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ASSESSING THE ECOLOGICAL CHARACTER OF WETLANDS AND THEIR IMPACT ON THE DISTRIBUTION AND ABUNDANCE OF WATERBIRDS IN SOME COASTAL WETLANDS IN GHANA

This thesis is submitted to the University of Ghana, Legon

BY

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DECLARATION

This thesis is the result of research by Stephen Addo Oduro of the Institute for Environment and Sanitation Studies (IESS), College of Basic and Applied Sciences, University of Ghana, Legon under the supervision of Prof. Chris Gordon (Institute for Environment and Sanitation Studies, IESS), Prof. Yaa Ntiamoa-Baidu (Department of Animal Biology and Conservation Science, DABCS) , Dr. Daniel Nukpezah (Institute for Environment and Sanitation Studies, IESS) and Dr. Benjamin Nyarko (Department of Geography and Regional Planning , University of Cape Coast) and the literature cited in the thesis duly acknowledged.

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ABSTRACT

This study sought to assess the ecological character of the Sakumo II, Laloi and Kpeshie coastal wetlands in Ghana as these wetlands face massive degradation largely driven by urbanization and the rapidly growing human population in these areas. Specifically, the study investigated the quality of water and sediments, the changes in the physical characteristics (land use/land cover), the distribution of benthic macroinvertebrates, the growth and condition factor of the predominant fish species in lagoons in Ghana (*Sarotherodon melanotheron*), and how they influence the abundance and distribution of waterbirds on these wetlands.

Data for this study were obtained from direct field observation and laboratory analysis. Counting of waterbirds was done by using a Swarovski 20 x 60 telescope while sampling and laboratory analysis of water and sediment were done by using approved standard methods (APHA, 2005). The sampling and sorting of benthic macroinvertebrates into their various taxa were also done by appropriate keys and guides. The standard length and weight of the blackchin tilapia (*Sarotherodon melanotheron*) were measured using the rule and Mettler Toledo Weighing balance while Landsat thematic images were freely downloaded from the United States Geological Survey (USGS) for the years 1986, 2002, and 2017.

A total of 24,247 individual waterbirds belonging to 13 families were counted monthly on all three wetlands over a period of one year. Fifty (50) different waterbird species were recorded with the most abundant species belonging to the family Scolopacidae (88.71%) which were mostly waders. In terms of abundance of waterbirds on each site, 12,143 individual waterbirds representing 50.1% of total count was recorded on the Laloi wetland with the Common Ring Plover (*Charidrius hiatucula*) being the dominant species. The Sakumo II had a record of 10,116 waterbirds representing 41.7% with the Collared Pranticole (*Glareola prantincola*) as the most dominant. The Kpeshie wetland recorded 1,988 representing 8.2% of the total count with the Common Sandpiper (*Actitis hypoleucos*) as the most abundant waterbird.

In terms of land use land cover changes (LULC) on the wetlands, there was a decrease change of 57.3% of the vegetative cover and 0.6% of waterbodies between 1986 and 2017 with a corresponding increase of built-up areas by 54.4% on the Sakumo II wetland. Vegetative cover and waterbodies also decreased by 58.3% and 6.6% on the Laloi wetland with a resultant increase of 53% in built–up areas over the same period. Furthermore, the vegetative cover and waterbodies decreased by 33.7% and 15.2% on the Kpeshie wetland while built-up increased significantly by 50.8%.There were significant positive correlation between conductivity and nitrite ($r=0.698$, $r=0.760$, $p<0.01$ respectively) likewise an inverse relationship between water depth, phosphate and nitrate ($r=-0.998$, $r=-0.920$, $r=-0.981$; $p<0.01$ respectively) and built-up on the Sakumo II wetland. Land use land cover variables together accounted for 26.8% of the changes in abundance of waterbirds during the study. Built-up and vegetation had a significantly negative relationship with waterbirds abundance [$\beta=-0.651$; $p<0.05$] [$\beta=-1.185$; $p<0.05$] while waterbodies and barelands had a significantly positively relationship with waterbird abundance [$\beta=0.487$; $p<0.05$] [$\beta=1.430$; $p<0.05$].

The mean pH(7.65 ±0.65, 8.05 ±0.65, 7.92±1.30) and temperature (29.23 ±1.35oC, 28.76 ± 0.74oC and 29.71 ±2.11oC) of water samples collected from the Sakumo II, Laloi and Kpeshie wetlands respectively were typical of shallow coastal waters in Ghana with ambient pH and temperatures within a narrow range of 6 - 9 and 25-35 ^{0}C. The BOD, turbidity, phosphate and nitrate levels in water samples on both the Sakumo II and Kpeshie wetland were above the WHO permissible limits. Based on the pollution load index (PLI) estimated for all the wetlands using the bottom sediment, there was no overall pollution of heavy metals in sediment although some sites showed extreme enrichment (PLI<1). Heavy metals in PC1, PC2 and PC3 jointly and significantly contributed 25%, 57% and 30% respectively to macroinvertebrates abundance at the Sakumo II, Laloi and Kpeshie wetlands [$R^2=0.25$ $p<0.05$; $R^2=0.57$, $p<0.05$; $R^2=0.30$, $p<0.05$].

A total of 4,474 macroinvertebrates individuals belonging to three major phyla (Annelida, Mollusca and Crustacean) were recorded during the study. *Hydrobia spp*, *Cerithedia* spp and the *Nereis spp* were the most abundant on the Sakumo II, Laloi and Kpeshie wetlands respectively. Macroinvertebrates abundance contributed 12%, 22% and 4% to waterbirds abundance at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.12$, $p>0.05$; $R^2=0.22$, $p<0.05$; $R^2=0.04$, $p>0.05$].

Sarotherodon melanotheron fishes in the Sakumo II lagoon exhibited isometric growth (‘b’ is nearer to 3) while a negative allometric growth pattern was observed in fishes from the Laloi and Kpeshie lagoons. Mean condition factors estimated for *Sarotherodon melanotheron* on all wetlands were greater than one (1) indicating a good environment for fish survival and abundance. Fish condition factor also significantly contributed to 25%, 34% and 35% of waterbirds abundance on the Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.25$ $p<0.05$; $R^2=0.34$, $p<0.05$; $R^2=0.39$, $p<0.05$].

There have been major changes in the quality of water and sediment on all three wetlands, likewise, significant changes in the vegetative cover, waterbodies and built-up areas between 1986 and 2017 due to human interferences on the wetlands. The unprotected Laloi wetland, however, supported the highest number of waterbirds compared to the protected Sakumo II wetland during the study.

Major stakeholders like the EPA, the Water Resources Commission, the Forestry Commission, the Ghana Wildlife Division as well as the District and Municipal Assemblies should enforce all existing laws that will help conserve and protect these wetlands from further deterioration. Education and awareness creation on the level of usage, importance and benefits derived from these urban coastal wetlands should be intensified within the catchment areas as human population continues to increase inorder to achieve Goal 6, 14 and 15 of the Sustainable Development Goals (SDG) in and around these urban wetlands.

DEDICATION

This thesis is dedicated to my wife, Rhoda Okwan Afful and my future leaders Nana Yaw Safo, Okatakyie Kofi Safo and Opanyin Yaw Safo for their love, prayers, understanding and unflinching support during my studies.

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LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometer
APHA	American Public Health Association
ASCR	Automatic Scattergram-Controlled Regression
ATSDR	Agency for Toxic Substances and Disease Registry
BOD	Biochemical Oxygen Demand
CF	Contamination Factor
CCME	Canadian Council of Ministers of the Environments
COP	Conference of Parties
CWMP	Coastal wetland management project
EF	Enrichment Factor
EPA	Environmental Protection Agency
FAAS	Flame atomic absorption spectrometry
DO	Dissolved Oxygen
GPHC	Ghana Population and Housing Census
GPS	Global Positioning System
GSS	Ghana Statistical Service
DWAF	Department of Water Affairs and Forestry
IUCN	International Union for Conservation of Nature

LULC	Land use/Land cover
LULCC	Land use/Land cover changes
LWR	Length-Weight Relationship
MCL	Maximum Contaminant Level
PCA	Principal Component Analysis
PLI	Pollution Load Index
SQG	Sediment Quality Guidelines
SSBP-G	Save the Seashore Birds Project-Ghana
TMA	Tema Municipal Assembly
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
WHO	World Health Organisation
WRC	Water Research Commission

CHAPTER ONE

INTRODUCTION

1.0 Background

Wetland ecosystems are essential for the wellbeing of humans and contribute to local and national economies (EPA, 2017). Globally, wetlands are the most dynamic ecosystem on the surface of the earth due to the diversity of the habitat which comprises key fauna and flora they support. Wetlands are generally characterised by shallow waters, covering waterlogged soil, interspersed by submerged and emergent vegetation which supports significant biodiversity throughout the world (Huang *et al.*, 2012, Zhang *et al.*, 2013, Mitsch & Gosselink, 2015).

Wetlands purify and replenish waters, provide fish and foodstuff that feed humankind, act as natural sponges against flooding and drought and protect coastlines as well as help fight climate change (Convention on Biological Diversity, 2015).Wetlands also serve as key habitats of the world's waterbirds; as migratory waterbirds make use of wetlands along their flyways either for staging (stopover), nesting, breeding, roosting, foraging and for the non-breeding periods (Stewart, 2001; Convention on Biological Diversity, 2015).

The Ramsar convention recognizes five main types of wetlands which include marine, estuarine, lacustrine; riverine and palustrine wetlands (Ramsar Convention Secretariat, 2016) and defines their ecological character as the structure and inter-relationships between the physical, biological, and chemical components of the wetlands which are derived from the interactions among the processes, functions, and values of the wetland ecosystem (Ramsar, 2016).

Ghana is a signatory to several international conventions such as the Ramsar Convention and the Bonn Convention that seek to conserve and protect wetlands and the biodiversity they support. Under these treaties and conventions, Ghana has an obligation to ensure the wise use of all wetlands in the country for the benefit of its human population, wetland habitats, wildlife, and migratory animals in a sustainable manner without compromising the natural properties of the ecosystem (Ntiamoa-Baidu, 1991, Ntiamoa-Baidu & Gordon, 1991). The Bonn convention for example obliges Ghana to specifically provide stringent protection for migratory species (Ntiamoa-Baidu & Gordon, 1991).

Ghana's 550 km coast has about one hundred (100) wetlands comprising mainly of non- tidal estuaries and lagoons (Ntiamoa-Baidu, 1991, Ryan, 2005). In 1992, Ghana designated five coastal wetlands as Ramsar sites based on their international significance for waterbirds in terms its population and species present in globally significant numbers (Ntiamoa-Baidu & Herpburn, 1988; Ntiamoa-Baidu, 1991; Willoughby *et al.*, 2001).

Gordon *et al.*, (1998) also reported of a number of non-protected wetlands in Ghana, which also supported many forms of biodiversity, including waterbirds. Attuquayefio and Gbogbo (2001) indicated that most of these non-protected wetlands in Ghana were publicly owned, unmanaged, unregulated and were being exposed to indiscriminate exploitation of the resources they provided.

Rapid population growth with associated anthropogenic interferences depletes wetland resources and reduces the ecosystem services they provide. The upsurge of these human pressures and the inefficient land-use management policies in Ghana has significantly affected wetland ecosystems especially urban coastal wetlands (Pinamang, 2001, Attuquayefio & Gbogbo, 2001).

With the intensification of human activities, wetlands in general have been subjected to heavy human pressure through encroachment and unsustainable exploitation of the wetland resources through agricultural activities leading to runoff, and siltation, likewise an increase in levels of industrial and domestic pollutants (Baral & Inskipp, 2005, Kafle *et al.*, 2008, Mitsch & Gossenlink, 2015). These threats on wetlands have severe consequences on biodiversity especially the waterbird species as it leads to changes in their community structure as well as a decline in their numbers and population (Millennium Ecosystem Assessment, 2005, Kloskowski *et al.*, 2009).

The survival and reproductive success of migratory waterbirds are determined mainly by the quality of the wetlands they encounter on their migratory route (Spellman, 2004) as the distribution, abundance and population dynamics of waterbird provide important ecological information which reflects the quality of wetlands. The diversity and population of waterbird species in an ecosystem is often a good indicator of the status of the ecosystem as waterbirds serve as key bioindicators of wetland quality (Schreiber & Burger, 2002, Abdourahamane, 2010).

Also, the density and composition of food sources on wetlands for waterbirds serves as an important bioindicator of the quality of the wetland habitat as well (Davis & Smith, 1998; Taft & Haig, 2005; Hartke *et al.*, 2009). Therefore, changes in the land cover and pollution of any coastal wetlands, mainly from the discharge of raw sewage, industrial waste and agricultural runoffs will also affect waterbird and the macroinvertebrates community structure and population (Tanalgo *et al.*, 2015). Low density of macroinvertebrates on wetlands will suggest few and less food source to support waterbirds especially waders who depend on macroinvertebrates for survival (Ntiamoa-Baidu & Hepburn, 1988).

1.1 Problem statement and relevance of the study

Although wetlands continue to support human survival by providing unique ecosystem services such as habitat for waterbirds, providing fish, fuel wood, and salt for domestic purposes as well as income for coastal dwellers, they face massive degradation largely driven by urbanization and rapidly growing human population in coastal areas (Hinrichsen, 1999; Nicholls, 2004, Ansa-Asare *et al.,* 2008). Human activities such as over-hunting, over exploitation of fish, cutting of mangrove vegetation for fuel wood, farming practice, and developments within the catchment have negatively impacted wetlands in terms of change in the land cover, water and sediment quality, habitat loss, extinction and reduction of waterbirds and loss of other forms of biodiversity with the least ecosystem disturbance (Gordon *et al.,* 1998, Mitsch, & Gosselink, 2000, Kangah-Kesse *et al.*, 2007).

According to a World Bank report, about 25% of the population of all Ghanaians who migrate into the cities generally live around and on coastal areas (EPA/World Bank, 1997) and contribute directly or indirectly to the amount of abuse of the coastal ecosystem with increase in untreated domestic waste discharged into wetlands especially in urban cities like Accra and Takoradi (Afoakwa *et al.*, 1998). The Greater Accra region like most cities in the world has a considerable number of coastal wetlands along its coast and most of these urban coastal wetlands have become final recipient of all domestic, municipal, agricultural and industrial wastes which are usually transported by streams and drain directly unto the wetlands (Biney, 1986; Doamekpor *et al.*, 2018). These wastes discharged carry large amounts of suspended solids and dissolved organic matter, as well as harmful metals thereby affecting the flora and fauna within these wetlands and its catchment (Nonterah *et al.*, 2015). The discharge of these potentially harmful wastes unto the wetlands causes changes in the aquatic species, changes in the waterbird distribution and the health of the ecosystem due to their accumulative behaviour (Allen, 1995, Okocha & Adedeji, 2011, Pandey & Madhuri, 2014).

Despite the immense value of these urban coastal wetlands for humans and biodiversity, they continue to be under constant threat from both natural and anthropogenic activities causing changes in the land cover and biodiversity especially waterbird populations and other wetlands resources (EPA, 2017).

The Sakumo II wetland, a protected wetland, in recent years has seen several landuse changes largely influenced by human interference such as the conversion of the land for residential and agricultural purposes coupled with the emergence of enormous aquatic weeds in the lagoon catchment, resulting in reduced freshwater inflow into the wetland (Anku, 2006). The Sakumo II wetland which used to support a total of 66 waterbird species with an estimated bird population of 32,500 during the coastal wetland management project in 1992 (CWMP) revealed sharp declines in bird populations in similar studies by the Centre for African Wetlands (2017, 2019) on report on wetlands and waterbirds, count of the east atlantic flyway, Gbogbo *et al,* (2009) and Gbogbo & Attuquayefio, (2010). The Sakumo II wetland which used to holds about 90-100% of the total populations of Black Heron, Teal, Black-tailed Godwit, Avocet, and Ruff recorded on the Ghanaian coast has shown sharp declines of these species on the same wetland and in most cases total collapse of some waterbird species over the years (Ntiamoa-Baidu & Gordon, 1991; EPA, 2017).

The decline in the waterbird population on most urban coastal wetlands in Ghana does not only affect the protected Sakumo II wetland but also the unprotected wetlands such as the Laloi and Kpeshie coastal wetlands in the Greater Accra region as there have been reports of sharp decline in waterbirds abundance on these unprotected wetlands as well, mainly due to the increased levels of anthropogenic activities and encroachment (Gbogbo *et al.*, 2009, Koney, 2010, Lamptey & Danson, 2014, EPA, 2017).

These anthropogenic activities in and around the Sakumo II, Laloi and the Kpeshie wetlands have become a key impairment to the quality of water, the sediments and the wetland biodiversity (Nonterah *et al.*, 2015, EPA, 2017, Doamekpor *et al.*, 2018). Though, reasons such as increased pesticide and chemical use from agricultural activities (Addo *et al.,* 2011, Nartey *et al.*, 2011, Doamekpor *et al.*, 2018), improper disposal of sewage and refuse (Nukpezah, 2001, Ansah, 2008) as well as expansion in residential buildings and settlements

(Nonterah *et al.*, 2015) have been suggested, further investigation is required to understand how the impact of the quality of water and sediment, the land use and land cover changes, the distribution of macroinvertebrate, the health and condition of fish in the lagoons have affected the distribution and abundance of waterbirds over a period of three decades for better understanding of these urban coastal ecosystem.

Few studies in Ghana have examined wholistically the status of waterbird distribution and abundance from the perspective of the land use/land cover changes, abundance of macroinvertebrates, growth and condition of fishes in the lagoon waters, the quality of water and sediment as studies conducted on these wetlands had focused primarily on the value of the wetlands for fish and waterbirds (Ntiamoa-Baidu, 1991; Koranteng, 1995; Gordon, 2000; Gbogbo & Attuquayefio, 2010; Ntiamoa-Baidu *et al.*, 2014).

Most studies on the waterbirds in Ghana have focused mostly on the designated wetlands at the expense of the non-designated ones like the Laloi, Kpeshie, Esiama, Mokwe, Korle which have been reported to support significant number of biodiversity especially waterbirds (Gbogbo, 2007, Gbogbo & Attuquayefio, 2010). The State of the Environment Report in 2016 by the Environmental Protection Agency (Ghana) established the fact that almost all the urban wetlands in Ghana were under enormous threats from urbanization, demand for the wetland for housing, industrial developments, subsistence agricultural farming activities on the wetlands, industrial pollution, domestic and agricultural waste pollution, over-exploitation of wetland resources have led to the degradation of these important urban wetlands (EPA, 2017). Currently, it is however unclear, what drives massive development leading to the degradation of these urban wetland ecosystem which was supposed to be regulated by legislations like the Wetland Management Regulation of 1999 (Legislative Instrument 1659), the Fisheries Regulations, 2010 (L.I. 1968), the Land Use and Spatial Planning Act, 2016 (Act 925) and Water Resources Commission, 1996 (Act 522) etc.

These changes and degradation on the wetlands have negatively affected waterbird populations and other forms of biodiversity, thus providing high quality wetland for waterbirds and other forms of biodiversity through effective wetland management strategies and studies is urgently needed in wetland conservation to ameliorate these impacts (Weber & Haig 1996; Sekercioglu *et al.*, 2004).

Furthermore, the need for ecological studies on the selected coastal wetlands becomes more imperative when considered against the background of general global declines in the populations of migratory waterbirds (International Wader Study Group, 2003) and the global trends in which wetlands are being degraded which affects the survival and abundance of waterbirds in Ghana.

In view of the importance of wetland sites locally and internationally, this current study sought to undertake an assessment of these urban wetlands in the capital of Ghana to understand the waterbird population trends to provide a basis for formulating policies for waterbird conservation in Ghana. Furthermore, assessing the changes that might have occurred on the Sakumo II, Laloi and Kpeshie wetlands over three decades will provide other possible further management strategies needed to enhance the sustainability of these urban wetlands by policymakers and other key stakeholders.

1.2 Objectives

The general objective of this study is to assess changes in the ecological character of the Sakumo II, Laloi and Kpeshie wetlands and their present capacity to support waterbirds and other forms of biodiversity.

The specific objectives are:

i. to assess changes in the chemical composition of water and sediments of the selected wetlands and their impact on waterbirds

ii. to investigate changes in the physical characteristics of the selected wetlands and the impact on composition and distribution of waterbirds over a period of three decades.

iii. to investigate the spatio-temporal variation in the composition and distribution of waterbirds within the selected urban wetlands

iv. to assess the growth pattern and condition factor of the predominant fish species in the coastal lagoons on the wetlands

v. to identify the drivers for changes on the wetlands if any and the best management practices to be adopted to sustainably manage these wetlands through a survey

1.3 Research Questions

1. Have there been any changes that have occurred in terms of the land use/land cover on the wetlands?
2. What is the current state of the lagoon waters and sediment on the wetlands?
3. What is the current distribution and abundance of waterbird species and benthic macroinvertebrates on the coastal wetlands?
4. What are the major drivers of changes on the wetlands?

1.4 Hypotheses

1. There have been major changes on the Sakumo II, Laloi and Kpeshie coastal wetlands due to changes in the land use/land cover which has affected the abundance and distribution of waterbirds
2. Anthropogenic activities have an effect on the quality of water and sediments on the coastal wetlands
3. The protected wetlands support more waterbirds than unprotected wetland

CHAPTER TWO

LITERATURE REVIEW

2.1 Global overview of wetlands

Wetlands occur everywhere on the surface of the earth. The total surface area of the earth presently covered by wetlands is exactly unknown; however, the UNEP-World Conservation Monitoring Centre has suggested an estimate of 5.7 million km^2 which is roughly about 6% of the Earth's landmass (Mitsch & Gosselink, 2015). The Ramsar Convention on Wetlands suggested global inland and coastal wetlands cover over 12.1 million km^2 (Ramsar, 2018). Wetlands are environments primarily controlled by water with its associated flora and fauna. They normally occur where the water table is at or near the surface of the land and includes other human-made wetlands such as wastewater treatment ponds and reservoirs (Ramsar, 2013, 2016).

In Africa, wetlands cover approximately 1% of the total landmass with some important wetlands like the Zaire swamps, the Sudd in Egypt and Sudan, Lake Victoria basin, the Chad Basin, the Okavango Delta in Botswana and the floodplains of Rivers Niger and Zambezi (Agbemehia, 2014, Mitsch & Gosselink, 2015). Ghana also has a number of important wetlands which include the protected and designated Keta, Songor, Sakumo II, Densu and Muni coastal wetlands, as well as relatively smaller unmanaged and unprotected wetlands such as the Esiama, Kpeshie, Fosu, Nakwa, Mukwe coastal lagoons, Lake Bosumtwi, Black, Red and White Volta (Ntiamoa-Baidu & Gordon, 1991, Ministry of Lands and Forestry, 1999, Ryan & Ntiamoa-Baidu, 2000).

2.1.1 Importance and threats to wetlands

Wetlands are among the world's most productive habitats supporting countless plants and animals as well as regulating global carbon levels which serve as warehouse for most plant genetic material which feeds more than half of humanity (US Environmental Protection Agency, 2002, Clarkson *et al.*, 2003, Ramsar, 2013).

Wetlands provide tremendous services in the form of water quality to communities, fisheries; agriculture, forest resources, building materials, wildlife resources, herbal medicines; recreation and tourism opportunities to humankind (Dugan, 1990, Davis, 1993; 1994, Ramsar, 2013). Wetlands and humans are ultimately interdependent as they play a major role in the form of their cultural heritage which is often linked to communities' religious beliefs and spiritual values (Toit & Perret, 2006, Ramsar, 2013).

Apart from the enormous benefit derived from wetlands, they are ecosystems with the most threatened habitats because of their attractiveness for development (Ntiamoa-Baidu & Hollis, 1988). Some of the major threats to coastal wetlands may be natural while others may be artificial. Some of the natural threats include floods, storms and naturally occurring processes that have the potential to destroy wetlands globally (Daryadel & Talaei, 2014). Soil erosion is a major natural threat to wetlands ecosystem because soil erosion leads to soil degradation and desertification which leads to the loss of soil nutrient (Yirdaw *et al.*, 2017). Soil erosion further leads to sedimentation which kills most aquatic macro and micro invertebrates and destroys the unique habitat they need to survive (Yirdaw *et al.*, 2017). Sediment re-suspend in the water columns as it turns cloudy and prevents penetration of sunlight making feeding difficult for aquatic animals which rely on sight to obtain their food source (Shakeri & Moore, 2010).

Drought is also another major natural threat which affects wetlands as flora and fauna depend on water for their survival. Frequent drought on wetlands reduces the ability of wetlands potential to act as carbon sinks and turns the carbon into sources of atmospheric carbon especially methane which is a greenhouse gas (GHG) and has a negative effect on the environment (Tian *et al.*, 2012).

The artificial threats to wetlands include anthropogenic sources of pollution such as the release of urban and industrial wastewater discharges to wetlands which has the tendency of altering the growth of aquatic plants and reducing waterfowl abundance on wetlands (Daryade & Talaei, 2014). Ecotourism which plays a significant role in most economies damages wetland and protected areas as they cause serious damages to wildlife and biodiversity through tourism-related activities like constructions of roads, use of water, treatment of wastewater, and rapid urbanisation in and around wetland communities (Kotios *et al.*, 2009).

2.1.2 Global effort to protect wetlands

The interest to protect wetlands internationally increased in the 1970's following concerns at the frightening rate with which wetlands in Europe were being destroyed, with a resulting decline in a large number of waterfowl (Ramsar, 2013). To improve the increasing trend in wetlands destruction, the International Convention on Wetlands (Ramsar Convention), especially as Waterfowl Habitat was signed in Ramsar, Iran in 1971. At the centre and core mission of the Ramsar convention is the "wise use" concept which is primarily defined as "the maintenance of the ecological character of all wetlands achieved through the implementation of sustainable ecosystem approaches for the benefit of humankind (Kumar & Kanaujia, 2014). Thus, changes in the ecological character of any wetlands by human alteration basically results in the adverse change or the negative impairment in any of the functions and benefits of the wetlands as captured in the definition of change in the ecological character by

Dugan & Jones (1993) which states that human-induced changes on wetlands include altered hydrological regimes; nutrient pollution, physical alteration in the form of the land use and land cover, the loss of habitat and the introduction of alien flora and fauna (Ramsar Convention Secretariat, 1996).

A variety of other management efforts have been undertaken over the years by continents and countiries to counteract many of the factors leading to wetland loss. Some of the strategies adopted to ameliorate the loss of wetlands included the MedWet initiative adopted by the European Commission in the early 1990s, among governmental and non-governmental bodies to conserve the Mediterranean wetlands. This initiative was to stop and reverse the rapid degradation of all Mediterranean wetlands in their effort to conserve biodiversity sustainably in the region (Ramsar, 2016).

The Glob Wetland Africa, launched by the European Space Agency and the Ramsar Secretariat was an initiative strategy to use satellite observations as an effective tool for the conservation, wise use of all wetlands, especially in Equatorial Africa (globwetland-africa.org).

In Ghana, the Ghana Coastal Wetlands Management Project (CWMP) was implemented by the Wildlife Division of the Forestry Commission in 1991 to protect and manage the five designated coastal wetland sites by using the ‘wise use’ concept to maintain the integrity of the wetlands and also enhance the benefits derived from the wetlands by local communities (Finlayson *et al.*, 2000, Nukpezah, 2001).

2.2 Wetlands in Ghana

Three major types of wetlands are identified in Ghana and these are the marine/coastal wetlands, inland wetlands, and man-made wetlands (Ministry of Lands and Forestry, 1999). The marine/coastal wetlands are within the coastal zones of Ghana and are primarily associated with flood plains of estuarine and large rivers while the inland wetlands are associated with shallow freshwater bodies. Humans have created man-made wetlands for aquaculture, salt harvesting, water storage, and urban/industrial use (Ministry of Lands and Forestry, 1999, Agbemehia, 2014).

Apart from the enormous benefit coastal wetlands provide in Ghana, there are major threats if not tackled, will lead to the destruction and degradation of the coastal ecosystem in Ghana. Excessive human use of the wetland, such as overfishing, excessive collection of mangroves, widespread drainage and cultivation for farmlands, heavy grazing by cattle and animals, and an unsustainable amount of salt winning are some of the primary dangers to Ghana's coastal wetlands (Ntiamoa-Baidu, 1991, Yeboah *et al.*, 2013). Additional threats to most coastal wetlands in Ghana include the increased use of pesticides and herbicide in farming activities, the damming and creating of channels for the purpose of expanding infrastructure, and the dumping of solid and liquid waste onto wetlands (Nonterah *et al.*, 2015).

The main driver of change of these coastal wetlands in Ghana is the increase in human population encroaching coastal wetlands and through their activities like agriculture has led to modification of the land to obtain food and other essentials resources. The increase in fertilisers, organic manure from livestock and other agrochemicals substantially increase the pollution load of surface water by runoff, pollution of groundwater by leaching of excess nutrients which may have a negative effect on waterbodies and biodiversity on the wetlands (Islam & Weil, 2000; Dye, 2003; Nonterah *et al.*, 2015).

2.3 Waterbirds

The Ramsar Convention defines waterbirds as species of birds that are "ecologically dependent upon wetlands" (Bolduc, 2009). They are categorised as seabirds (e.g. gulls and terns), shorebirds/waders (e.g. plovers, sandpipers, stilts) and waterfowl (e.g. ducks). Waterbirds are ecologically dependent on wetlands which serve as stopover sites along their migratory flyways. They use wetland habitats for foraging, nesting, roosting, moulting and comfort activities. More than a third of all non-migratory birds live on wetlands, and at least half of all migratory birds, depend on wetlands for temporary habitat (Bradshaw *et al.*, 2020).

Waterbirds are key biodiversity groups widely used in monitoring wetlands value and status, as well as being used as bioindicators of wetland quality (Scott & Rose, 1996, Ahulu et al., 2006). Waterbirds on wetlands represent an important tool in biodiversity conservation, due to their conspicuousness, abundance, high species turnover, and sensitivity to changes and are useful in determining the quality of the wetland in which they live as their abundance on wetlands may be an indication of the abundance of preys such as fishes and macroinvertebrates on which they feed (Temple & Wiens, 1989). Waterbirds also provide many supporting and provisioning services such as the dispersal of seeds vital in agricultural and also in fisheries as indicators of rich fish stock in the sea. Although they provide all these enormous services they are mostly exploited as food in many parts of the world (Ahulu *et al.*, 2006; Krcmar *et al.*, 2010).

2.3.1 Waterbird distribution and abundance on wetlands in Ghana

Waterbird distribution may be categorised as large-scale or local as large scale patterns in waterbird distribution are mainly due to their natural occurrence on wetlands, whereas local distribution is mainly influenced by food distribution within the wetlands (Piersma *et al.*, 1993, Knutson *et al.*, 1999).

Waterbirds may be abundant or widely distributed on wetlands if there are the presences of safe roosting sites in such ecosystems and the availability of prey items within the wetlands (van Gils *et al.*, 2003; Blanc *et al.*, 2006). According to Piersma & Ntiamoa-Baidu (1995) and Battley *et al.*, (2003) waterbirds concentrate in areas with high food density. Waterbirds feed on a large variety of food ranging from macroinvertebrates (e.g. plovers), small fishes (Black-winged Stilt and Herons) to seeds and plants (herbivorous ducks). However, most individual birds choose their foraging habitats based on expected food intake rate rather than food density, though there is a strong correlation between bird distribution and food density (Piersma *et al.*, 1993).

Coastal wetlands in Ghana are key habitats for permanent and wintering Palearctic migrant waterbirds that migrate across the East Atlantic and Mediterranean flyways (Smit & Piersma, 1989). Migrant waterbirds come on the Ghanaian coast primarily in August and September, and stay until April. The peak numbers of waterbirds usually occur from September to October and another peak season in March (Ntiamoa-Baidu *et al.*, 2014).

Waterbirds are most abundant during the dry season when water levels on wetlands are generally low. The shallow water levels expose large mudflats and offer favourable conditions for foraging (Ntiamoa-Baidu *et al.*, 2014).

Waterbird population monitored on key wetland sites along the Ghana coast initiated under the SSBP-G in 1988 estimated 48 species of waterbirds during a 12-year survey period on the Muni wetland. Of the 48 species, 29 species were waders of which nine species together accounted for 94% of the total of 72,860 waders counted during the survey period (Ntiamoa-Baidu, 2000).

The Sakumo II site supported about 66 waterbird species on the Ghana coast and internationally important populations of six wader species including the spotted redshank, greenshank, curlew sandpiper, little stint, black-tailed godwit (Ntiamoa-Baidu & Gordon, 1991). Gbogbo and Attuquaefio (2010) recorded a total of 198,836 individual waterbirds belonging to 59 species over two non- breeding seasons on both the protected and non-protected wetlands in the Greater Accra of Ghana.

A total of 25 waterbird species, of which 11 were waders, three were terns, one gull and 10 other species belonging to 10 families totaling 20, 217 individuals were reported on the Keta Lagoon (Anyanui, Anloga, Woe, and Floodplains) and the Muni Lagoon by Lamptey & Ofori-Danson (2014). Waterbirds recorded at the Keta lagoon site accounted for 97.7% of the total count compared to 2.3% on the Muni lagoon (Lamptey & Ofori-Danson (2014).

2.4 Water quality of coastal wetlands

Pollution of water bodies on coastal wetlands may originate from two main sources, point sources and diffuse sources (non-point sources) (Pierce et al., 1998). Point sources are pollutants that enter watercourses through pipes or channels whereas non-point sources come from farm runoff, construction site and other land use land cover disturbances (Pierce *et al.*, 1998). The accumulation of contaminants from terrestrial, freshwater, and marine habitats has been discovered to be sensitive and a pollutant in most coastal wetlands (UNEP, 1995).

Wetlands are known to process pollutants due to their unique properties due to the hydric nature of the soils. However, with high pollution load, the assimilative capacity of wetland gets exceeded and get polluted with nutrients, trace and heavy metals which in turn become very toxic and harmful to wetland biodiversity and to human health (UNEP, 1995).

The discharge of industrial and domestic sewerage and the dumping of refuse into coastal environments increases the organic loadings of the coastal waters making the waters turbid with increase in plant growth of algal blooms which further leads to an increased levels of pH and turbidity producing toxins and odour detrimental to aquatic and human health (Wild 1995; Gopalkrusna, 2011).

Studies on the hydrology of most coastal wetlands located near densely populated urban areas and industrial establishments are known to be grossly polluted (Fianko *et al.*, 2013; Nonterah *et al.*, 2015, Doamekpor *et al.*, 2018).

Wetlands like the Chemu lagoon in Tema, Korle and Kpeshie lagoons in Accra, Fosu lagoon in Cape Coast are all in different states of degradation due to impacts of human practices. Thus, the waters of these wetland lagoons are highly turbid and contain high levels of BOD, suspended solids as well as toxic and harmful heavy metals (Doamekpor *et al.*, 2018).

2.4.1 Impact of water quality on waterbird distribution

Poor water quality with high concentrations of pollutants endangers many aquatic species especially macroinvertebrates and waterbirds (Cao *et al.*, 1996).

Pollution through anthropogenic activities causes very low dissolved oxygen content in water while high nutrient pollution causes eutrophication and result in the decrease and functional feeding activity of biodiversity residing in a particular ecosystem like macroinvertebrates and waterbirds (Duan *et al.*, 2011).

Water depth, a key water quality parameter affects available food resources as it limits access by some waterbirds and can also influence invertebrate populations, which provide an important food source for waterfowl (Ntiamoah-Baidu *et al.*, 1998; Baschuk *et al.*, 2012).

Salinity is a vital variable in the management of waterbird habitats. Generally, high salinity is detrimental to the distribution of waterbirds as waterbirds that drink highly saline water loose body weight due to dehydration (Hannam *et al.*, 2003, Ma *et al.*, 2010). High water salinity is also unbearable to fish, renders such floodplains and wetlands inhabitable by waterbirds due to their inability to find food (Lamptey *et al.*, 2013).

Heavy metals are common pollutants in aquatic environments released from anthropogenic sources which are non-biodegradable and thus accumulate in the environment over time and become toxic to organisms (Islam *et al.*, 2015). In the aquatic environment, heavy metals are adsorbed by suspended solids and sink into bottom sediments which are ingested into the bodies of macroinvertebrates and eventually waterbirds through foraging (Ciutat *et al.*, 2005, Ali *et al.*, 2021).

2.5 Sediment quality of coastal wetlands

Sediments provide a deeper understanding of the long-term pollution status of any coastal environment as sediments act as ready sink or reservoir of pollutants including trace and heavy metals (Onyari *et al.*, 2003, Islam *et al.*, 2015). Heavy metals are introduced into the bottom sediment by two means, the natural processes and human activities by means of direct discharges or dumping (Clark, 2001, Ali *et al.*, 2021). The pollution history of any aquatic ecosystem can be studied through sediments analysis as sediments provide useful information about the water quality from past period (Oyewale & Musa, 2006).

Pollution load indices have been employed by many researchers to investigate the behaviour of heavy metals in the environment (Addo *et al.*, 2011; 2012, Rabee *et al.*, 2011; Akoto *et al.*, 2017).

Pollution load indices are widely used methods for assessing the possibility of any negative ecological consequences of heavy metal contamination in sediments. They are environmental pollution control techniques and tools for determining the pattern of metal contamination in sediments (Abdullah *et al.*, 2015).

Pollution indices like geo-accumulation index (Igeo), enrichment factor (EF), contamination factors (CF) and pollution load index (PLI) have been used extensively to establish pollutant distribution in sediments (Samir *et al.*, 2006; Addo *et al.*, 2011, Bentum *et al.*, 2011, Abdullah *et al.*, 2015).

The enrichment factor (EF) of metals is a useful indicator basically reflecting the status and degree of environmental contamination of sediments (Feng *et al.*, 2004). The enrichment factor informs the researcher the source of the metals polluting the environment whether they are from natural processes of rocks or from anthropogenic sources while the contamination factor (CF) and pollution load indices (PLI) relates the concentration of the elements with their geochemical background reference values (Manoj & Pradhy, 2014) to find out if the site is polluted with the particular metal. The pollution load index (PLI) assesses the pollution status of any heavy metals in a particular site on a wetland (Tomlinson *et al.*, 1980).

2.5.1 Impact of sediment quality on macroinvertebrates and waterbird distribution

Direct impacts of sediment pollution on aquatic organisms especially macroinvertebrates includes being lethal as well as reduced fertility and fecundity in organisms which are polluted by sediment pollution (Ford *et al.*, 2003, Townsend *et al.*, 2009). Environmental stress, such as the accumulation of inorganic contaminants (Richardson *et al.*, 2000), has a significant impact on benthic invertebrates. For example, the accumulation of heavy metals in sediments could lead to the death of benthic invertebrates (Lee *et al.*, 2006). Metal contamination has been shown to have several consequences on benthic communities, including decreased density

(Winner *et al.*, 1980, Diggins & Stewart 1998), a drop in the number of vulnerable taxa (LaPoint *et al.*, 1984), and changes in species distribution patterns (Clements, 1994, Clements *et al.*, 2010).

Studies in other parts of the world have shown that heavy metals can also have an influence on the general health of some waterbirds (Janssens *et al.*, 2003; Dauwea *et al.*, 2004). Contaminants such as cadmium, mercury, and selenium have revealed to negatively affect the condition of birds by reducing their growth or body weight (Takekawa *et al.*, 2002). The effect of heavy metals like chromium, lead and cadmium on the embryo of the mallard bird showed that the Cr, Pb and Cd had a negative effect on the hatching and embryonic development of the bird thereby affirming that heavy metals may have an impact on the growth and nestling stage of the eggs (Bize *et al.*, 2002).

2.6 Benthic macroinvertebrates

Benthic macroinvertebrates are sedentary aquatic fauna found in the bottom soils of their habitats at least for a greater part of their life cycle (Idowu & Ugwumba 2005, Basu *et al.*, 2018). Benthic macrofauna performs important roles in nutrient cycling and a major source of food for other aquatic waterbirds especially waders (Jana & Manna, 1995).

Benthic macroinvertebrates are an essential part of the food web as they play a critical role in the natural flow of energy and nutrient as well as a link in the aquatic food chain (Gordon, 2000; Basu *et al.*, 2018; Nuamah *et al.*, 2018). Macroinvertebrate feed on these leaves, algae, and bacteria, which are at the lower end of the food web. In turn, macroinvertebrates also become a source of energy (food) for larger animals such as fish, which in turn also act as a source of food for birds and amphibians (Aggrey- Fynn *et al.*, 2011).

They are also used as bioindicators to assess the quality of water as they frequently respond to pollution stress in polluted ecosystems (Ikomi *et al.*, 2005). Studies on benthic macroinvertebrates response to pollution have been carried out in a number of countries including Ghana (Thorne & Willians, 1997, Lamptey &Armah, 2008; Abdourahamene, 2010; Baa-Poku *et al.*, 2013, Nuamah *et al.*, 2018). Baa-Poku *et al.*, (2013) observed that the Nima Creek was indicative of a disturbing urban creek with effluents negatively impacting macroinvertebrate assemblage. Ikomi *et al.*, (2005) also reported pollution status on the composition, distribution, and abundance of macroinvertebrates in the upper reaches of River Ethiope, Delta State, Nigeria.

2.6.1 Macroinvertebrate abundance and its impact on waterbird distribution

In many environments, benthic macroinvertebrates play a significant role in food chains (Frost et al., 2009). Multiple environmental factors, such as anthropogenically caused contaminants and changes in physicochemical and biological conditions in aquatic ecosystems, have a significant impact on their species richness and diversity (Frost *et al.*, 2009; Rumisha *et al.*, 2012). Sensitive macroinvertebrate species hardly survive in polluted aquatic habitats as a result of their diverse responses to disturbances, impacting waterbirds that may frequent the aquatic environment (Connell *et al.*, 2009).

Waterbirds are known to rely heavily on benthic macroinvertebrates for food (Grond *et al.*, 2015), and the quantity of benthic macroinvertebrates available on wetlands is considered to be critical for the short- and long-term survival of shorebirds, given their high energy demands throughout migration and mating season (Zhang *et al.*, 2016).

Aquatic macroinvertebrates function as a link between producers and higher-level consumers such as waterbirds (Baldwin *et al.*, 2018). Many factors influence macroinvertebrate distribution which directly or indirectly influences waterbirds, this include water and sediment quality, quality vegetation, and healthy wetlands (Zmudczyska-Skarbek *et al.*, 2009).

2.7 Fishery resource in coastal wetlands in Ghana

Sarotherodon melanotheron is a group of tropical, hardy, fast-growing fresh cichlid which lives in fresh to brackish water environments between the depths of 0-3 metres (Hoover, 2006). *Sarotherodon melanotheron* is native to West Africa and acquired its name from the patches of black colour that usually occur on their neck and throat (Teugels & van den Audenaerde, 2003; Mireku *et al.*, 2016). Studies have shown that *Sarotherodon melanotheron* is the most dominant and abundant species in the coastal lagoon in Ghana (Koranteng, 1995, Shenker *et al.*, 1998, Entsua-Mensah *et al.*, 2000, Mireku et al., 2016).

Fish populations have been reported to be on the decline mainly attributed to degradation in the water quality in which they inhabit and periodic phenomena of low water inflows and floods (Ayoola & Kuton, 2009), habitat complexity as well as inputs such as agrochemicals from agricultural and urban land uses through human activities (Fausch & Bramblett, 1991**)**.

The assessment of fish especially the growth parameters and the condition factor provide a detail understanding of the fish's length-weight relationship (LWR) (Dulčić & Kraljević, 1996) on the wetland they inhabit.

The growth parameter "b" in the length-weight equation shows whether the growth of fishes is in the coastal lagoons exhibit either isometric or allometric growth. The growth parameter value is always between 2 and 4 and most often closer to 3. If the fish grows isometrically, then the growth exponent takes the value of 3. A value significantly larger or smaller than 3 indicates allometric growth, (positive allometric if $b > 3$, negative allometric if $b < 3$) (Ricker, 1979, Solomon *et al.*, 2017).

On the length weight studies in previous studies, Pauly (1976) reported maximum standard length of 19 cm for tilapia collected from the Sakumo II lagoon, Ntiamoa-Baidu (1991) reported standard length ranging from 2.8 –12.1cm whilst Sawyerr *et al.*, (2015) recorded a standard length ranging from 2.63 - 12.86 cm also in the Sakumo II lagoon.

Similarly studies by Koranteng (1995) during a report prepared for the Ghana Wildlife Department recorded standard lengths ranging from 3.0-11.6cm and 2.9-10cm respectively for 200 fish samples each of *Sarotherodon melanotheron* collected from both the Sakumo II and Densu Delta. Dankwa *et al.*, (2004) also reported standard lengths of tilapia ranging from 1.5–12.1cm and 3.0-10.2 cm on both the Songor and Keta lagoons respectively.

For the growth parameter, Blay and Asabere Ameyaw (1993) during a study on the assessment of *Sarotherodon melanotheron*, in a close lagoon in Ghana found the *Sarotherodon melanotheron* in the Fosu lagoon to exhibit negative allometric growth (b = 2.65) for 500 fish samples. Similarly, Koranteng (1995) documented negative allometric growth patterns (b= 2.63 and b= 2.77) for the black chin tilapia in the Sakumo II and Songor lagoons respectively.

The condition factor explains generally the condition of the fishes in their aquatic environment and is based on the length-weight parameters. The condition factor (CF) is an estimation of the general well-being of fishes and is based on the assumption of either the fish is being heavier at a given length or lighter at a given length. The condition factor of 1.0 or > 1 indicates good condition for fishes in their aquatic environment while condition factors < 1.0 indicate a stressful environment for fishes in their habitat (Khallaf *et al.*, 2003; Solomon *et al.*, 2017).

Previous studies on fish condition by Mireku *et al.*, (2016) estimated a condition factor for male *Sarotherodon melanotheron* between 3.95 - 4.94; while that for females ranged from 4.08 - 4.99 for a total of 457 *S. melanotheron* collected in the Brimsu reservoir. The high condition factor recorded indicated a good water environment for *S. melanotheron*. In other parts of Africa, Solomon *et al.*, (2017) recorded very high condition factor values for fish species like the periwinkle (*Tympanotonus fuscatus*), in the Okrika estuary, Niger-Delta Nigeria. The high mean condition factor value of 18.9 showed that the fish species collected were in good favourable conditions although the creek received refinery effluents in large amounts from the catchment.

2.7.1 Condition of fish as an indicator of waterbird distribution

Waterbirds and inland and coastal fisheries are intricately linked (Green & Elmberg 2014). Waterbird populations are dropping over the world as a result of habitat loss, disturbance, or changes in habitat quality, which are occasionally induced by fishing activities (Green & Elmberg, 2014; Bundy *et al.*, 2017). Waterbird wintering ranges have shrunk as wetlands have shrunk, causing changes in diet and habitat use patterns in many waterbird assemblages.

Aquatic communities including fish assemblage and other species act as biological indicators of water quality and serve as food for waterbirds (Davis, 1993).

Fishes can be used to detect changes in the natural environment, monitor the presence of pollution in the ecosystem in which the organisms lives especially in water for the presence of contaminants (Davis, 1993).

Fish abundance often significantly affects habitat use by waterbirds (Kloskowski *et al.*, 2010; Russell *et al.*, 2014). Aquatic environments supporting large number of fishes may be used by an assemblage of diving, piscivorous waterbirds (Paszkowski &Tonn, 2000). Fish-eating waterbirds always benefit from increases in fish populations (Lammens, 1999), whereas decrease in fish population adversely affect waterbird distribution especially for the diving piscivorous birds (Van Eerden *et al.*, 1993)

Humans have a long history of altering aquatic ecosystems through wetlands, agricultural runoff, and small to large-scale fishing activities, all of which can have an impact on habitat quality, fish quantity, and waterbird assemblage variety (Atkinson et al. 2010; Lunardi & Macedo 2013). According to several studies, waterbirds may congregate in response to a seasonal rise in fish quantity (De Nie 1995; Warke & Day 1995; Battley et al., 2003). In reaction to improved fish stocks, the population size of several species of cormorants increases dramatically (De Nie 1995; Warke & Day 1995). Fish are concentrated in narrow, shallow regions by social foraging of mixed species assemblages of herons, egrets, and long-legged shorebirds, permitting active predation (Battley *et al.*, 2003).

2.8 Land use land cover changes (LULCC) on wetlands

Land use/land cover changes on wetlands are mostly driven by anthropogenic activities or natural phenomenon which causes changes that impact human lives either positively or negatively (Loveland *et al.*, 2003, Kamusoko & Aniya, 2007).

The land cover of any wetlands encompasses the physical landscape which includes the forest, vegetative features, open water, bare lands, and the non-vegetative features while land use is the activities performed by humans on the land leading to either a change in the physical landscape (Xiangmei *et al.*, 2016, Izakovicová *et al.*, 2018). Land use and land cover are usually used together to avoid ambiguity (Lillesand *et al.*, 2004).

Physical changes in the land use and land cover may impact on wetlands either positively or negatively, spatially or temporally, but however, the balance is always tilted to the negative in most wetlands (Global Land Project, 2005).

Human populations through agricultural activities modify land through the increase use of fertilisers, organic manure from livestock and other agrochemicals which substantially increase the pollution load of surface water by runoff and also the groundwater by leaching of excess nutrients which may have a negative effect on waterbodies and biodiversity inhabiting it (Islam & Weil, 2000). Discharging domestic, agricultural and industrial waste on the ecosystem increases both nutrients load and the toxic heavy metals which in turn seriously contaminate the waterbodies endangering flora and fauna of the ecosystem (Dye, 2003).

2.8.1 Effect of LULC changes on biodiversity and waterbirds

Wetland degradation has a significant impact on waterbirds, as harvesting or introducing exotic species reduces the value of the wetland, making it of little or no use to wetland-dependent waterbirds (Stewart, Jr., 2016). The presence of surface water or sediments, as well as the duration and timing of flooding, alter the value of a wetland to a given waterbird species, as a shift or possible change causes a decline in waterbird abundance (Stewart, Jr., 2016).

According to Ma *et al.*, (2010), in addition to providing food for waterbirds in the form of seeds, leaves, tubers, and rhizomes, vegetation, which is a component of wetlands, is an important habitat that influences waterbird habitat use, as the effect and importance of vegetation varies depending on the season and waterbird group. The numbers of biodiversity often drastically reduce by changes in LULC when land is transformed from primary forest to other land use forms (Oteng-Yeboah, 1994). Non-native plant, animal, and disease incursions may also be more common in areas exposed to LULC alterations, particularly in areas closer to human settlements (Ryan & Ntiamoa-Baidu, 2000). Changes in vegetation, waterbodies, terrain, and mudflats of wetlands may alter the distribution and abundance of benthic macroinvertebrates, affecting the wetland's role as a waterbird feeding ground (Pan *et al.*, 2006)

2.9 Conceptual frame work for the study

In view of the importance of coastal wetlands in Ghana to support biodiversity, a conceptual framework was designed in line with the objective of the study to understand how some of these ecosystem variables such as water and sediments, macroinvertebrates, fish, LULC changes affect the quality of the wetlands and its ability to support the abundance and distribution of waterbirds.

Waterbirds are highly sensitive to environmental changes so they are considered excellent indicators of ecosystem health species and closely linked with surface water habitats (Bibby, 1999; Ogden *et al.*, 2014). Therefore, understanding the mechanisms and ecological variables that drive waterbird distribution and abundance is important to biodiversity and ecological conservation and wetlands management (Jamoneau *et al.*, 2018; Li *et al.*, 2019)

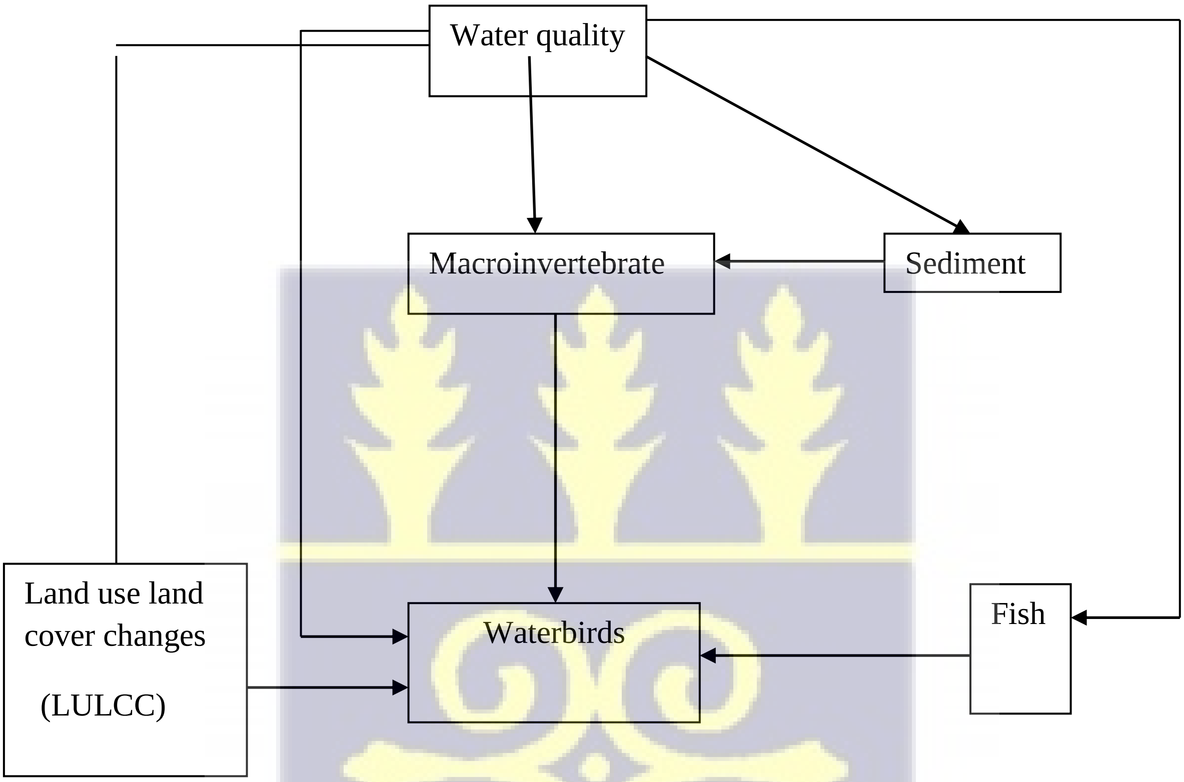


Figure 2.1 Conceptual framework showing linkages between ecosystem variables and waterbird abundance

Legend: The framework indicates how the various ecological variables impact on the distribution and abundance of waterbirds on the wetlands selected for the study. The water quality, sediment quality, macroinvertebrate assemblage, the condition factor of fish and the land use land cover changes are expected to influence the distribution and abundance of waterbirds either directly or indirectly from the above model.

The conceptual framework in Figure 2.1 shows how water quality parameters will affect benthic macroinvertebrate in the bottom sediments and how it in turns will affect the distribution and abundance of waterbirds. The framework further shows how LULC variables will be affected by water quality and its effect on waterbirds distribution, likewise, how water quality parameters will impact on the condition factor of the predominant fish in the lagoons and how they intend predict the distribution and abundance of waterbirds on the selected wetlands.

This study will further show how these ecological variables fill the gap of inadequate data and research findings on how LULC variables such as vegetation cover, built-up, landmass of waterbodies, macroinvertebrate assemblage, water and sediment quality, condition and wellbeing of fish affect the abundance and distribution of waterbirds on the protected Sakumo II and most importantly the unprotected Laloi and Kpeshie wetlands in Ghana.

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREAS

The study was carried out in three coastal wetlands sites: Sakumo II, Laloi and Kpeshie lagoons within the Greater Accra Region of Ghana over twelve months from August 2017 to July 2018. The GPS coordinates of all sampling locations within the study areas have been provided in Table 3.1. The Sakumo II wetland is a designated Ramsar site while the Laloi and Kpeshie wetlands are unprotected and not designated Ramsar sites.

3.1.1 Sakumo Ramsar Site

3.1.1.1 Location

The Sakumo Ramsar site is located within the Tema Municipal Assembly (TMA and comprises a coastal lagoon and floodplain. The Sakumo Ramsar site covers a total area of 13.4 km^2 (Gbogbo & Attuquayefio, 2010). The Sakumo lagoon on the wetland is permanently connected to the sea by an open sluice on the Accra-Tema Fishing Harbour road.

Fig 3.1 Google Earth Map of the Sakumo Ramsar site (2018)

3.1.1.2 Population

The settlements which directly impact on the wetlands are Sakumono, Tema, Lashibi, Ashaiman, and Tema Newtown and together these settlements make a total population of 483,745 of which 48.3% are male and 51.7% are female (GSS, 2014a)

3.1.1.3 Vegetation

The vegetation of the Sakumo Ramsar site is typical of the vegetation in most coastal zones of Ghana (Plate 3.1). The dominant vegetation found in the freshwater marsh is the succulent forbs, *Sessuvium portulacastrum.* The *Imperata cylindrical* dominates the higher ground areas. Other important species found on the site include *Paspalum vaginatum*, *Sporobolos virginicus*, *Avicennia africana* (Ntiamoa-Baidu & Gordon, 1991).

3.1.1.4 Fauna

The Sakumo II wetland supports large numbers of sea and seashore birds. The site serves as a habitat for some 66 waterbird species with an estimated population of 32, 500 birds (maximum count of individuals). Over 80% of the waterbird species at the Sakumo wetland are Palearctic migrants which are most abundant on the site between September and April (Ntiamoa-Baidu *et al.*, 2001).

The lagoon serves as nesting grounds for marine turtles; Olive ridley (*Lepidochelys olivacea*), Green turtle (*Chelonia mydas*) and Leatherback turtle (*Dermochelys coriacea*), all of which are of conservation concern (Seminoff, 2004; Abreu-Grobois & Plotkin, 2008; Tiwari *et al.*, 2013). Fish species observed in the lagoon include the black-chin tilapia (*Sarotherodon melanotheron)* (most abundant), Bonga shad (*Ethmalosa fimbriata),* mullets *Mugil spp*. (uncommon), snappers (*Lutjanus spp.*), Senegalese ladyfish (*Elops senegalensis)* and *Caranx spp.* (Ntiamoa-Baidu & Gordon, 1991; Asmah *et al.*, 2008), *Alestes baremoze, Heterobranchus bidorsalis* and *Oreochromis niloticus* (Sawyerr *et al.*, 2015). Invertebrates recorded on the site include polychaetes, mollusc, crustaceans (*Acartia spp*), Cladocera (water flea), guineashrimp, southern pink shrimp and other insects (Gordon, 1995).

3.1.1.5 Land Use

The major land use within the Sakumo II Ramsar site includes arable agriculture, animal grazing, fishing, fuelwood gathering, housing, and industrial development. The wetland is primarily used for agriculture cultivation as rice, cassava, and many other vegetable farming activities are undertaken mostly on the northern parts of the wetland and also along the banks of the rivers within the wetlands (Nonterah *et al.*, 2015).

3.1.2 Laloi coastal wetlands

3.1.2.1 Location

The Laloi lagoon and its catchment falls is located at Prampram and enters the sea at Kpone which lies in the Tema Export Processing Zone (Gordon *et al*., 1998). The lagoon is located behind the El Din Salt Mills Company Ltd at Prampram which has been operational for the past 40 years on the wetland.

Fig 3.2 Google earth map of the Laloi coastal wetland (2018)

3.1.2.2 Population

The settlement which directly impacts on the Laloi coastal lagoon includes Prampram Township, Vakpor, Kpoi-Ete, and Dawhenya. Together, these settlements make up about 22,562 of the population of the district (GSS, 2014b)

3.1.2.3 Vegetation

The vegetation within the lagoon and its catchment are made up of mangroves and rushes community which includes*Avicennia* spp, *Paspalum vaginatum*, *Imperata cylindrical* and *Sesuvium portulacastrums* .The edges of the lagoon water are dominated by *Typha domingensis*, a salt resistant aquatic plants (Attuquayefio & Gbogbo, 2001)

3.1.2.4 Fauna

The Laloi lagoon and its catchment support about 48 species of waterbirds of international importance (Gbogbo & Attuquayefio, 2010). The site supports an international population of waders such as the Bar-tailed godwit, Little Stint, Black-tailed godwit, Common Redshank, Black-winged stilt, Sanderlings and terns such as the royal tern, roseate tern and common tern (Gbogbo & Attuquayefio, 2010).

The site also supports important fish species like the black-chin tilapia *Sarotherodon melanotheron* (most abundant), Bonga shad *Ethmalosa fimbriata*, mullets *Mugil spp*. (uncommon), snappers (*Lutjanus spp)* (Koranteng, 1995).

Plate 3.1 Fish species caught from the Laloi lagoon during the study by a fisher

3.1.2.5 Land Use

The major land use within the catchment includes farming, animal rearing, fishing, fuelwood gathering, salt mining, housing, and industrial development. There are few vegetable farms located upland from the lagoon which has a tendency of nutrient leaching into the lagoon when it rains (Badu Bortey, 2012).

3.1.3 Kpeshie Coastal Wetland

3.1.3.1 Location

The Kpeshie lagoon and its catchment is located between the Teshie Military Barracks and the Trade Fair site. The Kpeshie lagoon is an open lagoon to the sea with only one broad opening under a constructed bridge (Addo *et al.*, 2011).

Fig 3.3 Google Earth Map of Kpeshie wetland (2018)

3.1.3.2 Population

The Kpeshie catchment includes the La Township, Burma camp, Labone, Cantoment and Airport. Together the catchment has a population of 183,528 with females constituting 52.7% while the males constitute 47.3% of the entire population. The Kpeshie wetland and its catchment is entirely urban (GSS, 2014c).

3.1.3.3 Vegetation

The vegetation of the Kpeshie lagoon and its catchment consists of dense clusters of small trees, shrubs, and grasses, which grow to an average height of about six metres (GSS, 2014c). The Kpeshie catchment has a good cover of mangrove vegetation as shown in Plate 3.4 consisting mainly of white mangrove *Avicennia germinans* with bottom mangrove *Conocarpus erectus* as a minor component which serves as a nursery ground for fishes and other marine life *Typha spp.*, *Cyperus articulants*, *Panicum maximum*, *Paspalum spp.*, *Sporobolus spp.* make up the grassland in and around the wetland (Ansah *et al.*, 2011).

Plate 3.2 Relatively dense vegetative cover around the Kpeshie lagoon

3.1.3.4 Fauna

The wetland and its catchment support important waterfowl species. The site supports waterbird species such as the African Jacanna, Senegal Thick-knee, Whimbrel, Senegal Wattled plover, etc. (Koney, 2010). The sand dunes on the beach of the site are used as roosting sites for marine turtles. Fish species in the lagoon on the wetland include the *Sarotherodon melanotheron*, Bonga shad (*Ethmolsa fimbriata*), grey mullets (*Mugil and Liza spp.*,) and mudskipper (*Periophthalmus papilio*). Shellfishes found in the lagoon include the blue legged swimming crab (*Callinectes ammicola*), and the fiddler crab (*Uca tangerii*) (Ansah *et al.*, 2011).

3.1.3.5 Land use

The soils within the catchment are mostly used to grow vegetables and fruits for both domestic and commercial purposes (Ansah et al., 2011). Most of the land and the lagoon sites are being used for the construction of houses, roads, estates, recreational facilities like football fields and other developmental projects as shown in Plate 3.3.

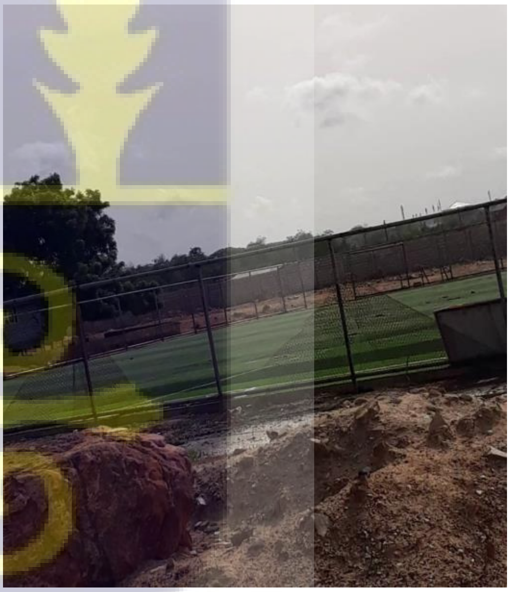
A. Road constructed over the Kpeshie lagoon 	B. Reclaiming of land for residential purposes at Kpeshie 
C. Construction of buildings along the Kpeshie lagoon catchment 	D. Land cleared for football AstroTurf at Kpeshie wetland 

Plate 3.3 Land use within the Kpeshie lagoon and its catchment

3.2 Study design and data collection

The study was carried out from August, 2017 to July, 2018. The study used both quantitative and qualitative data. The methods used during the study included direct field observations and laboratory analysis of samples collected.

3.2.1 Sampling Points

3.2.1.1 Description of sampling points

The locations of the sampling points were determined using a handheld GPS device (Garmin GPSmap 62). The sampling points are indicated in Table 3.1. All sampling sites were selected based on accessibility and the anthropogenic activities around the location using a map of the study area as shown in Figure 3.4.

- **SS (Sakumo South)**-is the southern part of the lagoon and connects the lagoon to the sea via two culverts.
- **SM (Sakumo Middle)** - is the middle portion of the lagoon where fishing activities concentrated around this part of the lagoon.
- **SN (Sakumo North)** - is the northern part of the lagoon closer to the industries and settlements.

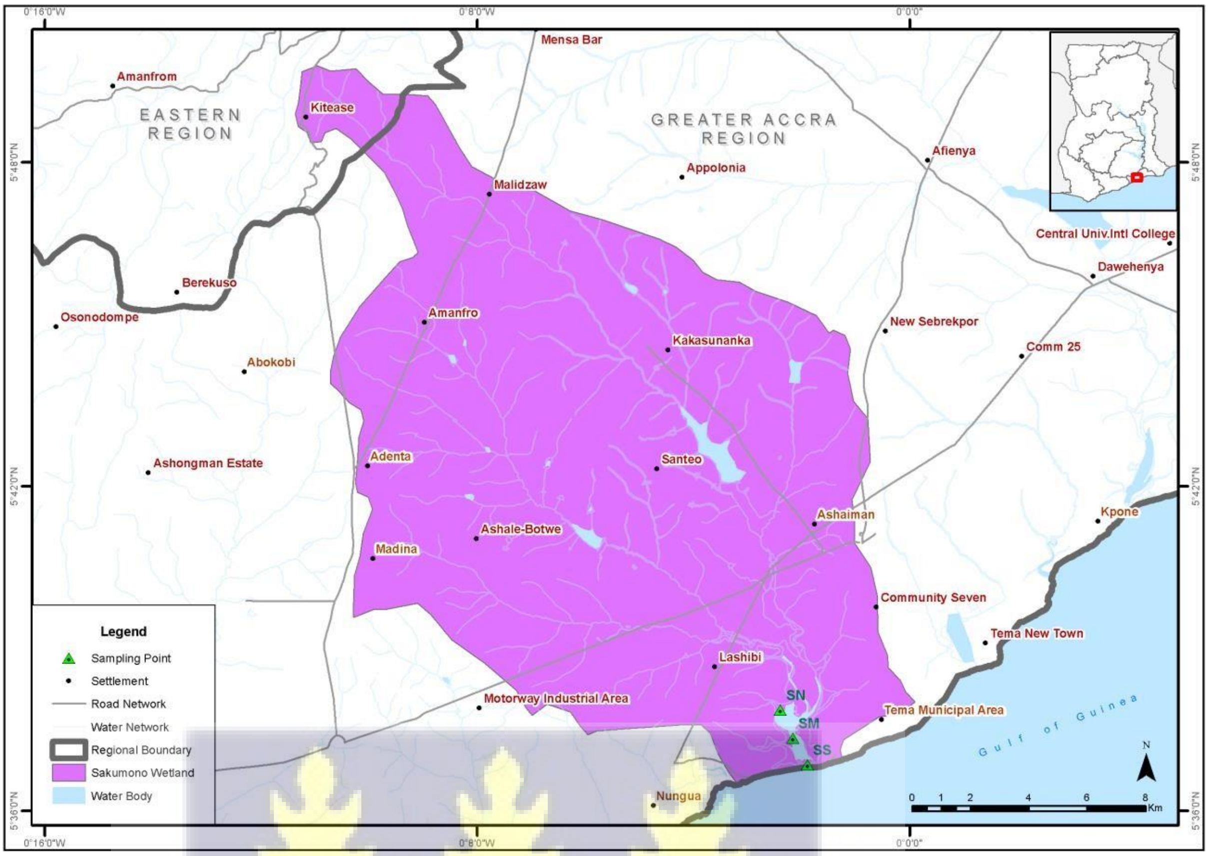


Fig 3.4 Map of Sakumo coastal wetland showing sampling points

For the Laloi coastal wetland, sampling was done on locations as shown in Figure 3.5.

- **LN (Laloi North)** – this is the northern part of the lagoon which has other streams flowing into the wetland.
- **LM (Laloi Middle)** – this is the middle portion of the lagoon which has most fishing activities and closer to the saltpans
- **LS (Laloi South)** – this is the southern part of the lagoon where lagoon water enters the sea
- **LA (Laloi Salt Pans)** – this is the area where salt mining is being undertaken by El- Din Salt Mills Ltd.

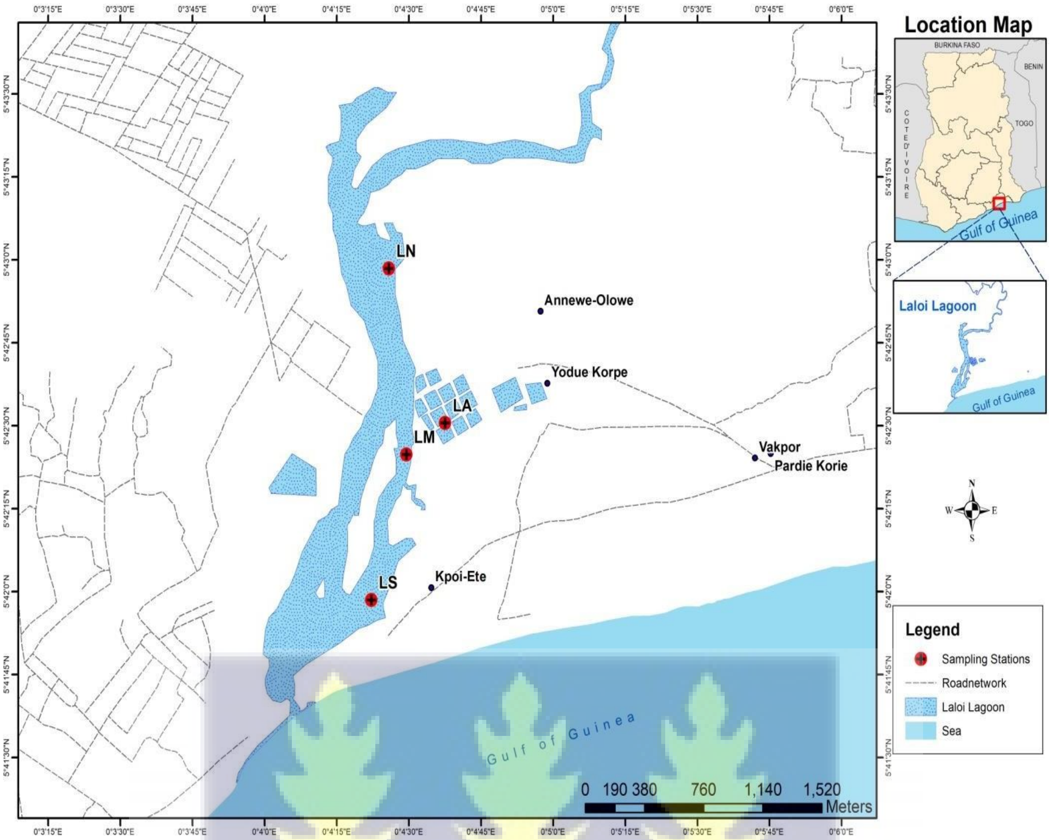


Fig 3.5 Map of the Laloi coastal wetland showing all the sampling points

The sampling sites at the Kpeshie coastal wetland from where samples were collected are indicated in Figure 3.6.

- **KB (Kpeshie Bridge)** – samples were collected under the bridge on the Kpeshie lagoon
- **KT (Kpeshie-Teshie Road) -** Samples were collected along the road heading towards Teshie township.
- **KS (Kpeshie-Sea end) -** Samples were collected from the area connecting to the sea adjacent La Palm Royal Beach Hotel.
- **KA (Kpeshie Africa Lake)** – Samples were collected from the African Lake area which is connected to the Kpeshie lagoon by culverts.

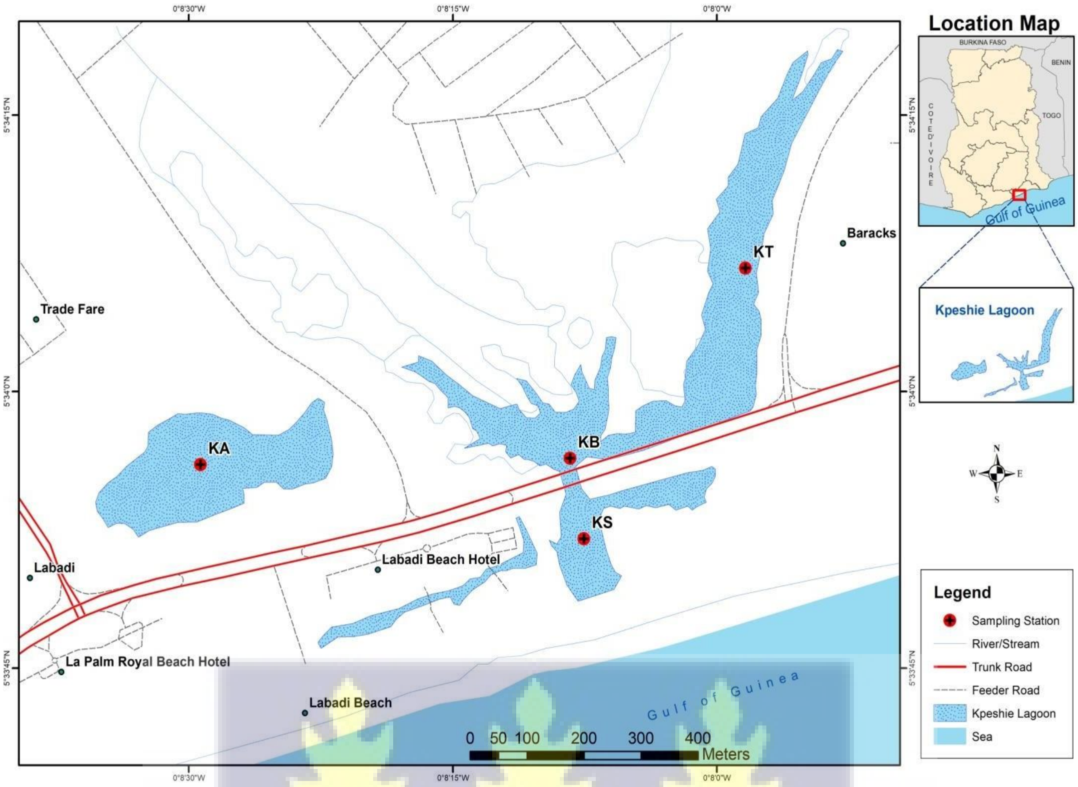


Fig 3.6 Map of Kpeshie coastal wetland showing sampling point

3.2.1.2 Sampling site and sampling locations

Table 3.1 below shows the sites and location water, sediment, macroinvertebrate samples were collected during the study period.

Table 3.1: GPS points of sampling sites

Site Name	Latitude	Longitude
Sakumo South (SS)	N 5^0 36' 53.61"	W 0^0 1' 58.12"
Sakumo Middle (SM)	N5 ^{0} 37' 13.76"	W 0^0 2' 8.28"
Sakumo North (SN)	N 5^0 37' 31.20"	W 0^0 2' 21.34"
Laloi North (LN)	N 5^0 42' 58.49"	W 0^0 4' 25.83"
Laloi Middle (LM)	N 5^0 42' 24.8"	W 0^0 4' 29.48"
Laloi South (LS)	N 50 41' 58.49"	W 00 4' 22.2"
Laloi Salt Pans (LA)	N 50 42' 30.52"	W 00 4' 37.5"
Kpeshie Bridge (KB)	N 50 33' 56.38"	W 00 8' 8.34"
KpeshieTeshie Road (KT)	N 50 33' 59.41"	W 00 8' 0.16"
Kpeshie Sea end (KS)	N 50 33' 52.02"	W 00 8' 7.56"
Kpeshie African Lake (KA)	N 50 33' 56.04"	W 00 8'29.34"

3.2.2 Land use land cover data acquisition and image preprocessing

Landsat Thematic Mapper satellite images for 1986, 2002 and 2017 were freely downloaded from the United States Geological Survey website (https://ear thexplorer.usgs.gov). Cloud-free Landsat satellite images were captured in the dry season for this present study to ensure that imagery had substantial clear observations.

Field surveys were carried out in February and March 2018 to collect ground data. Google earth maps, topographic maps from the Survey Department of the Lands Commission of Ghana and topographic data produced by the same agency were utilized. The Arc GIS 10.4 software was used to generate the database and the location of the study sites. Erdas Imagine version 14.0 was used for the image classification and Google Earth for verifying randomly generated points.

The characteristics of the data sets used in this study are summarized in Table 3.2. The Landsat guide (USGS, 2014) was utilized to ensure that the correct band combination was used and that various spectral indices were properly applied for the image classification.

Table 3.2 Details of satellite data used in the study

Satellite	Sensor	Dates of Acquisition	Resolution (m)	No. of Bands
Landsat (TM)	Landsat 5	20-01-1986	30 x 30	6
Landsat (ETM+)	Landsat 7	24-01-2002	30 x 30	6
Landsat (ETM+)	Landsat 8	21-01-2017	30 x 30	6

3.2.2.1 Landuse/Landcover (LULC) Classification: Supervised

A supervised classification method with the maximum likelihood classifier (supervised classification algorithm) in Erdas 14.0 was used to categorize each of the three images for each site. Supervised techniques deal with labeled data where the output data patterns are known to the system. This makes supervised classification models more accurate than unsupervised classificationmodels, as the expected output is known beforehand (Lillesand *et al.*, 2008).

Maximum likelihood classification is a pixel-based statistical classification method that aids in the classification of overlapping signatures by assigning pixels to the highest probability class. In using the maximum likelihood classification, knowledge about the land-cover present in the study area is important. The quality of the image, especially for those with low cloud cover, was a factor in selecting the Landsat satellite image dates (Jensen *et al.*, 2009).

In supervised classification, known representative training points were chosen to describe the spectral characteristics of each feature type of interest (Lillesand *et al.*, 2008).

The selected images were radiometrically corrected using the Automatic Scattergram-Controlled Regression (ASCR) method (Elvidge *et al.*, 1995). After defining an area of interest (AOI), which is referred to as training classes, the supervised classification was used. To represent a certain class, more than one training location was chosen based on the Landsat images, Google Earth, and Google Maps (Rwanga & Ndambuki, 2017).

Post-classification change detection techniques were used for detecting land use and land cover changes during the study. The various images were independently classified and registered after which the classified images were compared. About 50 random points were used for each land use/land cover type on the wetlands (Hailemariam *et al.*, 2016).

These random points were collected by using a Global Positioning System (Garmin GPS map 62) (MacLean & Congalton, 2012). Change detection involving the use of multi-temporal data sets to discriminate areas of land cover changes between dates of imaging was implored (Lillesand & Kiefer, 1994).

The field points were extracted from the GPS and converted into shapefiles using the DNR Garmin software.

Ground control points were collected by interviewing a group of five elders of the wetland communities to indicate what was found where during the olden days to aid in the image classification and accuracy assessment (Solomon *et al.*, 2018). The description of the land use land cover type used for the classification are shown in Table 3.3

Table 3:3 Descriptions of land use land cover units

LULC Unit	**General Description**
Bare land	Bare lands are land with limited ability to protect life, area has no vegetative cover or has a thin surface soil, sand, or rocks.
Built-up land	Built-up land encompasses lands covered by buildings including cities, towns, and villages.
Vegetation	Vegetation comprised of open and closed forest, agricultural lands, grasses, and coastal thickets
Waterbodies	Waterbodies include all zones within the land area that are covered by water. Categories of water bodies include stream, lakes, lagoons, estuaries, and swamps

Source: (USGS, 2007; Rwanga & Ndambuki, 2017)

3.2.2.2 Accuracy assessment

It is necessary to develop a confusion matrix in order to assess the accuracy of an image to be classified. The classified results are compared against supplementary reference data (Google maps) in a confusion matrix. A confusion matrix has the advantage of distinguishing both the nature and the quantity of the classification errors (Shodimu, 2016).

The fraction of properly identified pixels in relation to all pixels in the ground truth class was used to calculate producer accuracy. The number of successfully identified pixels in each class of ground truth pixels (row) is divided by the total number of ground truth or test pixels in that class (Akbari *et al.*, 2006).

The fraction of correctly classified pixels in relation to all pixels classified in the classified image was used to calculate the User Accuracy (Zhang, 2014).The overall accuracy was calculated as the number of correctly classified pixels (i.e., the sum of the diagonal cells in the error matrix) divided by the total number of sampled pixels that is:

Overall accuracy = Number of correct plots (values) x 100

Total number of plots (values)……. (Abubaker *et al.*, 2013)..(1)

Kappa coefficient (K) was calculated using the equation:

$$K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i} + X_{+i}}{N^{2} - \sum_{i=1}^{r} X_{i} + X_{+i}} \cdot \text{(Foody, 2002)……(2)}$$

where N is the total number of observations (pixels), Xii is the observation in row i and column, Xi+ is the marginal total of row i, and X+i is the marginal total of column and ‘r’ is the number of rows and columns in the error matrix (Foody, 2002).

3.2.2.3 Sampling and collection of water samples

This section comprises the sampling methods, chemicals and reagents used during the field study. All quality assurance and quality control measures were employed to ensure the consistency of analytical results. A reconnaissance assessment of the sites was carried out to determine the best feasible sampling locations. With the help of a GPS and Google maps, sampling sites were consciously chosen based on their accessibility.

3.2.2.3.1 Sample containers and sampling of water

Disposable nitrile gloves were used for sampling. To collect fairly representative water samples from each of the lagoons, samples were taken from several sites on the lagoons. From August 2017 to July 2018, water samples were taken from the Sakumo II, Laloi, and Kpeshie lagoons at strategic locations within the study sites once a month.

Three replicate water samples were obtained for analysis at each sampling point. Before usage, all polyethylene containers for water sampling (500 ml polyethylene bottles) were soaked in a 10% HNO_3 solution for 48 hours and rinsed carefully with double-distilled water (Mahapatra *et al.*, 2001; Momen *et al.*, 2006). The lagoon water was used to rinse the sampling bottles three times before being used to collect water. The sampling container was submerged in water (about 5-10 cm) and entirely filled with water. The bottles were capped and labeled right away. All samples were placed in thermo-insulated containers with ice packs and transported to the laboratory for processing and analysis.

All the laboratory glasswares used for the laboratory analysis were pretreated by washing with warm water and detergents, rinsed with water followed by a second rinsing with distilled water (Carvalho *et al.*, 2007). Distilled water was used for the preparation of all solutions for the laboratory analysis.

For the determination of sodium, potassium, nutrients and heavy metal content in the water samples, the water samples collected were filtered through a 0.45 µm membrane filter just after sample collection, then five (5ml) of 6M HNO_3 was added to keep the samples at $pH < 2$ to avoid loss of cations as they are subject to loss by adsorption or ion exchange with the walls of the sampling bottles (APHA, 2005). To minimize the potential for volatilization between the time of sampling on the field and sample analysis in the laboratory, water samples collected were kept as cold as possible on ice without freezing.

3.2.2.3.2 Glasswares, equipments, chemicals and reagents

The glassware used for the chemical analyses included the 250ml conical flask, 50ml volumetric flask, test tubes, digestion and filter flasks. The equipments used were the analytical balance, hot plate (burner), HACH DR/820, Sherwood Flame Photometer (Model 420), UV/VIS Spectrophotometer, and Varian AA 240 FS AAS.

Analytical grade chemicals and reagents were used for the laboratory analysis. The hydrochloric acid, sulphuric acid, hydrogen peroxide and nitric acid were gotten from the British Drug Houses (BDH) Lab in England.

Magnesium sulphate, sodium sulphate and sodium chloride were obtained from Reagent Chemicals in Korea and Glassworld in (South Africa). Fluka analytical, Sigma-Aldrich Chemie GmbH, in Switzerland, provided the reference standards for trace metal analysis.

3.2.2.3.3 Preparation of Solutions

Preparation of standard solutions for recovery analysis- stock standard solutions (1000ppm) was serially diluted. 5ppm, 10ppm, 15ppm, and 20ppm solutions were prepared by diluting 0.5ml, 1.0ml, 1.5ml and 2.0ml each of the standard solutions to 100ml. Preparation of concentrated H_2SO_4 and $HClO_4$ was done and 300ml of conc. H_2SO_4 and $HClO_4$ were transferred into 1L conical flask, shaken, allowed to cool and stored until needed to be used.

3.2.2.3.4 Laboratory analyses of water samples

The laboratory analyses of water samples collected from the sampling sites were carried out at the Ghana Atomic Energy Commission Chemistry Laboratory (GAEC). At the laboratory, samples for trace metal analyses were kept in a refrigerator at 4 °C and analyzed within one week.

Physico-chemical parameters including temperature, pH, electrical conductivity, salinity, water depth, total dissolved solids (TDS), were measured in situ using the Horiba Digital Water Quality Checker (Model V.10)

Determination of all major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, SO_4^{2-}, Cl^{-}) and nutrients (NO_3- N, PO_4 -P, NO_2-N) were carried out using the appropriate certified and acceptable international procedures and methods (APHA, 1995).

Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD)

Dissolved oxygen (DO) was determined using the Azide Modification Method. In the laboratory, 2 ml of concentrated H_2SO_4 was added to the water samples and shaken till dissolution was complete. By means of a pipette, 50 ml of the solution was transferred into an Erlenmeyer flask and titrated with standard concentration of 0.0125M sodium thiosulphate ($Na_2S_2O_3.5H_2O$) solution till a pale yellow colour was obtained.

Two (2) or three (3) drops of starch indicator was added to the solution and this turned the solution into a blue colour with continuous titration until the solution became colourless (APHA, 1995).

The DO was calculated using the equation:

$$\text{DO (mgl}^{-1}\text{ O}_2\text{)} = \frac{\text{Volume of thiosulphate consumed} \times 101.6}{\text{Volume of sample used.}} \quad \text{(APHA, 1995) ….(3)}$$

Water samples for BOD analysis were diluted and the diluted water was prepared by adding 1 ml each of phosphate buffer, $MgSO_4$, $CaCl_2$, and $FeCl_3$ solutions per litre of water (APHA, 1995). The 5-day BOD test was used. After day 5, the samples in the BOD bottles were fixed with 2ml of Winkler 1 and 2 solutions and firmly corked, making sure no air bubbles were trapped in the bottles. The solution was shaken and inverted several times allowing all precipitates allowed to settle.

The BOD was determined using the same procedure as described for DO for each of the samples The BOD was determined by subtracting the dissolved oxygen (DO_5) of diluted samples after 5-days incubation at 20°C from the dissolved oxygen (DO_1) after the initial measurement (APHA, 1995):

$$\text{BOD (mg/l)} = \frac{DO_1 - DO_5}{V} \text{……………………………………(4)}$$

where; D_1 = DO of diluted sample immediately after preparation, D_5 = DO of diluted sample after 5-day incubation at 20 °C, V= decimal volumetric fraction of sample used (APHA, 1995).

Turbidity

The Portable Turbidimeter (HACH Model 2100P) was used for turbidity measurements of the water samples and the concentration recorded in mg/l. A sample cell was filled with 20 ml of water and capped firmly. A soft-linen cloth was used to clean any spot on the sample cell including fingerprints. Silicone oil was spread on the film of the cell holder evenly over the entire surface. The water sample in the sample cell was read and levels recorded in Nephelometric turbidity unit (NTU) (HACH, 1992)

Total Suspended Solids (TSS)

The Photometric method was used for these measurements. Five hundred (500 ml) of the water sample was collected into a beaker and blended for about 10mins and transferred into a 1000 ml beaker. Twenty-five (25 ml) of the water sample was immediately placed into a sample cell. Before analyzing, blanks were run to standardize the machine. The stored program number for suspended solids (630) was entered and the wavelength was set to 810 nm, before analysis was done (APHA, 1995).

Alkalinity

For alkalinity measurements, the potentiometric method was used to determine the alkalinity for water samples with $pH > 4.5$. About 50 ml of water sample collected was transferred into a 500 ml conical flask and titrated with 0.02 M HCl solution. Three replicate titrations were done and the mean titre value calculated. To compute the alkalinity, the volume of water sample used for the titration, the volume of acid used (average titre), and the molarity of acid were substituted into the equation.

The alkalinity was calculated using the equation:

$$\text{Alkalinity (mg/l)} = \frac{K\text{-}\ M\text{-}\ (50000)}{V\ \text{sample}} \quad \ldots\ldots\ (5) \quad \text{(APHA, 1995)}$$

where K, is the titre value in ml; M is the molarity of the titrant and V_{sample} is the volume of the sample to be analysed.

Chloride

The chloride content in water was analysed using the Argentometric method (APHA 1995, 4500-Cl-B). The method is based on the titration of the water sample with silver nitrate ($AgNO3$) using potassium chromate (K_2CrO_4) as an indicator. About 0.8 ml of K_2CrO_4 was added to 25 ml of water and titrated with 0.0141M $AgNO3$ solution until the solution's greenish-yellow color changed to brick-red. The mean titer was calculated after three duplicate titrations. When the water sample was diluted, the computed concentration was multiplied by the dilution factor to get the true concentration of the analyte in the sample. The chloride content was calculated from the equation:

$$Cl^{-1}\,(mg/l) = \frac{(A-B) \times M \times N \times 1000}{V_{sample}} \text{ .... (6).... (APHA, 1995)}$$

where A is the mean titre value (volume of $AgNO_3$ solution used) in ml; N is the molarity of the titrant ($AgNO_3$ solution); M is the atomic molar mass of Cl, (M = 35.45 g mol-1); B is the titre value of the blank solution in ml, and V_{sample} volume of sample in ml.

Sodium and Potassium

The sodium and potassium content in water samples collected were determined using the Flame Photometric Method (Sherwood Model 420 Flame Photometer) after the addition of 2 ml of 100 ppm Lithium Standard. A blank solution of mixed double-distilled water-masking-agent was aspirated into the Sherwood 420 Flame Photometer's liquefied petroleum gas (LPG)-fed flame. The Na and K concentrations in the water samples were determined after the blank was analyzed.

A 5ml sample of water was transferred to a 10ml test tube, followed by the addition of 2 ml of masking agent. The mixture was shaken for around 2 minutes to homogenize. The homogenized solution was aspirated into the photometer's flame. The contents of sodium and potassium were measured at 589 nm and 768 nm, respectively.

Sulphate-Sulphur (SO_4–S)

The turbidimetric method based on the reaction of sulphate ion (SO_4^{2-}) with barium chloride ($BaCl_2$) under acidic conditions to precipitate barium sulphate ($BaSO_4$) was used to detect sulphate concentrations. The standard SO_4^{2-} solutions were quantitatively transferred into test tubes in a 10ml volume. 1 ml acid salt solution, 0.5ml glycerol solution (conc.) and 0.5g $BaCl_2$ were added to each test tube.

The cloudy solution was shaken for 60 seconds before being set aside for 10 minutes. On the

UV-visible spectrophotometer, the absorbance of the cloudy solution was measured at a wavelength of 420 nm after an appropriate quantity of the turbid solution was placed into a 1cm cell. The amounts of sulphate in the water samples were calculated using the calibration curve and the measured absorbance. Blank solutions were used to zero the spectrophotometer (APHA, 1995)

3.2.2.3.5 Nutrients in water samples

Nitrate –Nitrogen (NO_3-N)

Nitrate concentration in water samples collected was analysed using the cadmium reduction method. The diazonium salt formed when nitrates are reduced to nitrite in sulphuric acid combines with the acid to produce an amber-colored product, the strength of which is dependent on the concentration of nitrates in the sample. The contents of one NitraVer 5 nitrate reagent pillow powder were applied to 10 ml of water sample in a sample cell. To aid in the dissolution of the chemicals, the sample was forcefully agitated. To zero the instrument, a blank was created and inserted into the cell reader. The sample containing the NitraVer 5 were then inserted into a cell reader for nitrate readings (HACH, 1992).

Phosphate-Phosphorus (PO_4 -P)

The ascorbic acid method was used in determining phosphate concentration in the samples. 10ml of the water sample was pipetted into a 20 ml test tube and 2ml of combined reagent (potassium antimonyl and ammonium molybdate solutions) was added and left for about 3 minutes. The mixture was thoroughly mixed with ascorbic acid in the ratio 1:4 (1ml Ascorbic acid to 4ml combined reagent). In each test tube, the antimonyl-phosphomolybdate combination produced a blue color after 15 minutes. Each blue-colored solution was aliquoted into a 1 ml cuvette, which was then inserted into the spectrophotometer and the absorbance of each sample was read at a wavelength of 880 nm on the UV/VIS spectrophotometer. Phosphate concentrations of the water samples were determined from the calibration curve using the measured absorbance from a spectrophotometer. The spectrophotometer was zeroed with blank solutions (APHA, 2005).

Nitrite-nitrogen (NO_2-N)

Nitrite determination was based on the diazotization method using the HACH DR/820 Colorimeter where a sample cell was filled with 10ml of water sample with Nitriver 3 Nitrite reagent powder pillow added and capped firmly and shaken to dissolve. The sample is then placed in a cell holder and covered tightly with the instrument cap and read and the concentration recorded in mg/l nitrite nitrogen (HACH, 1992).

3.2.2.3.6 Digestion and analysis of water samples

The hot plate acid digestion method was used to digest and analyze heavy metals in water samples. The amounts of trace and heavy elements (Ca, Mg, Fe, Mn, Cu, Zn, Cd, Ni, Cr, Co) in water samples were determined using flame atomic absorption spectrometry (FAAS). The water samples were mineralized prior to the determination utilizing the ETHOS 900 microwave digester (Milestone, USA) to digest the water samples. Water samples that would be used to determine heavy metals were acidified immediately after sampling with sulfuric acid to a pH below 2.0 (Eaton *et al.*, 2005).

Forty (40 ml) of the water sample was poured into a 100 ml beaker in the lab. 5ml of Aqua Regia in a ratio of 4.5ml concentrated HCl to 0.5ml concentrated HNO_3 was added to the water sample. The experiment was carried out in a fume chamber. The beaker was placed on a hot plate, covered with cling film, and digested for 2 hours at 45^0C. After the acid digestion, the solution was allowed to cool to ambient temperature before being filtered into a 50ml volumetric flask using a Whatman no. 42 filter paper.

For heavy metal analysis, it was then made up to the 50ml mark using distilled water. After that, the solution was placed in a test tube for AAS analysis. For the calibration curves of the various metals, standard solutions ranging from 0.2 to 5.0 mg/l were prepared (APHA, 1992;

APHA, 2005).

The VARIAN AA 240FS (Fast Sequential Atomic Absorption Spectrometer) with deuterium background corrector was employed for the analysis. With the calibration standards for the elements determined, the atomic absorption spectrometer was calibrated. The absorbance obtained was plotted on calibration curves for each of the elements.

The absorbance of the samples aspirated into the absorption cell after calibration was used to determine each element. For each element, the absorbancewere used to create calibration graphs. The absorbances of the materials aspirated into the absorption cell were measured after the calibration to identify each element.

The air-acetylene flame atomizer, which uses air as an oxidant and acetylene as a fuel, was used to conduct flame atomic absorption spectrometric measurements. The concentrations of trace and heavy metals were calculated by multiplying the concentration detected by the equipment (AAS) by the appropriate dilution factor.

3.2.2.3.7 Quality control measures

To ensure the accuracy of the results, quality control procedures were followed. Analytical grade reagents were used. In the laboratory, deionized and distilled water were also used in all solution formulations and glassware washing. Standards and blanks were used to run the instrument's calibration before the samples were analyzed. Laboratory blanks and standards were mainly used to check for contamination and precision of the analytes, respectively.

The instrument and operational conditions were set up according to the manufacturer's instructions. Prior to measurement, all analytical instruments were properly calibrated. To minimize and possibly avoid contamination of samples, sampling processes were observed and followed strictly.

To reduce random error and assure reproducibility, each determination was repeated three times. Each stated result was the average of three measurements taken in triplicate. Standard

Reference Materials (SRMs) used were treated as samples to ensure that the equipment was working properly and to further validate the method.

3.2.2.4 Sediment sampling

Sediment samples were collected from all sampling points using a PVC corer for heavy metal analysis. Three replicate sediment samples were collected from each sampling station. The concentrations of Fe, Mn, Cu, Zn, Cd, Ni, Cr, and Co were determined in the sediment sample collected. The corer was used to sample sediment from the lagoon bed to a depth of about 30cm and placed in airtight polyethylene bags. The samples were then placed in thermo-insulated containers with ice packs for transportation to the laboratories for analysis.

3.2.2.4.1 Laboratory analysis

Debris and other undesired materials were removed from the samples before lyophilization (freeze-drying) in a Christ Gamma 1-16 lyophilizator in the laboratory (Donkor *et al.*, 2006). The ground sediment samples were sieved with a 2 mm sieve. The samples were kept in hermetically sealed double-bagged polyethylene bags. The samples were kept in refrigerators at 4^0C. A mass of 1.5 g of sediment sample was weighed in a beaker and acidified with the addition of 25 ml of Aqua Regia in the ratio of 1 ml concentrated HCl to 3 ml concentrated HNO_3 to the sediment sample. 0.25 ml of H_2O_2 was also added.

The experiment was carried out in a fume chamber. The beaker was placed on a hot plate, covered with cling film, and digested for 4 hours at 45^0C. After the acid digestion, similar steps as was used for water analysis were followed. The Varian AA 240 FS AAS was used for measuring the concentrations of heavy metals (Fe, Mn, Cu, Zn, Cd, Ni, Cr, Co) in the sediment samples.

3.2.2.4.2 Calculation of concentration of AAS readings

For sediment samples, the results of atomic absorption spectrophotometer (AAS) readings are provided in mg/kg dry weight, and for water samples, in mg/l. The concentration of each analyte in the water and sediment samples is calculated using the analyte's calibration curve. To acquire the required concentration, multiply the value by the sample's dilution factor and divide by the sample's underlying weight before digestion to get the actual concentration of the analyte in the samples (Al-Weher, 2008).

For water samples: C sample (mg/l) = (CAAS x Df x VN) / (WS)

For sediment samples: C sample (mg/kg) = (CAAS x Df x VN) / (WS)

> where: C sample = concentration of sample, CAAS = concentration of analyte obtained from calibration regression line, Df = dilution factor, VN = nominal volume (ml) and WS = weight of homogenised sample taken for digestion (g).

3.2.2.4.3 Statistical analysis of water and sedimemt data

Calculations and statistical analyses of water and sediment data were performed using Microsoft Excel 2016 and the Statistical Package for Social Scientists (SPSS) (v 20.0, SPSS Inc., Chicago, USA) softwares. These programs were used to calculate the mean, standard deviations, and draw graphs for better understanding of the data. Descriptive statistics and measure of dispersions such as standard deviations as well as inferential statistics non-parametric tests–Analysis of variance (ANOVA) were used to test the significance of the difference in the parameters observed for the various wetlands using both the SPSS v 20.0 and the Practistat® software (Ashcroft & Pereira, 2002).

A Pearson correlation analysis was performed using SPSS (v 20.0, SPSS Inc., Chicago, USA) to specify the possible correlation among variable series in water and sediment. A coefficient (r) value, which reflects the strength level of correlation between two variables, was used to recognize this link. The quantified variables would have high, moderate, or weak correlations if r is larger than 0.7, between 0.4 and 0.7 or if it is less than 0.4 (Shan *et al.*, 2013).

Principal Component Analysis (PCA) with Varimax normalized rotation was also employed to identify the sources. This method was utilized to figure out what the likely hidden relationship was between the acquired outcomes. In order to determine the origins of comparable pollutants, the PCA calculates the eigenvector values. For this study, eigenvalues greater than 1.0 were employed, and a component with factor loading > 0.75, 0.75–0.5, and 0.5–0.3 was considered strongly, moderately, and weakly important, respectively (Liu *et al.*, 2003).

3.2.2.4.4 Pollution Indices using the Sediments

The enrichment factor (EF), contamination factor (CF), pollution load index (PLI) and geo-accumulation index (Igeo) were calculated to ascertain the level of pollution or contamination in the bottom sediment of the lagoons. The EF was estimated using the method recommended by Sinex & Helz (1981):

$$\text{EF} = (\text{Me/Fe})\ \text{sample} \,/\, (\text{Me/Fe})\ \text{background} \ldots\ldots\ldots. \quad (7)$$

where (Me/Fe) sample is the metal to Fe ratio in the sample of interest; (Me/Fe) background is the natural background value of the metal to Fe ratio. In this current study, the background values were taken from world surface rock average proposed by Martin & Meybeck (1979) (Appendix I-16).

The contamination of the bottom sediment by heavy metals is expressed in terms of the contamination factor (CF) as proposed by Hakanson (1980) and calculated as:

$$\text{CF} = \text{Cm Sample} \,/\, \text{Cm Background} \ldots\ldots\ldots \quad (8)$$

where, Cm Sample is the concentration of a given metal in sediment, and Cm Background is the value of the metal which is equal to the world surface rock average given by Martin & Meybeck (1979)

The pollution load index was determined as the nth root of the product of the contamination factor as proposed by Tomlison *et al.*, (1980).

Thus PLI = $(CF_1 \times CF_2 \times CF_3 \times \ldots\ldots\ldots CF_n)^{1/n}$ where n is the number of metals.

Geo-accumulation Index (Igeo) is the enrichment of metal concentration above baseline concentrations and was calculated using the method proposed by Muller (1969, Chandra *et al.*, 2013). Igeo index are used to compute metal pollution from anthropogenic sources compared to precivilization background shale values (Long *et al.*, 1998). Geo-accumulation index is expressed as follows:

Igeo = log 2 (Cm sample / 1.5 x Cm background)…….. (9)

where Cm sample is the measured concentration of the element in the sediment sample and Cm background is the geochemical background value (world surface rock average).

Muller (1969; 1981) proposed seven grades or classes to determine the geo-accumulation index in sediments or soils which was applied in the study.

3.2.2.5 Avifauna data collection

The waterbirds within the study areas were counted using a Swarovski 20 x 60 telescope. Counting of waterbirds was made in the morning till evening depending on the light conditions (Namgail & Yom-Tov, 2009) on the wetlands. The bird counts were done on foot from fixed points on the landscape with good visibility by an expert from the Centre for African Wetlands (CAW-UG). Each wetland was divided into sectors (Piersma & Ntiamoa-Baidu, 1995) by natural and artificial objects such as trees, concrete pillars, buildings, allowing the entire area of each wetland to be covered and counted.

Waterbirds were counted successively from left to right of the researcher at a radius of 100 m to minimize the possibility of including the same birds which might fly to other areas of the wetland twice (Granadeiro *et al.*, 2004, Lamptey & Ofori-Danson, 2014). Waterbirds flying in the sky were included in the counts as counts were done at their point of first detection to ensure that individual birds were not counted twice. Bird counts were not made and recordings not done on rainy days.

Waterbirds surveys were done once every month during study period. Waterbirds were grouped into the waders, terns/gulls and heron, and egrets/others adopted from Ntiamoa-Baidu (1991) for easier comparison with previous studies on bird count on the wetlands. The birds were identified using field guides by (Borrow & Demey, 2001; 2013). The nomenclature and taxonomy of waterbirds were assigned according to BirdLife International (2013), with a species check list generated using Piersma & Ntiamoa-Baidu (1995) and Ntiamoa-Baidu *et al.*, (1998). The biodiversity indices were calculated directly from the data generated by the waterbird counts at each study location. The data generated from the waterbird counts at each study site were directly used to estimate the biodiversity indices.

3.2.2.5.1 Statistical analysis of avifaunal data

The relative abundance (%) of waterbirds was calculated using the expression:

$$\text{Relative Abundance} = \frac{n}{N} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

where n is the number of a particular waterbird species and N is the total observations of waterbird species (Zakaria *et al.*, 2009).

An ecological diversity index which is a mathematical measure of species diversity in a community (Magurran, 1988; 2004) was also used for the diversity analysis. The diversity indices were calculated using the Primer 6 & Permanova Software:

- *Simpson's index (entropy),* $1\text{-}D = 1-\sum p_i^2 \ldots\ldots\ldots\ldots\ldots\ldots (11)$

Where $1\text{-}\boldsymbol{D}$ = Simpson's index, Pi = the proportion of species '*i*' in the sample

- *Shannon diversity (entropy),* $(EXP(H^1)) = \sum p_i \ln p_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$

  where Pi = the proportion of species '*i*' in the sample

- *Shannon Evenness,* $E = H^1/H_{max}$ *or Pielous evenness* $(J)=$

  $H^1/\ln(S)$ -(13) where S = the total number of different species

  in the sample

- Margalef richness, $d^I = \frac{(S-1)}{\ln N}$ ------------- (14) (Zar,1974; Margurran, 1988)

where S = number of species recorded and N = total number of individuals summed over all the S species.

The principal component analysis (PCA), a function of the SPSS software, and the Primer (Plymouth Routine In Marine Ecological Research) 6 & Permanova Software + version 1.0.3, (Clarke & Gorley, 2006) were used for the analysis of the avifauna data.

The relationship between waterbird abundance and environmental parameters were analysed using the SPSS and the bio-env procedure (Clarke & Ainsworth, 1993) within the Primer software. A dendogram to display level of similarity amongst sampling sites was plotted based on Bray-Curtis similarity index estimated for the distribution of waterbirds on the wetlands.

3.2.2.6 Collection of benthic macrofauna

Five replicate benthic samples were collected at each of the sampling locations using a PVC corer. Benthic samples were taken from all the sampling locations on all three wetlands identified by the GPS cordinates.

The core area of the PVC corer was 0.196 m^2 and benthic samples were collected to core depths ranging from 2-15 cm. In areas of unconsolidated sediment where samples could not be retained by the corer, a stainless-steel sieve (mesh 250 microns) was used to scoop up bottom material and kept in containers (Cheal *et al.*, 1993). Samples were put in a 250 ml container in-situ and conserved with 4% formalin, mixed with Rose Bengal to assist in sorting macroinvertebrates in sediment samples.

Benthic sampling techniques outlined by Akita *et al.*, (2014) and Ntiamoa-Baidu *et al.*, (2014) were used to document macroinvertebrates abundances.

3.2.2.6.1 Laboratory processing of benthic macrofauna

In total, 55 different benthic samples were collected on each monthly visit. Benthic macrofauna samples collected were washed through a 500-micron mesh sieve to remove debris at the Ecological Laboratory, University of Ghana. In the lab, macroinvertebrates were removed from the fixative and air dried for 50 minutes to lessen the likelihood of individual macroinvertebrates clinging to each other and to avoid the pungent smell of formaldehyde on the samples.

The macroinvertebrates reserved were transferred onto a tray for sorting. The samples were sorted into broader taxonomic classes. Species were identified, examined under a microscope and classified with the help of keys and guides (Pennak, 1978; Dejoux *et al.*, 1982; Akita *et al.*, 2014) and confirmed by laboratory technician from the Ecological laboratory of the University of Ghana.

The benthic macrofauna were identified to the family or class levels where possible. The relative abundance of the different species was expressed as percentages of the total number of macroinvertebrates sampled from each wetland. The numbers of individuals per each species in the benthic samples were used to determine macroinvertebrate density:

Density = Number of individuals per species/ base area of corer (A)….(15)

The species diversity, richness, and evenness of the benthic macrofauna were estimated using the Shannon-Wiener diversity index (H'), Simpson Index (1-D), Margalef's species richness (d') and Pielou's species evenness (J') using the Primer 6 & Permanova Software.

3.2.2.7 Sampling and collection of fishery data

A total of 50 black chin tilapia fishes, were collected from fishers on a monthly basis during the survey period from each site. The fishes were either purchased from fishermen minutes after landing or where there were no fishers someone was paid to do the fishing.

Measurements of the fish species collected were carried out at the Ecological Laboratory, University of Ghana.

The fishes were weighed individually using the Mettler Toledo electronic balance (UK) in grams to the nearest 0.01 gram and standard lengths (SL) measured with a measuring rule in centimeters to the nearest 0.1cm. The fish was cleaned on a filter paper before they were weighed to remove excess water and any dirt from the body (Anderson & Gutreuter, 1985). The standard lengths of the fishes were measured from the snout to the tip of the caudal fin.

3.2.2.7.1 Statistical analysis of fishery data

The measurements on the predominant fish species (*Sarotheredon melanotheron*) were analysed for their length-weight relationships and condition factor using the length- weight relationship:

$$W = a L^b \quad \ldots\ldots\ldots\ldots \quad (16)$$

where W = weight of the fish in grams, a = describe the rate of change of weight with length (intercept), L = standard length of the fish in cm and b = exponent of growth (slope).

The growth of the fishes was described as allometric growth ($b < 3$ or $b > 3$) or isometric ($b = 3$) (King, 1995). The growth pattern was obtained by plotting the logarithm form of the equation $W = a L^b$ order to get a linear relationship in the form:

$$\text{Log } W = \log a + b \log L \text{ (King, 1995)} \ldots\ldots\ldots \text{ (17)}$$

where b (the growth constant) = the slope or gradient of the line of best fit. The correlation coefficient (r^2) between the length and weight was calculated from the linear regression analysis $R = r^2$. The condition factor (physiological wellbeing) of the fish species collected during the study was determined using the relationship:

$$K = \frac{W}{(L^3)} \times 100 \quad \text{(Tesch, 1968, Ricker, 1975)} \ldots\ldots \text{ (18)}$$

where K= condition factor W= body weight of fish (g), L= length (cm^3)

The R studio software was used for the statistical analysis of the length-weight relationship as well as generating length-weight graphs (R Core, 2018).

3.2.2.8 Socioeconomic survey

Questionnaires on the knowledge, usage, drivers of possible changes through human activities, and possible management practices were designed and administered within the study areas. This survey was to find out how anthropogenic activities have caused changes to the wetland ecosystem and its effect on waterbird distribution. The questionnaire administration was carried out in the months of June and July 2018. The sample questionnaires were in two parts. The first focused on the demographic information (age, gender, literacy etc.) of the respondents and the second part focused on the drivers of the changes observed, importance and benefits derived from the usage of the wetlands and management practices in their opinion which needs to be observed to sustainably protect and conserve the wetlands and its resources (Appendix I-15).

A total of 347 respondents were selected for the questionnaire administration using the Slovin formula which is based on the population of the wetlands sites to find out the changes that might have occurred on these wetlands over the years.

One hundred (100) questionnaires each were administered to users and residents in and around the Laloi and Kpeshie wetlands while 147 questionnaires were administered to users and resident in and around the Sakumo II wetland during the study period.

Random sampling using the purposive sampling technique was used for the questionnaire administration and the sample size was calculated using the Slovin formula based on the population of the study sites:

$$\mathbf{n = \frac{N}{1 + Ne^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)}$$

where N = total population, n = number of sample size, e = confidence level at 95%. Microsoft Excel® 2016 was employed in plotting relevant graphs, exporting data to other statistical programs as well as calculating some descriptive statistics. The chi squared statistics was used to test the relationship and significance of the responses from the respondents.

3.2.2.8.1 Hypothesis

The hypothesis of this study was tested using the Bayes Theorem, 1763 P(H/Y) concept. A one-way ANOVA at 95% confidence level was conducted in order to reject or not the hypothesis.

3.2.2.9 Data screening and examination

All data entries were double-checked to ensure that there were no errors. This was accomplished by employing frequencies to identify all conceivable data entry errors. The data was next analyzed for missing values, which revealed that no data was missing and that the data was a good fit. Prior to doing further statistical analysis, the normality test and outliers were evaluated.

3.2.2.9.1 Analysis of Missing Values

When missing values data is missing at random, it is necessary to deal with the data since it has the potential to damage the data's quality. Researchers have proposed a few approaches to dealing with missing data. Some academics believe that missing data should be removed entirely, while others believe that missing values should be updated. The researcher used the

Expectation Maximisation (EM) approach to see if the data was missing at random or not in the current study (Gold & Bentler, 2000). This laid the groundwork for dealing with missing values. The data demonstrated that missing values did not occur at random, and hence the missing data posed no risk to the data's quality.

3.2.2.9.2 Investigation of Outliers

In order to perform regression analysis, the data must be regularly distributed, which means there should be no outliers. Outliers were studied in both univariate and multivariate formats. Multivariate outlier occurs when a combination of scores from multiple variables is distant from other combinations, whereas univariate outlier occurs when one observation is away from other observations. The stem and leaf statistic was used to analyze univariate outliers, whereas the Mahalanobis Distance statistic was used to analyze multivariate outliers. The data's detected outliers were addressed.

3.2.2.9.3 Data normality test

Skewness and kurtosis were used to test the data's normality. Skewness and kurtosis should be between -2 and +2 according to researchers (George & Mallery, 2010). All of the study variables were found to be between -2 and +2, indicating that the data was normally distributed.

3.2.2.9.4 Multicollinearity test

The absence of multicollinearity is one of the basic assumptions underlying the usage of principle component analysis and multiple regressions. As a result, while there should be a relationship between the research variables, the relationship between the predictors should not be strong (not greater than 0.70). In keeping with this, variables with a high correlation (correlation coefficient > 0.70) were removed, while the rest were kept for further study.

CHAPTER FOUR

RESULTS

4.1 Accuracy assessment and land use /land cover changes (LULC) on the wetlands

The accuracy assessment and land use land cover matrix between 1986 and 2017 were analysed and the results presented below:

The overall accuracy levels for the three periods for the Sakumo II wetland for the years 1986, 2002 and 2017 ranged from 79% to 85%, with Kappa statistics ranging from 0.72 - 0.79 (Table 4.1). The Laloi coastal wetland recorded overall accuracy levels ranging from 84% to 86%, with Kappa statistics ranging from 0.78 - 0.82 respectively while the overall accuracy on the Kpeshie wetland ranged from 80% to 85%, with Kappa statistics between 0.73-0.79 respectively on the Kpeshie wetland (Table 4.2; 4.3).

Table 4.1: Summary of land use/land cover classification for Sakumo II for the years 1986, 2002 and 2017.

Sakumo II						
	1986		2002		2017	
Class	**Producer %**	**User%**	**Producer%**	**User%**	**Producer%**	**User%**
Bare land	75.6	65.8	72.0	72.0	81.5	71.0
Built up	68.1	82.1	85.4	91.1	81.6	93.0
Vegetation	88.6	81.3	91.3	84.0	97.6	81.6
Waterbodies	88.2	85.7	93.5	76.3	84.6	95.7
Overall Accuracy	0.79		0.82		0.85	
Kappa Accuracy	**0.72**		**0.76**		**0.79**	

Table 4.2: Summary of land use/land cover classification for Laloi for the years 1986, 2002 and 2017.

			Laloi			
	1986		**2002**		**2017**	
Class	**Producer %**	**User %**	**Producer%**	**User %**	**Producer%**	**User%**
Bare land	78.6	91.7	92.3	80.0	84.6	78.5
Built up	88.9	84.2	82.4	87.5	86.2	83.3
Vegetation	81.0	81.0	85.7	81.8	80.0	83.3
Waterbodies	95.7	84.6	83.9	96.3	84.0	84.0
Overall Accuracy	0.86		0.86		0.84	
Kappa Accuracy	**0.81**		**0.82**		**0.78**	

Table 4.3: Summary of land use/land cover classification for Kpeshie for the years 1986, 2002 and 2017.

			Kpeshie			
	1986		**2002**		**2017**	
Class	**Producer%**	**User%**	**Producer %**	**User %**	**Producer%**	**User%**
Bare land	78.6	88.0	75.0	85.7	68.4	81.3
Built up	80.0	74.1	90.0	81.8	83.3	80.0
Vegetation	88.9	72.7	75.0	85.7	87.0	83.3
Waterbodies	72.0	90.0	86.4	86.4	82.9	87.9
Overall Accuracy	0.80		0.85		0.84	
Kappa Accuracy	**0.73**		**0.79**		**0.77**	

4.1.1 Land use/land cover matrix of the wetlands

According to Abate (2011), determining which LULC type changed to the other type of LULC is a crucial part of change detection. The direction of change and the LULC type that remains unchanged at the conclusion of the period are depicted in the LULC changes matrix. As a result, a change in matrix for each period from 1986 to 2017 was evaluated to clearly understand the source and destination of key LULC units using the downloaded images in Fig 4.1, 4.2 and 4.3 and presented in tables 4.4 and figures 4.4, 4.5, 4.6.

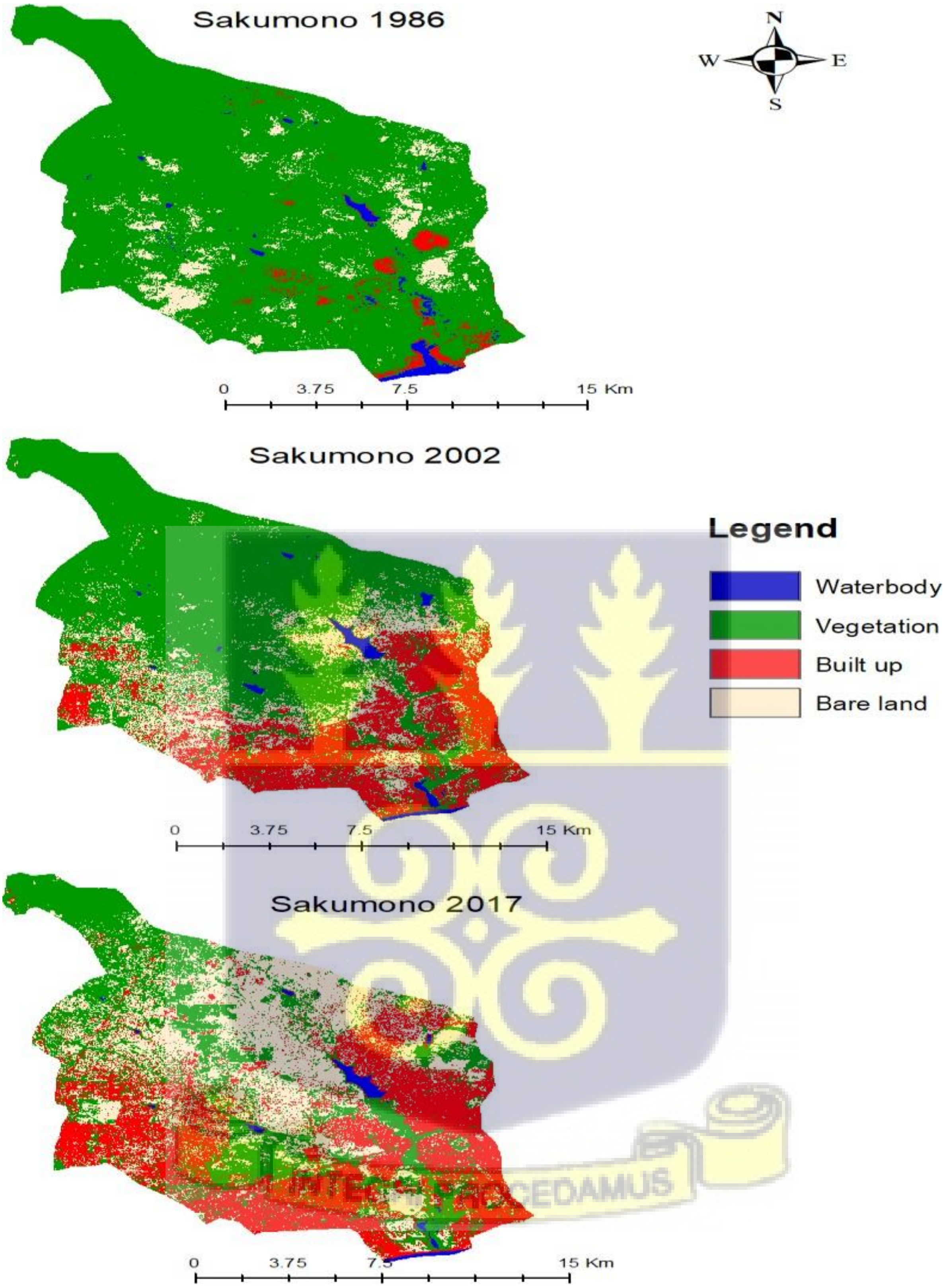


Figure 4.1: Land use/land cover maps for the Sakumo II wetland derived from satellite data for 1986, 2002 and 2017.

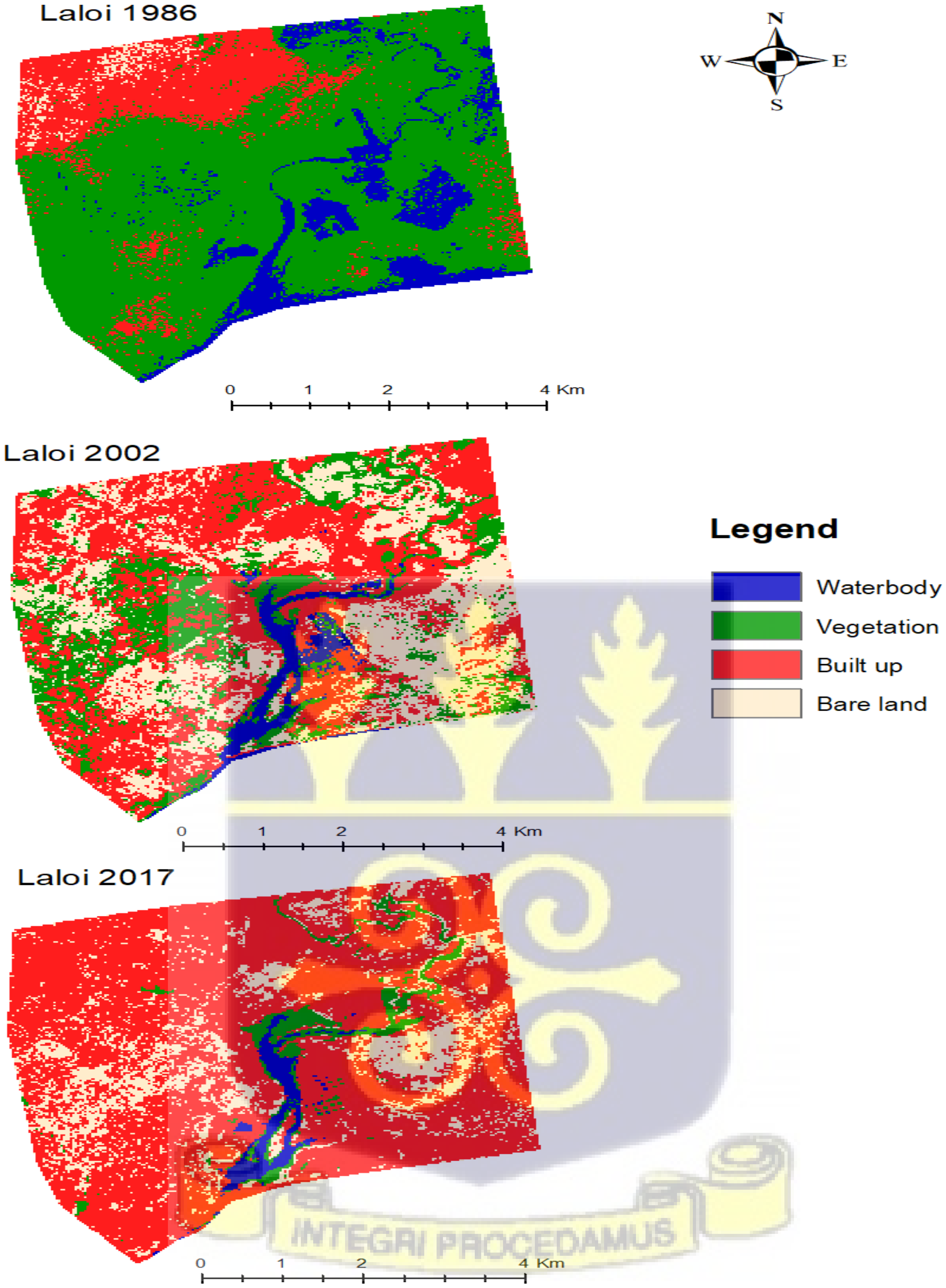


Figure 4.2: Land use/land cover maps for the Laloi wetland derived from satellite data for 1986, 2002 and 2017

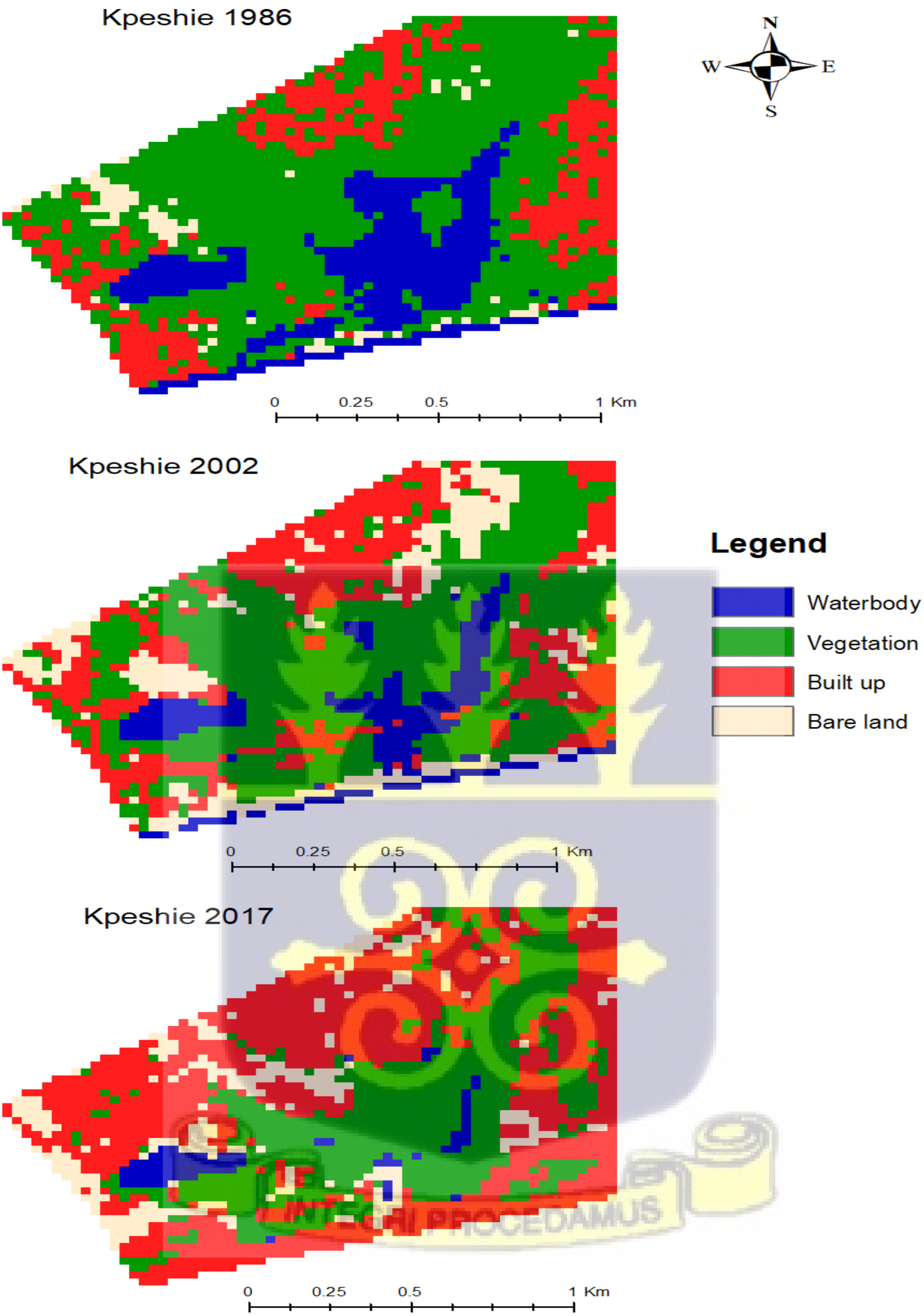


Figure 4.3: Land use/land cover maps for the Kpeshie wetland derived from satellite data for 1986, 2002 and 2017

The state of the wetlands from 1986 to 2017 was assessed and the change matrix was used to ascertain the level of change that had taken place on the wetlands between these periods. The landuse/land cover units assessed were the barelands, the vegetation, the waterbodies and built-up areas. In terms of the land size, the Sakumo II was the largest compared to the Laloi and Kpeshie wetlands. Vegetative cover was the most dominant land cover unit in the 1986's with a decrease in built up areas. This was however, not the case in 2017 with the built-up becoming the dominant LULC unit with vegetative cover reducing drastically on all wetlands. A summary of the LULC changes has been presented in Table 4.4 and Fig. 4.4, 4.5, and 4.6.

Table 4.4: Land use/land cover size/changes within the Sakumo II, Laloi and Kpeshie wetlands

		1986		**2002**		**2017**		**Change (1986-2017)**
	Land cover class	**Area (ha)**	**%**	**Area(ha)**	**%**	**Area(ha)**	**%**	**%**
Sakumo II	Bareland	1981.36	6.8	2253.97	7.8	2984.12	10.3	3.5
	Built Up	691.68	2.4	8962.76	30.8	16512.49	56.8	54.4
	Vegetation	25922.86	89.2	17491.98	60.2	9285.16	31.9	-57.3
	Waterbodies	474.69	1.6	361.88	1.2	288.82	1.0	-0.6
	Total	29070.59	100.0	29070.59	100.0	29070.59	100.0	
Laloi	Bareland	157.33	4.4	832.37	23.5	579.79	16.4	12.0
	Built Up	630.9	17.8	1163.21	32.9	2506.59	70.8	53.0
	Vegetation	2420.28	68.4	1381.12	39.0	356.66	10.1	-58.3
	Waterbodies	330.29	9.3	162.1	4.6	95.76	2.7	-6.6
	Total	3538.8	100.0	3538.8	100.0	3538.8	100.0	
Kpeshie	Bareland	7.56	3.7	5.28	2.6	3.56	1.7	2.0
	Built Up	41.76	20.3	109.25	53.0	146.66	71.1	50.8
	Vegetation	118.35	57.4	72.71	35.3	48.85	23.7	-33.7
	Waterbodies	38.52	18.7	18.95	9.2	7.12	3.5	-15.2
	Total	206.19	100	206.19	100	206.19	100	

Figure 4.4, 4.5, 4.6 shows bar-charts depicting the changes levels of the different land cover types with respect to the land size in hectares.

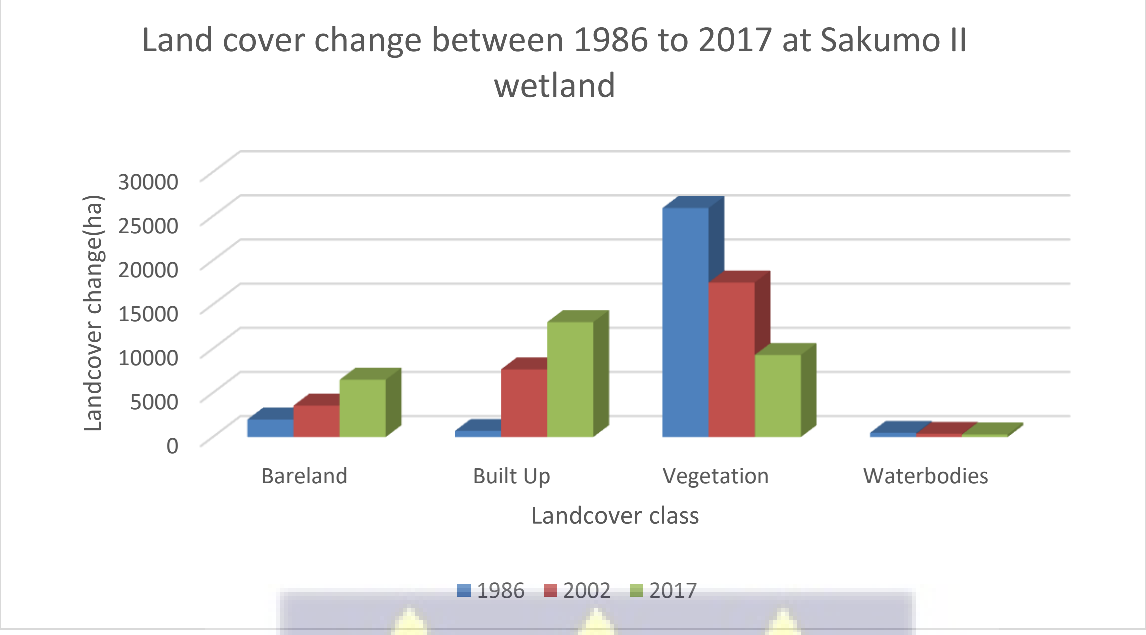


Fig 4.4: Changes in land cover type on the Sakumo II wetland

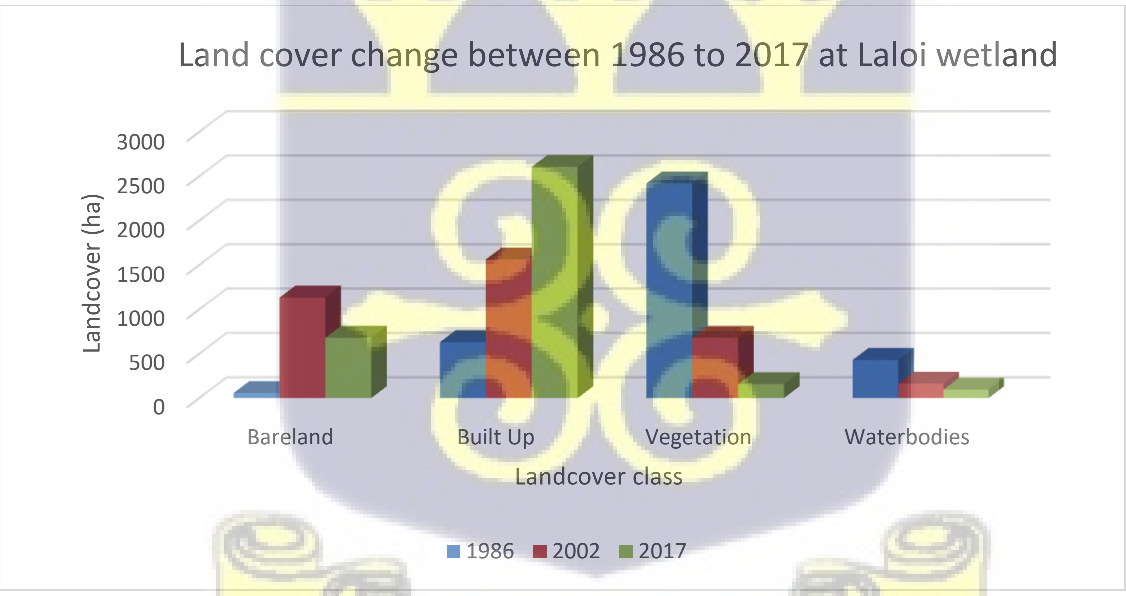


Fig 4.5: Changes in land cover type on the Laloi wetland

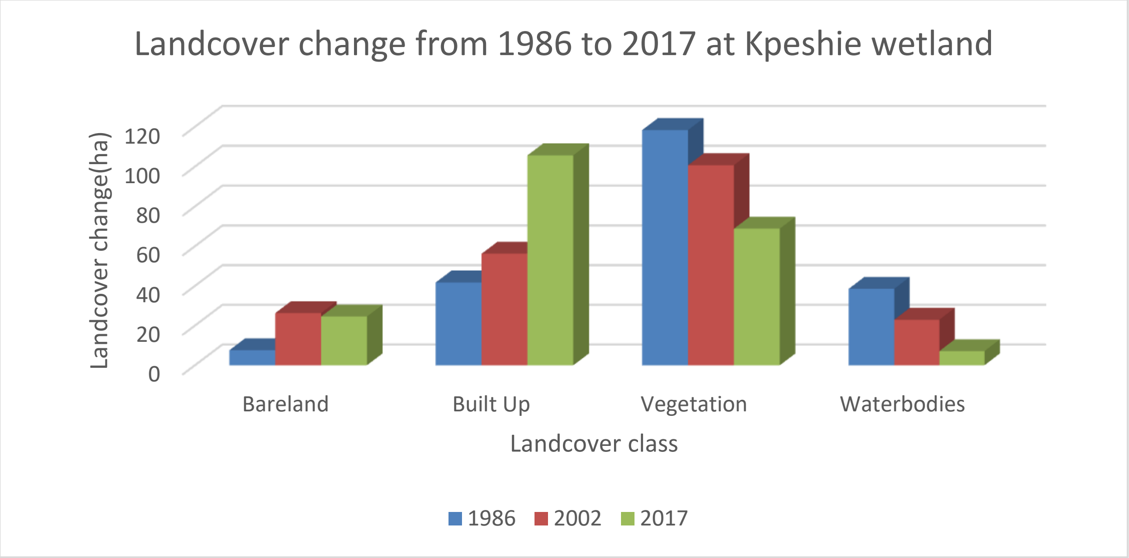


Fig 4.6: Changes in land cover type on the Kpeshie wetland

The most predominant LULC unit on the Sakumo II wetland in 1986 was the vegetative cover which occupied about 89.2% of the land mass with 6.8% being barelands. Approximately, 2.4% of the total land size of the wetland was covered by built-up areas with the remaining 1.6% covered by water bodies during the 1986's. There was however an upsurge in built-up areas by the year 2017 from the initial 2.4% to 56.8 %. As the built up areas were increasing there was a sharp decrease in vegetative cover from 89.2% to 31.9% over the period of 30 years (Table 4.30). From the change matrix, most vegetative covered areas were lost to built-up areas due to increase in urbanization and human population within the catchment. The waterbodies within the Sakumo II wetland and its catchment also showed a minimal decrease of 0.6 % between 1986 and 2017 (Table 4.4).

The most predominant LULC unit on the Laloi wetland was also vegetative cover which occupied about 68.4% of the land size followed by the built-up which occupied about 17.8%. From the change analysis between 1986 and 2017, vegetative cover lost a relatively higher land mass from 68.4% to 10.1% to built-up and the other LULC units (Table 4.4). The major drivers for the lost in vegetative cover were rapid urbanization due to the proliferation of residential buildings, the cutting of mangroves for firewood as well as the extension in the salt pans on the wetlands. The waterbodies on the wetland also reduced by 6.6 % between 1986 and 2017 which is likely to affect waterbirds who normally use the wetlands to forage, roost and rest on their migratory journey.

In the 1986's, the most predominant LULC unit on the Kpeshie wetland was vegetative cover which occupied about 57.4% of the land mass, followed by built-up areas of 20.3% because the area was more urban (Table 4.4). By the year 2017, the most dominant LULC unit was the built-up as most of the vegetative cover had been lost to built-up and the other LULC units within the catchment. The increase and upsurge in residential buildings and other recreational facilities such as football pitches, hotels in the catchment contributed to this. There was also an observed decrease in the size of the waterbodies from 18.7% in 1986 to 3.2 % in 2017 because of the filling activities of the lagoon areas with sand for residential purposes by encroachers.

From the change analysis on the wetlands, it was observed that the vegetative cover in 1986 has been lost mostly to built-up areas and also reduction in the size of the waterbodies by rapid expansion of residential facilities, and encroachment in the catchment. The observed changes in the LULC on the wetlands between the years 1986 to 2017 will therefore have either a direct or indirect effect on the other components of the wetlands such as the water, the sediment and biodiversity including waterbirds and fishes in the lagoons.

4.2 Water quality of the Sakumo II, Laloi and Kpeshie coastal wetlands

The results obtained from both the field and laboratory analysis of water samples collected monthly from the lagoon on all three wetlands are presented in this section.

4.2.1 Physicochemical parameter

The final results for the water samples collected are presented in Table 4.5, 4.6 and 4.7. The results obtained were compared to their respective World Health Organization (WHO) or the Environmental Protection Agency (EPA) recommended limits and other baseline studies on the wetlands.

Table 4.5: Statistical summary of physicochemical results of surface water in the Sakumo II, Laloi and Kpeshie lagoons

	Sakumo II	**Laloi**	**Kpeshie**	**WHO 2004**
Parameter	**Mean ±SD**	**Mean±SD**	**Mean±SD**	
pH	7.65±0.65	8.05±0.65	7.92±1.30	6.5-8
Temp (^{0}C).	29.23±1.35	28.76±0.74	29.71±2.11	25-30
Conductivity (mS/cm)	30.32±20.12	50.80±14.01	58.68±21.4	1500
TDS (g/l)	30.88±19.42	40.08±17.84	37.47±16.08	1000
TSS(mg/l)	45.35± 23.69	60.66± 22.41	361.13± 207.85	
BOD (mg/l)	4.66±3.36	2.66 ±1.13	24.64 ±10.43	<3
DO (mg/l)	5.86±2.57	8.66±1.63	3.28±1.37	> 5
Salinity (ppt)	6.92±4.47	28.08±15.35	25.85±2.34	
Turbidity (NTU)	20.24±7.60	28.60±16.26	190.92±127.44	
Water depth (m)	0.37±1.64	0.37±1.70	0.50±1.97	
Alkalinity(mg/l)	504.83±280.80	92.71±56.39	457.42±174.55	500

The pH range of natural water often falls between 4 and 9 (Amankona, 2010). The mean pH recorded for the Sakumo II, Laloi and Kpeshie lagoons were 7.65±0.65, 8.05±0.65 and 7.92±1.30 respectively indicating the lagoon water in the Laloi wetland was slightly alkaline (Table 4.5). Analysis of variance of the pH showed no significant difference among all three sites (ANOVA, p-value =0.056, $p > 0.05$ F ratio=0.589).

The mean temperatures recorded of 29.23±1.35^{0}C, 28.76±0.74^{0}C and 29.71±2.11^{0}C for the Sakumo II, Laloi and Kpeshie lagoons (Table 4.5). Analysis of variance among the site also showed no significant difference in temperature among the three sites (p-value= 0.34, $p > 0.05$, F ratio= 1.116).

The mean conductivity levels in the water samples were 30.32 ± 20.12mS/cm for the Sakumo II, 50.80±14.01mS/cm for the Laloi wetlands, and 58.68±21.40mS/cm for Kpeshie (Table 4.5). Analysis of variance showed significant variation in conductivity levels among all three sites (p-value = < 0.002, $p < 0.05$, F ratio= 7.284).

The sum of all the minerals dissolved in water is referred to as the total dissolve solid (TDS). Bicarbonates, carbonates, chlorides, phosphates, sulphates, and perhaps sodium, calcium, potassium, and magnesium nitrates, along with residues of manganese and iron, could be found in these materials. The mean level of TDS recorded was 30.88±19.42 g/l, 40.08±17.84 g/l and 37.47±16.08 g/l for the Sakumo II, Laloi and the Kpeshie lagoons respectively (Table 4.5). Analysis of variance showed no significant variation in the levels of total dissolved solids among all three sites (p= 0.438, p> 0.05, F ratio= 0.846).

Mean dissolved oxygen (DO) levels recorded for the study were 5.86±2.57 mg/l for Sakumo II lagoon, 8.66±1.13 mg/l for Laloi lagoon and 3.28±1.36 mg/l for the Kpeshie lagoon (Table 4.5). Analysis of variance showed significant differences in dissolved oxygen among all three sites (p=0.00, p <0.05, F ratio= 10.64). The results indicate the waters from the Laloi wetland was well oxygenated while the Kpeshie waters were poorly oxygenated a detriment to aquatic species.

In terms of salinity, Laloi lagoon recorded the highest mean level of 28.08±15.35 ppt, Kpeshie lagoon recorded mean salinity level of 25.85 ±2.34 ppt whilst Sakumo II lagoon recorded salinity level of 6.92 ±4.47 ppt (Table 4.5). Analysis of variance showed significant variation in salinity levels among all three sites ($p= 0.00$, $p < 0.05$, F ratio =18.64).

The Kpeshie lagoon water was highly turbid compared to the Sakumo II and Laloi lagoon. The Kpeshie lagoon recorded mean level of 438.17 ± 277.66 NTU, while Sakumo II and Laloi lagoons recorded mean levels of 22.92±11.78 NTU and 47.25±19.43 NTU respectively (Table 4.5). Analysis of variance showed significant differences in turbidity values recorded for all three sites ($p = 0.00$, $p < 0.05$, F ratio= 25.189).

The average water depth recorded for Sakumo II lagoon during the study was 0.37±1.64m, 0.37±1.7m for Laloi lagoon and 0.5±1.97m for the Kpeshie lagoon (Table 4.5). Analysis of variance of the water depth showed no significant variation among the sites ($p=0.145$, $p >0.05$, F ratio=2.049).

Alkalinity is the measure to resist changes in pH. The main compounds accountable for alkalinity in waters are carbonates, bicarbonates, ammonia, hydroxide ions, and organic acids (Meybeck *et al.*, 1992). The Sakumo II lagoon recorded mean alkalinity levels of 504.83 ± 280.80 mg/l, while mean levels of 92.71±56.39 mg/l and 457.42 ±174.55 mg/l were recorded in the Laloi and Kpeshie lagoons respectively (Table 4.5). Analysis of variance showed significant difference in alkalinity concentration for all three sites ($p=0.00$, $p < 0.05$, F ratio= 16.272) (Appewndix I-10).

4.2.2 Cations, anions and nutrients in water samples from coastal lagoons

Cations and anions are both ions with positive or negative charge. The major cations, anions and nutrients recorded in water samples during the study period in the Sakumo II, Laloi and Kpeshie wetlands after the PCA analysis are shown in Table 4.6.

Table 4.6: Cations, anions and nutrients on the wetlands sites

Parameter (mg/l)	Sakumo II	Laloi	Kpeshie	WHO 2004
SO_4^{2-}	**591.08**±329.09	**901.83**±234.55	**13541.42**±6430.47	**200**
Cl^-	8961.25±4868.30	9384.58±3995.59	12961.83±5264.21	250
Mg^{2+}	1354.50±727.36	678.42±360.38	931.17±424.13	100
Na	4531.59±1992.35	4670.92±3136.76	15841.75±6619.50	200
K	28.87±13.28	34.33±12.99	407.75±256.89	12
Ca^{2+}	789.17±482.41	620.08±247.79	461.58±360.71	75
NO_3-N	1.46±1.16	1.74±1.23	10.28±2.44	<10
NO_2-N	0.29±0.37	0.37±0.30	0.13±0.07	
PO_4-P	1.72±1.09	0.28±0.28	2.08±0.89	< 0.3

The mean chloride levels recorded for Sakumo II lagoon during the entire study was 8961.25 ± 4868.30 mg/l, 9384.58 ± 3995.59 mg/l for Laloi lagoon and 12961.83 ± 5264.21 mg/l for Kpeshie lagoon respectively (Table 4.6). Analysis of variance of chloride concentration showed no significant variation among the three study sites ($p=0.091$, $p>0.05$, F ratio=2.581, Appendix I-10).

The mean calcium recorded for Sakumo II lagoon was 789.17 ± 482.41 mg/l, 620.08±247.79 mg/l for Laloi lagoon and 461.58± 360.71 mg/l for the Kpeshie lagoon (Table 4.6). Analysis of variance in calcium concentration showed no significant variation among the sites ($p=0.081$, $p>0.05$, F ratio = 2.718). Likewise, magnesium levels recorded mean values of 1354.50 ± 727.36 mg/l, 678.42±360.38 mg/l and 931.17 ± 424.12 mg/l for the Sakumo II, Laloi and Kpeshie lagoon respectively with no significant differences among the sites ($p=0.013$, $p > 0.05$, F ratio=5.008, Appendix I-10).

The anions recorded was in the order $Cl^- > SO_4^{2-}$ whilst the cations was in the order $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ for the Sakumo II, Laloi and Kpeshie lagoons. All the cations and anions exceeded the WHO permissible levels in the water sample analysed.

In terms of nutrients in lagoon water of the coastal wetlands, the Kpeshie lagoon recorded the highest mean level of phosphate (2.08 ± 0.89 mg/l) followed by the Sakumo II lagoon and the Laloi lagoon (Table 4.6). Levels of phosphate in both the Kpeshie and Sakumo II lagoons exceeded the WHO permissible levels for surface water. Analysis of variance showed a significant difference in the phosphate levels among all three sites ($p=0.00$, $p <0.05$, Fratio=15.888, Appendix I-10)

Mean nitrite value of 0.13 ± 0.07 mg/l was recorded for the Kpeshie lagoon, 0.37± 0.3 mg/l in the Laloi lagoon and 0.29 ± 0.37 mg/l in Sakumo II lagoon during the study (Table 4.6). Analysis of variance showed no significant difference in the levels of nitrite from all the three sites ($p = 0.09$, $p < 0.05$ F ratio= 2.597, Appendix I-10).

4.2.3 Concentration of heavy metals in lagoon waters on wetlands

Heavy metals in water finally settle at the bottom sediment thereby leading to bioaccumulation in the water. Higher levels of heavy metals in the waters may lead to the contamination of the water, which in turn has a rippling effect on biodiversity which depends on those environments for survival. The levels recorded in the Sakumo II, Laloi and Kpeshie lagoons are provided in Table 4.7.

The levels of heavy metals for this study were compared to baseline water quality data or previous works carried out on these wetlands to find out if there has been an increase or decrease in the levels of these heavy metals in the lagoon waters.

Table 4.7: Mean concentration of heavy metals in surface water (mg/l) on wetlands

Parameter (mg/l)	**Sakumo II**	**Laloi**	**Kpeshie**	**WHO 2004**
Fe	***2.34±1.881***	***3.47±2.590***	***10.05±4.026***	***0.3***
Mn	**0.81±0.895**	**0.56±0.252**	**1.17±*1.038***	**0.1**
Cu	0.13±0.121	0.070±0.206	0.01±0.002	2.0
Zn	0.12±0.015	0.56±0.570	0.36±0.288	3.0
Pb	***0.02±0.008***	***1.17±0.060***	***2.71±0.320***	***0.01***
Cd	***0.05±0.040***	***0.10±0.029***	***0.14±0.048***	***0.003***
Ni	0.04±0.085	0.02±0.004	0.03±0.020	
Cr	***2.03±0.790***	***0.02±0.029***	***1.01±1.165***	***0.05***
Co	1.04±0.900	0.07±0.054	0.02±0.004	

NB. Bold and italics values are beyond the WHO thresholds for the particular metal

The mean levels of iron, manganese, cadmium, and chromium recorded in water samples collected from all three wetland sites were above the WHO recommended limit (Table 4.7). Analysis of variance showed significant difference in iron levels ($p = 0.000$, $p < 0.05$, F ratio $= 23.558$), zinc levels ($p = 0.000$, $p < 0.05$, F ratio$= 6.58$), cadmium levels ($p = 0.000$, $p < 0.05$, F ratio $= 15.383$), chromium levels ($p = 0.006$, $p < 0.05$, F ratio$= 5.957$) and cobalt levels ($p = 0.000$, $p < 0.05$, F ratio$= 14.51$) in water samples collected among all the three sites (Appendix I-10).

To cater for multicollinearrity, the PCA was used to ascertain the elements which behave the same way in the correlation matrix.

From the matrix in table 4.8, there were high and strong correlation between K^+ and Na *[r=0.93]*, SO_4^{2-} and Na *[r=0.93]*, BOD and Na *[r=0.91]*, Na and Fe *[r=0.77]*, NO_3 and Fe *[r=0.81]*, NO_3 and Na *[r=0.86]*, NO_3 and K+ *[r=0.86]*, NO_3 and SO_4^{2-} *[r=0.90]*, NO_3 and BOD *[r=0.87]*, K^+ and Fe *[r=0.76]*, SO_4^{2-} and Fe *[r=0.81]*, BOD and Fe *[r=0.88]*, K^+ and $SO_4{}^{2-}$ *[r=0.98]*, K^+ and BOD *[r=0.88]*, $SO_4{}^{2-}$ and BOD *[r=0.89]*.

A summary of the intercorrelation matrix showing the relationship between water quality elements is presented in Table 4.8 below.

Table 4.8 Summary of the intercorrelation matrix showing the relationship between water quality elements

	pH	Temperature	Conductivity	TDS	DO	Salinity	turbidity	H20 depth	Alkalinity	Cl	Mg^{2+}	Ca^{2+}	NO$_2$ -N	PO$_4$- P	Fe	Mn	Cu	Zn	Cd	Ni	Cr	Co	TSS	BOD	SO4	K$^+$	Na	NO$_3$	Pb
pH	1.00																												
Temperature	0.058	1.000																											
Conductivity	-0.061	0.122	1.000																										
TDS	-0.153	-0.085	0.200	1.000																									
DO	-0.310	0.188	-0.297	-0.076	1.000																								
Salinity	0.228	0.150	0.363	0.099	-0.575	1.000																							
Turbity	0.140	0.379	0.426	0.221	-0.232	0.33	1.000																						
H2O dethp	0.129	-0.241	-0.115	0.003	-0.185	-0.06	0.10	1.000																					
Alkalinity	-0.173	0.064	-0.143	0.170	0.286	-0.31	0.14	0.36	1.000																				
Cl-	0.051	-0.141	-0.049	0.583	-0.021	0.12	0.24	0.43	0.36	1.000																			
Mg2+	-0.149	-0.085	-0.283	0.367	0.382	-0.45	-0.07	0.16	0.37	0.419	1.000																		
Ca2+	-0.081	-0.300	-0.369	0.520	0.241	-0.31	-0.28	0.29	0.42	0.44	0.68	1.000																	
NO2-N	-0.130	-0.110	-0.039	0.491	0.024	-0.01	-0.26	0.03	0.11	0.26	0.18	0.48	1.000																
PO4-P	-0.008	0.097	-0.002	-0.069	0.185	-0.17	0.52	0.02	0.44	0.04	0.29	-0.10	-0.33	1.000															
Fe	0.227	0.172	0.286	0.006	-0.318	0.34	0.54	0.55	0.18	0.34	0.01	-0.20	-0.24	0.26	1.000														
Mn	0.000	-0.099	0.140	0.507	-0.064	0.05	0.33	0.21	0.54	0.50	0.33	0.37	0.34	0.33	0.29	1.000													
Cu	-0.126	0.101	-0.011	0.146	0.064	0.15	-0.25	-0.40	-0.08	-0.05	0.10	0.17	0.36	-0.20	-0.37	-0.01	1.000												
Zn	-0.004	0.151	0.448	0.362	-0.177	0.57	0.12	-0.34	-0.29	0.04	-0.23	-0.11	0.12	-0.19	-0.11	-0.07	0.27	1.000											
Cd	0.129	0.120	0.295	-0.021	-0.405	0.35	0.33	0.44	-0.17	0.28	-0.18	-0.25	-0.07	-0.10	0.54	-0.05	-0.42	0.06	1.000										
Ni	-0.103	0.204	-0.142	0.1663	-0.084	-0.06	0.04	-0.09	-0.07	-0.13	0.26	0.12	0.01	-0.07	0.06	0.04	0.22	-0.13	-0.06	1									
Cr	-0.270	0.0130	-0.0590	0.086	0.244	-0.34	-0.08	-0.01	0.45	-0.18	0.20	0.26	0.06	0.06	-0.14	0.17	0.21	-0.16	-0.35	0.57	1								
Co	-0.257	-0.223	-0.156	0.013	0.406	-0.60	-0.33	-0.0	0.32	-0.06	0.37	0.40	0.02	-0.01	-0.32	-0.02	0.37	-0.32	-0.49	0.01	0.48	1							
TSS	-0.041	0.227	0.210	-0.035	-0.094	0.27	0.55	0.44	0.08	0.34	0.01	-0.22	-0.27	0.19	0.55	-0.02	-0.22	0.03	0.62	0.07	-0.07	-0.281	1						
BOD	0.158	0.065	0.267	0.215	-0.327	0.38	0.52	0.55	0.27	0.61	0.20	0.02	-0.20	0.23	**0.88**	0.40	-0.25	-0.006	0.53	0.13	-0.06	-0.304	0.587	1					
SO4-2	0.112	0.142	0.177	0.193	-0.307	0.35	0.66	0.48	0.29	0.60	0.15	-0.10	-0.29	0.39	**0.81**	0.43	-0.27	-0.05	0.49	0.07	-0.16	-0.323	0.69	**0.89**	1				

K+	0.159	0.149	0.141	0.215	-0.332	0.34	0.65	0.46	0.28	0.65	0.18	-0.04	-0.25	0.35	**0.76**	0.46	-0.23	-0.06	0.48	0.08	-0.16	-0.29	0.62	**0.88**	**0.98**	1			
Na	**0.074**	0.049	0.296	0.237	-0.371	0.37	0.58	0.38	0.21	0.62	0.17	-0.11	-0.21	0.37	**0.77**	0.43	-0.18	0.045	0.49	0.08	-0.14	-0.34	0.56	**0.91**	**0.93**	**0.93**	1		
NO3	0.084	0.062	0.325	0.195	-0.346	0.34	0.73	0.46	0.31	0.51	0.04	-0.14	-0.22	0.41	**0.81**	0.43	-0.37	-0.003	0.51	0.002	-0.02	-0.35	0.68	**0.87**	**0.90**	**0.86**	**0.86**	1	
Pb	-0.191	0.147	-0.005	-0.097	-0.133	0.23	0.34	0.40	-0.029	0.33	-0.00	-0.18	-0.23	0.03	0.38	-0.14	-0.23	0.013	0.62	-0.05	-0.24	-0.28	**0.85**	0.45	0.60	0.58	0.485	0.53	1

NB: Strong and high correlation r> 0.70 were deleted from further analysis.

The presence of multicollinearity (strong correlation between the variables) paved way to delete these elements from further analysis whereas the others were maintained for advanced analysis. The principal component analysis (PCA) was conducted with the purpose of extracting the exact factors that contribute to the constructs. Six principal components, PC1 to PC6 were obtained for each of the three sites. The variances of the principal component and their contribution rates are shown in table 4.9 below.

Table 4.9: Summary of the PCA for water quality showing eigenvalues and variances

		Sakumo II			Laloi			Kpeshie	
Principal component	Eigen value	Contributing Rate	Cumulative contributing rate	Eigen value	Contributing rate	Cumulative contributing rate	Eigen value	Contributing rate	Cumulative contributing rate
1	7.746	35.208	35.208	5.791	26.324	26.324	7.557	34.350	34.350
2	3.347	15.211	50.419	4.461	20.279	46.603	3.962	18.008	52.358
3	2.842	12.917	63.336	3.505	15.934	62.537	2.749	12.494	64.852
4	2.326	10.575	73.911	2.076	9.437	71.974	2.565	11.658	76.510
5	1.952	8.875	82.786	1.889	8.588	80.562	1.435	6.522	83.032
6	1.337	6.076	88.862	1.552	7.054	87.616	1.269	5.768	88.800

The water quality parameters in PC1, PC2, PC3, PC4, PC5, and PC6 together contributed 88.86%, 87.62% and 88.80% to the variation in water quality data on the Sakumo II, Laloi and Kpeshie wetlands respectively (Table 4.9).

On the Sakumo II wetland, PC1 (TDS, alkalinity, Cl^{-1}, Ca^{2+}, PO_4-P, Mn) contributed 35.21%, PC2 (pH, Ni, Cr) contributed 15.21%, PC3 (Mg^{2+}, Cd) contributed 12.92%, PC4 (conductivity, Fe, Cu, Co) contributed 10.58%, PC5 (temp, water depth, Zn) contributed 8.89% and PC6 (DO, turbidity) contributed 6.08% of the data variation.

On the Laloi wetlands, PC1 (conductivity, turbidity, Alkalinity, Cl^{-1}, Mg^{2+}, PO_4-P, Mn, Cu, Ni) contributed 26.32%, PC2 (Temperature, DO, salinity, Fe) contributed 20.28%, PC3 (TDS, water depth, Ca^{2+}, Zn) contributed 15.93%, PC4 (pH, Co) contributed 9.44%, PC5 (Cd, No_2-N) contributed 8.59% and PC6 (Cr) contributed 7.05% of the data variation.

At the Kpeshie wetlands, PC1 (conductivity, DO, water depth, Cl^{-1}, Mg^{2+}, Ca^{2+}, Fe, Zn, Ni Co) contributed 34.35%, PC2 (TDS, turbidity, NO_2-N, PO_4-P, Mn) contributed 18.01%, PC3 (temperature, Cu) contributed 12.49%, PC4 (salinity, alkalinity, Cr) contributed 11.66%, PC5 (Ni) contributed 6.52% and PC6 (pH) contributed 5.77% of the data variation.

The first principal component PC1 on the Sakumo II showed a strong positive factor loadings for PO_4-P and Cl^{-1} with moderate loadings for TDS, alkalinity, Ca^{2+} and Mn. On PC2, there was also a strong positive loading for Ni and Cr with moderate loadings for pH.

For PC3, PC4, PC5 and PC6, there were strong positive loadings for Mg^{2+} , Cd, conductivity, temperature and turbidity respectively likewise positive moderate loadings of Fe, Zn and Co on PC4, moderately negative loadings of water depth and Zn on PC5 as well as DO on PC6.

On the Laloi wetland, there was a strong positive loading of TDS, moderate positive loading of alkalinity, Cl^{-1}, Mg^{2+}, Mn, Cu and also a moderate negative loading of PO_4-P, turbidity and Ni on PC1, there was a moderate positive loading of temperature, DO, salinity, Fe on PC2, strong positive loading of Ca^{2+}, moderate positive loading of water depth and Zn, moderate negative loading of TDS on PC3, weak positive loadings of pH and Co on PC4, weak positive loading of NO_3–N with moderate negative loading of Cd on PC5.

Furthermore, there was a moderate negative loading of Cr on PC6.

There were strong positive loadings of Cl^{-1}, Mg^{2+} and Ca^{2+} , moderate positive loading of water depth, Fe, Co and weak positive loadings of Ni, weak negative loading of conductivity, DO and Zn on PC1, strong positive loading of TDS, moderate loading of turbidity, NO_2-N, PO_4-P, Mn on PC2.

There were also strong positive loading of temperature, weak positive loadings of Cu on PC3, likewise a moderate positive loading of salinity, alkalinity and Cr on PC4, weak positive loading of Cd and moderate positive of pH on PC5 and PC6 respectively on the Kpeshie wetland as shown in the table below (Table 4.10).

Table 4.10: Summary of the principal component analysis for water quality showing the factor loadings

Variables		**Sakumo II**						**Laloi**						**Kpeshie**				
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
PH		-0.564								0.520								0.630
Temp					0.953			0.630							0.829			
Conductivity				0.903			0.809						-0.651					
TDS	0.673								-0.711					0.834				
DO						-0.569		0.579					-0.757					
Salinity								0.654								0.735		
Turbidity						0.904	-0.729							0.645				
Water depth					-0.799				0.701				0.634					
Alkanility	0.644						0.725									0.711		
Cl-	0.806						0.635						0.950					
Mg2+			0.879				0.619						0.935					
Ca2+	0.613								0.851				0.935					
NO2-N											0.478			0.631				
PO4-P	0.981						-0.795							0.724				
Fe				0.536				0.708					0.718					
Mn	0.750						0.680							0.732				
Cu				0.790			0.836								0.586			
Zn					-0.767				0.531				-0.779					
Cd			0.860								-0.619						0.512	
Ni		0.905					-0.667						0.550					
Cr		0.840										-0.639				0.579		
Co				0.716						0.520			0.660					

A post hoc analysis using the Least Significant Difference (LSD) method was used to show the significant differences in water quality parameters by site.

Table 4.11: Post hoc analysis showing differences in physicochemical water quality parameters by sites

Conductivity	**Sakumo II**	**Laloi**	**Kpeshie**
Sakumo II	-		
Laloi	20.486*	-	
Kpeshie	28.362*	7.876	-
DO			
Sakumo II	-		
Laloi	-2.004*	-	
Kpeshie	-1.014	0.99	-
Salinity			
Sakumo II	-		
Laloi	-3.198*	-	
Kpeshie	-2.578*	0.62	-
Turbidity			
Sakumo II	-		
Laloi	21.167*	-	
Kpeshie	18.933*	-2.233	-
Alkalinity			
Sakumo II	-		
Laloi	24.333	-	
Kpeshie	415.250*	390.917*	-

As shown in the table 4.11, conductivity level was significantly less at Sakumo II than Laloi *[mean difference=20.486, $p<0.05$]* and the Kpeshie wetlands *[mean difference=28.362, $p<0.05$]*. Likewise, the DO at Laloi was significantly lower than that at Sakumo II *[mean difference=-2.004, $p<0.05$]* .In the same vein, salinity at Sakumo II was significantly higher than at Laloi *[mean difference=-3.198, $p<0.05$]* and Kpeshie *[mean difference=-2.578, $p<0.05$]*. The table 4.11, further shows that the turbidity at Sakumo II was significantly lesser than at Laloi *[mean difference=21.167, $p<0.05$]* and Kpeshie *[mean difference=18.933,*

$p<0.05$]. In relation to alkalinity, Kpeshie recorded significantly higher levels than Sakumo II *[mean difference=415.250, $p<0.05$]* and Laloi *[mean difference=390.917, $p<0.05$]*.

Based on the significant differences observed in magnesium and phosphate levels in water samples, a post hoc analysis using the Least Significant Difference method (LSD) was done as shown in Table 4.12.

Table 4.12 Post-hoc analysis showing differences in cation and nutrient quality elements by sites

Mg^{2+}	**Sakumo II**	**Laloi**	**Kpeshie**
Sakumo II	-		
Laloi	-412.125*	-	
Kpeshie	-47.417	364.708*	-
PO_4-P			
Sakumo	-		
Laloi	-676.083*	-	
Kpeshie	-423.333*	252.750	-

From Table 4.12, the Mg^{2+} levels at the Laloi wetland was significantly less than that of Sakumo II *[mean difference=-412.125, $p<0.05$]* and Kpeshie *[mean difference=364.708, $p<0.05$]*.

However, PO_4-P at Sakumo II was significantly higher than that of Laloi *[mean difference=-676.083, $p<0.05$*] and the Kpeshie *[mean difference=423.333, $p<0.05$]* respectively.

Post hoc test was done to show the significant differences in the heavy metals of the water samples among the sites as shown in Table 4.13

Table 4.13: Post-hoc analysis showing differences in heavy metal elements by sites

Fe	**Sakumo II**	**Laloi**	**Kpeshie**
Sakumo II	-		
Laloi	-1.436*	-	
Kpeshie	0.367	1.803*	-
Zn			
Sakumo II	-		
Laloi	1.131	-	
Kpeshie	7.707*	6.575*	-
Cd			
Sakumo II	-		
Laloi	.542*	-	
Kpeshie	0.336	-0.206	-
Cr			
Sakumo II	-		
Laloi	.554*	-	
Kpeshie	.687*	0.133	-
Co			
Sakumo II	-		
Laloi	-.966*	-	
Kpeshie	-1.018*	-0.052	-
*$p<0.05$			

In relation to Fe, Laloi wetland recorded significantly less levels than that of Sakumo II *[mean difference=-1.436, $p<0.05$]* and Kpeshie wetlands *[mean difference=1.803, $p<0.05$]* while Zn levels at Kpeshie were significantly higher than at Sakumo II *[mean difference=7.707, $p<0.05$]* and Laloi wetland site *[mean difference=6.575, $p<0.05$]*.

Cadmium (Cd) at Laloi was significantly higher than at Sakumo II *[mean difference=0.542, $p<0.05$]*. In the same vein, Cr at Laloi was significantly higher than at Sakumo II *[mean difference=0.554, $p<0.05$]*. In addition, the levels of Co show that Sakumo II recorded a significantly higher level than that of Laloi *[mean difference=-0.966, $p<0.05$]* and Kpeshie *[mean difference=-1.018, $p<0.05$]*.

4.2.4 Comparing current state of wetland water quality to baseline and other studies.

The current water quality results obtained for 2017 were compared to baseline studies and other studies on the same wetlands by Biney (1982), Koranteng (1995), by Nonterah *et al.*, (2015), Apau, (2012) and the Environmental Management Associates (1991) in their study of coastal lagoons in Ghana to ascertain changes over the years on the wetlands (Table 4.14).

Generally, the lagoon waters appeared more polluted with nutrients than the baseline values recorded in the 1980's. The data show a trend of nutrient load of the lagoon aggregating over the years from the 1980s to the 2017s, the three nutrients (nitrate-nitrogen NO_3-N, and phosphate-phosphorus PO_4-P) mostly increased over the years and especially nitrate at the Kpeshie lagoon.

The high levels of nutrient load in the lagoon were attributed to the surface run-offs of residues of inorganic fertilizers from farming activities, domestic pollutants from waste waters from point sources, industrial discharge rates into streams that drain the lagoon and leaching or diffusion of nutrients from sediments into the water medium by the industries and encroachment in the catchment (Addo *et al.*, 2011; Nonterah *et al.*, 2015). Nitrite recorded in the Sakumo II lagoon was also higher compared to previous studies by Koranteng (1995) and Nonterah *et al.*, (2015) on the same wetland.

An independent t test to show the differences in water quality levels between 1982 (baseline studies) and 2017 revealed significant differences in pH $[t=-2.633, p<0.05]$, temperature $[t=-2.343, p<0.05]$, water depth $[t=-8.008, p<0.05]$, PO_4-P $[t=-2.676, p<0.05]$, Na $[t=-2.180, p<0.05]$, Ca^{2+} $[t=-6.477, p<0.05]$, Mg^{2+} $[t=-4.962, p<0.05]$, Cl $[t=-8.046, p<0.05]$ and SO_4 $[t=-3.172, p<0.05]$ (Appendix 1-9)

Table 4.14: Changes in some water quality parameters compared to baseline studies and other studies on the selected wetlands

Site		pH	Temp ^{0}C	Conductivity (mS/cm)	Salinity ppt	Water Depth (m)	PO_4-P (mg/l)	NO_3-N (mg/l)	NO_2-N (mg/l)
Sakumo II	**Current Study**	**8.30**	**30.58**	**30.32**	**11.39**	**0.37**	**2.81**	**2.62**	**0.66**
	Biney, 1982	8.00	29.50	3.3	1.90	0.06	0.09	1.80	*0.25
	Nonterah *et al.*, 2015	7.88	-	18.82	-	-	0.62	0.11	-
Laloi	**Current Study**	**8.70**	**29.50**	**64.81**	**43.43**	**0.37**	**0.56**	**2.97**	**0.37**
	Biney, 1982	8.10	28.80	22.30	13.60	0.07	0.01	2.70	-
	EMA ,1991	7.60	-	-	-	-	-	0.96	0.06
Kpeshie	**Current Study**	**9.22**	**30.58**	**80.08**	**28.19**	**0.50**	**2.97**	**12.72**	**0.20**
	Biney, 1982	8.00	29.4	36.20	22.70	-	0.11	3.40	0.006#
	Apau, 2012	6.32	31.60	87.31	-	-	**0.11	**0.48	
Site		**Na (mg/l)**	**K(mg/l)**	**Ca (mg/l)**	**Mg (mg/l)**	**Cl mg/l)**	**SO4 (mg/l)**	**DO (mg/l)**	**BOD (mg/l)**
Sakumo II	**Current Study**	**4531.59**	**28.89**	**789.17**	**1354.5**	**8961.25**	**591.08**	**5.86**	**4.66**
	Biney, 1982	27.10	1.50	2.80	1.60	29.30	3.10	8.00	20.00
	Nonterah *et al.*, 2015	3043.73	21.13	364.82	504.36	6244.18	302.35	**5.86	**4.66
Laloi	**Current Study**	**4670.92**	**34.33**	**620.08**	**678.42**	**9384.58**	**901.83**	**8.66**	**2.66**
	Biney 1982	195.20	8.50	9.80	9.60	212.90	13.80	7.50	5.00
	EMA, 1991	-	-	-	-	-	-	6.60	5.50
Kpeshie	**Current Study**	**15841.75**	**407.75**	**461.58**	**931.17**	**12961.83**	**13541.42**	**3.28**	**24.64**
	Biney,1982	315.20	11.80	18.30	16.30	353.80	17.80	7.40	6.00
	Apau, 2012	15165.71	672.86	331.43	258	9834.29	11852	**7.3	14.83

*** Koranteng, 1995, **Environmental Management Associates (EMA) (1991), #Fianko et al., 2013)**

4.2.5 Correlation between LULC changes and water quality parameters

Changes in the LULC through the anthropogenic activities on the wetlands are likely to affect the water quality which in turn will affect the biodiversity inhabiting these wetlands. In order to examine the relationship between land use land cover variables (bareland, built up, vegetation and waterbodies) and water quality, the Pearson correlation was used to show the relationship between the LULC variables and water quality parameters as shown in Tables 4.15, 4.16 and 4.17 respectively.

From the correlation analysis in table 4.15, the water quality elements at Sakumo II, pH [r=-0.982], conductivity [r=-0.587], salinity [r=-0.657] and NO_2-N [r=-0.538] significantly and negatively related with bare lands [$p<0.05$] respectively. Significant relationships were observed between pH and built-up [r=0.945, $p<0.01$], temperature and built-up [r=0.446, $p<0.05$] conductivity and built-up [r=0.698, $p<0.01$], salinity and built-up [r=0.760, $p<0.01$], NO_2-N and built-up [r=0.655, $p<0.05$], suggesting positive relationships between the water quality elements and built-up (Table 4.15)

There were significant relationships between pH and vegetation [r=0.990, $p<0.01$], conductivity and vegetation [r=0.550, $p<0.05$], salinity and vegetation [r=0.623, $p<0.05$], NO_2-N and vegetation [r=0.500, $p<0.05$] at Sakumo II. This suggests a positive relationship between the water quality elements and vegetation. There were also significant negative relationships between temperature and water body [r=-0.895, $p<0.01$], conductivity and waterbody [r=-0.716, $p<0.01$], salinity and water body [r=-0.650, $p<0.05$], water depth and waterbody [r=-0.998, $p<0.01$], PO_4-P and waterbody [r=-0.920, $p<0.01$], NO_3-N and waterbody [r=-0.981, $p<0.01$], NO_2-N and waterbody [r=-0.756, $p<0.01$] (Table 4.15)

Table 4.15.: A summary of the intercorrelation matrix showing the relationship between water quality elements and LULC elements at Sakumo II

	Bareland	pH	Temp	Conductivity	Salinity	Water depth	PO_4 – P	NO_3-N	NO_2- N	Built up	Vegetation	Waterbodies
Bare land	1.000											
pH	-0.982**	1.000										
Temp	-0.312	0.129	1.000									
Conductivity	-0.587*	0.425*	0.952	1.000								
Salinity	-0.657**	0.505*	0.921**	0.996**	1.000							
Water depth	0.081	-0.266	0.922**	0.759**	0.698**	1.000						
PO_4 – P	-0.253	0.068	0.998**	0.932**	0.896**	0.944**	1.000					
NO_3-N	-0.048	-0.140	0.964**	0.837**	0.784**	0.992**	0.978**	1.000				
NO_2- N	-0.538*	0.371*	0.969**	0.998**	0.989**	0.796**	0.952**	0.868**	1.000			
Built up	-0.989**	0.945**	0.446*	0.698**	0.760**	0.064	0.391	0.192	0.655*	1.000		
Vegetation	-0.999**	0.990**	0.269	0.550*	0.623*	-0.125	0.210	0.003	0.500*	0.982**	1.000	
Waterbodies	-0.145	0.327	-0.895**	-0.716**	-0.650*	-0.998**	-0.920**	-0.981**	-0.756**	0.000	0.189	1.000

$*p<0.05$ **$**p<0.01$**

At the Laloi wetland, significant relationships were established between pH and bareland [r=-0.614, $p<0.05$], temperature and bareland [r=0.914, $p<0.05$] conductivity and bareland [r=0.340, $p<0.05$], salinity and bareland [r=0.337, $p<0.05$], water depth and bareland [r=-0.338, $p<0.05$], PO_4-P and bareland [r=0.404, $p<0.05$] and NO_2-N and bareland [r=-0.655, $p<0.05$].

From the correlation table, significant relationships were established between pH and built up [r=0.969, $p<0.01$], conductivity and built up [r=0.725, $p<0.01$], salinity and built up [r=0.728, $p<0.01$], water depth and built up [r=0.998, $p<0.01$], PO_4 -P and built up [r=0.676, $p<0.01$], NO_3-N and built up [r=0.837, $p<0.01$], NO_2-N and built up [r=0.955, $p<0.05$], suggesting positive relationships between the water quality parameters and built-up.

There were significant relationships between pH and vegetation [r=0.756, $p<0.01$], temperature and vegetation [r=0.452, $p<0.05$], conductivity and vegetation [r=0.957, $p<0.01$], salinity and vegetation [r=0.958, $p<0.01$], water depth and vegetation [r=0.922, $p<0.01$], PO_4-P and vegetation [r=0.935, $p<0.01$], NO_3-N and vegetation [r=0.994, $p<0.01$], NO_2-N and vegetation [r=0.721, $p<0.01$] at Laloi. This suggests a positive relationship between the water quality elements and vegetation (Table 4.16).

There were however, significant negative relationships between pH and water body [r=-0.999, $p<0.01$], conductivity and water body [r=-0.488, $p<0.05$], salinity and water body [r=-0.491, $p<0.05$], water depth and water body [r=-0.933, $p<0.01$], PO_4-P and water body [r=-0.427, $p<0.05$], NO_3-N and water body [r=-0.637, $p<0.05$] also on the Laloi wetland (Table 4.16).

Table 4.16: A summary of the intercorrelation matrix showing the relationship between water quality elements and LULC variables at Laloi wetland

	Bareland	pH	Temp	Conductivity	Salinity	Water depth	PO_4 – P	NO_3-N	NO_2- N	Built up	Vegetation	Waterbodies
Bareland	1.000											
pH	-0.614*	1.000										
Temp	0.914**	-0.242	1.000									
Conductivity	0.340*	0.533*	0.692**	1.000								
Salinity	0.337*	0.536*	0.689**	1.000**	1.000							
Water depth	-0.338*	0.950**	0.073	0.771**	0.773**	1.000						
PO_4-P	0.404*	0.474*	0.740**	0.998**	0.997**	0.725**	1.000					
NO_3-N	0.165	0.677**	0.551*	0.984**	0.984**	0.873**	0.969**	1.000				
NO_2-N	-0.655*	0.999**	-0.292	0.488*	0.491*	0.933**	0.427*	0.637*	1.000			
Built up	-0.401*	0.969**	0.005	0.725**	0.728**	0.998**	0.676**	0.837**	0.955**	1.000		
Vegetation	0.052	0.756**	0.452*	0.957**	0.958**	0.922**	0.935**	0.994**	0.721**	0.894**	1.000	
Waterbodies	0.655*	-0.999**	0.292	-0.488*	-0.491*	-0.933**	-0.427*	-0.637*	.000	-0.955**	-0.721**	1.000

*p<0.05 **p<0.01

On the Kpeshie wetland, significant relationships were established between pH and bareland [r=-0.854, $p<0.01$], salinity and bareland [r=-0.930, $p<0.01$], water depth and bareland [r=-0.554, $p<0.05$], PO_4-P and bareland [r=-0.924, $p<0.01$], NO_3-N and bareland [r=-0.915, $p<0.01$] and NO_2-N and bareland [r=-0.554, $p<0.05$]. The finding suggests a negative relationship between water quality elements and bare land.

Significant relationships were also established between temperature and built up [r=-0.997, $p<0.01$], conductivity and built up [r=0.793, $p<0.01$], water depth and built up [r=0.596, $p<0.05$], NO_2-N_and built up [r=0.596, $p<0.05$], suggesting that with the exception of temperature, there were positive relationships between the water quality elements and built up. Likewise, there were significant relationships between temperature and vegetation [r=-0.986, $p<0.05$], conductivity and vegetation [r=0.738, $p<0.01$], water depth and vegetation [r=0.526, $p<0.05$], NO_2-N and vegetation [r=0.526, $p<0.05$] at Kpeshie wetland.

This suggests that with the exception of temperature, there were positive relationships between the water quality parameters and vegetation (Table 4.17). However, there were significant negative relationships between pH and waterbodies [r=0.973, $p<0.01$], conductivity and water body [r=0.587, $p<0.05$], salinity and water body [r=0.998, $p<0.05$], water depth and water body [r=0.786, $p<0.01$], PO_4-P and waterbodies [r=0.997, $p<0.01$], NO_3-N and waterbodies [r=0.995, $p<0.01$], NO_2-N_and waterbodies [r=0.786, $p<0.01$] (Table 4.17).

Table 4.17: A summary of the intercorrelation matrix showing the relationship between water quality elements and LULC elements at Kpeshie

	Bareland	pH	Temp	Conductivity	Salinity	Water depth	PO$_4$ – P	NO$_3$-N	NO$_2$- N	Built up	Vegetation	Waterbodies
Bareland	1.000											
pH	-0.854**	1.000										
Temperature	-0.260	-0.280	1.000									
Conductivity	-0.306	0.756**	-0.840**	1.000								
Salinity	-0.930**	0.986**	-0.114	0.635*	1.000							
Water depth	-0.554*	0.906**	-0.659*	0.962**	0.822	1.000						
PO$_4$- P	-0.924**	0.988**	-0.129	0.647*	1.000	0.831**	1.000					
NO$_3$- N	-0.915**	0.991**	-0.151	0.664*	0.999**	0.843**	1.000	1.000				
NO$_2$-N	-0.554*	0.906**	-0.659*	0.962**	0.822**	1.000	0.831**	0.843**	1.000			
Built up	0.338*	0.201	-0.997**	0.793**	0.033	0.596*	0.048	0.070	0.596*	1.000		
Vegetation	0.416*	0.117	-0.986**	0.738**	-0.052	0.526*	-0.036	-0.014	0.526*	0.996**	1.000	
Waterbodies	-0.950**	0.973**	-0.053	0.587*	0.998**	0.786**	0.997**	0.995**	0.786**	-0.028	-0.113	1.000

*$p<0.05$

**$p<0.01$

4.3 Concentration of heavy metals in bottom sediment in study areas

Concentrations of Cd, Co, Cr, Cu, Fe, Mn, Ni, Zn and Pb in sediments collected from the study sites are presented in Table 4.18. The levels of heavy metal recorded in the sediments were compared with sediment quality guidelines (SQG) by the WHO (2004), USEPA (1999) and CCME (1999) (Appendix I-14).

The mean concentration of Cadmium, Cobalt, Chromium, Copper, Nickel, Zinc and Lead in bottom sediment of the Sakumo II lagoon and Laloi were all below the WHO (2004), USEPA (1999) and CCME (1999) recommended limit. However, the levels of Fe and Mn on both wetlands were above the US EPA sediment quality guidelines. The mean levels of chromium, copper, Iron, manganese and nickel were also above the WHO (2004) and USEPA (1999) recommended SQG limits on the Kpeshie wetlands as shown in Table 4.18.

Table 4.18: Descriptive statistics on the concentration values of heavy metals (mg/kg) in sediments on the wetland sites

Site	Heavy metal	Min	Max	Mean ± SD	WHO SQG*	USEPA SQG*	CCME SQG*
Sakumo II	Cd	0.06	3.3	0.95± 1.32	6	0.6	0.6
	Co	0.94	7.84	3.77±2.26	-	-	-
	Cr	10.09	32.87	21.9±7.49	25	25	37.3
	Cu	4.67	44.64	18.26±11.92	25	16	35.7
	Fe	78.75	362.8	***179.04± 92,91***	-	***30***	-
	Mn	346.71	1021.25	***670.97± 217.85***	-	***30***	-
	Ni	3.5	18.74	9.08±5.00	20	16	-
	Zn	1.05	12.14	4.68±3.21	123	110	123
	Pb	0.01	3.07	1.14± 1.05	-	40	35
Laloi	Cd	0.03	0.15	0.09± 0.04	6	0.6	0.6
	Co	0.46	1.67	0.85± 0.35	-	-	-
	Cr	0.08	3.48	1.26± 1.20	25	25	37.3
	Cu	0.13	1.5	0.62±0.44	25	16	35.7
	Fe	128.79	1310.45	***669.34±428.75***	-	***30***	-
	Mn	11.9	121.11	***52.61± 37.07***	-	***30***	-
	Ni	0.42	2.76	1.23± 0.76	20	16	-
	Zn	0.08	2.11	0.92± 0.55	123	110	123
	Pb	0.26	3.83	2.05± 1.07	-	40	35
Kpeshie	Cd	0.22	3.14	1.52±1.02	6	0.6	0.6
	Co	0.46	10.78	2.8± 2.99	-	-	-
	Cr	12.69	125.77	***45.5±33.23***	***25***	***25***	***37.3***
	Cu	12.7	62.44	***30.63± 15.64***	***25***	***16***	***35.7***
	Fe	762.11	3200.54	***1984.04± 572.46***	-	***30***	-
	Mn	70.59	340.42	***197.85± 88.37***	-	***30***	-
	Ni	15.8	86.8	***40.61± 25.01***	***20***	***16***	-
	Zn	1.08	22.08	7.56±5.87	123	110	123
	Pb	4.31	17.45	10.88± 4.17	-	40	35

*World Health Organisation Sediment quality guidelines (SQG) (WHO, 2004),

*United States Environmental Protection Agency (SQG) (USEPA, 1999)

*Canadian Council of Ministers of the Environments (SQG) (CCME, 1999)

4.3.1 Principal Component Analysis and Correlation Matrix

To analyze the general characteristics of the heavy metals on the wetlands, the Pearson correlation and factor analysis were used. The Pearson correlation matrix was used to establish the relationship of heavy metal distribution in the wetlands and the results presented in Tables 4.19, 4.20 and 4.21.

Table 4.19: Pearson's correlation coefficient of heavy metals in Sakumo II lagoon sediments

	Cd	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	**Pb**
Cd	1.00								
Co	-0.239	1.00							
Cr	-0.174	**0.959***	1.00						
Cu	-0.277	0.235	0.243	1.00					
Fe	-0.231	-0.034	0.123	0.106	1.00				
Mn	-0.147	**0.964***	**0.982***	0.218	0.107	1.00			
Ni	**-0.664***	0.329	0.260	0.255	0.099	0.171	1.00		
Zn	-0.286	**0.967***	**0.879***	0.154	-0.136	**0.905***	0.320	1.00	
Pb	-0.427	0.236	0.315	-0.108	0.216	0.278	0.216	0.226	1.00

Bold * values indicate variables with strong/ positive correlation (p<0.05)

Table 4.20: Pearson's correlation coefficient of heavy metals in Laloi lagoon sediments

	Cd	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	**Pb**
Cd	1.00								
Co	-0.375	1.00							
Cr	**-0.709***	0.313	1.00						
Cu	-0.273	0.186	0.542	1.00					
Fe	**-0.671***	0.501	**0.840***	0.431	1.00				
Mn	**-0.621***	0.199	**0.826***	0.451	**0.769***	1.00			
Ni	**-0.547***	0.492	**0.617***	0.039	**0.751***	0.373	1.00		
Zn	-0.083	-0.058	0.065	0.505	0.189	-0.011	-0.047	1.00	
Pb	-0.328	**0.556***	0.456	**0.621***	**0.565***	**0.578***	0.057	0.066	1.00

Bold * values indicate variables with strong/ positive correlation (p<0.05)

Table 4.21: Pearson's correlation coefficient of heavy metals in Kpeshie lagoon sediments

	Cd	**Co**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	**Pb**
Cd	1.00								
Co	0.163	1.00							
Cr	**0.874***	0.169	1.00						
Cu	0.450	-0.098	0.212	1.00					
Fe	**0.953***	0.086	**0.853***	0.467	1.00				
Mn	**0.969***	0.170	**0.875***	**0.524***	**0.962***	1.00			
Ni	-0.014	-0.351	-0.065	0.132	-0.070	0.010	1.00		
Zn	**-0.847***	-0.239	**-0.731***	**-0.513***	**-0.843***	**-0.899***	-0.098	1.00	
Pb	**0.925***	0.168	**0.857***	**0.535***	**0.921***	**0.964***	0.134	**-0.827***	1.00

Bold * values indicate variables with strong/ positive correlation ($p<0.05$)

For the Sakumo II wetland, very strong positive correlations were observed between Co and Cr, Mn and Zn, Co and Zn and Cr and Mn likewise Cr and Zn. However, there also existed a relatively weak negative correlation between Cd and Ni (Table 4.19).

There was a strong positive correlation between Cr and Mn, Cr and Ni, Cr and Fe, Fe and Mn, Fe and Ni. There was also a relatively strong positive correlation between Cd and Ni, Co and Pb, Fe and Pb, Mn and Pb. However, a negative correlation existed between Cd and Cr, Cd and Fe, Cd and Mn, Cd and Ni on the Laloi wetland (Table 4.20).

In terms of elemental association in the bottom sediment of the Kpeshie lagoon, there was a strong positive correlation between Cd and Cr, Fe, Mn, Pb. Likewise, a very strong positive correlation between Cr and Fe, Mn, and Pb, Fe and Mn, and Pb and Mn. There was a relatively strong correlation between Cu and Mn and Cu and Pb. However, there existed negative correlations between Cd and Zn, Cr and Zn, Cu and Zn, Fe and Zn, Mn and Zn, likewise Zn and Pb (Table 4.21).

The PCA analysis yielded three significant components on both the Sakumo II and Laloi wetlands and two significant components on the Kpeshie wetland with eigenvalues greater than 1.00. The PCA analysis on the Sakumo II accounted for a total of 78.97% of the data variation with the PC1 containing 47.06%, PC2 containing 19.20% and PC3 containing 12.70%. The first principal component (PC1), which contained 47.06% of the calculated variance, showed a strongly positive load for Co, Cr, Mn, and Zn, but moderate loadings for Fe, Cu and Ni for PC2 (Table 4.22).

The PCA analysis for the Laloi wetland also accounted for 79.42% of the data variation with PC1containing, 49.35%, PC2 containing 18.66% and PC3 containing 11.40% of the calculated variance (Table 4.22). There was a strong positive loading between Cr and Mn on PC1, with moderate factor loadings between Cd, Fe and Pb. On PC2, there was also strong negative loading for Zn with weak loadings for Cu and Ni. On PC3 strong factor loading for Co and moderate loading for Pb. (Table 4.23)

The Kpeshie wetland accounted for 79.62% of the data with PC1 containing 63.69% and PC2 containing 15.93% of the variance respectively. There was strong positive load for Cd, Cr, Fe, Mn, and Zn on PC1 with moderately negative loading for Co on PC2. (Table 4.23)

Table 4.22: Summary of the PCA showing eigenvalues and variances explained for sediments on wetlands

		Sakumo II			**Laloi**			**Kpeshie**	
Principal component	Eigen value	Contributing rate	Cumulative contributing rate	Eigen value	Contributing rate	Cumulative contributing rate	Eigen value	Contributing rate	Cumulative contributing rate
1	4.236	47.064	47.064	4.442	49.352	49.352	5.732	63.686	63.686
2	1.729	19.207	66.271	1.680	18.663	68.015	1.434	15.935	79.621
3	1.143	12.703	78.974	1.026	11.403	79.418			

Table 4.23: PCA showing factor loadings for sediments on wetlands

Variables		**Sakumo II**			**Laloi**			**Kpeshie**
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**
Cd	-	-0.703	-	-0.608	-	-	0.970	-
Co	0.980	-	-	-	-	0.918	-	-0.779
Cr	0.969	-	-	0.965	-	-	0.879	-
Cu	-	0.753	-	-	-0.645	-	0.552	-
Fe	-	-	0.580	0.747	-	-	0.963	-
Mn	0.993	-	-	0 .954	-	-	0.994	-
Ni	-	0.752	-	-	0.596	-	-	0.800
Zn	0.949	-	-	-	-0.987	-	-0.909	-
Pb	-	-	0.826	0.725		0.738	0.969	-

Note: factor loadings < than 0.5 removed, extraction method: PCA, rotation method: Varimax and Kaiser normalization.

4.3.2 Degree of contamination in lagoon sediments

To evaluate the degree of contamination in the bottom sediment on the wetlands based on the results from this study, the enrichment factor, geo accumulation (Igeo), contamination factor and the pollution load index were used.

4.3.2.1 Enrichment Factor

The enrichment factors (EF) of heavy metals in the lagoon sediments at the three study sites are shown in Table 4.24. The EF values were interpreted: EF <1: indicates no enrichment, <3: minor enrichment; 3-5: moderate; 5-10: moderately severe; 10-25: severe: 25-50: very severe; >50: extremely severe as suggested by Birch, (2003) and Mmolawa *et al.*, (2011).

From table 4.24, there was an extremely severe enrichment of Cd, Co, Cr, Cu and Mn in sediment samples collected from the Sakumo II lagoon. There was also severe enrichment of Ni for sediment samples collected on the same wetland. The level of Zn in the sediment however showed a moderately severe enrichment in the sediments collected from the Sakumo II lagoon.

Sediments samples collected from the Laloi wetland showed extremely severe enrichment in Cd, moderately severe enrichment in Pb, moderate enrichment in Mn and Co as well as minor enrichment in Cu and Ni. There was, however, no enrichment in Cr and Zn for sediment samples collected from the Laloi lagoon.

The Kpeshie lagoon also showed extremely severe enrichment in Cd likewise a severely enriched Cr, Cu, Ni and Pb in the sediments. There was, however, moderate enrichment of Co and Mn with Zn showing minor enrichment in the sediments collected.

From the mean EF values estimated as shown in Table 4.24, the Sakumo II lagoon generally showed very high and extremely severe enrichment for all heavy metals during the study. The Kpeshie lagoon sediments also showed severe enrichment in all the heavy metals whilst the Laloi lagoon sediment showed moderate enrichment in all heavy metals evaluated.

Table 4.24 Enrichment Factor (EF) values of heavy metals in Sakumo II, Laloi and Kpeshie lagoon sediments

Heavy metals	Sakumo II	Laloi	Kpeshie
Cd	956.612	23.242	137.668
Co	58.144	3.507	3.898
Cr	61.856	0.951	11.596
Cu	114.447	1.038	17.320
Fe	1.000	1.000	1.000
Mn	179.385	3.762	4.773
Ni	37.152	1.350	14.996
Zn	7.386	0.388	1.078
Pb	14.229	6.858	12.307
Mean	**158.912**	**4.677**	**22.737**

4.3.2.2 Contamination factor (CF)

The contamination factor (CF) estimated for all the heavy metals in the Sakumo II lagoon sediment ranged from 0.005 to 4.771 with an average CF value of 0.793. The CF of heavy metals in Laloi lagoon sediment calculated showed a CF range of 0.007 to 0.433 with an average of 0.087 whilst the CF calculated for metals in the Kpeshie lagoon sediment showed a CF range from 0.055 to 7.608 with an average CF value of 1.257 as shown in Table 4.25.

Table 4.25: Contamination factor (CF) for heavy metals of the Sakumo II, Laloi and Kpeshie lagoon sediments

Heavy metals	Sakumo II	Laloi	Kpeshie
Cd	4.771	0.433	7.608
Co	0.290	0.065	0.215
Cr	0.308	0.018	0.641
Cu	0.571	0.019	0.957
Fe	0.005	0.019	0.055
Mn	0.895	0.070	0.264
Ni	0.185	0.025	0.829
Zn	0.037	0.007	0.060
Pb	0.071	0.128	0.680
Mean	0.793	0.087	1.257
PLI	**0.201**	**0.040**	**0.429**

From the results of the study, the heavy metal content in the lagoon sediment on all three wetlands showed low contamination levels according to the classification by Hakanson (1980) (Appendix I-23).

From Table 4.25, the Sakumo II wetland can be classified as having considerable contamination of cadmium in the lagoon sediment whilst the Kpeshie sediment can also be classified as having very high contamination levels of Cd. However, the sediment of the Laloi wetland can be termed as having low contamination of the metals analysed since the CF calculated for all the metals were less than one (1).

4.3.2.3 Pollution Load Index (PLI)

The pollution load index (PLI) calculated showed that the PLI values for the Sakumo II wetland were 0.201, Laloi wetland was 0.040 and the Kpeshie wetland was 0.429 respectively (Table 4.25). Tomlinson *et al.*, (1980) suggested that PLI less than one (1) denote a relatively perfect site with less pollution hence based on the sediments on the three wetland, the sites can be termed relative perfect with less pollution.

4.3.2.4 Geo-accumulation Index (Igeo)

The geo-accumulation Index (Igeo) values were used to assess the level of contamination of the sediment samples by the respective metals.

The Igeo values recorded for this study (Table 4.26) showed that almost all the heavy metals assessed had an Igeo values less than one (1) indicating the sediment in the lagoons were generally unpolluted with respect to Co, Cr, Cu, Fe, Mn, Ni, Zn, Pb metals in all three wetlands with the exception of Cd in both the Sakumo II and Kpeshie lagoons.

However, from Muller's classification of geo-accumulation, the sediment in the Sakumo II lagoon can be categorized as moderately polluted with Cd whilst the sediment in the Kpeshie lagoon can be classified as moderately to severely polluted with Cd. However, the total Igeo for each wetland showed that the sediments were generally not polluted with all metals evaluated.

Table 4.26: Geo-accumulation indices (Igeo) of heavy metals in Sakumo II, Laloi and Kpeshie lagoon sediments

Heavy metals	Sakumo II	Laloi	Kpeshie
Cd	1.66	-1.74	2.34
Co	-2.37	-4.52	-2.80
Cr	-2.28	-6.40	-1.23
Cu	-1.39	-6.27	-0.65
Fe	-8.23	-6.33	-4.76
Mn	-0.75	-4.42	-2.51
Ni	-3.01	-5.90	-0.86
Zn	-5.35	-7.69	-4.65
Pb	-4.4	-3.55	-1.14
Igeo (total)	-26.12	-46.83	-16.25

4.4 Macroinvertebrate assemblage of the coastal wetlands

A total of ten (10) macroinvertebrate species were identified and grouped into their respective class and phylum as indicated in Table 4.27.

The macroinvertebrate belonged to 3 main phyla, the Annelida, Mollusca, and Crustacean. The phyla Annelida was represented by *Polychaetes* and *Oligochaetes.* The polychaetes were made up of *Nereis spp*, *Glycera spp,* and *Capitellid spp*.

The phylum Mollusca was represented by the gastropods and bivalves. The gastropods included *Cerithidea spp*, *Hydrobia accrensis, Tympanotonus fuscata*, *Melanoides tuberculata* while the bivalve was represented by *Tivela tripla while* the phyla Crustacea was represented by the *Penaeus notialis.*

Table 4.27: Distribution and abundance of macroinvertebrates during the study

Taxa (Phylum)	**Class**	**Family**	**Sakumo II (N)**	**Laloi (N)**	**Kpeshie (N)**	**Total (N)**	**Relative Abundance (n/N*100)%**
Annelida	Polychaeta	Nereididae *(Nereis spp)*	135	191	534	860	19.22
	Polychaeta	Glyceridae (*Glycera spp*)	81	207	214	502	11.22
	Polychaeta	Capitellidae *(Capitellid)*	34	129	48	211	4.72
	Oligochaeta		27	87	17	131	2.93
Mollusca	Gastropoda	Potamidadae *(Cerithidea spp)*	245	637	64	946	21.14
	Gastropoda	Hydrobiidae *(Hydrobia accrensis)*	439	307	39	785	17.55
	Bivalvia	Veneridae *(Tivela tripla)*	105	105	41	251	5.61
	Gastropoda	*Potamidade (Tympanotonus fuscata)*	130	102	38	270	6.03
	Gastropoda	Thiaridae *(Melanoides tuberculata)*	386	32	27	445	9.95
Crustacea	Melascostraca	Penaeidae *(Penaeus notialis)*	27	36	10	73	1.63
Total			**1609**	**1833**	**1032**	**4474**	**100.00**
Relative Abundance %			35.76	40.97	23.07		100.00

NB: N = total number of species in a site n = number of individual species in a site

A total of 4,474 individual macroinvertebrates species were counted during the entire study period. The Sakumo II wetland recorded a total of 1,609 individuals; Laloi wetland recorded 1,833 individuals and Kpeshie wetland, a total of 1,032 individual macroinvertebrates respectively.

In terms of abundance of macroinvertebrates on the wetlands, the Sakumo II wetland recorded 35.96% of the total macroinvertebrate count with *Hydrobia spp* being the most abundant species while the Oligochaetes and *Penaeus notialis* were the least abundant species on the wetland. The Laloi wetland recorded 40.97 % of the total count with *Cerithedia spp* being the most abundant macroinvertebrate species while the *Melanoides tuberculata* was the least species on the wetland. The Kpeshie wetland recorded 23.07% of macroinvertebrate assemblage with the most abundant species being the *Nereis spp* and the least the *Penaeus notialis* (Table 4.27).

The most abundant macroinvertebrate species on all three wetlands was the *Cerithedia spp*. The *Cerithedia spp* accounted for about 21.14 % of the total count of macroinvertebrates and followed by the *Nereis spp* (19.22%) and then the *Hydrobia accrensis)* which accounted for 17.55% of abundance. The least macroinvertebrate counted was the *Penaeus notialis* (1.63%) which was more predominant on the Laloi wetland than the other sites (Table 4.27).

Collectively, the species belonging to the phylum Annelida represented 38.09% of the macroinvertebrate's assemblage; the phylum Mollusca represented 60.28% making it the most abundant taxa whilst the phylum Crustacea was 1.63% making it the least dominant taxa during the study. The gastropods belonging to the phylum Mollusca were the most abundant class of macroinvertebrates counted during the study. The gastropods were mainly found on the Sakumo II wetlands. The polychaetes were the second most abundant class and were predominantly found on the Kpeshie wetland

In term of the density of macroinvertebrates estimated on each wetland, the Laloi wetland recorded the highest density while the Kpeshie wetland recorded the least (Appendix I-5). The order of macroinvertebrate abundance on the wetlands was in the order, Laloi > Sakumo II > Kpeshie.

A one-way analysis of variance (ANOVA) was conducted to establish the differences in macroinvertebrates abundance among the sites. A summary of the result is presented in the Table 4.28

Table 4.28: ANOVA test showing differences in macroinvertebrates abundance by sites

	N	Mean	SD	*F*	*P*
Sakumo II	12	134.08	45.52	*5.45*	*0.01*
Laloi	12	152.75	74.32		
Kpeshie	12	124.28	57.24		

As indicated in table 4.28, there was a significant difference in the abundance of macroinvertebrates by sites $[F_{(2,12)}=5.45, p<0.05]$. The existence of a significant difference in the abundance of macroinvertebrates by sites warranted further analysis which is presented in the multiple comparisons in Table 4.29.

Table 4.29: Multiple comparison showing differences in the abundance of macroinvertebrates by sites

	Sakumo II	Laloi	Kpeshie
Sakumo II	-		
Laloi	18.67*	-	
Kpeshie	-48.08*	-66.75*	-

From table 4.29, the Laloi wetland recorded a significant higher abundance and distribution of macroinvertebrates than the Sakumo II site *[mean difference=18.67, $p<0.05$]* and the Kpeshie wetland *[mean difference=66.75, $p<0.05$]*. The Sakumo II wetland also recorded a significantly higher abundance of macroinvertebrates than the Kpeshie wetland [mean difference =48.08, $p<0.05$].

4.4.1 Spatio-temporal variation in the abundance of macroinvertebrates on wetlands

The monthly count of macroinvertebrates was recorded on all three wetland to know the spatio-temporal variation in the macroinvertebrates abundance (Fig. 4.17). The highest macroinvertebrates count on the Laloi wetland was recorded in the month of May (295 ind/m^2) followed by counts in June (279 ind/m^2) and then July (238 ind/m^2). The least count of macroinvertebrates on the Laloi wetland was recorded in the month of February followed by counts in March (Fig 4.7).

The highest number of macroinvertebrates counted on the Sakumo II wetland was recorded in the month of April, followed by the month of July while the least counts were recorded in the months of March (77 ind/m^2) and February (83 ind/m^2).

Macroinvertebrate count on the Kpeshie wetland was highest in the month of December followed by the month of June. Least counts were observed in the month of February (66 ind/m^2) and September (100 ind/m^2) respectively (Fig 4.7).

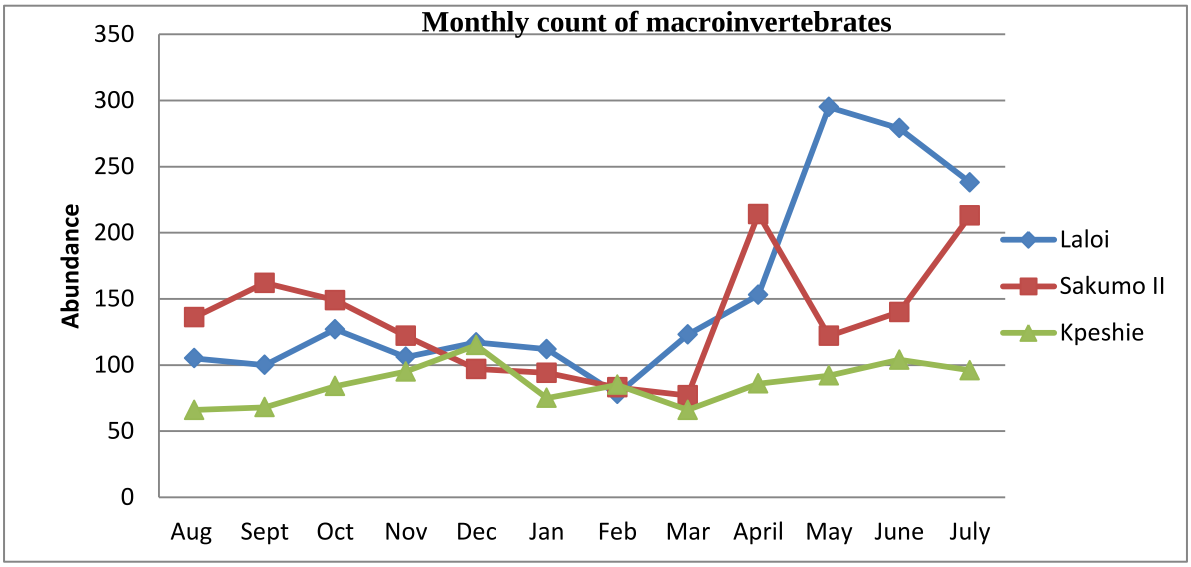


Fig 4.7: Monthly total count of macroinvertebrates on the wetlands

Generally, the months (March, April, May, June, and July) recorded the highest abundance of macroinvertebrates which was basically the rainy months during the survey as compared to the months (August, September, October, November, December, January, and February) which had less rainfall. The density of the macroinvertebrates available for waterbirds especially the waders was more on the Laloi wetland (9352.04 ind/m^2) as compared to the protected Sakumo II wetland (8209.18 ind/m^2) and Kpeshie wetland (5265.31ind/m^2) (Appendix I-6, 7, 8)

4.4.2 Diversity indices of macroinvertebrates on the wetlands

The diversity of macroinvertebrates assemblage on the Sakumo II, Laloi and Kpeshie wetlands were estimated using indices as Shannon (H') and Simpson (1-D), Magarlef (d'), and Pielou's evenness (J') as shown in Table 4.30.

Table 4.30: Species diversity, richness, and evenness for macroinvertebrates on the wetlands

Diversity Indices	**Sakumo II**	**Laloi**	**Kpeshie**
H'	1.942	1.952	1.564
1-D	0.8234	0.8133	0.6778
J'	0.8434	0.8479	0.6791
d'	1.219	1.198	1.297
Total (N)	**1609**	**1833**	**1032**

The diversity index (H') values for the entire study ranged from 1.564 to 1.952 whereas the Margalef's richness index (d') varied from 1.198 to 1.297. Pielou's evenness index, (J') varied between 0.679 and 0.848 (Table 4.30). The Sakumo II coastal wetland was the most diverse site in terms of macroinvertebrates assemblage while the Kpeshie wetland was the least diverse site. In terms of evenness on the sites, the Laloi wetland recorded the highest evenness compared to the Sakumo II and the Kpeshie wetlands. For richness of site, the Kpeshie wetland was the richest site compared to both the Laloi and Sakumo II wetland (Table4.30)

4.4.3 Relating macroinvertebrates distribution to water quality on wetlands

The distribution of macroinvertebrates was related to the quality of water to ascertain the environmental predictors of the macroinvertebrates on the wetlands.

The multiple linear regressions were used. In line with this, three main multiple linear regressions were conducted to ascertain the effects of the independent variables on the dependent variable. Multiple regression analysis was conducted for each wetland site (Sakumo II, Laloi and Kpeshie).

In the multiple linear regressions, the various water quality parameters extracted based on the PCA was used as the independent variables. The summary of the result is presented in Table 4.31

Table 4.31: Multiple linear regression showing water quality predictors of macroinvertebrates

Predictors	**Sakumo II**			**Laloi**			**Kpeshie**		
	β	*T*	*P*	*B*	*T*	*p*	*β*	*t*	*p*
PC1	0.09	0.41	0.70	-0.49	-3.57	0.00	-0.31	-2.61	0.00
PC2	-0.33	-2.59	0.00	0.43	2.58	0.00	0.59	4.30	0.00
PC3	0.38	3.81	0.00	0.78	4.55	0.00	0.06	0.16	0.88
PC4	-0.66	-4.18	0.00	-0.28	-2.51	0.03	0.43	4.27	0.00
PC5	-0.48	-4.10	0.00	0.07	0.29	0.79	-0.44	-4.27	0.00
PC6	-0.00	0.09	0.99	0.03	0.14	0.89	-0.32	-3.96	0.00
R^2		0.81			0.88			0 .60	
F change		3.46	.00		6.04	.00		1.27	0.03

From table 4.31, PC1, PC2, PC3, PC4, PC5, and PC6 jointly contributed 81%, 88% and 60% of macroinvertebrates at Sakumo II, Laloi and Kpeshie sites respectively [$R^2 = 0.81$, $p<0.05$; $R^2=0.88$, $p<0.05$; $R^2=0.60$, $p<0.05$].

At the Sakumo II site, the significant predictors of macroinvertebrates abundance are PC2 (pH, Ni, Cr) [$\beta=-0.33$; $p<0.05$], PC3 (Mg^{2+}, Zn) [$\beta=0.38$; $p<0.05$], PC4 (conductivity, Fe, Cu, Co) [$\beta=-0.66$; $p<0.05$] and PC5 (Temperature, water depth) [$\beta=-0.48$; $p<0.05$].

Similarly, PC1 (conductivity, turbidity, alkalinity, Cl-, Mg^{2+}, PO_4-P, Mn, Cu, Ni) [$\beta=-0.49$; $p<0.05$], PC2 (temperature, DO, salinity and Fe) [$\beta=0.43$, $p<0.05$]and PC3 (TDS, water depth, Ca^{2+}, Zn) [$\beta=-0.78$, $p<0.05$] and PC4 (pH and Co) [$\beta=-0.28$, $p<0.05$] were significant predictors of macroinvertebrates at the Laloi wetland site.

At Kpeshie, the significant predictors of macroinvertebrates abundance were PC1 (conductivity, DO, water depth, Cl^-, Mg^{2+}, Ca^{2+}, Fe, Zn, Ni, Co) [$\beta=-0.31$, $p<0.05$], PC2 (TDS, turbidity, NO_2-N, PO_4-P, Mn) [$\beta=0.59$, $p<0.05$], PC4 (salinity, alkalinity) [$\beta=0.43$, $p<0.05$], PC5 (Cd) [$\beta=-0.44$, $p<0.05$] and PC6 (pH) [$\beta=-0.32$, $p<0.05$].

4.4.4 Sediments predictors of macroinvertebrates

A multiple linear regression was used to ascertain the precise sediment predictors of macroinvertebrates on the wetlands. In the multiple linear regression, the various components extracted based on the PCA were used as independent variables. The summary of the result is presented in Table 4.32.

Table 4.32 shows that PC1, PC2 and PC3 jointly and significantly contributed 25%, 57% and 30% respectively to macroinvertebrates abundance at the Sakumo II, Laloi and Kpeshie wetlands [$R^2=0.25$ $p<0.05$; $R^2=0.57$, $p<0.05$; $R^2=0.30$, $p<0.05$].

At the Sakumo II wetlands, the significant sediment predictors of macroinvertebrates are PC1 (Co, Cr, Mn and Zn) [$\beta=-0.50; p<0.05$] *and* PC2 (Cd, Cu and Ni) [$\beta=0.26; p<0.05$] indicating that as heavy metals in PC1 had a negative effect on macroinvertebrates, heavy metals in PC2 had a positive effect.

At Laloi wetland, the significant predictors of macroinvertebrates abundance is PC1 (Cd, Cr, Fe, Mn) [$\beta=-0.19; p<0.05$] and PC3 (Co and Pb) [$\beta=0.78; p<0.05$] indicating that PC1 related negatively with macroinvertebrates while PC3 related positively. At Kpeshie wetland, the significant predictors of macroinvertebrates abundance are PC1 (Cd, Cr, Cu, Fe, Mn, Zn, Pb) [$\beta=0.35; p<0.05$] and PC2 (Co and Ni) [$\beta=0.44; p<0.05$] indicating a positive relationship between PC1 and PC2 variables and macroinvertebrates.

Table 4.32: Multiple linear regressions showing the sediment predictors of macroinvertebrates

Predictors	Sakumo II			Laloi			Kpeshie		
	β	*t*	*p*	*B*	*T*	*p*	β	*t*	*P*
PC1	-0.50	-2.57	.00	-0.19	-2.59	.00	0.35	2.24	.00
PC2	0.26	2.83	.00	-0.10	-1.40	.10	0.44	2.56	.00
PC3	0.03	.10	.92	-0.64	3.40	.00			
R^2		0.25			0.57			0.30	
F		2.89	.01		5.46	.00		3.92	.00

4.5 Distribution of waterbirds within the Sakumo II, Laloi and Kpeshie wetlands

A total of 24,247 individual waterbirds species belonging to six groups (waders, cormorants, ducks, herons, terns, gulls and egrets) were counted over the 1-year study period on all three wetlands. A total of 50 species of waterbirds belonging to 13 families were recorded with the protected Sakumo II wetland recording 44 waterbird species, the Laloi and Kpeshie wetlands recorded 45 and 27 waterbird species respectively (Appendix I-1). The relative abundance of the waterbirds counted has been shown in the Table 4.33

Table 4.33: Relative abundance of waterbirds at Sakumo II, Laloi and Kpeshie lagoons

Family	Sakumo II	Laloi	Kpeshie	Total	Rel. Abundance(%)
Scolopacidae (Waders)	2254	2709	877	5840	24.09
Charadriidae (Plovers)	2119	4205	442	6766	27.90
Laridae (Terns)	649	1138	10	1797	7.41
Ardeidae (Herons/Egrets)	711	1259	161	2131	8.79
Anatidae (waterfowls)	813	548	0	1361	5.61
Recurvirostridae (Winged Stilt)	786	708	94	1588	6.55
Jacanidae (Jacanna)	496	-	5	501	2.07
Burhinidae (Thick-knee)	65	66	302	433	1.79
Rostratulidae (Painted Snipe)	3	49	-	52	0.21
Glareolidae (Pranticole)	2082	77	-	2159	8.90
Threskiornithidae (Glossy ibis)	11	-	-	11	0.05
Phalacrocoracidae (Cormorant)	121	1384	80	1585	6.54
Podicipedidae (Grebe)	6	-	17	23	0.09
Total count	10,116*	12,143*	1988	24,247 ($p<0.05$)	100.00
Sum of species (S)	44	45	27		

In terms of the distribution and abundance of waterbird, species belonging to the family Scolopacidae (88.71%) which were mostly the waders were the most abundant, followed by the family Charadriidae (77.81%) mostly dominated by the plovers with the least number of birds counted belonging to the family Threskionithidae, which was the Glossy Ibis sighted only once on the Sakumo II wetland (0.11%) (Table 4.33)

On the Sakumo II wetland, the most abundant waterbird species counted were the Collared Prantincole (*Glareola pratincola*), Spur winged plover (*Vanellus spinosus*) and the White-faced Whistling tree duck (*Dendrocygna viduata*) while the Common Little bittern (*Ixobrychus minutus*) and the Garganey (*Spectula querquedula*) belonging to the family Anatidae were the least number of waterbirds recorded during the survey.

The Laloi wetland, however had the Common Ring Plover (*Charidrius hiaticula*) belonging to the family Charadriidae as the most abundant species on the wetland site accounting for 30.9% of the total waterbirds. The Long-tailed Cormorant (*Phalacrocorax africanus*) was the second most abundant on the wetland. The purple heron (*Ardea purpurea*) and the ruff (*Philomachus pugnax*) were the least waterbird species counted on the Laloi wetland (Appendix I-1).

The Common Sandpiper (*Actitis hypoleucos*) belonging to the family Scolopacidae and the Senegal Thicknee (*Burhinus senegalensis*) belonging to the family Burhididae were the most abundant waterbird species on the Kpeshie wetland. The Royal tern (*Thalasseus maximus*), and the Great white egret (*Ardea alba*) were the least number of birds counted on the Kpeshie wetland. Generally, species belonging to the families Scolopacidae and Charadriidae were the most abundant on the Kpeshie wetland (Appendix I-1).

In terms of the abundance of waterbirds on the wetlands, a total of 12,143 individual waterbirds were counted on the Laloi wetland representing 50.1%, a total of 10,116 representing 41.7% waterbirds on the Sakumo II wetland while the Kpeshie wetland recording a total count of 1,988 (8.2%) individual waterbird (Appendix I-1).

Of the 50 waterbird species recorded for the study, 28 species were waders, six species were terns, 11 species were herons and egrets, 3 species were ducks and one (1) species each of gull and cormorant. The number of individual waders on all three wetland sites during the study was 17,373 representing a significant majority of 71.65% of the total count. Of the total number of waders, 45.02 % was recorded on the Sakumo II wetland, 44.98% on the Laloi wetland and 0.1% recorded on the Kpeshie wetland (Appendix I-1). These counts made the Sakumo II wetland the most preferred habitat for waders during the study. The most dominant waders counted on each wetland were the Collared Pranticole on the Sakumo II, the Common Ringed Plover on the Laloi and the Common Sandpiper on the Kpeshie wetlands (Appendix 1-1).

In terms of the terns and gulls belonging to the family Laridae, the Common tern was the most abundant species counted on the Sakumo II wetland. Together, the terns and gulls represented 7.4% of the total number of individual waterbirds counted. There were however, no tern or gull species recorded on the Kpeshie wetland during the study, an indication the wetland did not support tern species. The Lesser black-backed gull was the only gull species sighted (only four times) on the Laloi wetland (Appendix I-1).

With the exception of the Bar-tailed Godwit and Black-tailed Godwit, all of the waders counted were in the least concerned (LC) category of the International Union for Conservation of Nature (IUCN Redlist) when it came to conservation status while the

Eurasian Curlew was in the Near Threatened (NT) category.

The Near Threatened Bar-tailed and Black-tailed Godwits were mostly found on the Sakumo II and Laloi wetlands but not on the Kpeshie wetlands. The Eurasian Curlew which belonged to the Near-threatened category was sited only thirteen times on the Laloi wetland (Appendix I-1).

4.5.1 Waterbird abundance among the site

A one-way analysis of variance (ANOVA) was conducted to establish the differences in waterbirds abundance by sites. A summary of the result is presented in the Table 4.34

Table 4.34: One-way ANOVA test showing differences in waterbirds abundance by sites

	N	Mean	SD	*F*	*P*
Sakumo II	12	843.00	560.55	*10.83*	*0.00*
Laloi	12	1011.92	584.32		
Kpeshie	12	165.67	106.60		

As indicated in table 4.34, there was a significant difference in waterbirds abundance by sites $[F_{(2,12)}=10.83,\ p<0.05]$. The existence of a significant difference in waterbirds abundance by sites warrants further analysis which is presented in the multiple comparisons Table 4.35.

Table 4.35: Multiple comparison showing differences in waterbirds abundance by sites

	Sakumo II	Laloi	Kpeshie
Sakumo II	-		
Laloi	168.92*	-	
Kpeshie	-677.33*	-846.25*	-

From the multiple comparison, the Laloi wetland recorded a significantly higher number of waterbird abundance than Sakumo II site *[mean difference=168.92,* $p<0.05$*]* and the Kpeshie site *[mean difference=846.25,* $p<0.05$*]*. Likewise the Sakumo II site, also recorded a significantly higher number of waterbirds than the Kpeshie site *[mean difference=677.33,* $p<0.05$*]*.

4.5.2 Spatio temporal distribution of waterbirds on the wetland

Waterbirds were counted each month to know the month in which the waterbirds were most abundant. On the Laloi wetland, the highest monthly count of 2,248 waterbird was recorded in the month of January while the least count was recorded in the month of April on the Laloi wetland (351), likewise the highest count of waterbirds on the Sakumo II wetland was recorded in the month of November (1,889) with the least count of 77 in June. For the Kpeshie wetland, the highest count was done in the month of February (315) with the least count also in June (25) (Figure 4.8)

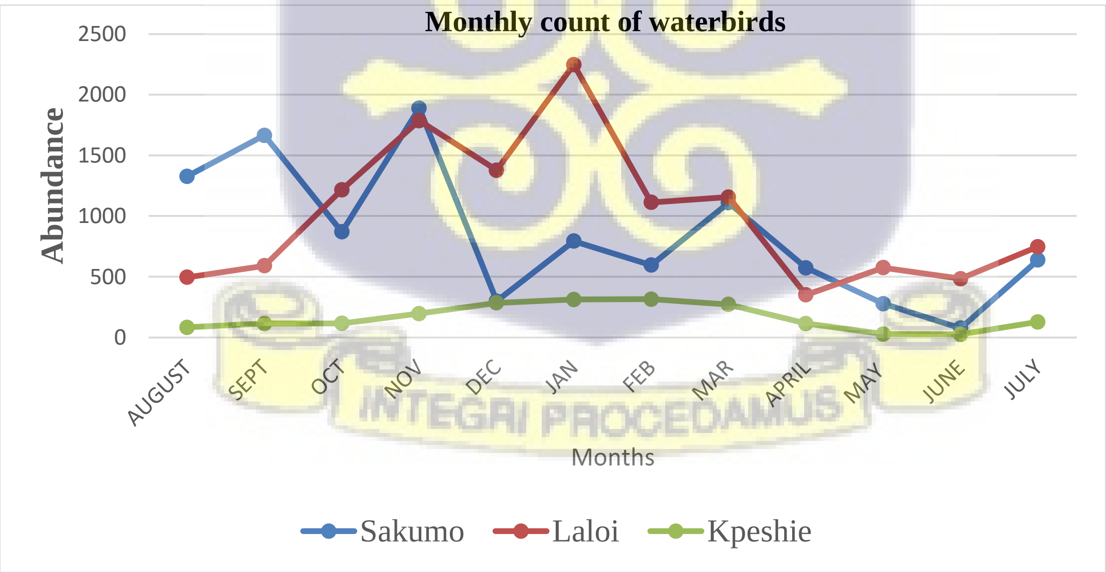


Fig 4.8: Monthly distribution of waterbird count on the wetlands

There was a general increase in waterbird numbers from the month of August to November which were the peak months for waterbirds abundance on coastal wetlands in Ghana as suggested (Ntiamoa-Baidu, 1991; Ntiamoa-Baidu *et al.*, 2014). The highest waterbird numbers were normally observed in the dry seasons when the water levels were lower due to evaporation of the waters while lower bird numbers were recorded during the rainy months when most of the wetlands got flooded (Appendix I-2, 3, 4).

4.5.3 Diversity of waterbirds on the Sakumo II, Laloi and Kpeshie lagoons

The species diversity, richness, and evenness were estimated using the Shannon (H^I) and Simpson Index (D), Magarlef index (d^I) and Pielou's evenness (J^I) respectively as shown in Table 4.36

Table 4.36: Diversity indices of waterbirds on wetlands

Diversity indices	Sakumo II	Laloi	Kpeshie
Shannon H^I	2.870	2.675	2.339
Pielou Evenness J^I	0.760	0.707	0.710
Simpson Index 1-D	0.913	0.871	0.853
Margalef Richness D^i	4.554	4.572	3.4233

In terms of species diversity, the Sakumo II wetland was the most diverse site (H^I= 2.870, 1-D =0.913) while the Kpeshie wetland was the least diverse site (H^I= 2.339, 1-D = 0.853). The Sakumo II wetland in terms of the species was the most evenly distributed site followed by the Kpeshie wetland with the richest site in terms of waterbirds being the Laloi wetland (Table 4.36)

4.5.4 Similarity indices of waterbird on the wetland sites

The group averaged utilizing the standardized fourth root transformed data was used in a Bray-Curtis similarity analysis (Bray & Curtis, 1957) to show similarities of waterbirds on the wetlands. From the Bray-Curtis analysis, waterbird numbers within the Sakumo II and Laloi wetlands were similar at 40.6%. The Sakumo II and Laloi wetland put together was also similar at 27.3% to waterbirds on the Kpeshie wetland (Fig. 4.9)

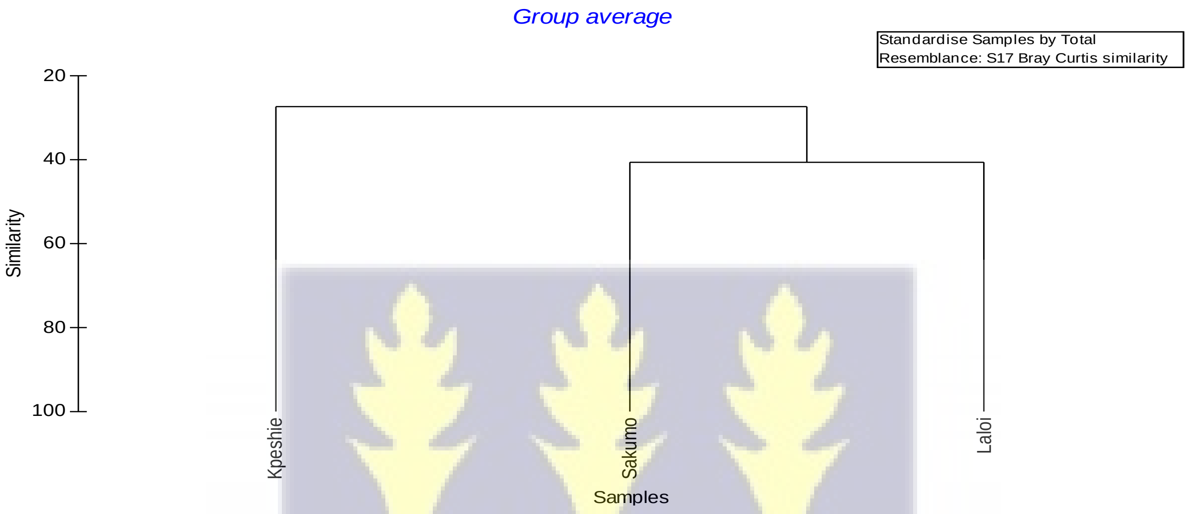


Fig 4.9: Bray Curtis Similarity index of study sites based on waterbird abundance

4.5.5 Linear regression of macroinvertebrates predictors of waterbirds on wetlands

This analysis was done to establish how the abundance and distribution of waterbirds on the wetlands were influenced by the abundance of macroinvertebrates (Table 4.37).

Table 4.37: Multiple linear regression showing macroinvertebrates predictors of waterbirds

Predictors	**Sakumo II**			**Laloi**			**Kpeshie**		
	B	*T*	*p*	*β*	*t*	*p*	*β*	*T*	*p*
Macroinvertebrate	-0.12	-0.05	0.96	0.46	-2.66	0.00	-0.07	-0.21	0.84
R^2		0.12			0.22			0.04	
F		0.20	0.96		2.74	0.00		0.04	0.84

From table 4.37, macroinvertebrates contributed 12%, 22% and 4% to waterbirds abundance at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.12$, $p>0.05$; $R^2=0.22$, $p<0.05$; $R^2=0.04$, $p>0.05$].

4.5.6 Linear regression between water quality and waterbirds on wetlands

As shown in table 4.38, water quality parameter like salinity, turbidity, water depth, NO_2-N and PO_4-P jointly contributed 67.4%, 66.5% and 34.1% respectively to waterbirds abundance on Sakumo II, Laloi and Kpeshie wetlands [$R^2=0.674$, $p<0.05$; $R^2=0.665$, $p<0.05$; $R^2=0.341$, $p<0.05$].

At the Sakumo II wetlands, the significant predictors that determines the abundance of waterbirds are turbidity [$\beta=0.309$; $p<0.05$], NO_2-N [$\beta=-0.249$; $p<0.05$] and PO_4 -P [$\beta=0.455$; $p<0.05$]. Thus, whereas NO_2-N negatively contributed to waterbird abundance, turbidity and PO_4-P related positively with waterbird abundance.

At Laloi, the significant predictors that determined the abundance of waterbirds are turbidity [$\beta=0.380$; $p<0.05$], water depth [$\beta=-0.644$; $p<0.05$] and NO_2-N [$\beta=0.501$; $p<0.05$]. This implies that water depth had an inverse relation with waterbirds while NO_2-N was positively related with waterbird abundance.

At Kpeshie, the significant predictors of waterbird abundance are turbidity [$\beta=-0.232; p<0.05$], water depth [$\beta=-0.276; p<0.05$], NO_2 -N [$\beta=0.449; p<0.05$] and PO_4-P [$\beta=0.181; p<0.05$]. This finding implies that while turbidity and water depth contributed negatively to waterbird abundance at Kpeshie, NO_2-N and PO_4-P were positive contributors to waterbird abundance.

Table 4.38: Multiple regression showing the water quality elements as predictors of waterbird abundance

Predictors	**Sakumo**			**Laloi**			**Kpeshie**		
	β	t	p	β	t	p	β	t	p
Salinity	0.142	1.49	.064	0.107	1.30	.074	0.068	1.14	.089
Turbidity	0.309	3.13	.000	0.380	2.42	.006	-0.232	-2.52	.006
Water depth	-0.131	-1.45	.066	-0.644	3.92	.000	-0.276	2.56	.005
NO_2–N	-0.249	-2.84	.000	0.501	3.02	.000	0.449	2.92	.000
PO_4-P	0.455	3.72	.000	-0.066	-1.23	.082	0.181	2.32	.000
R^2		.674			.665			.341	
F change		3.481	.001		3.378	.00		2.62	.00

To determine which of the variables, and pulling all variable together in the regression model, water quality (PC1, PC2, PC3, PC4, PC5, and PC6), macroinvertebrates and fish condition jointly contributed 88%, 73% and 83% respectively to waterbirds at Sakumo, Laloi and Kpeshie water sites [$R^2=0.88, p<0.05; R^2=0.73, p<0.05; R^2=0.83, p<0.05$].

From the regression model data, fish condition and water quality mostly contributed to the waterbird abundance onSakumo and Kpeshie, while macroinvertebtrates contributed to abundance on Laloi wetland,PC6 (DO, Turbidity) [$\beta=.36; p<0.05$] and fish condition [$\beta=.51; p<0.05$].

4.5.7 Relationship between land use land cover and waterbirds abundance

The study examined the longitudinal relationship between land use land cover variables (bareland, built up, vegetation and water body) and waterbird abundance over the past 30 years (from 1986-2017). The following analysis method was used as baseline data for waterbird counts in the year 1986 was unavailable for this study, so all the waterbirds count on all three wetlands were lump together assuming all sites received similar pressures. In order to examine this longitudinal relationship, a multiple regression was conducted and a summary of the results presented in the Table 4.39.

Table 4.39: Relationship between landuse/landcover variables and waterbirds abundance

LULC variables	*B*	*T*	*P*
Bareland	1.430	2.632	0.000
Built up	-0.651	-2.414	0.000
Vegetation	-1.185	-2.830	0.000
Waterbodies	0.487	2.568	0.000
R^2		0.268	
F		3.668	0.000

As indicated in Table 4.39, bareland, built up, vegetation and waterbodies collectively contributed to 26.8% in the abundance of water birds [$R^2=.268$, $p<0.05$].

Further evidence from the table 4.39 showed that all land use, land cover variables (bareland, built-up, vegetation and water body) significantly predicted the abundance of waterbirds on all wetlands [$\beta=1.430$, $p<0.05$; $\beta=-0.651$, $p<0.05$; $\beta=-1.185$, $p<0.05$; $\beta=.487$, $p<0.05$]. However, whereas bareland and waterbodies related positively with waterbird abundance, built-up and vegetation cover related negatively.

4.6 Length-weight relationship of Black Chin Tilapia (*Sarotherodon melanotheron)*

The blackchin tilapia was used as a bioindicator to assess the quality of the water on the wetlands and in effect the distribution and abundance of the waterbird species as *Sarotherodon melanotheron* (black chin tilapia) is the dominant fish species in most lagoons in Ghana (Koranteng, 1995)

The dominant fish species *Sarotherodon melanotheron* in the coastal lagoons located within the study sites were assessed for growth characteristics, condition, and well-being. The length-weight relationships was used for estimating fish condition factor, and used in comparing the "condition", "fatness" or "well-being" of fish (Froese, 2006).

A total of 1800 individual *S. melanotheron* species (600 individuals each from each study site) were selected for the determination of the growth parameters and general wellbeing. The standard length (SL) and body weights recorded for fishes collected ranged from 0.6cm - 16.0cm and 0.04g-68.46 g for the Sakumo II lagoon, 1.4cm -16.1 cm and 0.02g -74.14g for the Laloi lagoon and 0.4cm -14.8 cm and 0.05g - 46.57g for the Kpeshie lagoon.

The length-weight relationship of the black chin tilapia in the Sakumo II lagoon, Laloi lagoon and Kpeshie lagoon were described by the following equations $W= -1.71 \times SL^{2.95}$ (r = 0.98), $W= -1.74 \times SL^{2.94}$ (r=0.99) $W= -1.61 \times SL^{2.80}$ (r=0.96) respectively (Table 4.40).

Tesch (1968) attributed the discrepancies in the intercepts of 'a' in each equation to variances in sex ratios, the age of the fish, and the seasons for data collection. The correlation coefficient (r) recorded for *S. melanotheron* collected from each site were 0.98 for the Sakumo II lagoon, 0.99 for the Laloi lagoon and 0.96 for the Kpeshie lagoon indicating a strong correlation between the length and weight of fishes selected during the study ($p < 0.001$) (Table 4.40).

Table 4.40: Length-weight relationship parameters of *S. melanotheron* from study sites

Site	N	Length Type	a	b	R^2	Df	P-value
Sakumo II	600	SL	-1.71	2.98	0.98	598	<0.001
Laloi	600	SL	-1.74	2.94	0.99	598	<0.001
Kpeshie	600	SL	-1.61	2.80	0.96	598	<0.001

N= No of fish collected SL=standard length, a= constant, b= regression exponent, R = correlation coefficient

The 'b' value for Sakumo II lagoon indicated that blackchin fishes in the lagoon exhibited isometric growth ('b' is nearer to 3) whilst 'b' values recorded for both Laloi and Kpeshie lagoons indicated that fishes in the lagoons exhibited negative allometric growth (Table 4.40). The negative allometric growth indicates that the fishes in the Laloi and Kpeshie lagoons were growing slender as its length increases while the length and weight of the black chin fishes from the Sakumo II lagoon were increasing at the same rate (isometric growth).

4.6.1 Monthly length-weight relationship of *Sarotherodon melanotheron*

A total of fifty (50) blackchin tilapia fishes (*Sarotherodon melanotheron)* each were randomly selected each month from the catch of fishers to estimate the monthly length-weight relationship in the lagoons on the wetlands.

The monthly growth parameter 'b' from the analysis is shown in Figure 4.10 for all the three wetlands.

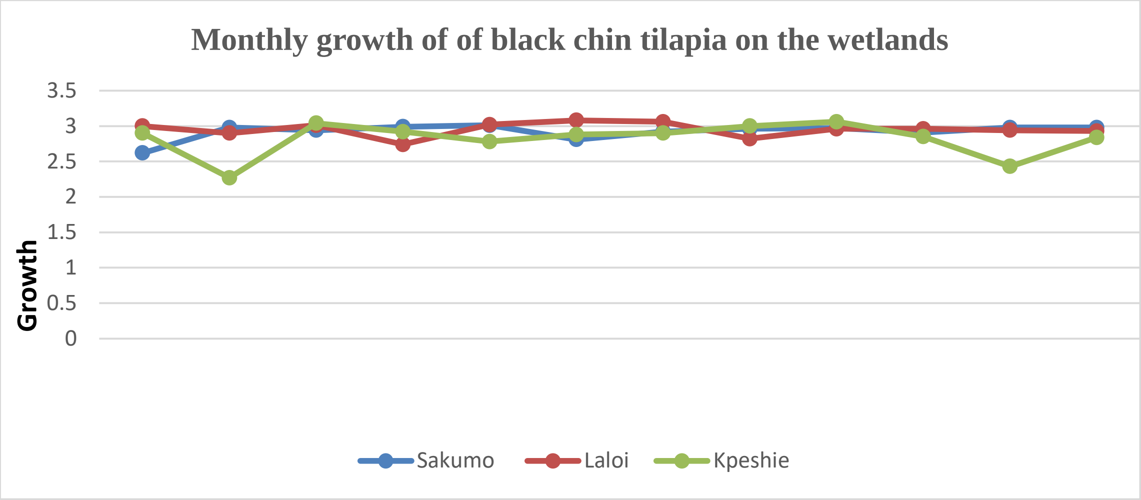


Fig 4.10 Monthly growth of black chin tilapia on the wetlands

From Fig 4.10 , the monthly growth parameter 'b' estimated for *S. melanotheron* collected from the Sakumo II lagoon ranged from 2.62 in August to 3.01 in December. The growth regression exponent estimated for the months of August, October, January, February and May showed a negative allometric growth pattern in the fishes collected in these months whilst fishes collected in the months of September, November, March, April, June, and July showed isometric growth patterns ("b" nearer to 3).

However, *S. melanotheron* fish samples collected in the month of December showed positive allometric growth patterns (b>3). The correlation coefficient 'r' ranged from 0.85 to 0.99 indicating a very strong significant correlation between the length and weight of the fishes collected for the study (Appendix I-11).

The growth parameter 'b' for *S. melanotheron* collected monthly from the Laloi lagoon also ranged from 2.74 in August to 3.08 in January. The growth exponent recorded for the months of November, December, January, February, March, June, and July showed an allometric growth pattern whilst fish collected in the month of August, September, October, April, May showed isometric growth patterns. There was a strong coefficient of determination ‘r’ which ranged from 0.97 to 0.99 for the study ($p < 0.001$) (Appendix I-13,).

The blackchin tilapia fishes collected from the Kpeshie lagoon had the growth parameter (‘b’) ranging from 2.27 in September to 3.06 in April. All fishes collected during the months of sampling showed allometric growth patterns except fishes collected in the month of March which showed isometric growth. The coefficient of determination ‘r’ ranged from 0.87 to 0.99 for the study ($p<0.001$) (Appendix I-14).

4.6.2 Condition factor of the black-chin tilapia *(Sarotherodon melanotheron) on wetlands*

Condition factors of fish changes with food abundance and the fish's reproductive stage, and they also serve as a measure of the fish's well-being in the water. Fish with a high condition factor are relatively large for their size in a good environment, whereas fishes with low condition factor are little for their size and indicate a stressed environment for survival (Tesch, 1968). The mean condition factor (K) estimated for black chin tilapia (*S. melanotheron*) was 2.97, 3.16 and 3.73 for the Laloi, Kpeshie, and Sakumo II lagoons respectively. The Sakumo II lagoon recorded the highest condition factor for black chin tilapia while the Laloi lagoon exhibited the least condition factor as shown in Fig 4.11.

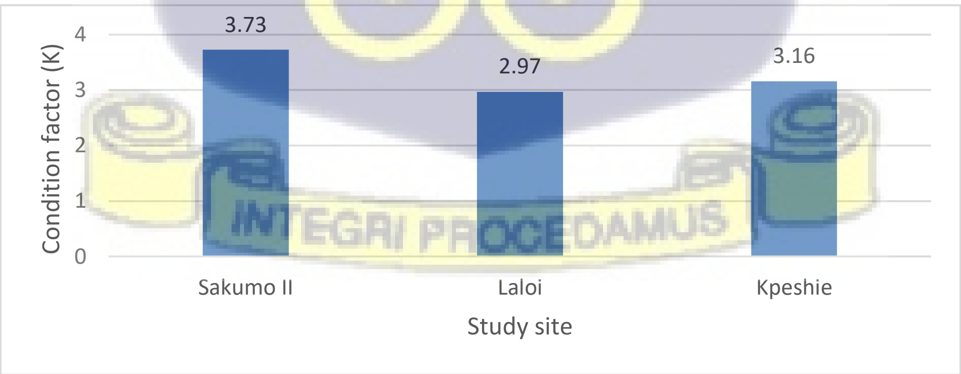


Figure 4.11: Mean condition factor (K) recorded for the study

The condition factors 3.73, 2.97 and 3.16 estimated for blackchin tilapia in the Sakumo II, Laloi and Kpeshie lagoons showed that, the fishes condition factor estimated was greater or higher than one (1) an indication of a healthy condition or environment on the wetlands for fishes (Ayode, 2011).

4.6.3 Multiple linear regressions between water quality and fish condition on wetlands

The condition factors of the predominant fish in the lagoons *Sarotherodon melanotheron* were used as an indicator of the water quality. Good and healthy water quality parameters will have a direct link with the distribution of macroinvertebrates and invariably the waterbirds.

From table 4.41 above, PC1, PC2, PC3, PC4, PC5, and PC6 jointly contributed 16%, 88% and 58% respectively to fish condition at Sakumo II, Laloi and Kpeshie sites [$R^2=0.16$, $p>0.05$; $R^2=0.88$ $p<0.05$; $R^2=0.58$, $p<0.05$ *respectively]*.

At the Sakumo II sites, the significant predictor of fish condition is PC1 (TDS, Alkalinity, Cl-, PO_4^{3-}-P, Mn) [$\beta=-0.22$; $p<0.05$] indicating a negative relationship between PC1 and fish condition. At Laloi wetland site, the significant predictors of fish condition are PC1 (conductivity, turbidity, alkalinity, Cl-, Mg2+, PO_4-P, Mn, Cu, Ni) [$\beta=0.64$; $p<0.05$], PC2 (temperature, DO, salinity, Fe) [$\beta=-0.72$; $p<0.05$], PC4 (pH and Co) [$\beta=-0.51$, $p<0.05$] and PC6 (Turbidity) [$\beta=-0.42$; $p<0.05$]. The finding indicates that with the exception of PC1 which had a positive relationship with fish condition, all other factors (PC2, PC4 and PC6) were negatively related with fish condition. At Kpeshie wetland, the significant predictors of fish condition are PC2 (TDS, turbidity, NO_2-N, PO_4-P, Mn) [$\beta=0.59$; $p<0.05$], PC4 (salinity, alkalinity) [$\beta=-0.61$; $p<0.05$], PC5 (Cd) [$\beta=-0.41$; $p<0.05$] and PC6 (pH) [$\beta=-0.69$; $p<0.05$]. The result also indicates that with the exception of PC2 which had a positive relationship with fish condition, all other factors (PC4, PC5 and PC6) were negatively related with fish condition.

Table 4.41: Multiple linear regression showing water quality predictors of fish condition

Predictors	Sakumo II			Laloi			Kpeshie		
	B	*t*	*p*	*β*	*T*	*P*	*β*	*t*	*p*
PC1	0.22	2.46	0.00	0.64	-2.52	0.00	0.02	0.01	0.99
PC2	-0.15	-1.34	0.14	-0.72	2.91	0.01	0.59	2.58	0.00
PC3	0.00	.00	0.99	-0.10	-.21	0.84	0.39	1.97	0.07
PC4	-0.12	-1.28	0.10	-0.51	-2.88	0.01	-0.61	-2.83	0.03
PC5	-0.05	1.10	0.92	-0.37	2.09	0.09	-0.49	-2.44	0.00
PC6	-0.19	-1.92	0.06	-0.52	-2.52	0.02	0.69	2.96	0.01
R^2		.16			.88			.58	
F		1.16	0.09		6.19	0.03		3.15	0.03

Table: 4.42 Regression analysis showing fish condition as a predictor of waterbird abundance

Predictors	Sakumo II			Laloi			Kpeshie		
	β	*t*	*p*	*β*	*t*	*P*	*β*	*t*	*p*
Fish condition factor	0.25	2.83	0.04	0.34	2.49	.00	0.39	2.34	0.02
R^2		0.25			0.34			0 .39	
F		2.68	0.04		2.32	.00		2.34	0.02

As shown in table 4.42, fish condition factors contributed 25%, 34% and 39% to waterbirds at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.25$ $p<0.05$; $R^2=0.34$, $p<0.05$; $R^2=0.39$, $p<0.05$]. The findings suggest that fish condition factors across the three sites significantly contributed to the abundance and distribution of waterbird on the wetlands.

4.7 Socio-Economic Survey

4.7.1 Profile of respondents

A total of 347 respondents were selected for the questionnaire administration to find out the benefits derived from the wetlands and changes that might have occurred on these wetlands over the years. In total, 260 of the respondents were male and 87 were female. The population sampled for the questionnaire administration on each of these wetlands was divided into categories based on the level of activity carried out by inhabitants in these catchment areas and the size of the wetland. About 9.2% of the respondents were below the age of 20 years, 22.5% of the respondents were between the ages of 21 and 30, 38.0% respondents were between 31-40 years, 17.6% respondents were between 41-50 years while 12.7% of respondents were above 50 years.

Most of the respondents were indigenes that have lived on the wetland and its catchment for several years. Two hundred and forty-one (241) respondents were self- employed while 106 of the respondents were employed by industries and factories within the catchment (Table 4.43

Table 4.43: Respondents' background information

Respondent Information		Number of Respondents	Percentage (%)
Sex	Male	260	74.9
	Female	87	25.1
	Total	**347**	**100**
Age	Below 20 years	32	9.2
	21-30 years	78	22.5
	31-40years	132	38
	41-50 years	61	17.6
	Above 50years	44	12.7
	Total	**347**	**100**
Employment Status	Self-employed	227	65.4
	Employed by someone	120	34.6
	Total	**347**	**100**
Marital Status	Married	184	53
	Single	117	33.7
	Divorced	44	12.7
	No response	2	0.6
	Total	**347**	**100**
Years resident on wetland	Below 5 years	25	7.2
	5-10 years	65	18.7
	11-20 years	82	23.6
	20-30 years	105	30.3
	Above 30 years	70	20.2
	Total	**347**	**100**

Source: Field survey 2018

4.7.1.1 Educational level of respondents

From the survey, one hundred and thirty-five respondents (38.9%) had JHS/Middle School education, one hundred and three representing 29.7% respondents had secondary, vocational or technical education, and twenty-four (6.9%) respondents had primary education, while thirty respondents (8.6%) had tertiary education. About 22 respondents (6.4%) had non-formal education while thirty-three respondents (9.5%) had no education at all (Fig. 4. 12)

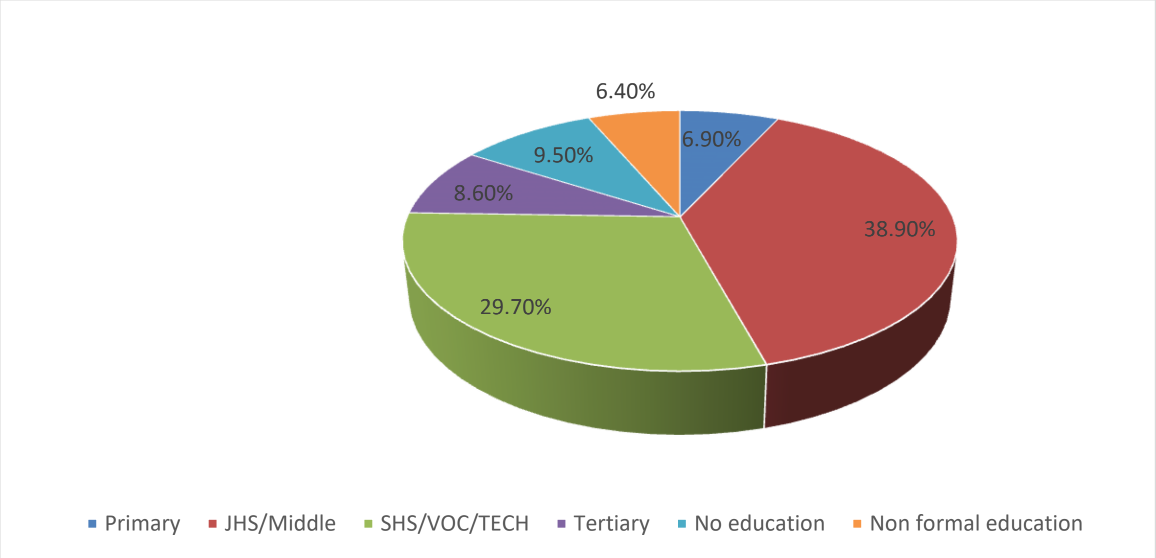


Fig. 4.12 Educational level of respondent Source: Field survey, 2018

4.7.1.2 Main occupation of respondents

Majority of the respondents (36.90%) were fishers mostly found on the Sakumo II, Laloi and Kpeshie lagoons. Almost all the fishers encountered were males during the survey. A significant proportion of respondents (30.60%) were also farmers and were mostly found in and around the northern part of the Sakumo II lagoon and southern part of the Laloi lagoon near the Vakpo and Kpoite settlements. A significant minority (21.60%) of the respondents were traders who normally visited the coastal lagoons to either buy or sell fish. About 6.3% of the respondents worked in the salt mining industry, working mostly with the El Din Salt Factory located close to the Laloi wetland. Artisans mostly masons, carpenters and auto mechanics accounted for 2.60% of the respondents while the remaining 1.70% of the respondents were either unemployed or employed as security men of companies around the wetlands (Fig 4.13).

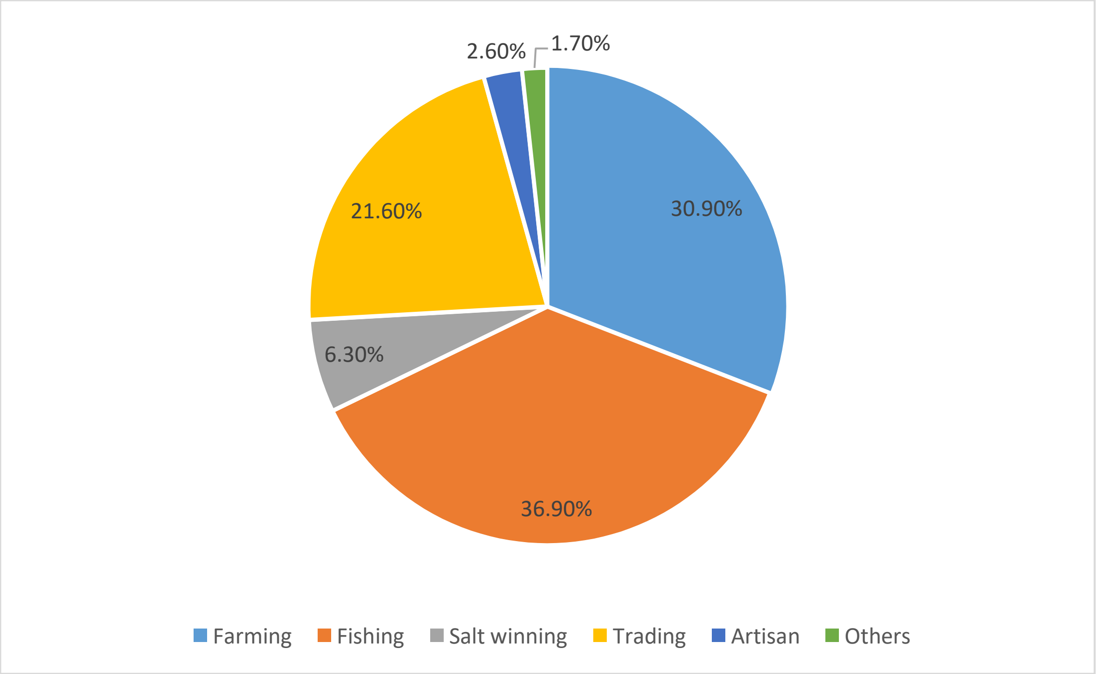


Fig 4.13: Main occupation of respondents Source: Field survey 2018

4.7.1.3 Benefits derived from the wetlands

On the benefits derived from the wetlands, 45.5% of the respondents indicated they obtained fish from the lagoons, 26.80% indicated they obtain vegetables and other food items through the farming activities, 9.20% harvested firewood from the wetlands, 3.2% visited the lagoon to swim especially on the Laloi wetland. Another, 0.9% visited the wetlands for bird watching/hunting mainly at the Sakumo II and Laloi wetland whilst 0.3% were involved in sand winning. Sand winning was predominant at the Laloi wetlands where it was mostly used for making blocks (Fig 4.14). About 12.4% of respondents mostly the youth indicated they hunt some of the waterbird especially the ducks on the wetlands mainly as pets, food, and also use them as recreation to try the efficiency of their catapults.

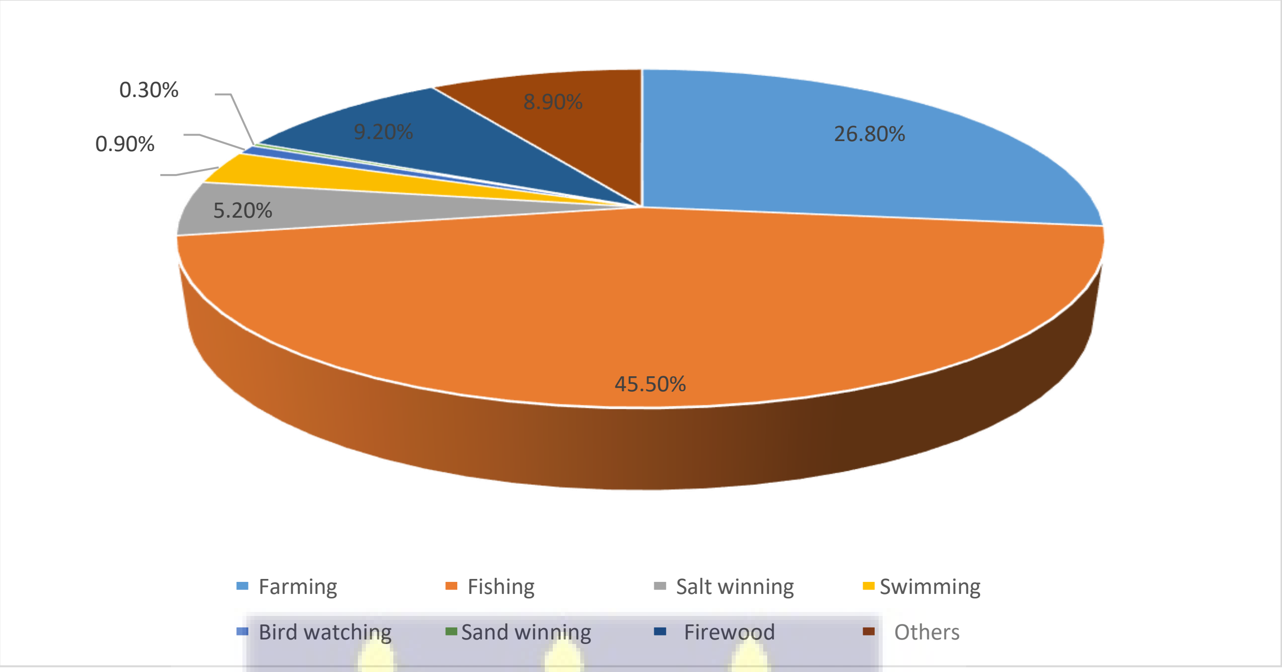


Fig 4.14 Benefits derived from wetlands by respondents

4.7.1.4 Respondents knowledge about the importance and changes on the wetland

The data analysis is to establish the relationships between respondents' knowledge about the importance of the coastal wetlands and the changes that have occurred on the wetlands. On the basis of this, series of chi-squares tests were conducted to establish these relationships. The results of the data analysis are summarised in the Table 4.44.

Table 4.44: A cross tabulation showing the relationship between importance of wetlands and changes in the wetlands.

	Frequency (%)	X^2	p-value (Fisher's exact)
Changes in the wetlands:			
There have been changes in the wetlands over the last 5-10 years	73 (21%)	4.43	0.35
Changes in the size of coastal lagoon	183 (52.7%)	.99	0.91
Changes in the mangrove and vegetation cover	191 (55%)	5.08	0.28
Upsurge in building around the wetland	189 (54.5%)	5.30	0.26
Agricultural activities on and around the wetland	145 (41.2%)	19.44	0.01
Number of migratory birds that visit the wetland	128 (36.9%)	15.46	0.01
Dumping of solid and liquid waster into the wetland	104 (30%)	7.33	0.12
Wildfire on the wetlands	37 (10.7%)	7.15	0.13
Weeds covering most surface part of coastal lagoon	116 (33.4%)	24.74	0.01
Reclamation of wetlands for other activities	64 (18.4%)	7.01	0.14
Appropriate methods of conserving the wetlands:			
Enforcing cultural values	34 (9.8%)	45.35	0.00
Enforcing strict adherence to laws of the MMDA/forestry commision	33 (9.5%)	57.30	0.00
District assembly should be responsible	83 (23.9%)	51.30	0.00
Dredging of coastal wetlands to avoid growth of weeds	115 (33%)	57.30	0.00
Public awareness and education	102 (29.4%)	44.74	0.00
Building sanitary facilities along the wetlands	119 (34.3%)	29.85	0.02

As indicated in in the table 4.44, significant relationships were observed between importance of the wetlands and agricultural activities on and around the wetlands *[X^2=19.44, p<0.01]*, importance of the wetlands and number of migratory birds that visit the wetland *[X^2=15.46, p<0.01]* and importance of the wetlands and weeds covering most part of the coastal lagoon *[X^2=24.74, p<0.01]*.

Table 4.44 also shows that there were significant relationships between importance of wetlands and enforcing cultural values *[X^2=45.35, p<0.01]*, importance of wetlands and enforcing strict adherence to laws *[X^2=57.30, p<0.01]*, importance of the wetlands and district assembly should be responsible *[X2=51.30, p<0.01]*, importance of wetlands and dredging of coastal wetlands *[*X^2*=57.30, p<0.01]*, importance of wetlands and public awareness and education *[*X^2*=44.74, p<0.01]*, importance of wetland and building sanitary facilities along the wetlands *[*X^2*=29.85, p<0.05]*.

4.7.1.5 Drivers of the changes on the coastal wetlands by respondents

Based on the perception of the respondents about the changes that has occurred on the wetland, the driver that may have caused these changes was elicited from respondents. It was revealed from the survey that approximately 97% of the respondents alluded to the fact that the intensification of human activities was the main drivers of change on the coastal wetlands.

The associated human activities that drove these changes on the wetlands were settlement expansion (54%), expansion of agriculture farms (23%), mangrove extraction for firewood and charcoal-making for domestic use (11%), salt mining for both commercial and domestic use (5.8%), livestock grazing (4.3%) and fishing (2.0%) as shown in Fig. 4.15.

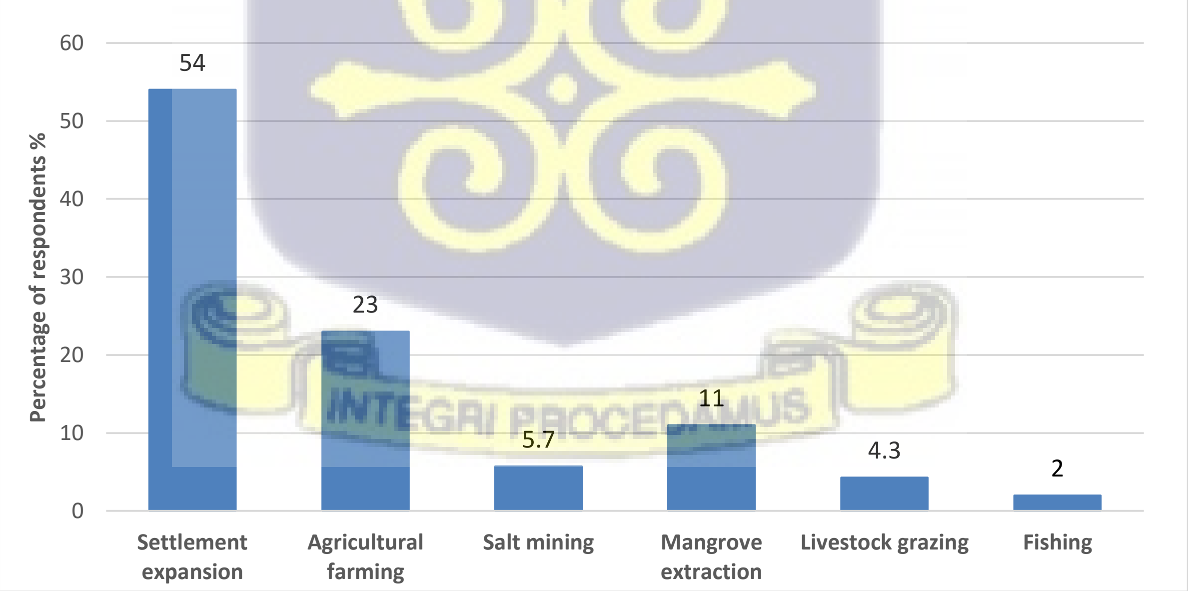


Figure 4.15: Contribution of human activities to LULC changes on wetlands. Source: Field survey, 2018

4.7.1.6 Level of usage and the changes in the wetlands by respondents

The table below shows the relationship of the level of usage of the wetland and the changes that has occurred on the wetlands by respondents. The chi square test was used to test for statistically significant differences in the responses by respondents on the level of usage of the wetland and the changes in the wetland thereof.

Table 4:45: A cross tabulation showing the relationship between level of usage and changes in the wetlands

	Frequency (%)	X^2	p-value (Fisher's exact)
Changes in the wetlands:			
There have been changes in the wetlands over the last 5-10 years	99 (28.5%)	16.99	.01
Changes in the size of coastal lagoon	213 (61.3%)	14.26	.03
Changes in the mangrove and vegetation cover	219 (63.1%)	19.73	.00
Upsurge in building around the wetland	215 (62%)	18.73	.01
Agricultural activities on and around the wetland	159 (45.8%)	34.20	.00
Number of migratory birds that visit the wetland	147 (42.4%)	12.79	.05
Dumping of solid and liquid waste into the wetland	120 (34.6%)	25.07	.00
Wildfire on the wetlands	31 (8.9%)	14.83	.02
Weeds covering most surface part of coastal lagoon	126 (36.3%)	25.03	.00
Reclamation of wetlands for other activities	88 (25.4%)	13.46	.04
Appropriate methods of conserving the wetlands:			
Enforcing cultural values and taboos	49 (14.1%)	68.18	.00
Enforcing strict adherence to laws of the MMDA	58 (16.7%)	62.57	.00
District assembly should be responsible	42 (12.1%)	89.43	.00
Dredging of coastal wetlands to avoid growth of weeds	119 (34.3%)	65.80	.00
Public awareness and education	105 (30.3%)	56.12	.00
Building sanitary facilities along the wetlands	137 (39.5%)	59.26	.00

Table 4.45 revealed significant relationships between level of usage and changes in the wetlands over the past 5-10 years *[X^2=16.99, p<0.01]*, level of usage and changes in the size of the coastal lagoon *[X^2=14.26, p<0.05]*, level of usage and changes in the mangrove and vegetation cover *[X^2=19.73, p<0.01]*, level of usage and agricultural activities on and

around the wetland [X^2=34.20, $p<0.01$], level of usage and number of migratory birds that visit the wetland [X^2=12.79, $p<0.05$], level of usage and dumping of solid and liquid waste into the wetland [X^2=25.07, $p<0.01$], level of usage and wildfire on the wetlands [X^2=14.83, $p<0.05$], level of usage and weeds covering most parts of the coastal lagoon [X^2=25.03, $p<0.01$] and level of usage and reclamation of wetlands for other activities [X^2=13.46, $p<0.05$].

Table 4.45 also indicates significant relationships between enforcing cultural values, enforcing strict adherence, district assembly should be responsible, dredging of coastal wetlands to avoid growth of weeds, public awareness and education and building sanitary facilities along the wetlands on one hand and the level of usage on the other hand [X^2=68.18, 62.57, 89.43, 65.80, 56.12 and 59.26; $p<0.01$ *respectively*]

4.7.1.7 Management practices to sustainably protect wetlands

Respondents were made to indicate the most appropriate method in their opinion to sustainably conserve and manage the wetlands and its resources during the study period. The opinions shared by respondents on the management practices needed to conserve and protect these wetlands are shown in Table 4.46.

Table 4.46: Respondents opinion about the management and conservation practices to protect the wetlands

Management practices	Frequency	Percentage (%)
❖ Enforcing the cultural /traditional values on the wetlands (taboos)	97	27.95
❖ Farming activities in and around coastal wetlands should be banned	25	7.20
❖ Dredging of coastal wetlands to avoid the growth of aquatic weeds on wetlands	44	12.68
❖ Private individuals/investors to manage all wetlands and their resources	11	3.17

❖ Public awareness and educative programs on the importance of coastal wetlands	47	13.55
❖ Building sanitary facilities in and around coastal wetlands	107	30.84
❖ District assemblies should manage coastal wetlands under their jurisdiction	16	4.61
Total	**347**	**100**

Source: Field survey, 2018

A total of One hundred and seven (107) respondents representing 30.84% indicated that the best way to protect, conserve and manage these wetlands and their resources were to build sanitary facilities such as toilets and incinerators around the lagoons to prevent the upsurge of open defecation and dumping solid and liquid waste into waterbodies on the wetlands as the population living in and around the catchment of the wetlands continue to increase.

Majority of respondents who selected this option were from the Laloi and Kpeshie catchment areas who complained of no or inadequate sanitary facilities in the Vakpo and Kpoite towns located close to the Laloi lagoon. Ninety-seven respondents (29.75%) revealed that enforcing the cultural and traditional values/taboos on the wetlands will help maintain, conserve and protect the lagoons and the wetlands at large. This will help control the number of users who visited the lagoon to either fish or harvest mangroves.

Respondents were of the view that offenders should be handed over to the traditional authorities to be sanctioned.

A cross tabulation between the importance of the wetlands and the appropriate conservation methods were analysed as shown in Table 4. 47.

Table 4.47: Relationship between importance of wetlands and appropriate methods of conserving the wetlands

		Enforcing cultural values						
		Strongly agree	Agree	Indifferent	Disagree	Strongly disagree	X^2	p
Do you know the importance of wetlands	Non response	0	2	1	0	0	45.35	.00
	Yes	13	21	82	28	14		
	No	25	15	18	16	18		
		Enforcing strict adherence						
Do you know the importance of wetlands	Non response	0	0	0	3	0	57.30	.00
	Yes	11	22	36	72	35		
	No	28	29	17	18	10		
		District assembly should be responsible						
Do you know the importance of wetlands	Non response	0	0	2	0	1	51.30	.00
	Yes	47	36	17	22	56		
	No	54	38	16	5	12		
		Dredging of coastal wetlands to avoid growth of weeds						
Do you know the importance of wetlands	Non response	2	0	0	0	0	57.30	.00
	Yes	110	5	12	9	25		
	No	20	5	14	21	26		
		Public awareness and education						
Do you know the importance of wetlands	Non response	0	0	0	0	0	44.74	.00
	Yes	54	48	15	11	11		
	No	56	25	11	7	5		
		Building sanitary facilities along the wetlands						
Do you know the importance of wetlands	Non response	1	1	0	0	0	29.85	.02
	Yes	73	46	13	12	13		
	No	33	11	15	10	8		

Table 4.47, shows that there were significant relationships between importance of wetlands and enforcing cultural values [$X^2=45.35$, $p<0.01$], importance of wetlands and enforcing strict adherence [$X^2=57.30$, $p<0.01$], importance of the wetlands and district assembly should be responsible [$X^2=51.30$, $p<0.01$], importance of wetlands and dredging of coastal wetlands [$X^2=57.30$, $p<0.01$], importance of wetlands and public awareness and education [$X^2=44.74$, $p<0.01$], importance of wetland and building sanitary facilities along the wetlands [$X^2=29.85$, $p<0.05$].

In terms of how the socioeconomic data informed the distribution of waterbirds on the wetlands, a total of 304 respondents representing 87.6% who responded to the questionaires, indicated they do not hunt for birds on the wetlands. However, 43 respondents representing 12.4% who were mostly the youth indicated they hunt some of the waterbird species especially the ducks on the wetlands. The 25 respondents out of the 43 who indicated they do hunt waterbirds indicated they hunt them as pets, food, and also use them as recreation to try the efficiency of their catapults.

CHAPTER FIVE

DISCUSSION

5.1 Land Use/Land cover changes on wetlands

Land use/land cover affects most prominently the natural landscape and happens most often in urbanized areas in developing countries (Lambin *et al.*, 2003). Anthropogenic influences and other natural processes drive changes in land use/cover, which in turn promote changes that affect biodiversity and humanity (Kamusoko & Aniya, 2007). Most often, LULC maps created from remotely sensed data are used to track these changes in the ecosystems.

Classification accuracies indicated that the image classification employed in this study performed well for all LULC types. According to Turan & Günlü (2010), the overall accuracy is acceptable if it is greater than 80%. The accuracy of the result therefore reasonably falls within the range of land cover classification accuracies proposed by Turan & Gunlu (2010). According to Congalton & Green (1999), any Kappa statistic ('K') value between 0.80 and 1 indicates strong agreement, while values between 0.40 and 0.80 indicate moderate agreement, and values less than 0.40 indicate poor agreement. Ismail & Jusof (2008) also defined the agreement criteria for Kappa statistics as poor when Kappa is less than 0.4, good when Kappa is less than 0.70, and exceptional when K is greater than 0.75. In this study, the Kappa statistics revealed a high level of agreement for the classified images, and the overall accuracy was also within acceptable limits for further LULC change analysis (Kindu et al., 2013).

The high percentages of discriminated classes/units that were true classes during the current study indicate that the combined use of aerial photos and field data in accuracy assessments is still an effective approach of LULC assessment (Turan & Gunlu, 2010).The overall accuracies for this study classified from thematic maps ranged from 79% to 86% with the Kappa statistics ranging from 0.72 to 0.82 on all the three wetland.

The overall accuracy is consistent with that of Tadese *et al.,* (2020) and Reis (2008) who reported a satisfactory overall accuracy between 86.6% and 87.1% in their studies respectively. The overall accuracy and Kappa statistics was relatively lower than obtained by Gbekor-Kove *et al.,* (2010) on the Sakumo II wetland from 1985 to 2010 but very similar to Atampugre (2010) on the land use/land cover changes on the Muni-Pomadze wetland which also recorded an overall accuracy of 85% and Kappa coefficient of 0.81. The accuracies obtained were also similar to what was obtained by Ekumah *et al.,* (2020) on the study of LULC changes in the Sakumo II, Muni and the Densu delta wetlands.

The study is also comparable to other studies in Africa which recorded similar accuracies like accuracy levels for three dates 1984, 1994, and 2011 in the Kasegra water basin in East Africa which ranged from 82 to 84%, with Kappa statistics ranging from 0.77 to 0.79 (Berakhi *et al.,* 2015) and other similar results with high overall accuracies between 86% – 93% reported in other regions of Ethiopia by Kindu *et al.,* (2013) and Fetene *et al.,* (2016).

Four LULC classes were discriminated from the Landsat images using the USGS classification system. From the results of the study, the landscape of the Sakumo II, Laloi and Kpeshie wetlands have experienced major changes during the last 30 years (1986-2017). LULC changes showed that vegetation and built-up areas were the most dominant LULC type on all three wetlands. In terms of the land use land cover matrix, this current study revealed that the dominant LULC type in the 1986's was the vegetative cover on all wetlands that has been over taken by built- up/residential expansion on the wetlands by 2017.

The results further indicated the general trend observed between1986-2017 was an increase in built-up areas due to population increase and a decrease in the remaining LULC types like the vegetation and the water bodies. On the Sakumo II wetland there was a decrease of about 57.3% in vegetation cover whereas there was an increase of 54.4% in built up areas. This same trend was observed on the Laloi and Kpeshie wetlands with a decrease of 58.3% and 33.7% respectively in the vegetative cover while there was an increase of 53% and 50.8% in built up areas on the both wetlands. Atampugre (2010) studies on land use land cover on the Muni wetland and Hailemariam *et al.*, (2016) in the Bale Mountains in Ethiopia reported significant loss of vegetation within an observation period of 30 years. Huang *et al.*, (2017) also found massive vegetation loss during land cover dynamics studies in Beijing over a period of 30 years. The land use/land cover results obtain for the current study was similar to previous studies by Ekumah *et al.*, (2020) in the Sakumo II, Densu and Muni wetlands.

Human population residing in and around the Sakumo II, Laloi, and Kpeshie wetlands has doubled between 1984 and 2010, according to the Ghana Statistical Service (2013), which has spurred the expansion of built-up areas in the wetlands at the expense of other LULC types. Rapid land cover changes could be driven by population growth, meaning that these urban wetlands would eventually become developed built environments in no time. The increase in human population around wetlands heightens the pressure on the limited land resources, and an increase in agriculture expansion and residential settlements leads to degradation of the wetlands (Ekumah *et al.*, 2020, Abebe et al., 2022). Studies by Wood *et al.*, (2004) found out that increased human population pressures resulted in an increase in built-up lands.

Other studies in Africa (Wingate *et al.*, 2016; Akinyemi, 2017; Padonou *et al.*, 2017) confirm that wetland exploitation, agriculture, population growth, expansion in built-up areas, are considered the main drivers of land use land cover changes as the trend of human population growth put pressure on the wetland ecosystems to an unsustainable level with irreversible consequences (Mucova, 2018).

From the study, waterbirds appeared less frequently in more urbanized areas as was observed on the Kpeshie wetland which was more urbanized with increase in built up facilities and encroachment activities in the catchment. Correlation between water quality parameters (Nitrates, phosphates, Conductivity, TDS, Nitrite) and the LULC unit (waterbodies) in the study indicated a negative relation, an indication that as the water quality parameters increase in the wetlands, the quality of the waterbody decreases which affects the assemblage of macroinvertebrates and waterbirds who forage on the wetlands.

As the concentration and the total amount of pollutants such as the nutrients, turbidity, TDS etc. on the wetlands increased, it leads to changes in the natural hydrological process on the wetlands (Chen *et al.*, 2013, Yang et al., 2020). In this case, waterbird become extremely vulnerable to stress on the wetlands, and leads to a decline in their abundance (Suri *et al.*, 2017; Andrade *et al.*, 2018) as was observed on the Kpeshie wetlands, Laloi and Sakumo II wetlands.

However, there was a positive correlation between water quality parameters such nitrates, phosphates, TDS and built up. This is an indication that as more people settle on these urban wetland and it catchment, it gradually leads to an increase in contaminants finding its way onto the wetlands. Human activities like agricultural farming, industrial waste waters generated by the industries in the catchment and other organic pollutants affect the abundance of biodiversity who depend on the wetlands (Nonterah *et al.*, 2015, Yang *et al.*, 2020)

5.2 Water and sediments quality and their impact on biological diversity

Physical disturbances, natural geological characteristics, land use patterns, and other human activities in a catchment affect the water quality of the aquatic ecosystems (Sundermann *et al.*, 2013). Influences on the water quality also results in changes in the aquatic biodiversity (Arimoro, 2011).

5.2.1 Changes in water quality parameters on wetlands

5.2.1.1 Physicochemical parameters

The pH is a critical water quality parameter of any aquatic ecosystem since all the biochemical activities of water are greatly dependent on the pH (Jalal & Kumar, 2013). The pH value recorded for the Sakumo II and Kpeshie wetland fell within the permissible range of 6.5 – 8.5 pH range for natural waters (US EPA, 2004; WHO, 2005). The pH recorded indicates that the waters in the Laloi wetland were slightly alkaline. The higher mean pH of the Laloi lagoon waters was attributed in part to the lagoon's lengthy residence time, which encourages algae population growth and proliferation, which contributes to a rise in pH through carbon dioxide uptake during photosynthesis (El-Gammal *et al.*, 2017) and the proximity of the lagoon to the sea as well as the abundance of phytoplankton which significantly increases pH in lagoons waters (El-Gammal *et al.*, 2017).

The pH recorded for this study was comparable to the pH recorded by Biney (1982; 1984) in his baseline studies which recorded pH values of 8.0 and 8.1 in the Sakumo II and Laloi lagoons respectively and higher than recorded by Fianko *et al.*, (2013) and Addo *et al.*, (2011) on the Kpeshie wetlands.

Temperature is an important physical water quality parameter to measure because it affects aquatic life by changing the dissolved oxygen (DO) content in the water, thereby making oxygen available for aquatic species' respiration and metabolic activity (Jalal & Sanalkumar, 2012; Tank & Chippa, 2013). Temperature affects aquatic organisms' metabolic activity, and most tropical fishes grow best between 21^0C and 32^0C, but cannot survive below 15^0C for long periods of time (Swift, 1993). The temperatures measured for the study were typical of Ghana's shallow coastal waters, where ambient temperatures are kept within a restricted range of 25–35^{0}C (Biney, 1990). The mean temperature value recorded for the lagoon waters on the Sakumo II, Laloi and Kpeshie wetlands were higher compared to mean values recorded by Biney (1982; 1984; 1986) at the same study areas.

The total quantity of dissolved elements in water is represented by the conductivity, which is also a measure of a waterbody's mineral content. The presence of cations and anions, their total concentration, mobility, valence, and temperature all affect conductivity (Fianko *et al.*, 2013). The Laloi and Kpeshie wetland recorded higher conductivity values because of greater interaction between lagoon waters with the sea compared to the Sakumo II lagoon due to the periodic mixture of the seawater and lagoon waters. Conductivity values recorded were extremely higher than the baseline values recorded by Biney (1982; 1984) on the same wetlands of study.

TDS levels in the lagoon waters may have a negative impact on water quality, making it unsuitable for fish and other kinds of aquatic biodiversity, such as macroinvertebrates, that live there (Cunningham & Saigo, 1997). High amounts of dissolved solids are also unsuitable for fish spawning because they make it difficult for fish to find food and can damage fish gill structures (Peirce *et al.*, 1998) reducing permeability to oxygen which may lead to homeostatic failure of fish (WRC, 2003a). The mean TDS values recorded were above the WHO permissible limit of 1000 mg/l (WHO, 2004) in natural waters and also higher than reported by Nonterah *et al.*, (2015), Asmah *et al.*, (2008) and Tay *et al.*, (2010) on the Sakumo II wetland, but similar to Fianko *et al.*, (2013) on the Kpeshie wetland. The high TDS levels in the wetland waters could be linked to domestic waste discharged into the waters from the catchment, which results in enormous amounts of organic waste, silt and debris being carried into the lagoons, particularly around the Kpeshie wetland.

The mean DO concentration recorded for both the Sakumo II and Laloi lagoons suggests that their lagoon waters are well oxygenated and favourable for most aquatic organisms growth while the DO in the Kpeshie is slightly stressed and unfavourable for most aquatic organisms. Comparing the DO levels of the present study to baseline studies by Biney (1982) showed a decrease in the levels of DO levels on all wetlands for the current study. Dissolved oxygen concentrations greater than 5 mg/l are considered favourable for most aquatic organisms' growth and activity, whereas DO concentrations less than 3 mg/l are considered stressful. Similarly, DO concentrations less than 2 mg/l may result in the death of most fishes or do not support aquatic life (Chapman, 1992).

Salinisation is defined as an increase in the concentration of naturally occurring mineral ions in water, mainly sodium, chloride, and sulphate (Davies & Day, 1998). Higher salinity values recorded in the Laloi and Kpeshie lagoon waters were basically due to the closeness of the lagoon to the constructed salt pans at Laloi and seawater intrusions at Kpeshie. The salinity levels on wetlands were higher compared to baseline values recorded on same wetlands by Biney (1982; 1984).

Turbidity is a measure of how transparent water becomes due to the presence of suspended particles. Sediments from erosion, waste discharge, urban runoff, algae or aquatic weeds and products of their breakdown in water, other organic compounds resulting from plant and leaf decay, and high iron concentrations that give waters a rust-red coloration are all factors that can affect water turbidity (US/EPA, 1999). The murkier the water, the higher the turbidity and the more total suspended solids there are in it (APHA, 1995). The lower turbidity values recorded at Sakumo II and Laloi were probably due to the low anthropogenic disturbance as compared to the Kpeshie wetland. Previous studies by Darko & Ansa-Asare (2014) recorded relatively high turbidity values ranging from 1.31 NTU to 309 NTU. Likewise, Gbogbo & Otoo (2015) also recorded very high mean turbidity in the Sakumo II lagoon. Baa-Poku *et* *al.*, (2013) recorded turbidity values ranging from 50.1 to 600.3 NTU for various zones of the Odaw River in the Greater Accra Region.

The concentration of alkalinity for good fish culture according to Boyd & Lichtkoppler (1979) should be within 20 to 300 mg/l. The lagoon waters in the Sakumo II wetlands, however, fell above the permissible level of 500 mg/l (WHO, 2004; EPA, 2000). The levels of alkalinity is comparable to similar results obtained by Addo *et al.*, (2011) and Nonterah *et al.*, (2015) in the Kpeshie and Sakumo II wetland respectively in Ghana. Comparing the alkalinity to baseline studies by Biney (1982; 1984) the levels recorded in this study was far greater than the baseline studies on the same wetlands.

5.2.1.2 Nutrients in coastal lagoons

Phosphorous is a nutrient that limits algae development and regulates a water body's primary productivity (Karikari *et al.*, 2007) as well as an indicator for anthropogenic biological pollution (Addo *et al.*, 2011). Phosphates can be found in surface water as a result of domestic waste, detergent, and fertiliser-laden agricultural run-offs (Kolawole *et al.*, 2011; Murhekar, 2011). Because phosphorus is taken up by plants, it is rarely present in high amounts in surface waters. Phosphorus levels in most natural surface waters range from 0.005 to 0.060 mg/l (Wild, 1995).

The relatively high phosphate concentrations found in the Sakumo II and Kpeshie lagoons have the potential to cause eutrophication, lowering the amount of oxygen available to aquatic organisms, particularly fish, for respiration (Fianko *et al.*, 2013). The high levels of phosphate in the Sakumo II lagoon are from effluents discharge from the beverage industries and other industries located within the Sakumo II catchments (Nonterah *et al.*, 2015). The low phosphate levels in the Laloi lagoon could be due to a buffering mechanism in which phosphorus is absorbed by the sediments based on its levels in the overlying waters (Biney, 1982).

The result of the present study is comparable to studies by Biney (1982), Fianko *et al.*, (2013) and Nonterah *et al.*, (2015) which recorded low levels of phosphate in the Sakumo II lagoon. However, Nartey *et al.*, (2011) reported high levels of phosphate which exceeded the EPA maximum guideline value of 2.0 mg/l in the Sakumo II wetland.

The presence of nitrites in high concentrations in waterbodies indicates organic contamination. Pollution of nitrite is detected when the concentration exceeds 0.50 mg/l (McCutcheon *et al.*, 1989). All three wetlands sites recorded nitrite concentrations less than the permissible level of 0.5 mg/l, an indication that nitrite levels were not alarming in the waters. Comparing the nitrite levels in present study on the Sakumo II lagoon to previous studies by Koranteng (1995), Nartey *et al.*, (2011), Nonterah *et al.*, (2015) however, showed an increased level in the current study. Addo *et al.*, (2011) recorded mean nitrite concentration of 0.006 mg/l far lower than the present study in his studies on the quality of waters on the Kpeshie wetland.

Nitrates in natural waters are important indicators of biological pollution. The principal nutrient that promotes algae growth in water is inorganic nitrogen, which is found in most waterbodies as nitrate (NO_3^-). Nitrate is found in water from a variety of natural sources as well as human activities such as agricultural practices, sewage disposal, and garbage dumping into waterbodies (Murhekar, 2011; Kuzelka & Ennenga, 2013). The high level of nitrate (10.28 ± 2.44 mg/l) in the Kpeshie lagoon which exceeded the permissible levels is basically from the sewage systems from households in the catchment, waste from domesticated animals and the small farmlands around the wetlands.

Comparative studies of nitrate concentrations in the present study to baseline studies by Biney (1982; 1984) and other studies on these same wetlands (Koranteng 1995; Yawson, 2003; Nartey *et al.*, 2011; Addo *et al.*, 2011; Fianko *et al.*, 2013; Nonterah *et al.*, 2015) showed elevated levels of nitrate basically due to anthropogenic activities.

Generally, the high levels of nutrient load have several consequences on the lagoon which may include eutrophication of the lagoon which leads to the depletion of oxygen in the water medium and may affect aquatic life and other users of the wetlands.

5.2.1.3 Trace and heavy metals in coastal lagoons

Magnesium and calcium are two of the most abundant alkali metals in the environment, occurring naturally in water bodies (Grochowska & Tandyrak, 2009). All concentrations of magnesium on all wetlands were above the permissible value of 100 mg/l in surface water (WHO, 2004). The comparatively high concentration of magnesium found in the Sakumo II lagoon can be linked to farming activities with the use of magnesium-containing fertilizers in the catchment. The present study recorded relatively higher levels of magnesium compared to the previous studies by Nonterah *et al.,* (2015) who recorded mean magnesium concentration of 504.36 mg/l in the Sakumo II lagoon and Fianko *et al.*, (2013) who also recorded mean level of 258±64.23 mg/l in the Kpeshie lagoon. Magnesium levels recorded in current study was also higher than baseline values on the same wetlands (Biney 1982; Biney 1984).

All calcium levels recorded in the present were above the WHO permissible value of 75 mg/l (WHO, 2004). Results were higher compared to baseline studies on the same wetlands by (Biney 1982; 1984) and other studies by Fianko *et al.*, (2013) who recorded calcium concentration of 331.43 ± 91.55 mg/l on the Kpeshie lagoon and Nonterah *et al.*, (2015) who also recorded mean calcium levels of 364.82 mg/l on the Sakumo II wetland in Ghana.

Chloride levels were generally greater than the EPA permissible limit of 5000 mg/l and the WHO permissible limit of 250 mg/l (WHO, 2004) at all three wetland sites. All groundwater and natural surface water contains chloride. Inorganic salts like $CaCl_2$, KCl, and NaCl are the principal sources of chloride (Meybeck et al., 1992; Murhekar, 2011). Humans are unaffected by chlorides, but in large concentrations, they can be fatal (Abulude et al., 2006).

The possible reason for the high levels of chlorides on all three wetlands basically is the seawater intrusion as a result of the proximity of the lagoons to the sea. The chloride levels in the present study were extremely higher than baseline studies on the same wetland by (Biney 1982; 1984) but similar to levels recorded by Nonterah *et al.*, (2015) on the Sakumo II and Apau *et al.*, (2012) on the Kpeshie wetlands.

Iron (Fe) is one of the most abundant metals on earth and mostly found in natural fresh and groundwater (Institute of Medicine, 2001). Increased iron levels in coastal waters make fish in lagoons more susceptible to infectious diseases. Extremely high levels of iron are hazardous to aquatic species and may impede enzyme processes (WRC, 2003a). Iron concentrations recorded for this study were above the WRC target water quality range of 0.01 mg/l and WHO permissible limit of 0.3 mg/l for natural waters (WHO, 2004).

The highest level of iron recorded in the Kpeshie lagoon may have come from the land-use practices in the catchment and the natural occurrences within the lagoon, because lagoons go through geochemical and biological processes that aid in the release of Fe (WHO, 2004). The mean levels of Iron recorded for this study was higher compared to studies by Tay *et al.*, (2010) and Nonterah *et al.*, (2015) on the Sakumo II wetland likewise Fianko *et al.*, (2013) and Laar *et al.*, (2011) who recorded mean Fe levels of 8.29±3.47 mg/l and 2.06 ±1.7mg/l in the Kpeshie lagoon waters.

Zinc (Zn) is a frequent environmental pollutant that can be found in large quantities in the aquatic environment (Lawson, 2011). Zinc is mostly used to coat iron in modern society to avoid corrosion. Zinc is mostly obtained from particles discharged by car tyres and brake linings (WHO, 2001). Zinc is known to be very toxic to fish (Alabaster & Lloyd, 1980; WRC, 2003b, Jesper, 2010). The high levels of Zn in the Laloi lagoon may be acting as a quick sink, absorbing metal loads such as Zn from runoff and natural pollution sources such as mineral weathering and soils (Merian, 1991), as well as atmospheric deposition, could be an influence in the Zn levels in the Kpeshie and Sakumo II lagoons. The zinc levels were higher compared to results obtained by Tay *et al.*, 2009. However, Doamekpor *et al.*, (2018) recorded Zn levels of 3.74 ± 0.17 in the Sakumo II lagoon, 17.83 ±0.41 in the Chemu lagoon and 13.94 ± 0.14 in the Kpeshie lagoon which were by far were higher than the present study.

Cadmium (Cd) is one of the most dangerous elements in the aquatic environment, causing widespread cancer in humans and aquatic animals (Goering *et al.*, 1994). Fish and other aquatic species have been proven to be harmful to cadmium (Woodworth & Pascoe, 1982). Cadmium has been linked to endocrine disruption, which could cause major health issues (Awofulu *et al.*, 2005). Aglanu & Appiah (2014) recorded lower mean levels of Cd in the Korle lagoon waters, likewise Tay *et al.*, (2010) in the Sakumo II wetland. Addo *et al.*, (2011; 2012) also recorded lower concentrations of cadmium in the Kpeshie and Mokwe lagoons in Accra lower compared to the levels recorded in this study.

Chromium concentrations have been shown to decrease when pH and water hardness increases (Codex, 1995). Cr in natural water should not exceed 0.05 mg/l, according to the World Health Organization (WHO, 1998). The hexavalent form of chromium is hazardous (Chiba & Masironi, 1992). Cr contamination is frequent in soils and in both ground and surface waters in industrial urban regions, according to Katz & Salem (1994). The high levels of Cr in the Sakumo II and Kpeshie lagoons above the WHO permissible limits of 0.05 mg/l may be due to industrialization in the catchment and leaching from topsoil and rocks. The levels of chromium measured in water are comparable to studies by Apau *et al.*, (2012), Addo *et al.*, (2011, 2012) who recorded lower chromium concentration in lagoon water in the Kpeshie and Mokwe lagoon.

Cobalt is commonly found in combination with other metals such as copper, nickel, manganese, and arsenic. Most rocks, soils, surface and underground waters, plants, and animals contain trace quantities. Soil, dust, seawater, volcanic eruptions, and forest fires are among natural sources of cobalt in the environment (DWAF, 1996b). Levels of 2.0×10^{-4} mg/l are the typical concentration of cobalt in unpolluted surface water (DWAF, 1996b). The mean levels recorded in the present study far exceeded these limits and hence all the lagoon waters can be said to be polluted with Co. Levels of Co were also higher compared to previous studies by Addo *et al.*, (2011) in the Kpeshie lagoon.

5.2.1.4 Correlation between physicochemical, nutrients, heavy metals in water and macroinvertebrates abundance

Wetland ecosystem services rely heavily on benthic macroinvertebrates, which are significant components of aquatic biotic communities. As a food source for fish, waterbirds, and other creatures, they are an important link in the aquatic food chain (Blay & Dongdem, 1996; Arslan *et al.*, 2007). Because of their reactions to changes in water quality, benthic macroinvertebrates are used as indicators of water quality (Blankson *et al.*, 2021).

In the current study, the benthic macroinvertebrates identified in the lagoons belonged to the Phylum Annelida, Mollusca and Crustacea. The dominant species in the Sakumo II, Laloi and Kpeshie wetlands were *Hydrobia accrensis, Cerithidea spp* and *Nereis spp* respectively.

Polychaetes like *Capitella capitata* and *Nereis spp.* have been linked to locations that are heavily polluted with organic matter and heavy metals, according to Ajao and Fagade (1990). These creatures are classified as opportunistic and tolerant species because they can thrive in low-oxygen conditions where other organisms struggle to survive. The abundance of *Nereis spp* on the Kpeshie can be attributed to their survival in the oxygen depleted Kpeshie wetland.

Macroinvertebrates density has implications for waterbirds that feed in lagoons especially the waders. Because lagoons and the adjacent marsh are so important to migrating waterbirds, a loss in benthic macroinvertebrates abundance could lead to a decrease in waterbird numbers. A depleted macroinvertebrates distribution in lagoons will lead to the movement of waterbirds to other wetland ecosystem in search of food (Piersma & Ntiamoa-Baidu, 1995, Gbogbo, 2007; Tay *et al.*, 2010). The results of the present study showed that the benthic macroinvertebrates community structure is similar to previous studies by Piersma & Ntiamoa-Baidu, (1995) and Gbogbo (2007).

Water quality parameters in PC1, PC2, PC3, PC4, PC5, and PC6 jointly contributed 81%, 88% and 60% respectively to macroinvertebrates abundance at the Sakumo II, Laloi and Kpeshie sites [$R^2= 0.81, p<0.05; R^2=0.88, p<0.05; R^2=0.60, p<0.05$].

From the correlation, water quality parameter in PC3 (Mg^{2+} and Zn) were directly related to the abundance of macroinvertebrates on the Sakumo II wetland which implies as their levels increase in the wetland, macroinvertebrates numbers also increase. However, parameters in PC2, PC4 and PC5 (pH, conductivity, temperature and water depth, iron, copper, nickel and chromium) showed a strong negative relationship with the macroinvertebrates abundance and as such as the levels of these water quality parameters increases on the Sakumo II wetland, the numbers of macroinvertebrates in the bottom sediment will decreases.

Water quality parameters in PC2 (temperature, dissolved oxygen, salinity and iron) had a strong positive relation with macroinvertebrates abundance on the Laloi wetland. Dissolved oxygen is a very important parameter for the survival of macroinvertebrate assemblages (Sharma & Rawat, 2009). Dissolved oxygen positively correlated with macroinvertebrates in the present study and this was also similar to a study by (Sharma & Rawat, 2009) in Central Himalayas in India which recorded the same positive correlation between DO and macroinvertebrates.

As pollution levels rises in waterbodies, the amount of dissolved oxygen in the water decreases, making it only appropriate for pollution-tolerant species such as *Nereis spp*. (Patrick & Drew, 1994; Kahlon *et al.*, 2018). The low levels of DO in the Kpeshie wetland could account for the survival of the *Nereis spp* hence its abundance on the site during the study.

The parameters on PC1, PC3 and PC4 (Conductivity, alkalinity, turbidity, TDS, water depth, pH, Ca, Mg^{2+}, Cl^-, PO_4-P, Mn, Cu, Ni, Co) had an inverse relationship with macroinvertebrates abundance on the Laloi wetland likewise the Kpeshie wetland which had PC1, PC 5, PC6 (pH, conductivity, DO, water depth, Mg^{2+}, Ca^{2+}, Cl^{-1}, Fe, Ni, Co, Zn, Cd) also having an inverse relationship to macroinvertebrates abundance.

The conductivity, pH, and the nutrient such as phosphates are significant variables that affect macroinvertebrate community structure although macroinvertebrates have a high adaptability range to these ecological conditions, as they actively select suitable non polluted aquatic habitats (Batzer *et al.*, 2004).

Nutrients strongly negatively affect macroinvertebrate abundance as the current study supports findings that nutrient load can reduce the abundance of macroinvertebrates (Steinman & Rosen, 2000; Bainbridge, 2009).

Low DO, high nitrogen, and phosphorous chemicals, as well as suspended organic materials, affect the taxonomic richness and composition of macroinvertebrates (Camargo, 1993).The TSS, nitrite, phosphorous and nitrate concentrations on the Sakumo II , Laloi and Kpeshie wetlands were high and could have affected the macroinvertebrate community composition and accounted for the decrease in abundance as there was a significant negative correlation between nutrients and macroinvertebrates on the wetlands (Dahl *et al.*, 2004).

A study by Yap *et al.*, (2006) had a different result compared to the present study as he observed a positive correlation existing between macroinvertebrates like the Oligochaetes and nutrients such as nitrates and phosphates but had a negative correlation with dissolved oxygen.

Temperature, salinity, dissolved oxygen, pH, turbidity, water transparency and depth, among other environmental variables, have been found to be inversely related to the abundance and density of macrobenthic organisms in lagoon systems (Mistri *et al.*, 2001, Lamptey & Armah, 2008, Blankson *et al.*, 2021).

This is consistent with our result as a substantial part of the total variation in macroinvertebrate assemblages is inversely related to these water quality parameters on the wetlands. The water depth on all three wetlands had a significantly inverse relationship with macroinvertebrate, as water depth level has significant links with the importance of macroinvertebrate community structure and composition with an effect on foraging waterbirds (Gbogbo *et al.*, 2009, Nhiwatiwa *et al.*, 2017).

The finding of this study is similar to findings by Ntiamoa-Baidu *et al.*, (1998) who reported water depth as a key environmental factor controlling the availability of food for macroinvertebrates and indirectly the waterbirds especially waders on Ghanaian wetlands.

Using dissolved oxygen as an example on the Laloi wetland, the significant role of dissolved oxygen in the abundance and diversity of macroinvertebrates is well corroborated in this present study, where high abundance of macroinvertebrates was recorded in Laloi wetland with the highest dissolved oxygen levels. This may be due to the wetland's huge surface area, which exposes the site to air and sunshine, as well as an abundance of organic debris, which supported the photosynthetic activities of aquatic plants (King & Nkanta, 1991, Ikomi *et al.*, 2005). These findings are consistent with other studies (Larocque *et al.*, 2006; Lencioni *et al.*, 2012), which found that the DO and temperature of overlying water affect the distribution of macroinvertebrates in aquatic habitats.

Heavy metals (Cr, Cd, Cr, Zn, and Ni) in water may also change the community structure of macroinvertebrates, as Mollusca and crustaceans are macroinvertebrates that thrive in water with high levels of heavy metals (Yi *et al.*, 2011, Bian *et al.*, 2016).

The Annelids (polychaetes) can only survive in water with low metal concentrations (Ali & Fishar, 2005) hence their reduced numbers on the Sakumo II wetland which recorded relatively lower concentration of heavy metals in the lagoon waters. The polychaetes which were most abundant on the Kpeshie wetlands was an indication of the tolerance of polychaetes to heavy metal pollution hence its abundance on the wetland.

5.3 Changes in sediment quality on wetlands

The heavy metals concentration in the bottom sediments from the lagoons were assessed and the results were compared with WHO (2004), USEPA (1999), (CCME, 1999) sediment quality guidelines (SQG) and any other previous studies on the wetlands.

Because heavy metal pollution persists in the environment and poses a number of ecological challenges (Li *et al*, 2004, Gbogbo & Otoo 2015), an integrated index analyses approach incorporating contamination factor (CF), pollution load index (PLI), enrichment factor (EF), and geo-accumulation index (Igeo) is required. to estimate enrichment and risks of heavy metals in the bottom sediments of the Sakumo II, Laloi and Kpeshie lagoons to prevent any challenges to macroinvertebrates inhabiting it. The concentrations of heavy metals in bottom sediment in lagoons are typically higher than in the water because sediments act as sink or reservoirs for pollutants in water (Onyari *et al.*, 2003; Samir *et al.*, 2006). This was consistent with the study as concentrations of heavy metals in the bottom sediments were higher than the lagoon waters.

The sediment samples collected from Kpeshie wetland contained higher heavy metal concentrations compared to the other wetlands. The highest concentrations of metals (Fe, Mn, Zn, Pb, Cd) found on the Kpeshie wetlands was related to anthropogenic activities such as the subsistence agricultural farms dotted around the wetland, domestic waste discharges as well as the automobile workshops in the catchment (Ansah *et al.*, 2008; Addo *et al.*, 2011).

The Fe values recorded for the study far exceeded the USEPA sediment quality guidelines of 30 mg/kg and EPA limit of 48 mg/kg. Fe showed a strong positive correlation with Mn and

Ni in the Laloi lagoon sediment and also showed a stronger positive correlation with Mn and Pb in the Kpeshie sediment indicating a common source or a common sink in the sediments (Fianko *et al.*, 2013; Nonterah *et al.*, 2015). Positive correlations among heavy metals indicated mutual dependence, common origins, and similar transportation behavior (Bastami *et al.*, 2015).

Likewise, the mean levels of Mn exceeded the USEPA sediment quality guidelines indicating contamination of the bottom sediments with manganese metal. Sediment samples from Sakumo II lagoon had higher Mn concentration compared to Laloi and Kpeshie lagoons and this could be attributed to the relatively high impact of human activities like farming with the use of fertilisers in the catchment of the wetland (Asmah *et al.*, 2008, Nonterah *et al.*, 2015). Manganese showed a strong positive correlation with Zn and Pb in the Sakumo II, Laloi and Kpeshie lagoons indicating a common contamination source.

The mean copper value recorded for all wetlands were lesser than the world surface rock average and the CCME guidelines. However, mean values of Cu in the Kpeshie lagoon sediment exceeded the mean shale concentration, WHO and USEPA values. According to USEPA guidelines, Sakumo II and Kpeshie lagoon sediments have little pollution by Cu. Cu had a positive significant correlation with Pb in the Laloi lagoon likewise Pb and Mn in the Kpeshie lagoon. Levels of Cu in sediment samples were lower compared to results obtained by Ansah et al., (2008), Addo et al., (2011) and Tay et al, (2010).

All concentrations of zinc recorded were less than the WHO, USEPA and CCME sediment quality guideline values of 123 mg/kg and 110 mg/kg respectively. Zinc levels showed a strong positive correlation with Co, Mn, and Cr in the Sakumo II lagoon and a strong negative correlation between Cd and Mn in the Kpeshie lagoon indicating different sources of contamination (Nonterah *et al.*, 2015).

Although, zinc (Zn) is found naturally, other sources of Zn in the environment are due to its broad use in industry and agriculture, where it is commonly used as a fertilizer and pesticide additive (Badr *et al.*, 2009). Thus, the high levels of Zn recorded in the Laloi and Kpeshie wetlands can be attributed to waste from industrial and agricultural sources that contain Zn.

The high concentrations of Cd in the Laloi and Kpeshie wetlands could be due to inputs from point sources such as phosphate fertilizer from agricultural farms, sewage effluents from built-up areas in the catchment, and other sources such as batteries, plating, pigments, and plastics in the urban areas (Oremo *et al.*, 2019). Cadmium levels recorded in the present study was lower compared to what Tay *et al.*, (2010) had on the Sakumo II wetland.

Because Lead is utilized in industrial processes and consumer products like gasoline, batteries, and paints, and the presence of auto mechanic shops and washing bays which uses such consumables and located adjacent to the lagoons could explain for the comparatively high occurrence of Lead (Pb) in the sediments of Kpeshie lagoons. Lead levels recorded in the bottom sediments of Sakumo II, Laloi and Kpeshie lagoons were all below the USEPA and CCME sediment quality guidelines. Pb showed a strong positive correlation with Fe and Mn for sediments in the Kpeshie lagoon and also a good correlation with Cu, Fe, and Mn in the Laloi lagoon sediment indicating an identical source or a common sink (Fianko *et al.*, 2013; Nonterah *et al.*, 2015).

The mean Ni concentrations recorded in the Sakumo II and Laloi lagoons were lesser than the WHO and USEPA permissible limits. Mean levels of Ni recorded in the Kpeshie sediment exceeded the permissible levels suggesting that the Kpeshie lagoon sediments are polluted with Ni. The high levels of Ni in Kpeshie sediment could be due to run-off from waste petroleum products into aquatic environments, causing Ni to accumulate in the water (Merian, 1984).

Chromium has no proven health benefits for humans or animals (Tchounwou et al., 2012).

According to Katz and Salem (1994), Cr pollution is common in soils and both ground and surface waters in industrial urban areas. Levels of chromium recorded in Sakumo II and Laloi were all below the WHO, USEPA, and CCME sediment quality guideline values, however, Cr concentration in the Kpeshie sediment were above the WHO, USEPA and CCME sediment quality guidelines. There was a strong positive correlation between Cr and Fe and Mn in the Kpeshie and Laloi wetlands as well as Cr and Mn, Zn in the Sakumo II wetland indicating common sources of pollution of these metals on the wetlands.

The general acceptable level of cobalt in sediments is between 4-20 mg/kg (Raju *et. al.*, 2012). These indicate that the bottom sediments of these lagoons are not polluted with cobalt metal and within the range proposed by Raju *et al.*, (2012). The mean value of cobalt in bottom sediment had a strong positive correlation with Cr, Mn, and Zn in the Sakumo II, and also a strong positive correlation with Pb in the Laloi lagoon. This indicates the metals do have a common contamination source on the wetlands (Salah *et al.*, 2012; Nonterah *et al.*, 2015).

Comparatively, the concentrations of the heavy metals in this current study are comparable to those reported in earlier sediment studies by Laar *et al.*, (2011), Doamekpor *et al.*, (2018), Addo *et al.*, (2011; 2012), Nonterah *et al.*, (2015), Tay *et al.*, (2010) and Acheampong *et al*,. (2014) for extremely polluted urban lagoons that no longer supports aquatic life in Ghana (Gordon *et al.* 1998).

Similarly, the concentrations found in this present study are lower than previously found in sediment from other Ghanaian mining sites (Serfor-Armah *et al.*, 2006; Akabzaa *et al.*, 2007) as well as other coastal wetlands (Blankson *et al.*, 2021).

5.3.1 Assessment of heavy metal contamination in sediments

Sediments are one of the primary sinks for heavy metals released into the environment as a result of human activities (Gibbs, 1977; Luoma & Bryan, 1981). In this present study, the enrichment factor, (EF), contamination factor (CF), the index of geoaccumulation (Igeo) and pollution load index were used to assess heavy metals contaminations in the bottom sediment of the Sakumo II, Laloi and Kpeshie wetlands.

Previous studies used an average lithogenic background value (Muller, 1969), an average concentration in shale (Ghrefat & Yusuf, 2006; Bhuiyan *et al.*, 2010), or an average value of measured concentration before industrialization to estimate heavy metal content in sediment (Hakanson, 1980).

Iron (Fe) has been effectively employed or suggested by several authors to normalize metal pollution (Loska *et al.*, 1997; Schiff & Weisberg, 1999; Bhuiyan *et al.*, 2010). Thus, Fe was used as a conservative tracer to distinguish natural from anthropogenic sources of metal pollution in wetlands bottom sediments.

The enrichment factor (EF) is a useful indicator for the state and severity of pollution in the environment (Feng *et al.*, 2004) as EF values close to one (1) indicates crustal origin and EF values greater than ten (10) indicates non-crustal origin (Ong & Kamaruzzman, 2009).

From the current study, Cd, Co, Cr, Cu, and Mn were extremely highly enriched metals in the Sakumo II sediment as EF values estimated were greater than 50.

Cadmium was also extremely highly enriched in the Kpeshie sediment as the EF calculated was also greater than 50. These extremely enriched metals strongly suggest that the sources of these metal contaminations on the wetlands were as a result of anthropogenic input such as agricultural activities, dumping of solid waste and effluents from industries into the lagoon waters which eventually sink into the bottom sediment as proposed by Birch (2003) and

Mmolawa *et al.*, (2011).

Similar EF values were obtained by (Addo *et al.,* 2011; 2012) in the Kpeshie and Mokwe lagoons which showed extremely high enrichment of Cr and Ni. In a comparative study of other wetlands in Africa, Salah et al. (2012) discovered that the sediments in the Euphrates River were highly enriched in Pb, extremely high in Cd, moderate in Zn, significant to very high in Ni, very high to extremely high in Co, moderate to significant in Mn, and very high to extremely high in Cu and significant to very high for Cr based on his estimation of enrichment factor (EF).

The pollutants load index (PLI) was calculated to compare whether the sampling sites suffered any contamination or not. PLI values estimated in the sediment samples for all the three wetland sites were less than 1. The pollution load index (PLI) is a simple but comparable technique of assessing site quality, with a PLI < 1 signifying site perfection, PLI = 1 showing the presence of pollutants but only at baseline levels, and PLI > 1 indicating site deterioration (Tomlinson *et al.*, 1980).

Based on the above classification, all the sites did not indicate any extreme deterioration of the wetlands based on the heavy metals analysed. Thus, the Sakumo II, Laloi and Kpeshie sediments suggested no overall pollution of these metals in the bottom sediment. Previous studies by Rabee *et al.,* (2011) on pollution indices in the Tigris River in Bagdad recorded Pollution Load Index (PLI) values between 0.301-0.970, indicating that the Tigris River was unpolluted. Based on PLI calculated by Salah *et al.*, (2012) on the Euphrates River, all sampling sites suggested no overall pollution.

From the contamination factor (CF) estimated for the present study, cadmium was responsible for very high contamination in both the Sakumo II and Kpeshie wetlands similar to contamination factor (CF) calculated in the study by Salah *et al.*, (2012), Cd and Cr were responsible for the very high contamination in the sediments of the Euphrates River.

The Igeo values describe the link between the measured element in sediment and the geochemical value in fossil sediment average shale/world rock average values). The Igeo values in the sediment calculated for most of the metals were all less than zero (0) for all three wetland sites and as such these sites can be considered as practically unpolluted with these metals.

However, cadmium levels recorded Igeo index range between 1- 2 an indication of moderate pollution in the Sakumo II sediment and an index range of 2-3 in the sediments from the Kpeshie wetlands moderate to strong pollution in the sediments.

It can, therefore, be concluded that Cd was the only major heavy metal pollutant in the sediments of the Sakumo II and Kpeshie wetlands based on the Igeo estimated and this could be due to its persistence in the environment as a result of human pressure, particularly the land use practices in the catchments.

Similar results were obtained by Addo *et al.*, (2011; 2012) who estimated Cd as being unpolluted to moderate pollution in the lagoon sediment while Cr also exhibited strong pollution to extremely polluted sediments in the Kpeshie and Mokwe lagoons. The geo-accumulation index of the sediment in majority of the analyzed stations was mildly polluted (grade 1) with respect to Pb and Cd, but unpolluted (grade 0) with respect to Mn, Cu, and Ni, according to Rabee *et al.,* (2011) on pollution indices in the Tigris River. The calculated Igeo values for heavy metal pollution in collected sediment samples from the Songor lagoon during a study by Sackey (2014) recorded Igeo < 0 indicating unpolluted sediment on the wetland.

The overall total geo-accumulation index (I_{geo} tot) for the entire study on each wetland was found to be negative, an indication that the mean concentration of heavy metals in sediments of the Sakumo II, Laloi and Kpeshie lagoon were lower than the world surface rock average

(Rabee *et al.*, 2011, Addo *et al.*, 2012).

5.3.2 Correlation between sediment quality and macroinvertebrates

Mining, industrial operations, sewage treatment plant effluents, and urban run-off all contribute to heavy metal contamination of aquatic environments (Sanchez, 2008). Heavy metals in sediments have a deleterious effect on macroinvertebrates, such as mortality; yet, in moderate concentrations, several heavy metals have a direct positive effect on macroinvertebrates, as they produce small amounts of micronutrients for many species (Han *et al.*, 2002). Because macroinvertebrates spend majority of their lives in the bottom sediments, the quality of the sediment is critical in determining the presence of various macroinvertebrates (Khudhair *et al.*, 2019). The assemblage of benthic macroinvertebrates that live in or on the sediments is directly affected by the sediment type, particle size, and other factors such as metal pollution (He *et al.*, 2016).

The relationship between the sediment and macroinvertebrates showed that heavy metals in PC1, PC2 and PC3 jointly and significantly contributed 25%, 57% and 30% respectively to macroinvertebrates abundance at Sakumo II, Laloi and Kpeshie wetlands [$R^2=0.25$ $p<0.05$; $R^2=0.57$, $p<0.05$; $R^2=0.30$, $p<0.05$]. From the analysis, there was a direct positive relationship between PC2 (Cd, Cu, Ni) on the Sakumo II wetland, PC3 (Co and Pb) on the Laloi and PC1 and PC2 (Cd, Cr, Cu, Fe Mn, Zn, Pb, Co, Ni) on the Kpeshie wetlands respectively. As the levels of these metals in the lagoon sediments increase, macroinvertebrates abundance also increases on the wetlands. However, an inverse relationship between sediment quality and macroinvertebrates was established between PC1 (Co, Cr, Mn, Zn) on the Sakumo II and PC1 (Cd, Cr, Fe, Mn) on the Laloi wetland.

A significantly negative correlation between these heavy metals and benthic macroinvertebrates implies an adverse negative effect of these heavy metals on the benthic communities. This study was consistent with other studies on wetlands in other parts of the world by Yi *et al.,* (2011) and (Bian *et al.,* 2016) in the Yangtze River basin and the Taihu Basin in China.

Different benthic organisms are sensitive to different types of environmental disturbances or pollution, as such some macroinvertebrate species may be able to survive and dominate in contaminated sediments due to their high tolerance (Podda *et al.,* 2014; Plachno *et al.,* 2015). In highly contaminated wetlands like the Kpeshie with higher levels of heavy metals recorded in the sediments above the SQG limits, highly tolerant macroinvertebrates like the polychaetes and gastropods were predominant and dominated the wetland, because these macroinvertebrates can aggregate heavy metals within their organs and survive in such environments. Aggregating these heavy metals in their organs potentially threaten the health of many organisms at higher trophic levels including the fishes and waterbirds (Demirak *et al.,* 2006; Hamidian *et al.,* 2016).

The levels of heavy metals like cadmium, lead recorded in the sediment from the present study was above the sediment quality guidelines which can lead to the contamination of the bottom sediment. These enrichment and contamination in sediments will in turn affect the composition and abundance of sensitive to tolerant macroinvertebrates in the waterbodies (Qu *et al.,* 2010).

The findings from the present study compares favourably with other studies worldwide. Lubna *et al.,* (2012) found a significant difference between molluscs and crustaceans and heavy metals like Cd, Cu, and Cr concentrations in Australia, while Qu *et al.,* (2017) also found a significant difference between heavy metals in sediments and benthic diversities in the Hun-Tai River in Northeast China. Significant differences in macroinvertebrates abundance and heavy metals in sediments were reported in other studies by Ryu *et al.,* (2011), Bian *et al.,* (2016) and Oremo *et al.,* (2019) in Kenya.

5.4 Macroinvertebrates distribution and abundance on wetlands

Wetland ecosystem services rely heavily on benthic macroinvertebrates, which are significant components of aquatic biotic communities. As a food source for fish, waterbirds, and other creatures, they play a vital role in the aquatic food chain (Blay & Dongdem, 1996; Arslan et al., 2007).

Macrozoobenthos have been used to assess the ecological integrity of aquatic habitats because they exhibit a distinct reaction to changes in the aquatic environment, making them a good bioindicator of hydrological stress and the health of aquatic ecosystems (Acharyya & Mitsch, 2000; Nazarova, 2004). The hydrobiology of water, sediment substrate, and food availability are all elements that influence the quantity and distribution of benthic macroinvertebrate fauna in a specific community or ecosystem (Coleman *et al.*, 2007; Li *et al.*, 2012; Basu *et al.*, 2013).

Macroinvertebrates abundance recorded showed that the Laloi lagoon which is relatively a closed lentic waterbody was the most suitable wetland for the survival of macroinvertebrate, hence the highest density of macroinvertebrates recorded. The Laloi wetland is mostly dominated by marshes and as marshes are not influenced by external factors and conditions such as turbidity, BOD, DO, nutrient levels makes the site relatively easier for macroinvertebrates to survive in it (Khudhair *et al.*, 2019).

Macroinvertebrates collected in sediments on the Laloi wetland during the study contained more endobenthic organisms (Oligochaetes, bivalves, polychaetes gastropods, etc.) which thrive very well in marshes (Khudhair *et al.*, 2019).

Macroinvertebrates recorded belonged to the phyla Annelida, Mollusca, and Crustacea. The phyla Annelida was represented by *polychaetes* and *oligochaetes*. The polychaetes were made up of *Nereis spp*, *Glycera spp*, and *Capitellid spp*. The phyla Mollusca were represented by the gastropods and bivalves. The gastropods included *Cerithidea spp, Hydrobia accrensis, Tympanotonus fuscata, Melanoides tuberculata* while the bivalve was *Tivela tripla while* the phyla Crustacea was represented by the *Penaeus notialis.*

In terms of the taxa, similar taxa composition was recorded by Lamptey & Armah (2008) in the Keta lagoon and Baa-Poku *et al., (*2013) in an urban creek in Accra. Finlayson *et al.,* (2000) also recorded similar taxonomic assemblage in the Songor and Keta lagoons. The macroinvertebrate taxa described in this study are comparable to macroinvertebrates found in the Ankobra Basin (Osafo & Paintsil, 1994), Lamptey, (2003) in the Keta lagoon and the Odaw stream (Thorne *et al.*, 2000).

The Cerithidea spp which is a gastropod was the most abundant species on all three wetland accounting for about 22.14% of the total count of macroinvertebrates. These species are mainly found in low-oxygen and lentic habitats, where the substratum is immobile and shallow, facilitating their growth (Spyra, 2010, Zybek *et al.*, 2012). These gastropods were mostly found on the Sakumo II and Laloi wetlands similar to what was obtained by Lamptey &Armah (2008) in the Keta lagoon.

The polychaetes preferred fine to medium type of sandy bottom with an adequate abundance of a combination of silt and clay (Al-khayat, 2005) which was a characteristic of the bottom sediment in the Kpeshie lagoon hence the highest number of *Nereis spp* recorded on the wetland. The abundance of *Nereis spp.* on the Kpeshie wetland site suggests a strong indication of organic enrichment. Polychaetes like *Capitella capitata* and *Nereis spp.* were linked to areas that were heavily polluted with organic matter, heavy metals, and petroleum hydrocarbons, according to Ajao & Fagade (1990). These groups of organisms are classified as opportunistic and tolerant species because they can thrive in low-oxygen conditions where other organisms struggle to survive (Ajao & Fagade, 1990).

The presence of high numbers of gastropods which are also pollution-tolerant or semi tolerant groups indicated that the study area especially the Sakumo II and Laloi wetlands were being subjected to different degrees of anthropogenic interference and heavy metal contamination (Zhang *et al.*, 2015).

In terms of faunistic abundance, the present study recorded a total of 4,474 benthic macroinvertebrates individuals which was higher compared to 2,152 individuals recorded by Lamptey & Armah (2008) in the Keta Lagoon. Finlayson *et al.*, (2000), however, recorded a total of 19,198 which was relatively higher and 3,895 individuals which was lower compared to the present study in the Keta and Songor wetlands in Ghana.

Ikomi *et al.*, (2005) recorded 830 ind/m^2 of macroinvertebrates density in the upper reaches of River Ethiope, Delta State, Nigeria which was below the numbers recorded in the present study. Basu *et al.*, (2018) also reported lower macroinvertebrate numbers from the upper, middle, and downstream of River Ichamati in India. The low population density of benthic macroinvertebrates found in most months on all wetland types is, however, consistent with low numbers in the dry season due to hypersaline conditions in the lagoons (Piersma & Ntiamoa-Baidu, 1995). The densities recorded for this study were, however, similar compared to Abdourahamane (2010) who recorded lower macroinvertebrates abundance on the Muni wetland.

5.4.1 Macroinvertebrates as predictors of waterbirds on wetlands

Macroinvertebrates contributed 12%, 22% and 4% to waterbirds abundance at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.12,\ p>0.05;\ R^2=0.22,\ p<0.05;\ R^2=0.04,\ p>0.05$]. The abundance of macroinvertebrates on the Laloi wetland accounted for the significantly high number of waterbirds on the wetland as there was a significant positive relationship between waterbirds and macroinvertebrates.

The lower number of macroinvertebrates generally recorded on the Kpeshie wetland could be attributed to the fact that most of the abundant species on the wetland, the *Nereis spp* and *Glycera spp* were cyclic colonisers whose juveniles' life stages cannot withstand a prolonged reduction in water levels and polluted water quality likewise high turbidity and TDS levels (Ajao & Fagade, 1990). The poor water quality with high turbidity, high TDS, and high levels of nutrients that characterized the Kpeshie wetland contributed to the low abundance of the macroinvertebrates (Mabidi *et al.*, 2017) and in effect low abundance of waterbirds.

The number of waterbirds a wetland can support is determined by its size, food availability, human and other anthropogenic interferences (Piersma & Ntiamoa-Baidu, 1995; Schreiber & Burger, 2002). In terms food (macroinvertebrates) availability for the waterbirds, the Laloi wetland had the highest density of macroinvertebrates thus making it the most suitable for waterbirds. This is also similar to findings by Abdourahamane (2010) who found the Muni wetland to contain high number of waterbirds due to high densities on macroinvertebrates on the wetland and other studies by Lamptey & Ofori-Danson (2014) on the Keta wetland.

In Banc d' Arguin in Mauritania and Guinea-Bissau, Lourenço *et al.*, (2016; 2017) discovered the polychaetes *Nereis spp.* and *Glycera spp.*, as well as the gastropod *Hydrobia spp.*, crustaceans, and isopods, as essential prey for waterbirds especially the sanderlings influencing their abundance on those wetlands. This study is similar to studies by Patra *et al.*, (2010) in Santragachi Jheel, India who also established positive significant correlation between waterbirds and macroinvertebrates abundance as was observed on the Laloi wetland.

5.5 Waterbird distribution and abundance on coastal wetlands

5.5.1 Changes in waterbird populations

Understanding the structure of the waterbird community, the health of wetland habitats, and developing a robust and adequate guide to establish efficient bird conservation necessitates determining the distribution, abundance, and diversity of waterbird species that inhabit the wetlands (Zakaria & Rajpar, 2013). The abundance of waterbirds on any wetland is determined by factors such as the wetland's size, health (excellent water and sediment quality), food availability, human and other anthropogenic interferences such as noise, increase in built-up area and cutting of mangroves (Piersma & Ntiamoa-Baidu, 1995; Schreiber & Burger, 2002).

The present study showed a decline in avian species and abundance on the Sakumo II and Laloi wetlands as compared to counts and species obtained by Ntiamoa-Baidu & Gordon (1991), Gbogbo *et al.,* (2009) and Gbogbo & Attuquayefio (2010) on the Sakumo II and Laloi wetlands. There was, however, an increase in the avifauna species and abundance on the Kpeshie wetland compared to Koney (2010) on the same wetland.

The 50 waterbird species belonging to 13 families recorded on all three wetlands indicated the suitability of the wetland habitat for the wide range of waterbird species. The present study recorded a total waterbird count of 24,247 compared to a total of 20,217 individuals waterbirds (Keta Lagoon = 19,757, Muni Lagoon = 460) reported by Lamptey & Ofori-Danson (2014) on the Keta and Muni lagoons.

The Sakumo II wetland was designated as a Ramsar site on the basis of having significant number of waterbirds. An estimated total population of 32,500 waterbirds was recorded during the count (Ntiamoa-Baidu & Gordon, 1991). Comparing, this count to the present study, showed a major decline of about 69% of waterbird numbers on the Sakumo II wetland. There was also a general decline in the number of the nine waterbird species which occurred in internationally important numbers which were used in designating the Sakumo II wetland in 1992 as a Ramsar site (EPA, 2017). The Avocet (*Recurvirostra avosetta*) which was one of the nine shorebirds used in designating Sakumo II as a Ramsar site was not encountered during the survey on all wetlands as Avocet from previous studies on the same wetland recorded peak counts of 450 and maximum count of 3,750 during the 1991 survey (Ntiamoa-

Baidu & Gordon, 1991) as well as a peak count of 53 in 2015 (EPA, 2017). The spotted redshank which was one of the shorebirds used in the designation which recorded peak counts of 3,280 in 1991 and 560 in 2015 was also not encountered during the entire period on the wetland (EPA, 2017).

The total numbers of waterbirds recorded on the Sakumo II and Laloi wetlands during the current study were much lower compared to waterbird population of 46,290 and 23,208 recorded by Gbogbo *et al*, (2009) on the same wetlands. The decline in species numbers in Sakumo II wetland could be due to the lower density of food and high levels of nutrients like the phosphate, TDS (PC1) and the temperature and water depth (PC5) as these water quality parameters significantly correlated inversely with the abundance of waterbirds during the multiple regression analysis.

The higher number of waterbird on the Laloi wetland could be due to macroinvertebrate abundance as waterbird abundance correlated positively with the abundance of macroinvertebrates on the Laloi wetlands hence can be said the high number of waders recorded during the study (Abdourahmane, 2010, Hassen-Aboushiba, 2017, Mensah *et al.*, 2018).

The low water levels recorded on the Sakumo II and Laloi lagoon could also account for the high number of waterbirds on these two wetlands compared to the Kpeshie wetland as the low water levels could lead to the aggregation of fish for waterbird consumption as lower water depth and large mudflats offered ideal foraging sites for waterbirds that feed on fishes (Piersma & Ntiamoa-Baidu, 1995, Elbin & Tsipoura, 2010).

The declining trend observed in the total waterbird population counted for three wetlands could be the redistribution of waterbirds unto other large number of smaller coastal wetlands in Ghana in search of food. This could be due to unfavorable conditions such as the human activities and disturbances such as the salt mining at Laloi, the increase in construction activities on the Sakumo II and Kpeshie wetlands which generates lots of noise on these wetlands (Gbogbo, 2007; Tay *et al.*, 2010).

Similar research on waterbird abundance by Korschgen & Dahlgren (1992), Horn *et al.*, (2008), Phillips (2008) around the world showed a declining trend in various waterbird populations due to anthropogenic influences.

Almost all of the waterbirds encountered in this study are classified as "least concern" (LC) (IUCN, 2010, Birdlife, 2013: 2016: 2017), with the exception of the Black-tailed Godwit, Bar-tailed Godwit, and Eurasian Curlew, which were classified as "near threatened" (NT) (IUCN, 2010, Birdlife, 2013: 2016: 2017) which means that it is most likely to be threatened in the near future.

These 'near threatened' species were mostly found on the Sakumo II and Laloi wetlands and as such these wetland sites need constant monitoring to prevent its degradation which will further lead to these near threatened species migrating to the wetlaands.

5.5.2 Relationship between LULC variables and waterbirds

Bareland, built-up, vegetation and waterbodies which are variables of the LULC collectively contributed 26.8% of LULC changes to waterbird abundance on the wetlands. Built-up and vegetation respectively had a significantly negative correlation with waterbirds abundance [$\beta=-0.651; p<0.05$] [$\beta=-1.185; p<0.05$] while waterbodies significantly correlated positively with waterbird abundance [$\beta=0.487; p<0.05$].

The considerable beneficial relationship between waterbirds and waterbodies confirms our findings to other studies (Sebastian-Gonzalez *et al.* 2010; Zhang *et al.*, 2019). This implies that an increased surface area of waterbodies will provide more feeding resources for waterbirds while also reducing interference and competition (van Dijk *et al.* 2012).

Results from the study showed built-up areas were adversely linked with waterbird abundance, showing the significant negative impact of human presence on waterbird abundance in wetlands. Some disturbance-intolerant species of waterbirds may be forced to quit otherwise profitable feeding places on wetlands in order to forage in less optimum habitat nearby, lowering their numbers (Chudziska *et al.* 2015, Zhang *et al.*, 2019).

During the present, waterbird species richness increased more rapidly in the Sakumo II wetland than in the unprotected wetlands such as the Kpeshie and Laloi wetlands. Although the Sakumo II was richer in waterbirds, the wetland conservation has been ineffective in halting biodiversity losses and hence a decreasing population trend of many waterbird species over the years (Jia *et al.*, 2018). The species richness found in this study is similar to that found in other studies in Ghana and Africa by Gbogbo (2007), Gbogbo &Attuquayefio (2010), Ntiamoah-Baidu (2014), and Kleijn *et al.* (2014) in Morocco.

5.6 Growth parameter of *S. melanotheron*

5.6.1 Length-weight relationship (LWR)

The correlation coefficients (r) for LWR were very high (> 90) for *S. melanotheron* which indicate a strong correlation between the length and weight. This correlation coefficient recorded agreed with other studies involving fishes from different aquatic ecosystems (Entsua-Mensah, 1998, Laléyé, 2006). The mean 'b' values recorded for *S. melanotheron* from all three wetlands were within the expected range of 2.5-3.5 for tropical fish stocks (Froese, 2006). Fishes from both the Laloi and Kpeshie lagoons had poor length and weight growth, becoming thinner as their length increased (Tesch, 1971; King, 1996, Wootton, 1998).

However, the growth parameter estimated for black chin tilapia in the Laloi and Kpeshie lagoons indicated negative allometric growth which basically means as the length of the fishes increased, it became lighter, thinner or less plumpy.

When an organism's weight increases more than its length (b>3), it is said to be positive allometric, and when length increases more than weight (b<3), it is said to be negative allometric (Wootton, 1998). The negative allometric growth pattern recorded for blackchin tilapia from the Laloi and Kpeshie lagoons could be attributed to low food items for *S. melanotheron* species in the ecosystem, reduction of their body size to escape predation, high fishing mortality or intensity, malnourishment through competition for available food items, age, the abundance of predators and environmental degradation from human activities and adverse effects of pollution on their growth (Chilaka *et al.*, 2014, Ogunola *et al.*, 2018).

The range of the growth parameter 'b' which is 2.80 -2.95 obtained for this current study is similar to other growth parameters values 2.63 and 2.61 obtained by Koranteng (1995) for the length-weight relationships of *S. melanotheron* in the Sakumo II lagoon and Densu Delta respectively. It was also similar to 2.61 - 3.25 recorded by Agboola & Anetekhai (2008) who studied the length-weight relationships of 35 fish species from the Badagry Creek, Lagos. This growth parameter 'b' value agrees with similar findings reported by Tah *et al.*, (2012) and Konan *et al.*, (2007) in small coastal rivers in Southeastern Ivory Coast.

In terms of the standard length (SL), the current study was comparable to other studies by (Mireku et al., 2016) who recorded SL between 7.5cm -17.6cm, for blackchin tilapia (*Sarotherodon melanotheron*, Cichlidae) from Brimsu reservoir, and 6.5cm –14.5cm by Pauly, (1976), likewise, 2.8cm -12.1cm by Ntiamoah-Baidu (1991) and 2.63cm - 12.86cm by Sawyer et al., (2015). The relatively small size of the fish measured in the current study and decline in fishery in the lagoons may be attributed to overexploitation and pollution due to increased levels of domestic and industrial effluents into the lagoon (Ntiamoah-Baidu, 1991; Koranteng *et al.*, 2000). Several other factors, including the season, the sampling size, habitat, gonad development, sex, diet and stomach fullness, trophic level, and seasonal growth rates, can all influence the length-weight relationship's growth characteristics (Bagenal & Tesch, 1978).

5.6.2 Condition factor of *Sarotherodon melanotheron*

The condition factor is used in fisheries science to compare the "condition," "fatness," or "wellness" of fish. It's based on the idea that heavier fish of a certain length are in better physiological shape (Bagenal, 1978).

The condition factor can also be used to monitor the fish feeding intensity, age, and growth rates (Ndimele *et al.*, 2010). The condition factor is based on the assumption that fish of a particular length are heavier and are in better condition. This condition factor is also employed as a growth and feeding intensity indicator (Seher & Suleyman, 2012).

Both biotic and abiotic environmental variables have a considerable influence on the condition factor, which can be used as an index to measure the state of the aquatic ecosystem in which fish dwell (Anene, 2005). A condition factor of less than one (1) indicates that the fish is elongated, famished, and not in excellent condition, whereas a condition factor of one (1) indicates that the fish is well fed and in favorable environmental conditions (Ujjania *et al.*, 2012).

The mean condition factors 2.97, 3.16 and 3.73 obtained for the Kpeshie, Laloi and Sakumo II wetlands were within the ranges of 2.9 - 4.8 recommended as suitable for matured freshwater fishes (Bagenal & Tesch, 1978).The mean condition factor for the current study was similar to K values obtained by Alhassan *et al.*, (2014) in the Botanga Reservoir in the Northern Region of Ghana and Mireku *et al.*, (2016) from the Brimsu Reservoir in Cape coast.

The mean condition factor values recorded for this study were also lower compared to what was recorded by Koranteng (1995) and Entsua-Mensah (1998) in the Abrubi lagoon and Densu lagoon respectively. A similar pattern of $K>1$ was obtained for blackchin tilapia species in Lake Eleiyele, Ibadan, and Lake Nokoué and Lake Ahémé (Ayoade & Ikulala, 2007; Niyonkuru &Laléyé, 2012).

The findings of this research also agree with Soyinka & Ayo-Olalusi (2009) and Atama *et al.*, (2013) who reported K values greater than one (1) for tilapia (*Tilapia mariae*, a related species) in Ologe Lagoon and Anambra River respectively.

5.6.2.1 Relationship between water quality, fish condition and waterbirds

A variety of good and negative factors influence the growth of fish. Temperature, dissolved oxygen (DO), transparency, turbidity, pH, alkalinity, hardness, ammonia, nitrite, nitrate, and biological oxygen demand requirement are examples of abiotic variables while biotic factors like phytoplankton population, among others, have been shown to affect the growth and condition of fishes on wetlands (Bhatnagar & Devi, 2013).

Water quality parameters in PC1, PC2, PC3, PC4, PC5, and PC6 jointly contributed 16%, 88% and 58% respectively to fish wellbeing in the Sakumo II, Laloi and Kpeshie sites [$R^2=0.16$, $p>0.05$; $R^2=0.88$ $p<0.05$; $R^2=0.58$, $p<0.05$ *respectively*]. At the Sakumo II sites, the significant predictor of fish condition was PC1 (TDS Alkanility, Cl-, PO_4^{3-}-P, Mn) which indicated a negative relationship between water quality and fish condition factor. The PC2 (temperature, DO, salinity, Fe), PC4 (pH and Co) and PC6 (Turbidity) [$\beta=-0.42$; $p<0.05$] also had an inverse relationship with the fish condition in the Laloi wetland. This suggests that the fish species were affected negatively by high level of these water quality parameters like salinity, turbidity which could be a factor responsible for low values of the condition factor recorded monthly on the Laloi wetland. High concentration of DO in lagoons are probably due to high concentration of green algae and according to Riche & Garling (2003), the preferred DO for optimum growth of tilapia is above 5 mg/l. which was observed for both the Sakumo and Laloi lagoons (Nehemia *et al.*, 2012).

At Kpeshie wetland, the significant predictors of fish condition are PC2 (TDS, turbidity, NO_2-N, PO_4-P, Mn) which had a direct relationship with the condition factor of the fish and an inverse relation with PC4 (salinity, alkalinity), PC5 (Cd) and PC6 (pH) an indication that as these water quality variable decrease the health and condition of the fish species in the lagoon improves.

The ideal temperature for tilapia reproduction varies from 25 to 30°C, and temperature has been established as a factor impacting sexual development and spawning in tilapias (Eyeson, 1983; Popma & Lovshin, 1996). The temperature range obtained in this study is within the ideal range for these species' reproduction, as a rise in water temperature, combined with a drop in water pH, has been found as a cause for fish growth and well-being in most wetlands (El Naggar *et al.*, 2000, Mireku *et al.*, 2016). Therefore, the higher temperatures recorded on the Laloi wetland will be most likely a detriment to the fishes in the water as temperature correlated negatively with fish condition on the wetland.

The most preferred temperature range for optimal growth of tilapia is 25 to 30 °C, while the ideal pH ranges between 6 and 9 (Haas *et al.*, 2007) and this was consistent with the current study on the Sakumo II and Kpeshie wetlands as the temperature and pH recorded were between these optimal and ideal values. During the night, carbon dioxide builds up in the water, lowering the pH and as such the low pH levels recorded in Sakumo II compared to the other sites could be due to carbon dioxide build up in the night.

Crane (2006) found that highly acidic water with a pH less than 5.5 inhibited fish growth and reproduction, adding that the best pH range for fish survival and reproduction is between 6.5

and 7.0, however a pH range of 6.1 to 8.0 is also acceptable. Most fishes would thrive better in waters with a pH near 7.0, according to Bryan et al. (2011), whereas waters with a pH less than 6.0 may result in stunting or reduced fish output (Haas *et al.*, 2007, Makori *et al.*, 2017).

Fish condition factor (wellbeing) significantly contributed 25%, 34% and 35% to waterbirds abundance at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.25$ $p<0.05$; $R^2=0.34$, $p<0.05$; $R^2=0.39$, $p<0.05$]. The abundance of waterbirds on the Sakumo II and Laloi wetlands which recorded higher of ducks and cormorants would undoubtedly benefit from such fish aggregations since fish is a major component of their diet and they fishes thrive very well in waterbodies with excellent conditions (Piersma & Ntiamoa-Baidu, 1995). Several other studies have found that waterbirds congregate in response to a rise in fish abundance in a healthy and quality waterbody (De Nie 1995; Battley et al. 2003) as rising fish abundance causes a dramatic rise in the abundance of many waterbird species especially the cormorants dramatically (De Nie 1995; Warke and Day 1995).

Fleury & Sherry (1995) also found out in a similar study that, fishes in a healthy ecosystem leads to their abundance and as such waterbirds like the egrets and herons that eat fishes as a substantial part of their diet also increases on those wetlands.

The Laloi wetland accounted for high number of waterbirds especially the cormorants, egrets and herons partly due to the healthy environment for fishes to grow from the condition factor estimated which will eventually lead to increase in fishes which inhabit the waters.

5.7 Human interactions with the coastal wetlands

A wide range of human activities are carried out in the coastal wetlands by the local communities. The dominant activities are fishing, farming, and salt winning. Farmers interviewd during the study said most of them used various techniques including burning for land preparation and the use of pesticides in their farming activities. Most of these farmers are located on the northern part of the Sakumo II wetland and the Laloi wetland with evidence of pesticide usage which contains chemicals like NPK; sunphosates etc. as this could be deleterious to the environment. The effect of pesticide use on the environment has been extensively discussed in previous studies on wetlands by (Sackey, 2014; Mattah *et al.*, 2015; Ngolo *et al.*, 2018). The negative impacts of pesticide use on the environment include the pollution of coastal waters through eutrophication thereby compromising its usage by macroinvertebrates and waterbirds as high levels of turbidity, salinity etc. are detrimental to biodiversity. Bioaccumulation and concentration of heavy metals in organisms that use wetlands for foraging and as nursery are also affected (Mahmood *et al.*, 2015).

The survey in the wetlands indicated that population pressure had a great impact on the changes in the wetlands and the main driver of these changes. Previous studies in the country and other parts of Africa also reported population pressure as a major driver of LULC changes (Atampugre, 2010; Kindane *et al.*, 2012, Solomon *et al.*, 2018; Ekumah *et al.*, 2020)

About 83% percent of respondents admitted most users and inhabitants dump most of their solid and liquid waste onto the wetlands which eventually find its way into the lagoons through run off when it rains as most the respondents indicated the unavailability of toilets and other sanitary incinerators in and around the wetlands. Open defaecation was pronounced on the Laloi wetland as most residents in the Kpoite and Vakpo communities complained of no toilet facility in the catchment so had no other option than resort to open defaecation. The defaecation along the coast and in the wetlands pollutes the shallow water resource (Finlayson *et al.*, 2000).

5.7.1 Perception of respondent towards changes in the wetlands

Most of the respondents believed there have been major changes in the coastal wetlands and these changes may come from anthropogenic influences. Significant differences were found in perceptions among respondents regarding changes in the wetlands. For instance, almost 71% of respondents perceived that the wetland has seen an upsurge in agricultural activities on the wetland ($x^2=19.44$, $p<0.05$), about 80% of respondents perceived a reduction in the number of migratory birds that visit the wetlands ($x^2=15.46$, $p<0.05$), and about 44% also perceived that there has been increase in the aquatic weeds on the surface of the lagoon inhibiting waterbirds from frequenting the wetlands compared to the early 1980's ($x^2=24.74$, $p<0.05$).

Most respondents indicated agricultural farms located on the wetlands and within the catchments are on the increase as most inhabitants use farming as an alternative livelihood activity in addition to fishing or working in the salt industry. This was evident on the Laloi and Sakumo II wetlands. Reduction of the number of migratory birds who visit the wetlands has also seen decrease due to the human activities on the wetlands as those activities normally generate noise which scares and deters waterbirds most often on the wetlands.

5.7.2 Management strategies to conserve coastal wetlands

Findings from this study indicated that most of the respondents were undecided on which strategy was best to manage and protect the coastal wetlands. This could be attributed to the fact that most of the respondents were not so much aware of the importance of the coastal wetlands. There were significant relationships between importance of wetlands and enforcing cultural values and enforcing its strict adherence, importance of the wetlands and district assembly responsibility of dredging coastal wetlands, importance of wetland and building sanitary facilities along the wetlands and its catchment.

Pettus (1976) and Ntiamoa-Baidu (2001) argued that cultural beliefs and background dictate people's actions and as such enforcing cultural values and the adherence of same will help conserve and protect the wetlands as respondents believed in the traditional conservation strategies such as the ban on fishing and the taboos of not using the wetlands on particular days of the week such as Tuesdays and Fridays on the Laloi and Kpeshie wetlands.

If these conservation management strategies are well executed, it will lead to the quality of the wetlands which will in turn lead to more migratory and resident waterbirds visiting the wetlands. Also the urge to hunt waterbirds especially the waterfowls by residents in the catchment will be controlled.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The main aim of the study was to determine the changes in the ecological character of the Sakumo II, Laloi and Kpeshie wetlands and how variables like the land use/land cover changes, the quality of the water and sediment, the abundance of macroinvertebrates and the growth and condition factor of the black chin tilapia as bioindicators impacted on the distribution of waterbirds on the wetlands.

Changes in the land use land cover over the years showed a sharp decrease in the vegetative cover on all there wetlands by 57.3%, 58.3% and 33.7% respectively. The waterbodies on the wetlands also showed a decrease in size by 0.6% on the Sakumo II, 6.6% on the Laloi and 15.2% on the Kpeshie wetlands respectively. However, there was an increase in the built-up areas by 54.4% on the Sakumo II wetland, 53% on the Laloi wetland and 50.8% on the Kpeshie wetland.

The overall accuracy assessment for the LULC maps downloaded for the Sakumo II wetland ranged between 0.79 - 0.85, 0.84 - 0.86 for the Sakumo II and Laloi and 0.80 - 0.84 for the Kpeshie wetlands. The kappa statistic obtained was between 0.72 - 0.79, 0.78 - 0.82, and 0.73-0.79 for the Sakumo II, Laloi and Kpeshie wetlands respectively for images classified between 1986 -2017. The overall and kappa statistics showed a strong agreement for all the classified images and was within the acceptable range for LULC change analysis.

In terms of the relationship between the LULC changes and water quality, there was a significant positive correlation between water quality parameters like the pH, conductivity, nitrites ($r = 0.945$, $r = 0.698$, $r = 0.655$; $p < 0.05$ respectively) and the LULC unit built-up, whereas water depth, nitrates, phosphates ($r = -0.998$, $r = -0.981$, $r = 0.920$ $p < 0.01$ respectively) also was significantly inversely correlated to the LULC unit waterbodies on the Sakumo II wetland. An inverse relationship indicates that as the levels of these water quality parameters like nutrient increases, the quality of the water decreases, as there is the likelihood of eutrophication which will likely affect the abundance of waterbirds on the Sakumo II wetland. Similar correlation results of water quality and LULC changes were obtained for the Laloi and Kpeshie wetlands. Built-up and vegetation cover respectively had a significantly negative relationship with waterbirds abundance [$\beta=-0.651; p<0.05$] [$\beta=-1.185; p<0.05$] while waterbodies significantly correlated positively with waterbird abundance [$\beta=0.487; p<0.05$].

In terms of the quality of water, the pH and temperature recorded all on three wetlands were typical of coastal waters in Ghana and conducive for fish and aquatic organisms. There were significant increases in the turbidity levels (20.24±7.60, 28.60±16.26 and 190.92±127.44) NTU, conductivity levels (30.32±20.12, 50.80±14.01, 58.68±2.14) mS/cm respectively on the Sakumo II, Laloi and Kpeshie wetlands. These levels were above the WHO permissible levels and higher compare to other baseline results and previous studies on the same wetlands. The DO (3.28±1.37) and BOD (24.64±10.43) levels recorded for the Kpeshie wetland indicated a less oxygenated water body stressful for aquatic organism with high organic load in the lagoon water. In terms of the nutrients loads, nitrate levels recorded on the Kpeshie wetland (10.28±2.44) and phosphate levels on the Sakumo II and Kpeshie (1.72±1.09 and 2.08±0.89 respectively) wetlands were also above the WHO permissible levels. The higher levels are an indication of organic loadings in the waters due to anthropogenic activities like the intensive agricultural farming, waste discharged from the industries and dumping of sewage into lagoons from inhabitants in the catchments. Heavy metals such as Fe, Mn, and Cd concentration in the water samples collected on all three sites were above the WHO permissible limits.

The multiple linear regressions between water quality parameter and macroinvertebrates abundance indicated the water quality parameters analysed contributed 81%, 88% and 60%

respectively to the abundance of macroinvertebrates at the Sakumo II, Laloi and Kpeshie wetlands.

Water quality parameters in PC2, PC4, PC5 (pH, temperature, water depth, conductivity, Ni, Cr, Fe, Co, Cr) had an inverse relationship with macroinvertebrate abundance on the Sakumo II wetland [$\beta=-0.33; p<0.05$], [$\beta=-0.66; p<0.05$], [$\beta=-0.48; p<0.05$] respectively.

Similarly, PC1, PC3 and PC4 which contains water quality parameters like conductivity, turbidity, alkalinity, Cl^-, Mg^{2+}, PO_4-P, Mn, Cu, Ni, TDS, water depth, Ca^{2+}, Zn, pH and Co also had a negative relation with abundance of macroinvertebrates on the Laloi wetland [$\beta=-0.49, p<0.05$] [$\beta=-0.78; p<0.05$] [$\beta=-0.28; p<0.05$] respectively. However, PC2 and PC4 (TDS, turbidity, NO_3-N, PO_4-P, Mn, salinity and alkalinity had a positive relationship with macroinvertebrates on the Kpeshie wetlands [$\beta=0.59; p<0.05$] [$\beta=0.43; p<0.05$].

The mean levels of Fe and Mn analyzed in bottom sediment collected from the Sakumo II and Laloi wetlands were above the US EPA (1999) sediment quality guidelines, likewise, the mean levels of Cr, Cu, Fe, Mn and Ni were also above the WHO (2004) and USEPA (1999) sediment quality guidelines. In terms of the pollution indices estimated for the bottom sediments, the enrichment factor (EF) calculated showed an extremely severe enrichment of Cd, Co, Mn, Cr, and Cu for the Sakumo II wetland, an extremely severe enrichment for Cd in the Laloi lagoon and an extremely severe enrichment of Cd, Cr, Cu and Ni in the bottom sediment of the Kpeshie lagoon. These enrichments are an indication of the influence of human activities impacting on the bottom sediments on the wetlands. From the contamination factor (CF) estimated, cadmium (Cd) is responsible for very high contamination in the sediment of Sakumo II and Kpeshie lagoons. The geoaccumulation index (Igeo) values estimated were within the classification of non-contaminated to severely contaminated sediments. The Sakumo II lagoon showed moderate contamination of Cd while the Kpeshie lagoon showed moderate to severe contamination of Cd. In general, Igeo (total) indices for all heavy metals analysed were negative; which implies that the mean concentration of these heavy metals in the Sakumo II, Laloi and Kpeshie sediments were lower than the world surface rock averages. The pollution load index (PLI) calculated indicated a perfect or no overall pollution of the sediment quality on the wetlands.

In relating sediment quality to abundance of macroinvertebrates, heavy metals in PC1, PC2 and PC3 jointly and significantly contributed 25%, 57% and 30% respectively to macroinvertebrates abundance at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.25$ $p<0.05$; $R^2=0.57$, $p<0.05$; $R^2=0.30$, $p<0.05$]. Heavy metals like Co, Cr, Mn and Zn had an inverse relationship with macroinvertebrate abundance on the Sakumo II wetland, likewise Cd, Fe, Cr and Mn on the Laloi wetland. However, Cr, Fe, Ni, Cu had a positive significant relationship with macroinvertebrates abundance on the Kpeshie wetland.

A total of ten (10) macroinvertebrate species were identified during the study. The *Cerithidea spp, Nereis spp and Hydrobia accrensis* were the three most dominant macroinvertebrate species in the benthic samples accounting for 21.14%, 19.22% and 17.55% on all wetlands. The *Cerithidea spp* was the most dominant on the Laloi wetland, while the *Nereis spp* and *Hydrobia accrensis* were the most dominant species on the Kpeshie and the Sakumo II wetland. In terms of macroinvertebrates abundance the Laloi wetland recorded the highest (1833 ind/m^2) compared to the other sites. Multiple linear regression between macroinvertebrate abundance and waterbird distribution showed that macroinvertebrates abundance contributed 12%, 22% and 4% to waterbirds abundance at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.12$, $p>0.05$; $R^2=0.22$, $p<0.05$; $R^2=0.04$, $p>0.05$]. There was a significant positive correlation between abundance of waterbird and macroinvertebrates on the Laloi wetland [$\beta=0.46$, $p<0.05$] as compared to the Sakumo II and Kpeshie wetlands respectively [$\beta=-0.12$, $p=0.96$, $p>0.05$] and [$\beta=-0.07$, $p=0.84$, $p>0.05$].

A total of 50 species of waterbirds belonging to 13 families were recorded during the study.

The protected Sakumo II wetland recorded 44 waterbird species while the Laloi and Kpeshie wetlands recorded 45 and 27 waterbird species respectively. Species belonging to the family Scolopacidae (88.71%) which were mostly the waders were the most abundant, followed by the family Charadriidae (77.81%) mostly dominated by the plovers while the least number of waterbirds counted belonged to the family Threskionithidae, which was the Glossy Ibis sighted only once on the Sakumo II wetland. In terms of the abundance of waterbirds on the wetlands, the Laloi wetland recorded 50.1%, Sakumo II recorded 41.7% while the Kpeshie wetland recording 8.2% during the survey.

The most dominant waterbird species were the Collared Prantincole (*Glareola pratincola*) on the Sakumo II wetland, the Common Ring Plover (*Charidrius hiaticula*) on the Laloi and the Common Sandpiper (*Actitis hypoleucos*) on the Kpeshie wetland. In terms of the conservation status of the waterbird species, all the waterbirds counted belonged to the least concerned (LC) category of the International Union for the Conservation of Nature (IUCN Redlist) with the exception of the Bar-tailed Godwit, Black-tailed Godwit and Eurasian Curlew sandpiper which were in the Near Threatened (NT) category. The Sakumo II wetland was the most diverse and rich site [H^{l}=2.870 and D^{I} = 4.554] compared to the other sites. From the Bray-Curtis analysis, waterbird numbers within the Sakumo II and Laloi wetlands were similar at 40.6% while the Sakumo II and Laloi wetland put together was similar at 27.3% to waterbirds on the Kpeshie wetland.

The blackchin tilapia which is the predominant species in lagoon was used to estimate the condition factor as a bioindicator of the quality of water on the wetlands. The standard length (SL) and body weights recorded for *Sarotherodon melanotheron* fishes collected ranged from 0.6 -16.0 cm and 0.04 - 68.46 g for the Sakumo II, 1.4 -16.1cm and 0.02 - 74.14g for the Laloi and 0.4 -14.8cm and 0.05 - 46.57g for the Kpeshie wetlands respectively. The correlation coefficient (r) recorded for *S. melanotheron* collected from each site were r= 0.98

for the Sakumo II lagoon, r=0.99 for the Laloi lagoon and r= 0.96 for the Kpeshie lagoon indicating a strong correlation between the length and weight of fishes selected during the study. The growth parameter 'b' for Sakumo II lagoon indicated that *Sarotherodon melanotheron* fishes in the lagoon exhibited an isometric growth ('b' is nearer to 3) whilst *Sarotherodon melanotheron* fishes in the Laloi and Kpeshie lagoons exhibited negative allometric growth. The mean condition factors 3.73, 2.97and 3.16 estimated for *Sarotherodon melanotheron* fishes in the Sakumo II, Laloi and Kpeshie lagoons indicated a good condition in the lagoons waters for fish survival.

The water quality parameter PC1, PC2, PC3, PC4, PC5, and PC6 jointly contributed 16%, 88% and 58% respectively to the condition factor of fish in the Sakumo II, Laloi and Kpeshie sites [$R^2=0.16$, $p>0.05$; $R^2=0.88$ $p<0.05$; $R^2=0.58$, $p<0.05$ *respectively]*. At the Sakumo II sites, the significant predictor of fish condition factor is PC1 (TDS, Alkanility, Cl-, PO_4^{3-}-P, Mn) [$\beta=-0.22$; $p<0.05$] which had a negative relationship between PC1 and fish condition factor. The fish condition factors on the wetlands contributed 25%, 34% and 35% to waterbirds abundance at Sakumo II, Laloi and Kpeshie wetlands respectively [$R^2=0.25$ $p<0.05$; $R^2=0.34$, $p<0.05$; $R^2=0.39$, $p<0.05$]. The findings suggest that fish condition factors across the three sites significantly contributed to waterbird abundance on the wetlands.

Human related activities such as salt mining, agricultural farming, mangrove cutting for firewood, construction and expansion of settlement in the catchment, were the most frequently observed activity on all three wetlands. The associated human activities that drove these changes on the wetlands according to questionnaires administered to respondents were settlement expansion (54%), expansion of agriculture farms (23%), mangrove extraction for firewood and charcoal-making for domestic use (11%), salt mining for both commercial and domestic use (5.8%), livestock grazing (4.3%) and fishing activities (2.0%).

From the opinion of respondents, the most appropriate top two methods to manage and protect the wetlands was the enforcement of the cultural values and taboos existing on the wetlands [$x^2=45.35$, $p<0.01$], as well as the need to build sanitary facilities on the wetlands to avoid dumping of both solid and liquid waste into the lagoon [$x^2=29.85$, $p<0.05$].

In summary, there have been major changes in the water and sediment quality on the wetlands basically through human interference, there has also been changes in the LULC variables like the vegetation, barelands, waterbodies and built-up areas between 1986 and 2017 which directly and significantly affected the distribution and abundance of waterbirds and macroinvertebrates during the study. The unprotected Laloi wetland supported the most number of waterbirds counted compared to the protected Sakumo II wetland during the study.

6.2 RECOMMENDATIONS

The outcomes of this study have contributed to a better understanding of the ecological character of three important coastal urban wetlands, the Sakumo II, Laloi and Kpeshie in Ghana and how the selected ecological variables impacted directly or indirectly on the distribution and abundance of waterbirds.

The findings of the study provide further information that describes the quality of the Sakumo II, Laloi and Kpeshie wetlands as habitats for migratory waterbirds. However, in order for humans and these waterbirds to coexist on these wetlands harmoniously, sustainable management practices and laws need to be put in place to ensure the right balance.

The Environmental Protection Agency and the district assemblies should enforce all existing laws that help protect and conserve these wetlands especially the Sakumo II wetland and all coastal wetlands to prevent further pollution and degradation of the wetland and its resources.

The Laloi wetland which proved to accommodate significant number of waterbirds during the study than even the protected Sakumo II wetland should be considered to be designated as a Ramsar site (i.e. wetland of international importance) and protected, so the site will continue to provide vital ecological support for migratory birds. The protection of the Laloi wetland in particular will allow managers and stakeholders of the site to help conserve this wetland and ensure the sustainable utilization of its resources by communities within the catchment.

The Ghana Wildlife Society and other institutions like the Centre for African Wetlands should also consider waterbird monitoring on the Kpeshie wetlands as it also host a significant number of waterbird species.

An increase in human population in and around the urban wetlands means an increase in the generation of liquid and solid waste, therefore it is recommended that basic and essential sanitation infrastructures such as toilet facilities, refuse dump and sewage systems should be constructed by the various Metropolitan Municipal District Assemblies on these wetlands especially the Kpeshie and Laloi wetlands to prevent liquid and solid waste finding its way onto the wetlands which will eventually pollute the wetlands directly or indirectly negative affecting biodiversity.

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APPENDICES

Appendix I-1: Total individual waterbird count on the Sakumo, Laloi and Kpeshie wetlands

Name of waterbird (Common Name)	Family	Scientific name	Sakumo II	Laloi	Kpeshie	Total	Relative Abundance (%)	Conservation status
Common sand piper	Scolopacidae	*Actitis hypoleucos*	98	67	581	746	3.08	LC
Wood Sand piper	Scolopacidae	*Tringa glareola*	691	17	140	848	3.50	LC
Green Shank	Scolopacidae	*Tringa nebularia**	192	700	81	973	4.01	LC
Whimbrel	Scolopacidae	*Numenius phaeopus**	20	49	50	119	0.49	LC
Ruddy Turnstone	Scolopacidae	*Arenaria interpres**	11	24	3	38	0.16	LC
Marsh sandpiper	Scolopacidae	*Tringa stagnatilis**	11	60		71	0.29	LC
Ruff	Scolopacidae	*Philomachus pugnax*	91	2		93	0.38	LC
Bar tailed Godwit	Scolopacidae	*Limosa lapponica*	8	20		28	0.12	NT
Black tailed Godwit	Scolopacidae	*Limosa limosa*	132	11		143	0.59	NT
Curlew Sandpiper	Scolopacidae	*Calidris ferruginea*	748	548		1296	5.34	NT
Little Stint	Scolopacidae	*Calidris minuta*	218	667		885	3.65	LC
Sanderling	Scolopacidae	*Calidris alba*	21	437	19	477	1.97	LC
Common Redshank	Scolopacidae	*Tringa totanus*	13	41	3	57	0.24	LC
Eurasian Curlew	Scolopacidae	*Numenius arquata*		13		13	0.05	NT
Spotted RedShank	Scolopacidae	*Tringa erythropus*		53		53	0.22	LC
Spur Winged Plover	Charadriidae	*Vanellus spinosus*	994	193	107	1294	5.34	LC
Common Ringed Plover	Charadriidae	*Charidrius hiaticula*	764	3749	36	4549	18.76	LC

Grey Plover	Charadriidae	_Pluvialis squatarola_*	58	83	5	146	0.60	LC
Senegal wattled plover(African wattle Lapwing)	Charadriidae	_Vanellus senegalensis_*	242	22	294	558	2.30	LC
Kittlitz Sand plover	Charadriidae	_Charadrius pecuarius_	61	109		170	0.70	LC
White-fronted sandplover	Charadriidae	_Charadrius marginatus_*		49		49	0.20	LC
Little Tern	Laridae	_Sternula albifrons_*	79	325	2	406	1.67	LC
Black Tern	Laridae	_Chlidonias niger_**	212	6	6	224	0.92	LC
Common tern	Laridae	_Sterna hirundo_**	283	207		490	2.02	LC
Sandwich tern	Laridae	_Thalasseus sandvicensis_**	43	292		335	1.38	LC
Caspian tern	Laridae	_Hydroprogne caspia_		23		23	0.09	LC
Royal tern	Laridae	_Thalasseus maximus_**	32	281	2	315	1.30	LC
Lesser Black-backed Gull	Laridae	_Larus fuscus_		4		4	0.02	LC
Blacked Winged stilt	Recurvirostridae	_Himantopus himantopus_	786	708	94	1588	6.55	LC
African Jacana	Jacanidae	_Actophilornis africana_	496		5	501	2.07	LC
Senegal Thick-knee	Burhinidae	_Burhinus senegalensis_	65	66	302	433	1.79	LC
Greater Painted-snipe	Rostratulidae	_Rostratulla benghalensis_	3	49		52	0.21	LC
Collared Prantincole	Glareolidae	_Glareola pratincola_	2082	77		2159	8.90	LC
Green-backed Heron	Ardeidae	_Butorides striata_	9	9	33	51	0.21	LC
Black-crowned night-heron	Ardeidae	_Nycticorax nycticorax_		5	4	9	0.04	LC
Purple Heron	Ardeidae	_Ardea purpurea_	11	1		12	0.05	LC

Little Egret	Ardeidae	*Egretta garzetta*	133	538	14	685	2.83	LC
Yellow-billed Egret (Intermediate Egret)	Ardeidae	*Ardea brachyrhncha*	86	6		92	0.38	LC
Great white Egret	Ardeidae	*Ardea alba*	112	124	1	237	0.98	LC
Common Little Bittern	Ardeidae	*Ixobrychus minutus*	2			2	0.01	LC
Glossy ibis	Threskiornithidae	*Plegadis falcinellus*	11			11	0.05	LC
Grey Heron	Ardeidae	*Ardea cinerea*	56	194	6	256	1.06	LC
Western Reef Heron	Ardeidae	*Egretta garzetta gularis*	51	346	74	471	1.94	LC
Squacco Heron	Ardeidae	*Ardeola ralloides*	170	9	12	191	0.79	LC
Black Heron	Ardeidae	*Egretta ardesiaca**	81	27	17	125	0.52	LC
Fulvous Whistling-duck	Anatidae	*Dendrocygna bicolor*	17	17		34	0.14	LC
Garganey	Anatidae	Anas querquedula	1			1	0.00	LC
White-faced Whistling tree duck	Anatidae	*Dendrocygna viduata*	795	531		1326	5.47	LC
Long-tailed Cormorant	Phalacrocoracidae	*Phalacrocorax africanus*	121	1384	80	1585	6.54	LC
Little grebe	Podicipedidae	*Tachybaptus ruficollis*	6		17	23	0.09	LC
TOTAL			10116	12143	1988	24247	100.00	

Appendix I-2: Total individual monthly count of waterbirds on the Sakumo II wetland

Name of waterbird	**Scientific name**	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MARCH	APRIL	MAY	JUNE	JULY	TOAL	Abundance %
Waders (Common Name)															
Blacked Winged stilt	*Himantopus himantopus*	132	148	68	250	30	13	18	17	9	9	0	92	786	7.77
Spur Winged Plover	*Vanellus spinosus*	105	82	30	32	16	88	124	233	129	81	12	62	994	9.83
Common sand piper	*Actitis hypoleucos*	12	19	15	14	8	10	5	3	12	0	0	0	98	0.97
Wood Sand piper	*Tringa glareola*	103	215	74	59	34	93	47	19	40	6	0	1	691	6.83
Green Shank	*Tringa nebularia**	4	8	28	46	6	29	19	37	7	3	0	5	192	1.90
Collard Prantincole	*Glareola pratincola*	333	481	193	189	28	216	123	250	123	68	0	78	2082	20.58
Whimbrel	*Numenius phaeopus*	3	3	0	2	4	0	0	4	1	0	0	3	20	0.20
Turnstone	*Arenaria interpres*	8	3	0	0	0	0	0	0	0	0	0	0	11	0.11
Ringed Plover	*Charidrius hiaticula*	78	10	77	202	0	112	38	144	103	0	0	0	764	7.55
Grey Plover	*Pluvialis squatarola*	12	2	1	14	0	2	9	9	6	0	0	3	58	0.57
Senegal wattled plover	*Vanellus senegalensis*	24	43	20	11	14	1	57	9	26	19	2	16	242	2.39
African Jacana	*Actophilornis africana*	61	67	27	46	41	56	45	49	26	29	14	35	496	4.90
Marsh sandpiper	*Tringa stagnatilis**	1	0	7	0	0	1	0	2	0	0	0	0	11	0.11
Ruff	*Philomachus pugnax*	14	20	9	16	0	7	13	12	0	0	0	0	91	0.90
Black tailed Godwit	*Limosa limosa*	18	49	1	32	0	0	14	7	0	0	0	19	140	1.38
Curlew Sandpiper	*Calidris ferruginea*	0	42	96	553	0	40	17		0	0	0	0	748	7.39
Little Stint	*Calidris minuta*	0	38	60	68	0	0	9	28	15	0	0	0	218	2.16
Sanderling	*Calidris alba*	0	7	0	14	0	0	0	0	0	0	0	0	21	0.21
Redshank	*Tringa totanus*	1	6	0	0	3	0	0	3	0	0	0	0	13	0.13
Senegal thicknee	*Burhinus senegalensis*	4	3	2	7	0	2	5	6	4	15	6	11	65	0.64
kittlitz Sand plover	*Charadrius pecuarius*	**0**	26	0	14	0	6	0	15	0	0	0	0	61	0.60
Little grebe	Tachybaptus ruficollis	0	6	0	0	0	0	0	0	0	0	0	0	6	0.06
Garganey	Anas querquedula	0	0	0	0	0	1	0	0	0	0	0	0	1	0.01

Glossy ibis	*Plegadis falcinellus*	0	9	0	0	2	0	0	0	0	0	0	0	11	0.11
Painted Snipe	*Rostratulla benghalensis*	0	3	0	0	0	0	0	0	0	0	0	0	3	0.03
Heron and Egret and others															
Grey Heron	*Ardea cinerea*	5	8	0	3	11	3	7	3	7	0	0	9	56	0.55
Reef Heron	*Egretta garzetta gularis*	9	20	2	11	0	2	2	3	0	2	0		51	0.50
Little Egret	*Egretta garzetta garzetta*	25	14	26	17	0	10	10	9	6	10	3	3	133	1.31
Long tailed Cormorant	*Phalacrocorax africanus*	10	7	14	21	15	7	5	7	4	5	6	20	121	1.20
Black Heron	*Egretta ardesiaca*	8	16	6	0	0	0	0	12	19	0	0	20	81	0.80
Squacco Heron	*Ardeola ralloides*	23	11	15	19	18	12	14	18	24	7	2	7	170	1.68
Yellow billed Egret	*Egretta intermedia*	10	7	4	7	23	4	7	3	5	7	8	1	86	0.85
Great white Egret	*Egretta alba*	8	14	14	7	17	13	6	6	6	13	0	8	112	1.11
Purple Heron	*Ardea purpurea*	2	2	0	0	3	1	0	0	1	0	0	2	11	0.11
White faced tree duck	*Dendrocygna viduata*	72	84	58	168	26	0	2	202	0	4	0	179	795	7.86
Fulvons tree duck	*Dendrocygna bicolor*	0	0	0	0	0	0	0	0	0	0	0	17	17	0.17
Little bittern	*Ixobrychus minutus*	2	0	0	0	0	0	0	0	0	0	0	0	2	0.02
Green Backed Heron	*Butorides striatus*	3	5	0	1	0	0	0	0	0	0	0	0	9	0.09
Terns and Gulls															
Little Tern	*Sterna albifrons*	18	10	5	20	0	0	0	0	0	0	0	26	79	0.78
Black Tern	*Chlidonia niger*	9	48	18	32	0	65	0	0	0	0	24	16	212	2.10
Common tern	*Sterna hirundo*	138	126		14	0	0	0	0	0	0	0	5	283	2.80
Sandwich tern	*Sterna sandvicensis*	40	3	0	0	0	0	0	0	0	0	0	0	43	0.43
Royal tern	*Sterna maxima*	32	0	0	0	0	0	0	0	0	0	0	0	32	0.32
TOTAL		1327	1665	870	1889	299	794	596	1110	573	278	77	638	10116	100.00

Appendix I-3: Total individual monthly count of waterbirds on the Laloi wetland

Common name	**Species**	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	TOTAL	ABUNDANCE %
Blacked Winged stilt	*Himantopus himantopus*	12	10	2	67	79	70	108	88	51	75	46	100	708	5.83
Spur Winged Plover	*Vanellus spinosus*	13	6	2	0	2	3	6	30	19	27	31	54	193	1.59
Common sand piper	*Actitis hypoleucos*	25	4	6	5	3	14	6	4	0	0	0	0	67	0.55
Wood Sand piper	*Tringa glareola*	0	0	3	0	0	9	0	4	0	0	1	0	17	0.14
Curlew Sandpiper	*Calidris ferruginea*	36	29	71	117	90	90	0	103	0	0	0	12	548	4.51
Curlew	*Numenius arquata*	0	0	0	0	0	5	0	6	0	0	0	2	13	0.11
Little Stint	*Calidris minuta*	25	17	128	196	47	94	92	22	46	0	0	0	667	5.49
Sanderling	*Calidris alba*	82	89	49	58	30	68	37	24	0	0	0	0	437	3.60
Green Shank	*Tringa nebularia**	51	4	6	59	145	133	193	51	24	19	0	15	700	5.76
Collard Prantincole	*Glareola pratincola*	3	11	0	0	0	0	11	0	2	42	8	0	77	0.63
White fronted sandplover	*Charadrius marginatus**	0	0	0	0	5	8	4	9	4	6	4	9	49	0.40
Marsh sandpiper	*Tringa stagnatilis**	0	2	9	0	17	12	18	2	0	0	0	0	60	0.49
Ruff	*Philomachus pugnax*	0	0	0	0	0	0	0	0	2	0	0	0	2	0.02
Bar tailed Godwit	*Limosa limosa*	3	3	2	0	0	3	3	6	0	0	11	0	31	0.26
Whimbrel	*Numenius phaeopus*	1	0	6	1	4	17	10	4	1	0	1	4	49	0.40
Turnstone	*Arenaria interpres*	0	5	2	0	3	10	0	0	4	0	0	0	24	0.20
Ringed Plover	*Charidrius hiaticula*	2	58	589	985	316	842	445	371	141	0	0	0	3749	30.87

Grey Plover	*Pluvialis squatarola*	5	0	6	5	13	18	6	11	11	0	4	4	83	0.68
Spotted Redshank	*Tringa erythropus*	23	0	0	0	0	30	0	0	0	0	0	0	53	0.44
Senegal wattled plover	*Vanellus senegalensis*	0	0	0	2	0	8	0	4	0	0	5	3	22	0.18
Redshank	*Tringa totanus*	3	2	1	0	18	7	7	2	0	0	0	1	41	0.34
Senegal thicknee	*Burhinus senegalensis*	4	5	4	4	6	3	4	5	6	13	4	8	66	0.54
kittlitz Sand plover	*Charadrius pecuarius*	50	8	4	12	8	12	8	4	3	0	0	0	109	0.90
Painted Snipe	*Rostratulla benghalensis*	16	28	3	2	0	0	0	0	0	0	0	0	49	0.40
Herons/ Egrets/ Ducks															
Long tailed Cormorant	*Phalacrocorax africanus*	28	130	40	164	206	148	42	114	3	77	184	248	1384	11.40
Grey Heron	*Ardea cinerea*	11	10	8	27	40	28	14	35	8	0	5	8	194	1.60
Reef Heron	*Egretta garzetta gularis*	4	11	7	39	69	58	21	22	6	23	33	53	346	2.85
Yellow billed Egret	*Egretta intermedia*	0	0	0	0	6	0	0	0	0	0	0	0	6	0.05
Little Egret	*Egretta garzetta*	10	18	27	32	128	12	68	59	7	48	73	56	538	4.43
Black Heron	*Egretta ardesiaca*	0	2	0	0	7	6	0	0	0	0	12	0	27	0.22
Great white Egret	*Egretta alba*	2	3	3	6	42	21	4	19	8	3	10	3	124	1.02
Purple Heron	*Ardea purpurea*	0	0	1	0	0	0	0	0	0	0	0	0	1	0.01
White faced tree duck	*Dendrocygna viduata*	20	0	0	0	0	254	6	7	5	226	0	13	531	4.37
Fulvons tree duck	*Dendrocygna bicolor*	0	0	0	0	0	17	0	0	0	0	0	0	17	0.14
Green Backed Heron	*Butorides striatus*	0	3	0	1	1	3	0	0	0	0	0	1	9	0.07
Squacco Heron	*Ardeola ralloides*	0	0	0	0	0	0	0	0	0	0	0	9	9	0.07
Night Heron	*Gorsachius*	0	0	0	0	0	0	0	0	0	0	5	0	5	0.04

	leuconotus														
Lasser black backed gull	*Larus fuscus*	0	0	0	0	4	0	0	0	0	0	0	0	4	0.03
Terns and Gulls															
Little Tern	*Sterna albifrons*	65	46	17	0	0	0	0	0	0	16	43	138	325	2.68
Black Tern	*Chlidonia niger*	0	0	0	0	0	0	0	0	0	0	0	6	6	0.05
Common tern	*Sterna hirundo*	2	49	60	0	16	0	0	76	0	0	4	0	207	1.70
Sandwich tern	*Sterna sandvicensis*	0	16	88	1	26	128	0	33	0	0	0	0	292	2.40
Royal tern	*Sterna maxima*	0	22	73	4	37	117	0	28	0	0	0	0	281	2.31
Caspian tern	*Hydroprogne caspia*	0	0	0	0	10	0	0	13	0	0	0	0	23	0.19
Total		**496**	**591**	**1217**	**1787**	**1378**	**2248**	**1113**	**1156**	**351**	575	484	747	12143	100.00

Appendix I-4: Total individual monthly count of waterbirds on the Kpeshie wetland

Name of waterbird (Kpeshie)	**Scientific Names**	AUG	SEPT	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	TOTAL	Abundance %
WADERS															
Common Sand piper	*Actitis hypoleucos*	29	20	33	29	116	124	86	87	27	0	0	30	581	29.2
Senegal thicknee	*Burhinus senegalensis*	4	0	0	22	40	58	38	84	26	10	5	15	302	15.2
Black winged Stilt	*Himantopus himantopus*	5	18	19	15	3	6	8	0	3	0	0	17	94	4.7
Wood sandpiper	*Tringa glareola*	0	0	0	1	14	29	46	48	2	0	0	0	140	7.0
African Jacana	*Actophilornis Africana*	0	0	0	0	2	0	0	1	2	0	0	0	5	0.3
Red Shank	*Tringa totanus*	0	0	0	0	1	1	0	0	1	0	0	0	3	0.2
Whimbrel	*Numenius phaeopus*	2	8	7	10	4	5	3	7	2	1	0	1	50	2.5
Spur winged plover	*Vanellus spinosus*	3	3	3	10	5	3	17	3	18	4	3	35	107	5.4
Senegal wattled plover	*Vanellus senegalensis*	3	2	23	80	42	33	56	9	15	8	0	23	294	14.8
Green Shank	*Tringa nebularia**	0	9	3	5	13	6	35	6	3	0	0	1	81	4.1
Sanderlings	*Calidris alba*	0	17	0	2	0	0	0	0	0	0	0	0	19	1.0
Grey Plover	*Pluvialis squatarola*	0	0	0	0	0	3	0	2	0	0	0	0	5	0.3
Ring plover	*Charidrius hiaticula*	0	0	1	5	8	7	6	4	5	0	0	0	36	1.8
Turnstone	*Arenaria interpres*	0	0	0	0	0	0	3	0	0	0	0	0	3	0.2
Little Grebe	Tachybaptus ruficollis	0	0	0	0	1	2	5	4	4	1	0	0	17	0.9
Heron /Egret/Ducks															
Long tailed cormorant	*Phalacrocorax africanus*	7	16	7	3	14	17	4	5	2	1	3	1	80	4.0

Squacco heron	*Ardeola ralloides*	0	0	1	0	4	2	0	2	1	0	2	0	12	0.6
Western Reef Heron	*Egretta garzetta gularis*	14	8	13	9	6	9	5	2	1	0	4	3	74	3.7
Green backed Heron	*Butorides striatus*	6	5	2	2	3	3	3	2	2	1	2	2	33	1.7
Grey Heron	*Ardea cinerea*	0	0	0	1	2	2	0	1	0	0	0	0	6	0.3
Black heron	*Egretta ardesiaca*	4	5	3	2	3	0	0	0	0	0	0	0	17	0.9
Night Heron	Gorsachius leuconotus	0	0	0	0	2	0	0	2	0	0	0	0	4	0.2
Little Egret	*Egretta garzetta*	5	2	0	1	0	2	0	0	1	1	2	0	14	0.7
Great White Egret	*Egretta alba*	0	0	1	0	0	0	0	0	0	0	0	0	1	0.1
Terns															
Royal tern	*Sterna maxima*	0	0	0	0	2	0	0	0	0	0	0	0	2	0.1
Little tern	*Sterna albifrons*	1	1	0	0	0	0	0	0	0	0	0	0	2	0.1
Black tern	*Chlidonia niger*	0	0	0	0	0	0	0	2	0	0	4	0	6	0.3
Total		**83**	**114**	**116**	**197**	**285**	**312**	**315**	**271**	**115**	**27**	**25**	**128**	**1988**	**100.0**

Appendix I-5: Total abundance and distribution of macroinvertebrates during the study period

Taxa (Phylum)	**Class**	**Family**	**Sakumo II (N)**	**Laloi (N)**	**Kpeshie (N)**	**Total (N)**	**Density (N/0.196) ind/m^2**	**Relative Abundance (n/N *100) %**
Annelida	Polychaeta	Nereididae *(Nereis spp*)	135	191	534	860	4,387.76	19.22
	Polychaeta	Glyceridae (*Glycera spp*)	81	207	214	502	2,561.22	11.22
	Polychateta	Capitellidae *(Capitellid spp)*	34	129	48	211	1,076.53	4.72
	Oligochaeta		27	87	17	131	668.37	2.93
Mollusca	Gastropoda	Potamidadae *(Cerithidea spp)*	245	637	64	946	4,826.53	21.14
	Gastropoda	Hydrobiidae *(Hydrobia accrensis)*	439	307	39	785	4,005.10	17.55
	Bivalvia	Veneridae*(Tivela tripla)*	105	105	41	251	1,280.61	5.61
	Gastropoda	*Potamidade (Tympanotonus fuscata)*	130	102	38	270	1,377.55	6.03
	Gastropoda	Thiaridae *(Melanoides tuberculata)*	386	32	27	445	2,270.40	9.95
Crustacea	Melascostraca	Penaeidae *(Penaeus notialis)*	27	36	10	73	372.45	1.63
Total			**1609**	**1833**	**1032**	**4474**	**22,826.53**	**100.00**

Appendix I-6: Monthly abundance and distribution of macroinvertebrate at Sakumo II lagoon

Taxa	**Family**	**Scientific Name**	**Aug**	**Sept**	**OCt**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Total**	**Density (N/0.196) ind/m2**
ANNELIDA	Polychaeta	*Nereis spp*	8	17	4	16	8	15	9	12	18	7	15	6	135	688.78
	Polychaeta	*Glycera spp*	7	8	7	7	8	8	5	8	10	5	4	4	81	413.27
	Polychateta	*Capitellid*	4	3	1	4	3	0	2	4	4	0	2	7	34	173.47
	Oligochaeta		3	1	5	2	1	1	1	1	1	4	4	3	27	137.76
MOLLUSCA	Gastropoda	*Cerithidea spp*	14	32	16	14	14	10	18	15	65	6	14	27	245	1250.00
	Gastropoda	*Hydrobia*	32	43	37	15	6	32	13	5	60	56	41	99	439	2239.80
	Bivalvia	*Tivela tripla*	11	8	17	13	20	2	2	3	8	10	5	6	105	535.71
	Gastropoda	*Tympanotonus fuscata*	6	4	8	2	3	7	7	4	25	6	4	54	130	663.27
	Gastropoda	*Melanoides tuberculata*	49	46	50	47	33	18	24	21	23	26	46	3	386	1969.39
Crustacea	Melascostraca	*Penaeus notialis*	2	0	4	2	1	1	2	4	0	2	5	4	27	137.76
Total			136	162	149	122	97	94	83	77	214	122	140	213	1609	8209.18

Appendix I-7: Monthly abundance and distribution of macroinvertebrate at Laloi lagoon

Taxa	**Family**	**Scientific Name**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Total**	**Density (N/0.196)Ind/m^2**
Annelida	Polychaeta	*Nereis spp*	11	10	16	16	8	18	10	11	19	21	41	10	191	974.49
	Polychaeta	*Glycera spp*	16	5	7	13	8	11	9	9	32	44	46	7	207	1056.12
	Polychateta	*Capitellid*	4	1	1	4	3	4	3	5	1	48	10	45	129	658.16
	Oligochaeta		1	1	2	2	3	5	1	0	2	29	2	39	87	443.88
Mollusca	Gastropoda	*Cerithidea spp*	27	52	71	47	58	47	14	69	17	63	87	85	637	3250.00
	Gastropoda	*Hydrobia*	15	10	8	7	20	5	20	9	45	73	59	36	307	1566.33
	Bivalvia	*Tivela tripla*	6	8	9	3	7	8	8	4	29	9	8	6	105	535.71
	Gastropoda	*Tympanotonus fuscata*	10	6	6	11	5	7	9	6	5	6	23	8	102	520.41
	Gastropoda	*Melanoides tuberculata*	10	1	5	3	3	1	2	4	0	0	1	2	32	163.27
Crustacea	Melascostraca	*Penaeus notialis*	5	6	2	0	2	6	2	6	3	2	2	0	36	183.67
Total			105	100	127	106	117	112	78	123	153	295	279	238	1833	9352.04

Appendix I-8: Monthly abundance and distribution of macroinvertebrate at Kpeshie lagoon

Taxa	Family	Scientific Name	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Tot al	Density (N/0.196)Ind/m^2
Annelida	Polychaeta	*Nereis spp*	24	32	48	49	35	33	48	32	53	66	52	62	534	2724.49
	Polychaeta	*Glycera spp*	13	11	14	19	20	17	15	15	11	16	40	23	214	1091.84
	Polychateta	*Capitellid*	4	4	9	3	4	5	4	3	2	4	2	4	48	244.90
	Oligochaeta		1	2	1	0	0	4	2	0	1	1	3	2	17	86.73
Mollusca	GastropodA	*Cerithidea spp*	13	4	3	7	21	3	3	1	4	1	2	2	64	326.53
	GastropodA	*Hydrobia*	6	1	2	5	5	5	2	4	4	1	2	2	39	198.98
	Bivalvia	*Tivela tripla*	2	8	2	3	14	2	3	3	2	2	0	0	41	209.18
	GastropodA	*Tympanotonus fuscata*	2	4	3	4	7	5	4	4	3	1	1	0	38	193.88
	GastropodA	*Melanoides tuberculata*	1	2	1	4	9	0	2	2	4	0	2	0	27	137.76
Crustacea	Melascostraca	*Penaeus notialis*	0	0	1	1	0	1	2	2	2	0	0	1	10	51.02
Total			66	68	84	95	115	75	85	66	86	92	104	96	1032	5265.31

Appendix 1-9: A summary of the independent t test showing differences in water quality elements by year

Parameters	Year	Mean	SD	t	p
pH	1982.00	8.0333	.05774	-2.633	.03
	2017.00	8.7400	.46130		
Temp	1982.00	29.2333	.37859	-2.343	.03
	2017.00	30.2200	.62354		
Conductivity	1982.00	20.6000	16.51575	-1.455	.219
	2017.00	35.0700	4.88519		
Salinity	1982.00	12.7333	10.42705	-1.352	.247
	2017.00	27.6700	16.02633		
water depth	1982.00	.6250	.10607	-8.008	.004
	2017.00	2.1833	.25007		
PO4_P	1982.00	.0300	.05196	-2.676	.005
	2017.00	2.1133	1.34760		
NO3_N	1982.00	.6000	1.03923	-1.636	.177
	2017.00	6.1033	5.73287		
NO2_N	1982.00	.2500	.	-.596	.612
	2017.00	.4100	.23259		
Na	1982.00	179.1667	144.71767	-2.180	.009
	2017.00	8348.0867	6490.07672		
K	1982.00	7.2667	5.25959	-1.194	.299
	2017.00	156.9900	217.18156		
Ca	1982.00	10.3000	7.76209	-6.477	.003
	2017.00	623.6100	163.82353		
Mg	1982.00	9.1667	7.35957	-4.962	.008
	2017.00	988.0300	341.60772		
Cl	1982.00	198.6667	162.71756	-8.046	.001
	2017.00	10435.8867	2197.74757		
SO4	1982.00	11.5667	7.60022	-3.172	.009
	2017.00	5011.4433	7388.81031		
DO	1982.00	7.6333	.32146	1.087	.338
	2017.00	5.9333	2.69075		
BOD	1982.00	10.3333	8.38650	-.038	.972
	2017.00	10.6533	12.15402		

Appendix 1-10: A summary of the ANOVA analysis showing differences in water quality elements by sites

		N	Mean	SD	F	P
pH	Sakumo II	12	7.65	0.651	0.589	0.56
	Laloi	12	8.05	0.651		
	Kpeshie	12	7.92	1.303		
Temperature	Sakumo II	12	29.23	1.350	1.116	0.34
	Laloi	11	28.76	0.735		
	Kpeshie	12	29.71	2.110		
Conductivity	Sakumo II	12	30.32	20.117	7.284	0.002
	Laloi	12	50.80	14.025		
	Kpeshie	12	58.68	21.400		
TDS	Sakumo II	12	30.88	19.452	0.846	0.438
	Laloi	12	40.08	17.848		
	Kpeshie	12	37.47	16.075		
DO	Sakumo II	12	5.86	2.570	10.64	0
	Laloi	12	2.66	1.132		
	Kpeshie	12	3.28	1.369		
Salinity	Sakumo II	12	6.92	4.473	18.64	0
	Laloi	12	28.08	15.353		
	Kpeshie	12	25.85	2.340		
Turbidity	Sakumo II	12	22.92	11.782	25.189	0
	Laloi	12	47.25	19.433		
	Kpeshie	12	438.17	277.666		
water depth	Sakumo II	12	0.37	0.164	2.049	0.145
	Laloi	12	0.37	0.170		
	Kpeshie	12	0.50	0.197		
Alkalinity	Sakumo II	12	504.83	280.804	16.272	0
	Laloi	12	92.71	56.390		
	Kpeshie	12	457.42	174.554		
Cl-	Sakumo II	12	8961.25	4868.303	2.581	0.091
	Laloi	12	9384.58	3995.595		
	Kpeshie	12	12961.83	5264.211		
Mg2+	Sakumo II	12	1354.50	727.361	5.008	0.013
	Laloi	12	678.42	360.379		
	Kpeshie	12	931.17	424.126		
Ca2+	Sakumo II	12	789.17	482.409	2.718	0.081
	Laloi	12	620.08	247.793		
	Kpeshie	12	461.58	247.619		
NO2 –N	Sakumo II	12	0.29	0.336	2.597	0.09
	Laloi	12	0.37	0.302		

	Kpeshie	12	0.13	0.069		
PO4 –P	Sakumo II	12	1.72	1.088	15.888	0
	Laloi	12	0.28	0.280		
	Kpeshie	12	2.08	0.891		
Fe	Sakumo II	12	2.34	1.881	23.558	0
	Laloi	12	3.47	2.591		
	Kpeshie	12	10.05	4.026		
Mn	Sakumo II	12	0.81	0.895	1.721	0.195
	Laloi	12	0.56	0.252		
	Kpeshie	12	1.17	1.038		
Cu	Sakumo II	12	0.13	0.121	2.283	0.118
	Laloi	12	0.07	0.206		
	Kpeshie	12	0.01	0.002		
Zn	Sakumo II	12	0.02	0.015	6.58	0
	Laloi	12	0.56	0.571		
	Kpeshie	12	0.36	0.288		
Cd	Sakumo Ii	12	0.05	0.040	15.383	0
	Laloi	12	0.60	0.329		
	Kpeshie	12	0.74	0.448		
Ni	Sakumo II	12	0.04	0.085	0.676	0.516
	Laloi	12	0.02	0.004		
	Kpeshie	12	0.03	0.020		
Cr	Sakumo II	12	2.03	2.170	5.957	0.006
	Laloi	12	0.02	0.029		
	Kpeshie	12	1.01	1.165		
Co	Sakumo II	12	1.04	0.902	14.51	0
	Laloi	12	0.07	0.054		
	Kpeshie	12	0.02	0.004		

Appendix I-11: Equation parameters of length-weight for *Sarotherodon melanotheron* from the Sakumo II lagoon

Month	B	a	R^2	df	Significance	F Stat
August	2.62	-1.43	0.850	48	<0.001	272
September	2.98	-1.73	0.996	48	<0.001	119300
October	2.94	-1.71	0.998	48	<0.001	28320
November	2.99	-1.74	0.998	48	<0.001	31600
December	3.01	-1.76	0.995	48	<0.001	96630
January	2.81	-1.59	0.880	48	<0.001	344.9
February	2.92	-1.70	0.980	48	<0.001	2691
March	2.96	-1.71	0.970	48	<0.001	1470
April	2.97	-1.73	0.998	48	<0.001	27180
May	2.91	-1.68	0.996	48	<0.001	10730
June	2.98	-1.73	0.998	48	<0.001	30730
July	2.98	-1.73	0.999	48	<0.001	43070

Appendix I-12: Equation parameters of length weight for *Sarotherodon melanotheron* from the Laloi lagoon

Month	B	a	R^2	df	Significance	F Stat
August	3.0	-1.76	0.99	48	< 0.001	3636
September	2.90	-1.65	0.98	48	< 0.001	2255
October	3.01	-1.75	0.99	48	< 0.001	5558
November	2.74	-1.55	0.97	48	< 0.001	1497
December	3.02	-1.78	0.99	48	< 0.001	7605
January	3.08	-1.81	0.99	48	< 0.001	7343
February	3.06	-1.81	0.99	48	< 0.001	14490
March	2.82	-1.60	0.99	48	< 0.001	9659
April	2.96	-1.69	0.97	48	< 0.001	1437
May	2.96	-1.71	0.99	48	< 0.001	7087
June	2.94	-1.70	0.99	48	< 0.001	5611
July	2.93	-1.69	0.99	48	< 0.001	3804

Appendix I-13: Equation parameters of length-weight for *Sarotherodon melanotheron* from the Kpeshie lagoon

Month	B	a	R^2	df	Significance	F Stat
August	2.90	-1.69	0.99	48	< 0.001	5702
September	2.27	-1.17	0.87	48	< 0.001	314.9
October	3.04	-1.81	0.98	48	< 0.001	2256
November	2.92	-1.71	0.99	48	< 0.001	6341
December	2.78	-1.59	0.99	48	< 0.001	3156
January	2.88	-1.65	0.99	48	< 0.001	5599
February	2.90	-1.69	0.99	48	< 0.001	5398
March	3.00	-1.77	0.98	48	< 0.001	2039
April	3.06	-1.83	0.95	48	< 0.001	919.2
May	2.85	-1.66	0.98	48	< 0.001	2012
June	2.43	-1.35	0.92	48	< 0.001	553.4
July	2.84	-1.66	0.99	48	< 0.001	6366

Appendix I-14: Sediment quality guideline (SQG) values

	Geochemical background values				
Metal	**World surface rock average [1]**	**Mean shale concentration[2]**	**WHO SQG*[3]**	**USEPA SQG*[4]**	**CCME SQG*[5]**
Cd	0.2	0.3	6	0.6	0.6
Co	13	29	-	-	-
Cr	71	90	25	25	37.3
Cu	32	11.2	25	16	35.7
Fe	35900	46700	-	30	-
Mn	750	850	-	30	-
Ni	49	68	20	16	-
Zn	127	95	123	110	123
Pb	16	20	-	40	35

1. Martin and Meybeck (1979); 2. Venkatesha Raju (2012) ; 3. WHO (2004); 4. USEPA (1999); 5. CCME (1999) ; *Sediment quality guidelines (SQG).

Appendix I-15: Questionnaire on the changes in the coastal wetlands, its usage, associated problems and measures to conserve /protect the wetlands.

This study is the social impact component on 'assessing the ecological character of wetlands and their impact on the distribution and abundance of waterbirds in some coastal wetlands in Ghana. Any information provided would be treated exclusively as academic and not made public. We assure you of the utmost privacy. Thank you for your cooperation.

SECTION A: Demographic information of respondent

1. Community/ Settlement …………………………………………………………...

2. Age: a) below 20 yrs [ ] b) 21-30 yrs [ ] c) 31-40 yrs [ ] d) 41-50 yrs [ ] e) Above 50 yrs [

3. Sex: a) Male [ ] b) Female [ ]

4. Marital Status a) Married [ ] b) Single[ ] c) divorced [ ]

5. Are you an a) Indigene [ ] b) Migrant [ ]

6. Are you a) Self-employed [ ] b) Employed by some [ ]

7. Main Occupation: a) Farming [ ] b) Fishing [ ] c) Salt winning [ ] d) Trading [ ] e) Sand Winning f) Artisan (Specify)..........................

8. Secondary occupation: a) Farming [ ] b) Fishing [ ] c) Salt winning [ ] d) Trading [ ] e) Sand Winning g) Artisan (Specify)..........................

9. Level of Education: a) Primary [ ] b)JHS/Middle [ ] c) SHS/VOC/TECH [ ] d) Tertiary [ ] e) No education [ ] f) Non-formal education [ ] g) Others (specify)……………………….

10. Years Resident in the area: a) below 5 yrs [ ] b) between 5-10 yrs [ ] c) between 11-20 yrs [ ] d) between 20 -30 yrs [ ] e) above 30 yrs [ ]

KNOWLEDGE AND USE OF COASTLAND WETLANDS

11. Do you know this wetland is an important resource and need to be protected?

a. Yes [ ] b. No [ ]

12. What is your level of usage of this wetland? a) High [ ] b) Moderately high [ ] c) Very high [ ]

13. What activities do you use this coastal wetland and its catchment for?

a) Farming [ ] b) Fishing [ ] c) Salt winning [ ] d) Swimming [ ] e) Bird watching [ ] f) Sand Winning[ ] g) harvesting wood for fuel [ ] g) Other (Specify)..

14. How are solid waste disposed of in this area? a). open pit [ ] b. burning [ ] c. around the house or compound [ ] d. into or around the coastal lagoon [ ] e.) Others specify…………………

15. How is liquid waste disposed of in this area? a). open pit [ ] b) open defaecation [ ] c. into or around the coastal lagoon [ ] d.) Others specify………………….

16. Do people in the area practice open defaecation along the coastal lagoon? a) Yes [ ] b.) No

17. Does the wetland have any cultural/traditional significance to you? Yes [ ] No [ ]

18. If yes what is its significance? ………………………………………………………………

CHANGES IN THE WETLANDS

19a. Has there been any changes in the wetland over the last 5-10 years? Yes [ ] No [ ]

19b. In your opinion what is the major driver of change on the wetlands?………………………

19c. List other factors in your opinion that may also account for the changes on the wetlands?

……………………………………………………………………………………………

20 Tick the appropriate: Major changes that you have observed on the wetlands over these years?

CHANGE	**Tick yes or no for the appropriate change**	**INCREASE**	**DECREASE**	**NO MAJOR CHANGE (SAME)**
Change in the size of coastal lagoon	Yes[ ] No[ ]			
Change in the mangrove and vegetation cover	Yes[ ] No[ ]			
Upsurge in building/settlement around the wetland	Yes[ ] No[ ]			
Agricultural activities (farms) on and around the wetland	Yes[ ] No[ ]			
Number of migratory birds that visit the wetlands	Yes[ ] No[ ]			
Dumping of solid and liquid waste into the wetland	Yes[ ] No[ ]			
Wildfires in the wetlands	Yes[ ] No[ ]			
Have weeds covered most surface part of coastal lagoon	Yes[ ] No[ ]			

Reclamation of part of wetlands for other activities like markets, road, mechanic shops etc.	Yes[ ] No[ ]			

21. What do you think might have caused this state of change in the wetland?

a). human activities [ ] b. natural [ ] c. others specify…………………..

21 b. List some of these human activities that has caused changes on the wetlands in your opinion? (List as many as you can) ……………………………………………………………………………………………

22. What has been the effect of these changes on your livelihood activities around the wetland? ……………………………………………………………………………………………

23. Do you receive any education on the use of this wetland and its resources from time to time?

a. Yes [ ] b. No [ ] c. Not at all [ ]

24. If yes, then from whom? a. NGO's [ ] b. District Assembly [ ] c. Traditional rulers [ ] d. Government Agencies (Wildlife) [ ] e. Others (specify)…………………………………

HUMAN ACTIVITIES AROUND WETLANDS

25. Do you fish in the coastal lagoon? a. Yes [ ] b. No [ ]

26. If yes, how many days within a week do you fish in the lagoon? …………………………..

27. Which days don't you fish in the lagoon? …………………………………

28. Why don't you fish on that particular day?? …………………………………

29. How long do you spend on the lagoon in a day when you go fishing?

a.1-3 hrs [ ] b.4-6 hrs [ ] c. 7-9 hrs [ ] d. 10-12 hrs [ ] e. Above 12 hrs [ ]

30. In terms of fish caught from the lagoon, how would you describe your daily catch from the lagoon? a. low [ ] b. average [ ] c. high [ ] d. very high [ ]

31. Have you used any chemical in fishing activities on the lagoon before? Yes [ ] No [ ]

32. Do you hunt for birds on these wetlands? a) Yes [ ] b. No [ ]

33. If yes why do you hunt them?

a. Food [ ] b. Sell for money [ ] c. hunt them as pet [ ] d. recreation [ ] d. others (specify) …………………..

34. How often do you hunt these birds? a) Daily [ ] b.) weekly [ ] c.) Monthly [ ] d) Others specify……………

35. What do you use to hunt these birds? a) traps [ ] b) Guns [ ] c. Others (Specify) ……

36. Which type of birds do you normally hunt or kill? …………………………………..

37. Do you engage in any farming activities along the coastal wetlands and its catchment

a) Yes [ ] b) No [ ]

38. Do you or any of the farmers use pesticides or agrochemicals in their activities?

a) Yes [ ] b) No [ ]

39. Have your activities caused any major change to the quality of water/land on the wetland?

a) Yes [ ] b) No [ ]

40. What in your opinion is your assessment of the quality of water in the lagoon?

A) clean [ ] b) dirty [ ] c. polluted [ ] d. Others (specify) …………………

41. Which of the following do you think is the most appropriate methods of conserving/protecting these coastal wetlands (Rank them in order of importance in your view)

- Enforcing the cultural values/traditional values on the wetlands [ ]
- Enforcement of strict adherence of the closed season for fishing on the wetlands [ ]
- District assembly should be responsible for managing wetlands in their jurisdiction [
- All forms of farming activities in and around wetlands should be banned [ ]
- Dredging of coastal wetland to avoid the growth of aquatic weeds on the waterbodies
- Private individuals/ investors to manage wetlands and their resources [ ]
- Public awareness and education programmes on the use of wetlands [ ]
- Building sanitary facilities along the coast of the wetlands [ ]

Appendix I-16: Pollution Indices (Geo-accumulation Index, Contamination factor and Enrichment factors)

Muller's classification for geo-accumulation index (Igeo).

Igeo Value	Grade	Sediment Quality
≤0	0	Unpolluted
0< I-geo ≤1	1	Slightly polluted
1 < I-geo ≤ 2	2	Moderately polluted
2< I-geo ≤3	3	From moderately to strongly polluted
3< I-geo ≤4	4	Strongly polluted
4< I-geo ≤5	5	From strongly to extremely polluted
I-geo > 5	6	Extremely polluted/ contaminated

Enrichment factor proposed by Birch (2003)/ (Mmolawa *et al.*, 2011)

Enrichment factor (EF)	Enrichment factor (EF) Categories
EF EF<1	indicates no enrichment,
<3	minor enrichment;
3-5	moderate;
5-10	moderately severe;
10-25	severe;

25-50	very severe
>50	extremely severe.

Contamination factor (CF) as defined by Hàkanson (1980)

$\mathrm{CF} < 1$ indicates low contamination;

$1 \leq \mathrm{CF} < 3$ implies moderate contamination,

$2 \leq \mathrm{CF} < 6$ indicates a considerable contamination

while $\mathrm{CF} > 6$ implies a high contamination.