-.001183	.009545
Co 59 (ppm)	MUNI LAGOON	NTAKOFA RIVER	-.0004277	.0108492	.999	-.028608	.027753

		PRATU RIVER	-.0219658	.0108492	.140	-.050146	.006215
	NTAKOFA RIVER	MUNI LAGOON	.0004277	.0108492	.999	-.027753	.028608
		PRATU RIVER	-.0215381	.0108492	.150	-.049718	.006642
	PRATU RIVER	MUNI LAGOON	.0219658	.0108492	.140	-.006215	.050146
		NTAKOFA RIVER	.0215381	.0108492	.150	-.006642	.049718
	MUNI LAGOON	NTAKOFA RIVER	.0043262	.0264102	.985	-.064273	.072926
		PRATU RIVER	-.0493445	.0264102	.182	-.117944	.019255
Cr 52 (ppm)	NTAKOFA RIVER	MUNI LAGOON	-.0043262	.0264102	.985	-.072926	.064273
		PRATU RIVER	-.0536707	.0264102	.139	-.122270	.014929
	PRATU RIVER	MUNI LAGOON	.0493445	.0264102	.182	-.019255	.117944
		NTAKOFA RIVER	.0536707	.0264102	.139	-.014929	.122270
	MUNI LAGOON	NTAKOFA RIVER	.0433747	.0427649	.580	-.067706	.154455
		PRATU RIVER	-.0312969	.0427649	.749	-.142378	.079784
Cu 63 (ppm)	NTAKOFA RIVER	MUNI LAGOON	-.0433747	.0427649	.580	-.154455	.067706
		PRATU RIVER	-.0746716	.0427649	.221	-.185752	.036409
	PRATU RIVER	MUNI LAGOON	.0312969	.0427649	.749	-.079784	.142378
		NTAKOFA RIVER	.0746716	.0427649	.221	-.036409	.185752
	MUNI LAGOON	NTAKOFA RIVER	-.0321460	.8565426	.999	-2.256990	2.192698
Mn 55 (ppm)		PRATU RIVER	-1.8265624	.8565426	.117	-4.051406	.398282
	NTAKOFA RIVER	MUNI LAGOON	.0321460	.8565426	.999	-2.192698	2.256990

		PRATU RIVER	-1.7944164	.856542 6	.125	-4.019260	.430428
	PRATU RIVER	MUNI LAGOON	1.8265624	.856542 6	.117	-.398282	4.051406
		NTAKOFA RIVER	1.7944164	.856542 6	.125	-.430428	4.019260
	MUNI LAGOON	NTAKOFA RIVER	.0014261	.032897 2	.999	-.084023	.086876
		PRATU RIVER	-.0685234	.032897 2	.127	-.153973	.016926
Ni 60 (ppm)	NTAKOFA RIVER	MUNI LAGOON	-.0014261	.032897 2	.999	-.086876	.084023
		PRATU RIVER	-.0699495	.032897 2	.118	-.155399	.015500
	PRATU RIVER	MUNI LAGOON	.0685234	.032897 2	.127	-.016926	.153973
		NTAKOFA RIVER	.0699495	.032897 2	.118	-.015500	.155399
	MUNI LAGOON	NTAKOFA RIVER	-.0009150	.066811 1	1.000	-.174455	.172625
		PRATU RIVER	-.1356399	.066811 1	.139	-.309180	.037900
Pb 208 (ppm)	NTAKOFA RIVER	MUNI LAGOON	.0009150	.066811 1	1.000	-.172625	.174455
		PRATU RIVER	-.1347249	.066811 1	.142	-.308265	.038815
	PRATU RIVER	MUNI LAGOON	.1356399	.066811 1	.139	-.037900	.309180
		NTAKOFA RIVER	.1347249	.066811 1	.142	-.038815	.308265
	MUNI LAGOON	NTAKOFA RIVER	.0507018	.020856 2	.068	-.003472	.104875
		PRATU RIVER	.0307922	.020856 2	.330	-.023381	.084966
Se 78 (ppm)	NTAKOFA RIVER	MUNI LAGOON	-.0507018	.020856 2	.068	-.104875	.003472
		PRATU RIVER	-.0199096	.020856 2	.615	-.074083	.034264
	PRATU RIVER	MUNI LAGOON	-.0307922	.020856 2	.330	-.084966	.023381

		NTAKOFA RIVER	.0199096	.0208562	.615	-.034264	.074083
	MUNI LAGOON	NTAKOFA RIVER	1.2760394	1.0392219	.456	-1.423309	3.975387
		PRATU RIVER	-.6435486	1.0392219	.812	-3.342897	2.055799
Sr 88 (ppm)	NTAKOFA RIVER	MUNI LAGOON	-1.2760394	1.0392219	.456	-3.975387	1.423309
		PRATU RIVER	-1.9195880	1.0392219	.188	-4.618936	.779760
	PRATU RIVER	MUNI LAGOON	.6435486	1.0392219	.812	-2.055799	3.342897
		NTAKOFA RIVER	1.9195880	1.0392219	.188	-.779760	4.618936
	MUNI LAGOON	NTAKOFA RIVER	-.0043476	.5312820	1.000	-1.384337	1.375642
		PRATU RIVER	-1.0845300	.5312820	.137	-2.464519	.295459
	NTAKOFA RIVER	MUNI LAGOON	.0043476	.5312820	1.000	-1.375642	1.384337
Zn 66 (ppm)		PRATU RIVER	-1.0801824	.5312820	.138	-2.460172	.299807
	PRATU RIVER	MUNI LAGOON	1.0845300	.5312820	.137	-.295459	2.464519
		NTAKOFA RIVER	1.0801824	.5312820	.138	-.299807	2.460172

APPENDIX D

ANOVA FOR SEDIMENT HEAVY METAL CONCENTRATIONS

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
As 75 (ppm)	Between Groups	212.590	2	106.295	5.790	.014
	Within Groups	275.369	15	18.358		
	Total	487.959	17			
B 11 (ppm)	Between Groups	151.669	2	75.834	9.267	.002
	Within Groups	122.743	15	8.183		
	Total	274.412	17			
Ba-1 137 (ppm)	Between Groups	47918.160	2	23959.080	9.709	.002
	Within Groups	37016.975	15	2467.798		
	Total	84935.136	17			
Be 9 (ppm)	Between Groups	.605	2	.302	5.584	.015
	Within Groups	.812	15	.054		
	Total	1.416	17			
Cd 111 (ppm)	Between Groups	.002	2	.001	3.054	.077
	Within Groups	.005	15	.000		
	Total	.007	17			
Co 59 (ppm)	Between Groups	1419.175	2	709.587	8.123	.004
	Within Groups	1310.326	15	87.355		
	Total	2729.501	17			
Cr 52 (ppm)	Between Groups	26888.875	2	13444.437	7.216	.006
	Within Groups	27947.709	15	1863.181		
	Total	54836.584	17			
Cu 63 (ppm)	Between Groups	2889.575	2	1444.787	31.660	.000
	Within Groups	684.514	15	45.634		
	Total	3574.089	17			
Mn 55 (ppm)	Between Groups	1553432.396	2	776716.198	9.569	.002

	Within Groups	1217542.258	15	81169.484		
	Total	2770974.654	17			
Ni 60 (ppm)	Between Groups	1797.201	2	898.600	14.982	.000
	Within Groups	899.678	15	59.979		
	Total	2696.878	17			
Pb 208 (ppm)	Between Groups	114.571	2	57.286	5.500	.016
	Within Groups	156.234	15	10.416		
	Total	270.806	17			
Se 82 (ppm)	Between Groups	.459	2	.229	5.160	.020
	Within Groups	.667	15	.044		
	Total	1.126	17			
Hg	Between Groups	.002	2	.001	8.404	.004
	Within Groups	.001	15	.000		
	Total	.003	17			
Zn 66 (ppm)	Between Groups	2425.042	2	1212.521	8.480	.003
	Within Groups	2144.755	15	142.984		
	Total	4569.797	17			

Multiple Comparisons Sediment Heavy metal concentrations

Tukey HSD

Dependent Variable	(I) location	(J) location	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Ag 107 (ppm)	PRATU RIVER	MUNI LAGOON	.0246416*	.0073364	.011	.005586	.043698
		NTAKOFA	.0097288	.0073364	.403	-.009327	.028785
	NTAKOFA	PRATU RIVER	-.0097288	.0073364	.403	-.028785	.009327
		MUNI LAGOON	.0149128	.0073364	.139	-.004143	.033969
As 75 (ppm)	MUNI LAGOON	PRATU RIVER	-7.0776343*	2.473724 3	.030	-13.503060	-.652209
		NTAKOFA	.4080525	2.473724 3	.985	-6.017373	6.833478
	NTAKOFA	PRATU RIVER	-7.4856867*	2.473724 3	.022	-13.911112	-1.060261
		MUNI LAGOON	-.4080525	2.473724 3	.985	-6.833478	6.017373
B 11 (ppm)	PRATU RIVER	MUNI LAGOON	-4.9093911*	1.651550 7	.024	-9.199245	-.619537
		NTAKOFA	1.9995820	1.651550 7	.465	-2.290272	6.289436
	MUNI LAGOON	PRATU RIVER	4.9093911*	1.651550 7	.024	.619537	9.199245

		NTAKOFA	6.9089731*	1.6515507	.002	2.619119	11.198827
	NTAKOFA	PRATU RIVER	-1.9995820	1.6515507	.465	-6.289436	2.290272
		MUNI LAGOON	-6.9089731*	1.6515507	.002	-11.198827	-2.619119
	PRATU RIVER	MUNI LAGOON	122.6012705*	28.6809945	.002	48.103240	197.099301
		NTAKOFA	34.7255255	28.6809945	.465	-39.772505	109.223556
		PRATU RIVER	-122.6012705*	28.6809945	.002	-197.099301	-48.103240
Ba-1 137 (ppm)	MUNI LAGOON	NTAKOFA	-87.8757450*	28.6809945	.020	-162.373775	-13.377715
	NTAKOFA	PRATU RIVER	-34.7255255	28.6809945	.465	-109.223556	39.772505
		MUNI LAGOON	87.8757450*	28.6809945	.020	13.377715	162.373775
	PRATU RIVER	MUNI LAGOON	.4109395*	.1343185	.020	.062051	.759828
		NTAKOFA	.0490349	.1343185	.930	-.299853	.397923
	MUNI LAGOON	PRATU RIVER	-.4109395*	.1343185	.020	-.759828	-.062051
Be 9 (ppm)		NTAKOFA	-.3619046*	.1343185	.042	-.710793	-.013016
	NTAKOFA	PRATU RIVER	-.0490349	.1343185	.930	-.397923	.299853
		MUNI LAGOON	.3619046*	.1343185	.042	.013016	.710793
	PRATU RIVER	MUNI LAGOON	.0235593	.0106423	.101	-.004084	.051202
Cd 111 (ppm)		NTAKOFA	.0016504	.0106423	.987	-.025993	.029293

	MUNI LAGOON	PRATU RIVER	-.0235593	.0106423	.101	-.051202	.004084
		NTAKOFA	-.0219089	.0106423	.133	-.049552	.005734
	NTAKOFA	PRATU RIVER	-.0016504	.0106423	.987	-.029293	.025993
		MUNI LAGOON	.0219089	.0106423	.133	-.005734	.049552
	PRATU RIVER	MUNI LAGOON	21.7260044*	5.396142 0	.003	7.709686	35.742323
		NTAKOFA	9.9802430	5.396142 0	.188	-4.036075	23.996561
Co 59 (ppm)	MUNI LAGOON	PRATU RIVER	-21.7260044*	5.396142 0	.003	-35.742323	-7.709686
		NTAKOFA	-11.7457614	5.396142 0	.108	-25.762080	2.270557
	NTAKOFA	PRATU RIVER	-9.9802430	5.396142 0	.188	-23.996561	4.036075
		MUNI LAGOON	11.7457614	5.396142 0	.108	-2.270557	25.762080
	PRATU RIVER	MUNI LAGOON	87.1346890*	24.92107 93	.009	22.402927	151.866451
		NTAKOFA	75.6278846*	24.92107 93	.021	10.896122	140.359647
Cr 52 (ppm)	MUNI LAGOON	PRATU RIVER	-87.1346890*	24.92107 93	.009	-151.866451	-22.402927
		NTAKOFA	-11.5068044	24.92107 93	.890	-76.238567	53.224958
	NTAKOFA	PRATU RIVER	-75.6278846*	24.92107 93	.021	-140.359647	-10.896122

		MUNI LAGOON	11.5068044	24.9210793	.890	-53.224958	76.238567
	PRATU RIVER	MUNI LAGOON	28.1564094*	3.9001829	.000	18.025800	38.287018
		NTAKOFA	25.3833427*	3.9001829	.000	15.252734	35.513952
	MUNI LAGOON	PRATU RIVER	-28.1564094*	3.9001829	.000	-38.287018	-18.025800
Cu 63 (ppm)		NTAKOFA	-2.7730667	3.9001829	.761	-12.903676	7.357542
	NTAKOFA	PRATU RIVER	-25.3833427*	3.9001829	.000	-35.513952	-15.252734
		MUNI LAGOON	2.7730667	3.9001829	.761	-7.357542	12.903676
	PRATU RIVER	MUNI LAGOON	626.4332638*	164.488851	.005	199.179057	1053.687471
		NTAKOFA	6.5504884	164.488851	.999	-420.703718	433.804695
	MUNI LAGOON	PRATU RIVER	-626.4332638*	164.488851	.005	-1053.687471	-199.179057
Mn 55 (ppm)		NTAKOFA	-619.8827754*	164.488851	.005	-1047.136982	-192.628569
	NTAKOFA	PRATU RIVER	-6.5504884	164.488851	.999	-433.804695	420.703718
		MUNI LAGOON	619.8827754*	164.488851	.005	192.628569	1047.136982
	PRATU RIVER	MUNI LAGOON	.2231265*	.0500217	.001	.093197	.353056
Mo 95 (ppm)		NTAKOFA	.1449280*	.0500217	.028	.014998	.274858
	MUNI LAGOON	PRATU RIVER	-.2231265*	.0500217	.001	-.353056	-.093197

		NTAKOFA	-.0781986	.0500217	.291	-.208128	.051731
	NTAKOFA	PRATU RIVER MUNI	-.1449280*	.0500217	.028	-.274858	-.014998
		LAGOON	.0781986	.0500217	.291	-.051731	.208128
	PRATU RIVER	MUNI LAGOON	24.4259311*	4.4713347	.000	12.811772	36.040090
		NTAKOFA	13.5659655*	4.4713347	.022	1.951807	25.180124
	MUNI LAGOON	PRATU RIVER	-24.4259311*	4.4713347	.000	-36.040090	-12.811772
Ni 60 (ppm)		NTAKOFA	-10.8599656	4.4713347	.069	-22.474125	.754193
	NTAKOFA	PRATU RIVER	-13.5659655*	4.4713347	.022	-25.180124	-1.951807
		MUNI LAGOON	10.8599656	4.4713347	.069	-.754193	22.474125
	PRATU RIVER	MUNI LAGOON	5.0216238*	1.8632962	.042	.181767	9.861480
		NTAKOFA	-.6085341	1.8632962	.943	-5.448390	4.231322
	MUNI LAGOON	PRATU RIVER	-5.0216238*	1.8632962	.042	-9.861480	-.181767
Pb 208 (ppm)		NTAKOFA	-5.6301579*	1.8632962	.022	-10.470014	-.790301
	NTAKOFA	PRATU RIVER	.6085341	1.8632962	.943	-4.231322	5.448390
		MUNI LAGOON	5.6301579*	1.8632962	.022	.790301	10.470014
Se 82 (ppm)	PRATU RIVER	MUNI LAGOON	.3892072*	.1217522	.016	.072959	.705455

		NTAKOFA	.1611719	.1217522	.404	-.155076	.477420
	MUNI LAGOON	PRATU RIVER	-.3892072*	.1217522	.016	-.705455	-.072959
		NTAKOFA	-.2280353	.1217522	.181	-.544283	.088213
	NTAKOFA	PRATU RIVER	-.1611719	.1217522	.404	-.477420	.155076
		MUNI LAGOON	.2280353	.1217522	.181	-.088213	.544283
	PRATU RIVER	MUNI LAGOON	.2712250	.2663347	.577	-.420571	.963021
		NTAKOFA	-.2103641	.2663347	.715	-.902161	.481432
Sn-1 118 (ppm)	MUNI LAGOON	PRATU RIVER	-.2712250	.2663347	.577	-.963021	.420571
		NTAKOFA	-.4815892	.2663347	.201	-1.173386	.210207
	NTAKOFA	PRATU RIVER	.2103641	.2663347	.715	-.481432	.902161
		MUNI LAGOON	.4815892	.2663347	.201	-.210207	1.173386
	PRATU RIVER	MUNI LAGOON	8.3262995	4.2512854	.157	-2.716288	19.368887
		NTAKOFA	-7.8111641	4.2512854	.191	-18.853751	3.231423
Sr 88 (ppm)	MUNI LAGOON	PRATU RIVER	-8.3262995	4.2512854	.157	-19.368887	2.716288
		NTAKOFA	-16.1374635*	4.2512854	.005	-27.180051	-5.094876
	NTAKOFA	PRATU RIVER	7.8111641	4.2512854	.191	-3.231423	18.853751
		MUNI LAGOON	16.1374635*	4.2512854	.005	5.094876	27.180051

	PRATU RIVER	MUNI LAGOON	221.5329266	96.32349 49	.087	-28.6644 86	471.730339
		NTAKOFA	229.7431401	96.32349 49	.074	-20.4542 73	479.940553
Ti 47 (ppm)	MUNI LAGOON	PRATU RIVER	-221.5329266	96.32349 49	.087	-471.730 339	28.664486
		NTAKOFA	8.2102135	96.32349 49	.996	-241.987 199	258.407626
	NTAKOFA	PRATU RIVER	-229.7431401	96.32349 49	.074	-479.940 553	20.454273
		MUNI LAGOON	-8.2102135	96.32349 49	.996	-258.407 626	241.987199
	PRATU RIVER	MUNI LAGOON	.0765987*	.0220868	.009	.019229	.133969
		NTAKOFA	.0430269	.0220868	.160	-.014343	.100397
Tl 205 (ppm)	MUNI LAGOON	PRATU RIVER	-.0765987*	.0220868	.009	-.133969	-.019229
		NTAKOFA	-.0335719	.0220868	.310	-.090942	.023798
	NTAKOFA	PRATU RIVER	-.0430269	.0220868	.160	-.100397	.014343
		MUNI LAGOON	.0335719	.0220868	.310	-.023798	.090942
	PRATU RIVER	MUNI LAGOON	.4154190	.1711594	.069	-.029162	.860001
		NTAKOFA	.1884632	.1711594	.528	-.256118	.633045
U 238 (ppm)	MUNI LAGOON	PRATU RIVER	-.4154190	.1711594	.069	-.860001	.029162
		NTAKOFA	-.2269558	.1711594	.403	-.671537	.217626
	NTAKOFA	PRATU RIVER	-.1884632	.1711594	.528	-.633045	.256118

V 51 (ppm)	PRATU RIVER	MUNI LAGOON	.2269558	.1711594	.403	-.217626	.671537
		NTAKOFA	84.2910066*	22.1543056	.005	26.745857	141.836156
			63.8089008*	22.1543056	.029	6.263751	121.354051
	MUNI LAGOON	PRATU RIVER	-84.2910066*	22.1543056	.005	-141.836156	-26.745857
		NTAKOFA	-20.4821058	22.1543056	.634	-78.027256	37.063044
	NTAKOFA	PRATU RIVER	-63.8089008*	22.1543056	.029	-121.354051	-6.263751
		MUNI LAGOON	20.4821058	22.1543056	.634	-37.063044	78.027256
Zn 66 (ppm)	PRATU RIVER	MUNI LAGOON	27.9620135*	6.9037104	.003	10.029831	45.894196
		NTAKOFA	18.4368819*	6.9037104	.044	.504699	36.369064
	MUNI LAGOON	PRATU RIVER	-27.9620135*	6.9037104	.003	-45.894196	-10.029831
		NTAKOFA	-9.5251316	6.9037104	.376	-27.457314	8.407051
	NTAKOFA	PRATU RIVER	-18.4368819*	6.9037104	.044	-36.369064	-.504699
		MUNI LAGOON	9.5251316	6.9037104	.376	-8.407051	27.457314
Hgsed	Pratu River	Muni Lagoon	.0163086*	.0057691	.032	.001324	.031294
		Ntakofa River	-.0066804	.0057691	.495	-.021665	.008305

Muni Lagoon	Pratu River	-.0163086*	.0057691	.032	-.031294	-.001324
	Ntakofa River	-.0229891*	.0057691	.003	-.037974	-.008004
Ntakofa River	Pratu River	.0066804	.0057691	.495	-.008305	.021665
	Muni Lagoon	.0229891*	.0057691	.003	.008004	.037974

*. The mean difference is significant at the 0.05 level.

APPENDIX E

Table presenting Background concentration and recommended standard values.

Parameters	stand (Si)	Background
As	0.01	0.1982
B	2.4	1.3249
Ba	0.7	2.3605
Cd	0.003	0.00094
Co	0.05	0.2333
Cr	0.05	1.762
Cu	2	0.9814
Mn	0.4	5.9588
Hg	0.006	0.00972
Ni	0.02	0.5844
Pb	0.01	1.3955
Se	0.04	0.0124
Sr	4	5.481
Zn	4	2.3677

APPENDIX F

REGRESSION ANALYSIS RESULTS

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.362[a]	.131	.127	.29959
2	.408[b]	.166	.158	.29419
3	.468[c]	.219	.207	.28541

a. Predictors: (Constant), Building_1

b. Predictors: (Constant), Building_1, Firewood_1

c. Predictors: (Constant), Building_1, Firewood_1, Agric_1

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.682	1	2.682	29.881	.000[b]
	Residual	17.771	198	.090		
	Total	20.453	199			
2	Regression	3.404	2	1.702	19.667	.000[c]
	Residual	17.049	197	.087		
	Total	20.453	199			
3	Regression	4.488	3	1.496	18.364	.000[d]
	Residual	15.966	196	.081		
	Total	20.453	199			

a. Dependent Variable: eco1

b. Predictors: (Constant), Building_1

c. Predictors: (Constant), Building_1, Firewood_1

d. Predictors: (Constant), Building_1, Firewood_1, Agric_1

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2.549	.366		6.959	.000
	Building_1	.444	.081	.362	5.466	.000
2	(Constant)	1.859	.432		4.308	.000
	Building_1	.376	.083	.307	4.524	.000
	Firewood_1	.215	.075	.196	2.889	.004
3	(Constant)	.286	.601		.476	.634
	Building_1	.323	.082	.263	3.942	.000
	Firewood_1	.282	.075	.256	3.778	.000
	Agric_1	.323	.089	.239	3.647	.000

a. Dependent Variable: eco1

Excluded Variables

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	Firewood_1	.196[b]	2.889	.004	.202	.920
	Agric_1	.178[b]	2.720	.007	.190	.988
	Industry_1	.064[b]	.957	.340	.068	.968
2	Agric_1	.239[c]	3.647	.000	.252	.929
	Industry_1	.004[c]	.062	.951	.004	.870
3	Industry_1	-.048[d]	-.694	.488	-.050	.834

a. Dependent Variable: eco1

b. Predictors in the Model: (Constant), Building_1

c. Predictors in the Model: (Constant), Building_1, Firewood_1

d. Predictors in the Model: (Constant), Building_1, Firewood_1, Agric_1

APPENDIX G

QUESTIONNAIRE

Introduction

I am Twumasi Ankrah Kwarteng a Ph.D. Environmental science student of the University of Ghana Graduate School, conducting a research into the quality of Muni lagoon and its tributaries. As part of the study, this instrument solicits information on the impact of anthropogenic activities on the Muni lagoon and its tributaries as well as resources in the catchment area. You are among the identified persons who can help by answering the questions intended for the research. I would want to assure you of maximum confidentiality of any information you may provide and also your responses are only for this research.

SECTION A: Socio-Demographic Characteristics of Respondents

1. Gender: a) Male [ ] b) Female [ ]
2. Age group a) 10 – 19 [ ] b) 20 – 29 [ ] c) 30 – 39[ ] d) 40 -49 [ ]
   e) 50 – 59 [ ] f) 60 and above [ ]
3. What is your level of education?

a) No Formal [ ] b) JHS [ ] c) 'A'/ 'O'/ SHS level [ ] d) HND/ BA/BSc [ ]

SECTION B: Impact of Anthropogenic activities on Ecosystem services

Strongly agree (SA) =5 Agree (A)=4, undecided (U)=3, Disagree(D)= 2, strongly disagree(SD)=1

s/n	Items	5	4	3	2	1
	Ecosystem Services					
E1	Rivers in the muni catchment area are not used for drinking due to pollution.					
E2	Wood fuel is scarce to get from the Muni catchment area.					
E3	Most herbal plants are destroyed due to farming and deforestation.					

E4	Deforestation is high and has resulted in timber loss in the Muni catchment area.					
E5	Recreational and Tourism to the Ramsar site has reduced due to pollution					
E6	Hunters hardly get bush meat from the forest in the Muni catchment area due to habitat loss					
E7	Polluted water bodies are not suitable for irrigation					
	Wood collection					
W1	Firewood collected from the Muni catchment area degrades forest resources.					
W2	Firewood is the main energy source for cooking and smoking of fish by inhabitants near muni catchment area.					
W3	Charcoal is a source of energy for cooking by the inhabitants in the catchment area					
W4	Charcoal production does not occur in the Muni catchment area					
W5	Mangrove along the Muni lagoon has depleted due to firewood collection					
W6	Burning of charcoal has reduced firewood collected in the study area					
	Agriculture activities					
A1	Fertilizer use is negatively affecting water and land resources.					
A2	Pesticides used in farms contaminate water bodies					
A3	Poultry farms along the water bodies contaminate the rivers.					
A4	Farmers in the area use excess pesticides to control pests in their farms.					
A5	Water sediment has increased due to soil erosion from bare farmlands					
A6	The poor fishing method has contributed to the depletion of fish catch in the Muni Lagoon					

A7	Farmers wash spraying machines at the banks of either the Pratu or Ntakofa Rivers.					
	Industrial Activities					
I 1	Hospital waste is not discharged into any of the tributaries.					
I2	Some industries discharge their wastewater into either Muni Lagoon or Pratu River					
13	Mining activities occur along river Pratu and it contaminates Muni Lagoon with heavy metals					
I4	Mining activities occur along river Ntakofa and it contaminates Muni lagoon with heavy metals					
I5	Industrial wastewater is not treated before discharging into water bodies					
I6	Industrial pollution of Muni Lagoon and its tributaries is increasing the heavy metal load in them.					
	Building and Encroachment					
B1	Encroachment has degraded part of the forest in the muni catchment area.					
B2	Building close to the lagoon has increased sand winning at the beach.					
B3	Encroachment has threatened the lives of many animals in the muni forest resource.					
B4	Building close to river banks has enhanced flooding in my community					
B5	Filling wetlands and putting up buildings in the Muni catchment area put residents at risk in terms of flooding					
B6	Workshops built near water banks contaminate rivers					

APPENDIX H

UNIVERSITY OF GHANA

ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES (ECBAS)

P. O. Box LG 1195, Legon, Accra, Ghana

Ref. No: ECBAS 097/21-22

17th February, 2023

Mr. Twumasi Ankrah Kwarteng
Department of Environmental Science and Sanitation
University of Ghana
Legon, Accra

Dear Mr. Kwarteng,

ECBAS 097/21-22: QUALITY OF MUNI LAGOON AND ITS TRIBUTARIES IN EFFUTU MUNICIPALITY, GHANA

This is to inform you that the above referenced study has been presented to the Ethics Committee for Basic and Applied Sciences for a full board review and the following actions taken subject to the conditions and explanation provided below:

Expiry Date:	18 /02/2024
On Agenda for:	Initial Submission
Date of Submission:	19/11/2022
ECBAS Action:	Approved
Reporting:	Annually

Please accept my congratulations.

Yours sincerely,

ETHICS COMMITTEE FOR BASIC AND APPLIED SCIENCES
APPROVED
17 FEB 2023
UNIVERSITY OF GHANA

Professor Dorcas Osei-Safo
ECBAS Chairperson

INTEGRI PROCEDAMUS

APPENDIX I

FORESTRY COMMISSION
(WILDLIFE DIVISION)
P.O. BOX MB 239, ACCRA, GHANA
TEL: (233-0302) 401210 / 401227 / 401216 / 401231 / 401249
FAX: (233-0302) 401179
E-MAIL: info_wd@hq.fcghana.com

Our Ref No.: WD/A30/Vol.12/65
Your Ref No.:
Date: 17th May, 2021

UNIVERSITY OF GHANA
INSTITUTE FOR ENVIRONMENT AND SANITATION STUDIES
P. O. BOX LG 209
ACCRA

Dear Sir,

RE: LETTER OF INTRODUCTION: MR. TWUMASI ANKRAH KWARTENG

We make reference to your letter number IESS.AC13/03/10704529 of 12th April, 2021 on the above subject matter.

This is to inform you that permission has been granted Mr. Twumasi Ankrah Kwarteng, a third year PhD Environmental Science candidate of your Institute to conduct a research on the ***"Quality of Muni Lagoon and its feed rivers in the Effutu Municipality"*** from the 1st June, 2021 to 31st May, 2021.

As a precondition, be informed that the Wildlife Division is very much interested in the research and development of this kind and would like to be a collaborator in the data collection for the research and also contribute towards joint publications arousing from this research work.

The Division has waived the research permit fee of the Cedi equivalent of Six Hundred US Dollars (US$600.00) in support of the research work. He will however pay all other charges such as park entry and guide fees.

He will carry out your collection under the following conditions

1. Samples will be taken guided by staff of the Ramsar Site
2. Submit two (2) copies of report to the Executive Director
3. Provide the Executive Director with three (3) copies of any publication emanating from the research.

You are required to cooperate with the Ramsar Site Authorities and follow strictly all the conservation guidelines of the Conservation Area to enable you have a successful research.

By copy of this letter, the Manager in charge of the Ramsar Site has been urged to give you the necessary assistance to make your study a success.

Thank you.

Yours faithfully,

RICHARD GYAMAH (PhD)
DIRECTOR, STAKEHOLDERS & ECOTOURISM
for: EXECUTIVE DIRECTOR

Cc: The Park Manager
Muni-Pomadze Ramsar Site.