UNIVERSITY OF CAPE COAST

GEOSPATIAL ASSESSMENT OF ECOSYSTEM HEALTH OF COASTAL URBAN WETLANDS IN GHANA

BERNARD EKUMAH

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BY

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A Thesis submitted to the Department of Environmental Science of the School
of Biological Sciences, College of Agriculture and Natural Sciences,
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award of a Master of Philosophy (M.Phil.) degree in Environmental Science

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: ……………………….…..… Date: …………………..

Name: ………………………………………………………………………..….

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature: ………………….…… Date: …………….

Name: ……………………………………………………………………………..

Co-Supervisor's Signature: …………………….……….. Date: …………….

Name: ……………………………………………………………………………..

ABSTRACT

This study employed geospatial techniques to assess the ecosystem health of some coastal urban wetlands in Ghana over 32-year period and predicted changes that will occur in the next 15 years. Landsat satellite images of 1985, 2002 and 2017 were obtained for this study. The study was carried out in three coastal urban wetlands; Muni-Pomadze, Densu Delta and Sakumo II Ramsar Sites. The ecosystem health of the wetlands was assessed using structure, function and resilience indicators. The results indicated that between 1985 and 2002 about 21 percent of the total area of the wetlands were subjected to land use land cover (LULC) changes and almost half of the total area (48%) experienced changes in 2002-2017 period. The annual change rate in 1985-2002 was relatively slow whereas the annual change rate in 2002-2017 was relatively fast due to increasing anthropogenic activities. The natural LULC classes progressively became more fragmented over the study period due to the expansion of built-up areas. It was estimated that about 30 percent of the total area of the wetlands in 2017 will be subjected to LULC changes as result of built-up expansion in 2032. In 2002, ecosystem health of Densu Delta experienced the least decline (12%) from the 1985 state among all the three wetlands and Sakumo II recorded the highest deterioration (38%). Contrary to 2002, in 2017 the health of Densu Delta experienced the worse deterioration (46.3%) whereas Sakumo II recorded the least decline (26.2%). Ecosystem health of Muni Pomadze Ramsar Site deteriorated at a similar magnitude, 27 percent and 29.1 percent for 2002 and 2017 respectively. An urgent pragmatic intervention is needed to protect the coastal urban wetlands in Ghana to save them from being wiped out completely.

KEY WORDS

Built-up

Land use land cover

Intensity analysis

Population Growth

Ramsar Site

Wetland Fragmentation

LIST OF ACRONYMS

AGL	Above Ground Level
AHP	Analytic Hierarchy Process
ANOVA	Analysis of Variance
CA	Cellular automata
CCA	Canonical Correspondence Analysis
CWED	Contrast-Weighted Edge Density
DEM	Digital Elevation Model
DJI	Dà-Jiāng Innovations
ED	Edge Density
GMA	Ghana Meteorological Authority
LULC	Land Use Land Cover
DFAS	Department of Fisheries and Aquatic Sciences
FAO	Food and Agriculture Organisation
FSA	Food Security Act
GIS	Geographic Information System
GPS	Global Positioning System
GRoWI	Global Review of Wetland Resources and Priorities for Wetland Inventory

IBI	Index of Biological Integrity
ILDD	Integrated Land-Use Dynamic Degree
IUCN	International Union for Conservation of Nature
KMO	Kaiser-Meyer-Olkin
LCM	Land Change Modeler
LPI	Largest Patch Index
LDD	Landscape Deviation Degree
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
OECD	Organisation for Economic Co-operation and Development
PCA	Principal Components Analysis
PD	Patch Density
RSIS	Ramsar Sites Information Service
SDGs	Sustainable Development Goals
SGS	School of Graduate Studies
SLDD	Single Land-Use Dynamic Degree
TE	Total Edge
UAV	Unmanned Aerial Vehicle

UCC	University of Cape Coast
UN	United Nations
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
WCED	World Commission on Environment and Development
WGS	World Geodetic System
WWF	World Wildlife Fund

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DEDICATION

To my mother, Elizabeth Ekuful

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CHAPTER ONE

INTRODUCTION

Wetlands are fragile ecosystems characterized by complexity, dynamism, and diversity with variety of functions (Keddy, 2010). These ecosystems serve as the transitional link between aquatic and terrestrial ecosystems (Kadlec and Wallace, 2009) and provide important ecosystem services (Becani et. al., 2016). Nonetheless, due to rapid urbanization, and industrialization (Zedler and Kercher, 2005) coupled with extreme climatic conditions, wetlands have been degraded, generating several environmental and social problems (Becani et. al., 2016).

Assessing ecosystem health of wetlands has been identified as an important activity that precedes any remediation and restoration activities (Fennessy et al., 2009). However, the conventional methods used in evaluating wetland ecosystem health largely rely on field observational data (Chen & Wang, 2005) which cannot be widely applied on a large spatial scale and also difficult to provide spatio-temporal perspective to the assessments (Kerr & Ostrovsky, 2003). Geospatial technologies such as Remote Sensing and Geographic Information System (GIS) have enormous potentials for assessing and monitoring ecosystem health at varying temporal and spatial scales (Ludwig, Bastin, Chewings, Eager, & Liedloff, 2007). In this regard, the study sought to employ geospatial techniques to assess ecosystem health of coastal urban wetlands in Ghana over the past 32 years using structure, function and resilience ecological indicators.

1.1 Background to the study

Wetlands are among the most important and productive ecosystems on earth and provide a wide variety of unique services and commodities to humanity (Wu et al., 2018; Zhang, Zhang, Yang, & Yuan, 2013). The Ramsar Convention describes wetlands as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporal, with water that is static or flowing, fresh, brackish or slat, including areas of marine water, the depth of which at low tide does not exceed six metres" (Ramsar Convention, 1971). Coastal wetlands collectively comprise saltmarshes, mangroves and associated unvegetated intertidal areas (Nicholls, 2004). The Ramsar Convention Secretariat (2008), defines urban wetlands as wetlands lying within the boundaries of cities, towns and other conurbations.

All over the world, coastal regions are known to be overburdened with migration and high population growth rate (Hinrichsen, 1999). Moreover, coastal areas are in the very focus of environmental change in recent years, with coastal erosion, sea level rise, and destruction of mangroves (Hillmann & Ziegelmayer, 2016). Coupled with anthropogenic activities, it is projected that a 1m rise in sea level could wipe out about half of the world's coastal wetlands and even those that survive could be critically damaged affecting their functions (Nicholls, Hoozemans, & Marchand, 1999). However, the most significant factor compromising the future state of the global coastal wetlands is the degree of direct and indirect human-induced destruction (Nicholls, 2004).

Urbanisation is one of the greatest environmental changes the developing world is experiencing. Hence, urban landscapes are under severe pressure for various uses and wetlands bear the heaviest of them all (Ramsar Convention Secretariat, 2008). Despite the technological advancement in city infrastructure, it is not able to meet the incessant pressure from the growing population on urban biodiversity (Eppink, Bergh, & Rietveld, 2004). The Ramsar Convention Secretariat (2008), has therefore called on all Contracting Parities to review the state of their urban and peri-urban wetlands and to take appropriate measures to conserve and protect these wetlands. All Contracting Parties were also urged to put in place schemes for their restoration and rehabilitation so that they can deliver their full range of ecosystem services to humanity. To bring more attention on urban wetlands, the theme for World Wetlands Day 2018 was "Wetlands for a sustainable urban future". The focus on urban wetlands in recent years buttresses the need to protect urban wetlands which are threatened by multiple stressors.

Ghana is not an exception to the concerns raised by the Ramsar Convention Secretariat. The Country became a signatory to the Ramsar Convention in 1988. Wetland ecosystems in Ghana constitute about ten percent of the country's total land surface (Ministry of Lands and Forestry, 1999). The efforts to protect wetlands as per the dictates of the Ramsar Convention and other local and international regulations have not been implanted effectively. Studies have revealed that in Ghana, urbanization, high population growth, fuel wood gathering, salt and sand winning are the main factors threatening wetland ecosystems along the coast (Anku, 2006).

1.2 Statement of the Problem

The world has lost about 50 percent of its wetlands since 1900 and at a faster rate of 3.7 times during the 20th and early 21st centuries (Davidson, 2014). In the past, wetlands in Ghana were considered as waste lands and were dredged to facilitate drainage of water, reclaimed for other uses, or simply considered as dumping sites for waste (Ministry of Lands and Forestry, 1999). In recent times, rapid urbanisation and industrialization as a result of high population growth rate in coastal cities have led to detrimental changes in the extent and functioning of coastal urban wetlands in the country (Ryan & Attuquayefio, 2000). The problem has been exacerbated by constant influx of migrants from the interior to coastal urban areas which contributes to rapid population growth and urbanization of coastal urban areas (Reed, Andrzejewski, & White, 2010).

Despite the fact that the wetland ecosystems are subjected to unbridled destruction by anthropogenic activities, studies evaluating their states are patchy and limited, especially for Africa, the Neotropics and Oceania (Davidson, 2014). Comprehensive assessments of wetlands have been done in areas such as United States of America (Dahl, 1990, 2006), China (Zheng, Zhang, Niu, & Gong, 2012) and Europe (EEA, 2011). However, same cannot be said about the developing countries like Ghana. A comprehensive assessment of wetland ecosystem health is needed to guide protection and restoration plans (Brooks, Wardrop, & Perot, 1999; Zheng et al., 2012).

Researchers have used different indicators to assess wetland ecosystem which evaluate some aspects while others are ignored (Liu & Sun, 2010). For instance, a lot of studies in Ghana have mainly focused on biodiversity (Kyerematen, Acquah-Lamptey, Henaku, Anderson, & Baidu-Ntiamoa, 2014), hydrology (Nonterah, Xu, Osae, Akiti, & Dampare, 2015), pollutants (Anim, Osei, & Bimi, 2011; Fianko, Osae, & Achel, 2009) and fragmentation (Adade, Nyarko, Aheto, & Osei, 2017) separately. The conventional methods of assessing ecosystem health of wetlands largely depend on field observation data (Chen & Wang, 2005) which cannot be employed in studies of large spatial scale at different times to provide spatio-temporal perspective (Kerr & Ostrovsky, 2003). Data availability for the quantification of respective indicators on suitable spatial and temporal scales is critical in ecosystem health assessment.

To address the afore-discussed challenges, novel approaches or methods are required to undertake a comprehensive assessment of wetland ecosystem health. Data from geospatial techniques such as Remote Sensing have enormous potentials for assessing wetland ecosystem health at different temporal and spatial scales (Kerr & Ostrovsky, 2003). Remote sensing techniques have proved to be an effective way of assessing wetlands particularly, at large scale (Fritz, Cid, & Autrey, 2017). It has numerous advantages over the conventional methods and comparatively cost-effective and timely. It is also suitable for repeated studies and capable of acquiring images from inaccessible places which is typical of wetland areas (Mahdavi et al., 2017). The information obtained from remotely sensed data can be used when there are no or limited resources to support field data collection (Weller et al., 2007). This approach is suitable for a country like Ghana which has limited resources for scientific research and also lacks historical data on wetlands. This study therefore sought to undertake a comprehensive assessment of ecosystem health of coastal urban wetlands in Ghana using geospatial techniques.

1.3 Purpose of the Study

The purpose of the study was to explore the potentials of geospatial techniques in evaluating ecosystem health of wetlands. This study also sought to contribute to knowledge on the status of coastal urban wetlands over the past 32 years. The study also sought to predict the state of Ghana’s coastal urban wetlands in the next fifteen (15) years (2032).

1.4 Research Objectives

The main objective of the study is to assess ecosystem health of Sakumo II, Densu Delta and Muni-Pomadze Ramsar Sites over the past 32 years using geospatial techniques.

The specific objectives of the study were to:

1. Assess the land use land cover (LULC) changes in the three wetlands in the time periods 1985-2002 and 2002-2017.
2. To evaluate the extent of fragmentation in the wetlands in 1985, 2002 and 2017
3. Predict LULC changes in the three wetlands in 2032.
4. Assess the ecosystem health of the three wetlands using structure, function and resilience indicators in 2002 and 2017 using the health of 1985 as a reference year.

1.5 Research Questions

In order to achieve these objectives, this research answered the following questions:

1. a. What are the LULC changes that have occurred in the wetlands in the time periods 1985-2002 and 2002-2017?

   a. Is the intensity of LULC change decreasing or increasing with time?

   b. Which of the LULC classes are gaining in the wetlands?

   c. Which of the LULC classes are losing in the wetlands?
2. Are the wetlands becoming more fragmented with time?
3. What will be the state of the three wetlands in 2032?
4. Is the health of the wetland ecosystem deteriorating or improving with time compared to 1985

1.6 Significance of the Study

In order to sustain the benefits derived from coastal ecosystems, extensive evaluation of the overall ecosystem health of coastal urban wetlands is needed to understand the status and factors affecting the systems. This fundamental understanding will help engage political and public interest to come out with informed remediation and restoration efforts.

The findings of this study provide useful information on sustainable development goal 15, which is about life on land. The present study reports on two important sub-indicators under indicator 15.3.1 which are LULC change and land productivity. The findings of this study also provide information on

Aichi Biodiversity Target 5, which seeks to combat loss of natural habitats and also significantly reduce fragmentation.

The findings of the study could be useful in setting science-informed goals and priorities leading to better wetland restoration outcomes. The projections about the future state of the wetlands are important for policy formulation and planning. The presentation of the findings in the form of maps and graphs makes it easier for a lay person to appreciate the extent of destruction coastal urban wetlands are subjected to which generate public discourse on ways to protect them. The study approach has demonstrated to researchers and the scientific community the immense potentials of Remote Sensing and Geographical Information System in evaluating and monitoring ecosystem health of wetlands.

1.7 Delimitations of the Study

In Ghana, coastal urban wetlands are not only the three considered under this study. However, these wetlands were selected for the following reasons; among the six wetlands designated as wetlands of international importance in Ghana, they are the ones that are found in or close to urban settlements (Ministry of Lands and Forestry, 1999; Ramsar, 2019; Stevenson & Frazier, 2001), several studies have reported that these wetlands are threatened by anthropogenic activities (Attuquayefio, Wuver, & Enu-Kwesi, 2003; Nartey, Edor, Doamekpor, & Bobobee, 2011; Wuver & Attuquayefio, 2006), they also have well defined boundaries that enable spatio-temporal studies.

The purpose of the study was to employ geospatial techniques in assessing ecosystem health of wetlands in effect, only indicators that could be extracted from satellite images were considered. The study also tracked the changes that have occurred in the wetland before and after the wetlands were designated as Ramsar Sites and this informed the choice of the study years.

1.8 Limitations of the Study

Some important LULC classes such as built-up and bareland were classified together as one class because, the resolution of the satellites images (30m) was not high enough to enable the separation of these LULC types. Similar studies also put the two LULC types in one class (Ashiagbor, Amoako, Asabere, & Quaye-ballard, 2019). The chemical indicators of ecosystem health of wetlands were not considered because such data could not be extracted from the Landsat satellite images used in this study. Finally, the two time intervals considered for this study were not equal. Even though there are Landsat images available for every year since 1972, some of the images did not meet the criteria set for this study. Distorted images and images with clouds covering the study areas were not considered. However, the intensity analysis took into consideration the differences in the time intervals.

1.9 Organisation of the Study

The study was well thought out right from the outset from proposal writing, to field surveys, data collection and documenting the whole research into this thesis. The thesis is structured according to guidelines provided by the School of Graduate Studies (SGS), University of Cape Coast (UCC).

There are six chapters in this thesis. Chapter 1 introduces the whole concept of the study, giving a background and stating the problem and purpose of the study clearly. The Chapter further outlines the objectives to be achieved and the significance of the study, situated in the global and national perspective. Various setbacks by natural and uncontrollable occurrences, as well as methods used and the reasons are presented in the delimitations and limitations sections respectively.

Chapter 2 reviews literature relevant to the study into detail. Here, topical issues covering two broad themes; wetlands and ecosystem health assessment. With regards to wetlands, a thorough review was done on ecosystem services, extent, classification, loss, sustainability and Ramsar Convention. The global perspective, regional variations as well as the case of Ghana for the various issues were considered in the review. An in-depth review was also carried out on ecosystem health concept, assessment and indicators.

In Chapter 3, all methods employed during the research are explained, using annotated diagrams where necessary. All procedures are presented chronologically to paint a clear picture of what transpired during the experimental process. Study locations are well-described and statistical tools and applications used to analyse data collected explained.

Chapters 4 and 5 present results and discussion respectively. Results obtained from the research are presented in graphs, maps, charts and tables with brief descriptions in Chapter 4. Detailed analysis of results and inferences are drawn in Chapter 5, in the form of a discussion structured under various headings guided by the objectives of the study.

Conclusions and recommendations are given in Chapter 6. Other sections presented in this thesis include a list of references and appendices respectively.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews the literature relevant to the study. It covers issues pertaining to two broad themes; wetlands and ecosystem health assessment. With regards to wetlands, a thorough review was done on ecosystem services, extent, classification, loss, sustainability and Ramsar Convention. The global perspective, regional variations as well as the case of Ghana for the various issues were considered in the review. An in-depth review was also carried out on ecosystem health concept, assessment and indicators.

2.1 Wetlands

All through ages, wetlands have been intricately linked with humankind and they played essential roles in the civilization era when development of communities were supported by the inundated and fertile floodplain environments of the Nile, Tigris, and Euphrates Rivers (Hook, 1993; Keddy, 2010). This give credence to the long association humans have had with wetlands. In different parts of the world, people have put different meanings and values on wetlands primarily due to the distinctive relationships they have had with wetlands (Barker, 2009). The different perspectives may be attributed to cultural beliefs, historical antecedents and the socioeconomic benefits they derive from wetlands. Even though the relationship between humans and wetlands have existed for long, the term “wetland” is a contemporary word and became common in the scientific community in the second half of the twentieth century, in the 1950s (National Research Council, 1995).

There are numerous definitions for wetlands based on the purpose (Keddy, 2010; LePage, 2011; National Research Council, 1995; Tiner, 1996). The purpose could be general habitat classification, natural resource inventories, and environmental regulations (Tiner, 1996). Some of the definitions are predominantly based on science and others on law. The scientific definitions have undergone a lot of revision as and when the knowledge of the discipline grows but the legal definitions have not seen much evolution (Keddy, 2010). National Research Council (1995), categorized the definitions into two broad themes; the reference definition which is derived from scientific principles and the regulatory definition from environmental laws by the regulatory agencies. The Committee on Wetlands Characterization came out with a broad reference definition of wetland: "*an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate* (National Research Council, 1995).

With regards to regulatory definition, this review considered the more recent one from the 1985 Food Security Act (FSA) (P.L. 99-198, 99 Star. 1504) and amended by the Food, Agricultural, Conservation, and Trade Act of 1990 (P.L. 101-624, 104 Stat. 3587). A wetland is a land that: *(A) has a predominance of hydric soils; (B) is inundated or saturated by surface or ground water at a frequency and duration sufficient to support a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions; and (C) under normal circumstances, does support a prevalence of such vegetation* (National Research Council, 1995).

The controversies around wetland definition was arguably put to rest in 1971, when delegates from 18 countries met in Ramsar, Iran and adopted the convention on Wetlands (Ramsar Convention). The Convention came out with a broad definition of wetlands in Article 1:*"areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporal, with water that is static or flowing, fresh, brackish or slat, including areas of marine water, the depth of which at low tide does not exceed six metres*" (Ramsar Convention, 1971).

In Ghana, the Ramsar Convention definition is what is found in official government documents (Ministry of Lands and Forestry, 1999). This is probably because the country is a signatory to the Ramsar Convention.

2.1.1 Wetland Ecosystem Services

Wetlands are among the most important and productive ecosystems on earth and provide a wide variety of unique services and commodities to humanity (Wu et al., 2018; Zhang et al., 2013). Literature have described wetlands as kidneys of the landscape due to their function of storing, assimilating and transforming contaminants from land before entering waterbodies (Mitsch & Gosselink, 2015). They are also referred to as nature's supermarkets because of the diverse life forms and the extensive food chain they support (Mitsch & Gosselink, 2015). The essential services wetlands provide have led to an increasing global recognition and the need to conserve them (Cherry, 2011).

Until the Millennium Ecosystem Assessment (2005), the term 'ecosystem values' was used instead of 'ecosystem services' to describe the importance of wetland ecosystems (Mitsch & Gosselink, 2015). The two terms have anthropocentric orientation and signify that something important or useful to humankind (Mitsch & Gosselink, 2015). The ecosystem services provided by wetlands emanate from the interactions between the biological diversity constituents and their abiotic components (Millennium Ecosystem Assessment, 2005).

Ecosystem services are defined as the benefits humans derive directly or indirectly form the functions of the ecosystem (Millennium Ecosystem Assessment, 2005). Ecosystem services are categorized into four main groups namely; provisioning, regulating, supporting and cultural services. The provisioning services of wetlands include food and water; wetland regulating services are services that regulate land degradation, floods and drought, erosion and water purification: Soil formation and nutrient cycling fall under wetland ecosystem supporting services and cultural services include religious, spiritual, educational and recreational services. In a broader sense, ecosystem services of wetlands contribute to human wellbeing, cultural identity and local and global economies (Millennium Ecosystem Assessment, 2005).

2.1.2 Wetland Classification

Wetlands have been classified several times at national and regional scale. The classification usually precedes wetland inventory. The purpose of classification is to group together various kinds of wetlands that share similar characteristics (Cowardin, Carter, Golet, & Laroe, 2005). Classifying wetlands is useful for describing and managing their natural variability (Brooks, Brinson, Wardrop, & Bishop, 2013). Wetlands have been classified for diverse reasons but the most recent one is based on priorities for protection, with highest protection given to the wetlands with the greatest value (Mitsch & Gosselink, 2015).

The first documented classification was done in the 1900s which classified peatlands of Europe and North America (Mitsch & Gosselink, 2015). In the early 1950s, there was the need to determine the distribution, extent, and quality of existing wetlands with respect to their value as wildlife habitat by the United States Fish and Wildlife Service (Genet & Bourdaghs, 2006). A classification system known as "*Circular 39 Classification*" was therefore developed to undertake an inventory and the outcome was published by the United States Fish and Wildlife Service (Genet & Bourdaghs, 2006; Mitsch & Gosselink, 2015). In all twenty wetlands were identified under four main categories.

The next classification, which is well known, was published in 1979 by the United States Fish and Wildlife Service (Cowardin et al., 2005). The name of the Classification is "*Classification of Wetlands and Deepwater Habitats of the United States*". This classification is still in use in the United States. This classification uses hierarchical approach to group wetlands in a way that is useful to resource managers, provide units for mapping, and establish uniformity with regards to concepts and terms. The hierarchical structure is divided into different levels comprising systems, sub-systems, classes and sub-classes (Finlayson & Van Der Valk, 1995). Five major systems were proposed; marine, estuarine, riverine, lacustrine and palustrine (Cowardin et al., 2005).

Another wetland classification system is the "*Hydrogeomorphic approach*" which was developed by Brinson in 1993 to meet the needs of United States Army Corps of Engineers, United States Environmental Protection Agency and

Natural Resources Conservation Service (Brinson, 1993; King, Wainger, Bartoldus, & Wakeley, 2000). Hydrogeomorphic approach classifies wetlands based on their position in the landscape, water source, and the flow of that water (Brooks et al., 2013). This was intended to support effort to develop methods to assess the physical, chemical and biological functions of wetlands and its strength lies in the extent to which it clarifies the relationship between hydrology and geomorphology and wetland function (Brinson, 1993). This classification system puts wetlands into seven major classes, which can be further divided into subclasses (King et al., 2000). The major flaw to this classification is that it does not cover man-made wetlands (Turner, Georgiou, & Fisher, 2012).

The current international wetland classification system which is widely accepted and in use in most countries is the one developed by the Ramsar Convention (Finlayson & Van Der Valk, 1995). It was recommended in the Fourth Meeting of the Conference of the Contracting Parties in 1990 (Fritz et al., 2017). The Contracting Parties are mandated to carry out wetland inventory to be incorporated in the various national wetland policy (Finlayson & Van Der Valk, 1995). It has been adopted by the International Union for Conservation of Nature (IUCN) and is currently used to describe the major habitats (Fritz et al., 2017)

In Ghana, it is stipulated in the National Wetlands Conservation Strategy that the Country’s classification is based on the Ramsar classification system (Ministry of Lands and Forestry, 1999). The three main wetland types found in

Ghana are marine/coastal, inland and man-made. Examples of wetland types and their location are listed in the National Wetlands Conservation Strategy.

2.1.3 Wetland Extent

With the exception of Antarctica, wetlands are found everywhere in the world. The global extent of wetlands is estimated to be approximately between 15.2 million and 16.2 million km^2 (Davidson & Finlayson, 2018). Of this, permanently inundated areas cover 54 percent and seasonally inundated areas account for 46 percent (Davidson, Fluet-Chouinard, & Finlayson, 2018). Inland wetlands make up 93 percent of global wetland extent and the remaining 7 percent is marine/coastal wetlands (Davidson et al., 2018).

Previous estimates of the extent and distribution of wetlands vary considerably. The significant increase of global area of wetlands over time does not indicate real temporal increase but can be attributed to the refinements in remote sensing methods and associated spatial analysis techniques (Davidson et al., 2018).

Asia has the largest areas of wetlands, 32 percent of the global extent, North America has 27 percent, Latin America and the Caribbean has 16 percent, Europe accounts for 13 percent, 10 percent for Africa and Oceania has the least of 3 percent of the total global area (Davidson et al., 2018).

Wetlands constitute about 4 percent (1.23 million km^2) of Africa land surface (Stevenson & Frazier, 2001). In sub-Saharan Africa wetlands cover approximately 4.7 percent (1.15 million km^2) of the land surface of the sub-region (Rebelo, McCartney, & Finlayson, 2010). The published studies on wetland extent and distribution in Africa is inadequate (Davidson, 2014;

Finlayson et al., 1999, Rebelo et al., 2010) compared to other geographical regions like North America and Europe. This is largely because many countries on the continent have not done national wetland inventory (Stevenson & Frazier, 2001).

Wetlands constitute about 10 percent of total land surface of Ghana and are distributed over the entire country (Ministry of Lands and Forestry, 1999). According to Stevenson & Frazier (2001), Ghana has about 14,730.75 km^2 of wetlands which is about 6.2 percent of the total land surface. Artificial wetlands have the largest area of about 8,952.25 km^2, inland wetlands cover an area of 4,600.50 km^2 and Marine/coastal wetlands have the least of the total area which is 1,1178.00 km^2 (Stevenson & Frazier, 2001). Based on Global Review of Wetland Resources and Priorities for Wetland Inventory (GRoWI) Africa dataset, Ghana falls under countries with some but inadequate national wetland inventory information. This implies that more work has to be done to obtain a more accurate data with regards to wetland extent, distribution and types.

2.1.4 Wetland Loss

Several studies have reported that the world has lost about 50 percent of its original wetlands since 1900 (Davidson, 2014; OECD, 1996) but this estimate was based on insufficient data (Davidson, 2014). A recent study by Hu et al. (2017), estimated global wetland loss until 1990 to be 33 percent. North America and Europe have experienced the largest losses (Davidson, 2014; Hu et al., 2017). A detailed comparison of continental wetland loss among two studies and a report is presented in Table 2. 1.

Wetlands are dynamic ecosystems and they continually change naturally as a result of natural processes such as drought, sea level rise, erosion and siltation (OECD, 1996). The changes driven by natural processes are considered normal and expected. However, direct or indirect anthropogenic activities have substantially altered the rate of wetland loss (Hu et al., 2017; OECD, 1996). In spite of the numerous services wetlands provide, they were widely seen as wastelands and were drained and converted into other human land use types such as urban space and agriculture (Millennium Ecosystem Assessment, 2005; Mitsch & Gosselink, 2015). According to Hu et al. (2017), one principal factor accounting for the vast wetland loss is high population growth which is often accompanied by high demand for food and housing facilities which accelerate agriculture development and urbanization.

Table 2.1 – *Estimated Regional Wetland Loss*

Continent	OECD (1995)	Davidson (2014)	Hu et al. (2017)
Period	Until 1985	Long term Average	Until 1990
Europe	50.6%	56.3%	45%
North America	50.6%	56%	8%
Asia	27%	45.1%	27%
Africa	2%	43%	16%
South America	6%	-	32%
Oceania	-	44.3%	18%
World	50%	54-57%	33%

2.1.5 Threats to Wetlands

Wetlands are among the most sensitive habitats in the world and affected by any little changes that occur in their environment (Moore, 2006). They are among the most threatened natural habitats on earth and serve as home to some important and endangered species that are essential for human survival (Daryadel & Talaei, 2014). Degradation or changes in the wetland extent affects its ability to provide goods and services for human population and also support biological diversity (Daryadel & Talaei, 2014).

Despite the increased public awareness and education towards conserving important natural ecosystems particularly wetlands, the threats continue to escalate. Threats to wetlands are classified into natural and human threats. The natural threats even though significant are minimal as compared to human threats. The natural threats include flooding, subsidence, drought and soil erosion (Daryadel & Talaei, 2014). Wetlands around the world are subjected to varied degree of disturbances by anthropogenic activities. The rapid growth of world population and the resulting demand for food and agricultural lands have led to the draining and converting of wetlands (Hollis, 1990). High population rate also drives urbanization which has negative repercussions on the wetland ecosystems. Other human threats to wetlands are release of urban, agricultural and industrial waste water and introduction of invasive species.

Data from the Ramsar Sites Information Service (https://rsis.ramsar.org/) database indicates that globally, pollution is the highest reported threat to Ramsar Sites and climate change/severe weather is the least reported threat. In Africa, biological resource use is the highest reported threat and geological events is the least reported threat. In Ghana, biological resource use and Human settlements share the top spot for reported threats and climate change/severe weather and water regulation are least reported threats (https://rsis.ramsar.org/). One key thing that runs through the threats ranking is that anthropogenic driven threats rank highest irrespective of the location of the Ramsar Site and natural processes are always the least reported threats.

2.1.6 Land Use Land Cover Changes of Wetlands

Land use/land-cover (LULC) change has become an important issue in global environmental change Studies. Assessing and tracking LULC changes are necessary for the evaluation of impact of change on the ecosystem at different scales and time (Devi, Vijayasekaran, & Kangabam, 2013). LULC Change is defined to include conversion of natural habitats into agricultural lands, pastures, reforestation of degraded lands and urban sprawl (Kilic, Evrendilek, Berberoglu, & Demirkesen, 2006). Studies have shown that globally, over the last 300 years areas of natural vegetation like forest has decreased and areas of human-induced lands like agricultural lands and built environment have increased (Houghton, 2003). Studies have also shown that the rate and the intensity at which LULC change is happening are becoming far greater than what it is used to be in the past (Rai, Zhang, & Paudel, 2018).

LULC changes account for loss of ecosystem and fragmentation of wetland landscapes (Torbick et al., 2006). The primary factor that drives LULC change is anthropogenic activities (Kilic et al., 2006). Assessment and monitoring of LULC change from remotely sensed data along with advancement of geospatial techniques have come to support field inventory of wetland resources

(Davidson et al., 2018) In recent times, remote sensing has been used to study LULC dynamics. Remote sensing provides numerous advantages in LULC studies and even more useful to wetlands and other areas that are unreachable.

2.1.7 Fragmentation of Wetland Landscapes

Fragmentation of natural habitats is currently an essential area in ecological studies and nature conservation because of its consequences on the ecosystem. Fragmentation is defined as breaking up of contiguous habitat into smaller and more isolated fragments as a result of both natural processes and human activities (Mcgarigal, 2015). Fragmentation analyses are carried out to quantify ecosystem changes and stress in order to assess ecosystem health of wetlands at different scales and time (Torbick et al., 2006). Fragmentation of habitats affects the structure and function of ecosystem (Ojoyi, Odindi, & Mutanga, 2016). It reduces the size and increases the isolation of habitats and population (Lienert & Fischer, 2003). Worldwide, fragmentation is considered as one of the major drivers of biodiversity loss (Cosentino & Schooley, 2018). Arif & Nakagoshi (2007), found out that fragmentation is increasing in wetland landscapes than in forest landscapes. Increase in wetland fragmentation is associated with the rise of anthropogenic activities in wetland landscapes (Liu, He, & Wu, 2016).

2.1.8 Wetland Sustainability

The wetland sustainability concept is derived from the sustainable development concept promulgated by IUCN, United Nations Environment Programme (UNEP), and World Wildlife Fund (WWF) (Lee, 1999). The purpose of the sustainable development concept is to ensure that development meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). Lee (1999), defined wetland sustainable use as "*ensuring that it increases the needs of environment, economy, and culture of the present generation without compromising the ability of future generations to meet their own needs*" However, there is always a challenge to achieve a win-win situation for all the three needs in the definition. Barker (2009), stated that wetlands are found in areas of competing pressures and that the commercial economic opportunities often overrides any other uses.

The growing populations and global-scale economics demand for large-scale developmental projects which results in the manipulation of the natural environment and its resources. Wetlands are usually more vulnerable compared to other natural habitats because they were previously perceived as unexploited wastelands (Daryadel & Talaei, 2014; Omagor & Barasa, 2018) which are available for developmental projects. Besides, issues of wetlands hardly feature in the discussions of formal economy of a country unless there is public outcry to protect them (Lee, 1999).

Apart from the anthropogenic activities that affects the sustainability of wetlands, some natural processes also affects the integrity of wetlands. Low-lying coastal wetlands are being eroded as result of rising sea levels (Kibria, 2016) degrading their ecological functions. Barker (2009), predicted that many more coastal wetlands will be eroded, whereas others will be formed on existing terrestrial areas. The challenge now is to find ways of retaining the integrity of wetland ecosystems in the presence of multiple stressors mainly from anthropogenic activities and periodically from natural phenomena.

2.2 Coastal Urban Wetlands

Coastal wetlands collectively comprise salt marshes, mangroves and associated unvegetated intertidal areas (Nicholls, 2004). The definition has been expanded to include coral reefs and sea grass beds (Li, Bellerby, Craft, & Widney, 2018). Coastal wetlands serve as habitats for diverse terrestrial and marine species and provide food sources for varied wild animals and waterbirds (Li et al., 2018). Approximately, two-thirds of marine organisms spend part of their life history on coastal wetlands (Li et al., 2018; Maltby, 1986). Coastal wetlands serves as spawning, nursery, and feeding grounds for several fish species and shellfish (Hinrichsen, 1999). More than 90 percent of marine fisheries are obtained from coastal areas through harvesting of wild animals and mariculture (Hinrichsen, 1999). Comparatively, area covered by coastal wetlands is smaller than other terrestrial ecosystems but their productivity is not significantly different from the others (Li et al., 2018). Coastal ecosystems play crucial role in the global Carbon sequestration (McLeod et al., 2011).

The coastal wetland being the transitional area between land and sea are threatened from both sides. Coastal areas are currently subjected to intense pressure from a wide range of natural processes and anthropogenic activities (Mitsch & Gosselink, 2015). Globally, more than 50 percent of coastal wetlands have been lost (Li et al., 2018). The fundamental factors contributing to coastal wetland loss are the increasing human population and needs (Hinrichsen, 1999; Nicholls, 2004). About two thirds of world population lives along the banks of wetlands, including rivers, lakes and beaches (Daryadel & Talaei, 2014). More than 10 percent of the world population live in coastal areas less than 10m above sea level and 40 percent in coastal areas within 100km of the coast (United Nations, 2017). Coastal areas are the most densely populated and economically developed areas (Zhang, Su, & Ding, 2017). In most countries in the world, coastal areas are characterized by overcrowding and overexploitation (Hinrichsen, 1999). These threats have led to degradation of coastal ecosystems and in some cases the damages are irreparable.

In developing countries, most of the fast growing towns and cities are found in coastal areas and are the hotspots for most of the economic activities and job opportunities (Hinrichsen, 1999). This has led to mass movement of people from the interior to coastal urban areas especially in the developing regions (Hinrichsen, 1999). Currently, about 55.3 percent of the world's population live in urban settlements and it is estimated to increase to 60 percent by 2030 (United Nations Department of Economic and Social Affairs Population Division, 2018).

Urban landscape transformation, has progressively become a major issue facing metropolitan areas in many parts of the world (Ji et al., 2015). According to Ramsar Convention Secretariat (2008), urban landscapes are under severe pressure for various uses and wetlands bear the heaviest of them all. Even though there has been rapid development in technology, it is unable to take away the intense pressure from the growing population and urbanization on urban natural habitats (Eppink et al., 2004). As urbanization processes progress, landscapes are reconfigured according to the increasing needs of the people, which amplifies the instability of natural systems and intensifies environmental impacts and risk situations (Souza, Vale, & Oliveira, 2017).

2.3 The Ramsar Convention on Wetlands of International Importance

In 1971, representatives from eighteen (18) countries met in Ramsar, a city in Iran to develop a framework for national action and international cooperation for the conservation and wise use of wetlands and their resources (Moore, 2006). This conference gave birth to an inter-governmental treaty called "*Convention on Wetlands of International Importance especially as Waterfowl Habitat*" and commonly known as Ramsar Convention. The primary goal that led to the Convention was to protect the essential habitats of migratory birds (Barker, 2009). Ramsar Convention acknowledges the importance of protecting wetlands that are interconnected at the global level to safeguard resting, feeding and breeding sites for migratory birds (Barker, 2009). Currently, 170 countries are signatory to the convention with 2,341 designated sites covering 252,479,417 hectares of the earth surface (Ramsar, 2019). Figure 2.1 illustrates the cumulative annual number of Ramsar Sites and area covered from 1974 to 2016.

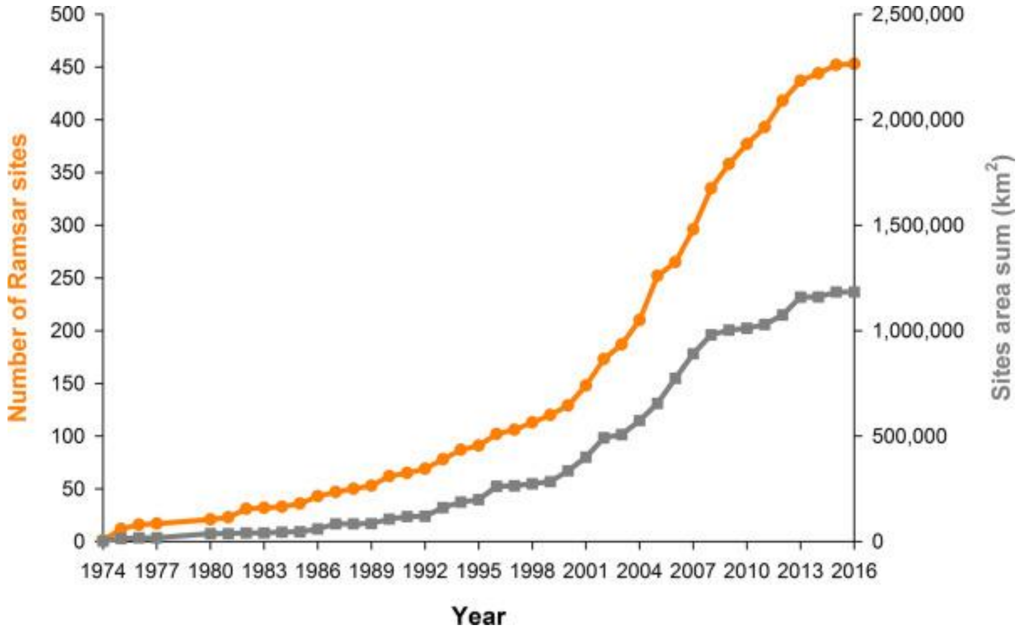


Figure 2.1: Cumulative annual number and area of Ramsar Sites (Fritz et al., 2017)

The United Kingdom has the highest number of Ramsar Sites of 170 and Bolivia is the country with the largest area of 148,000 km^2 covered by Ramsar Sites (“Ramsar Sites around the World | Ramsar,” n.d.). In terms of regional variations, Europe has the highest number of Ramsar Sites and Africa has the largest area covered by Ramsar Sites (Ramsar Sites Information Service, 2014). Figure 2.2 provides the detail information on the regional variations.

Ghana became a signatory to Ramsar Convention on 22th June, 1988. Currently, the country has designated 6 sites as Wetlands of International Importance covering land surface area of 176,134 hectares.

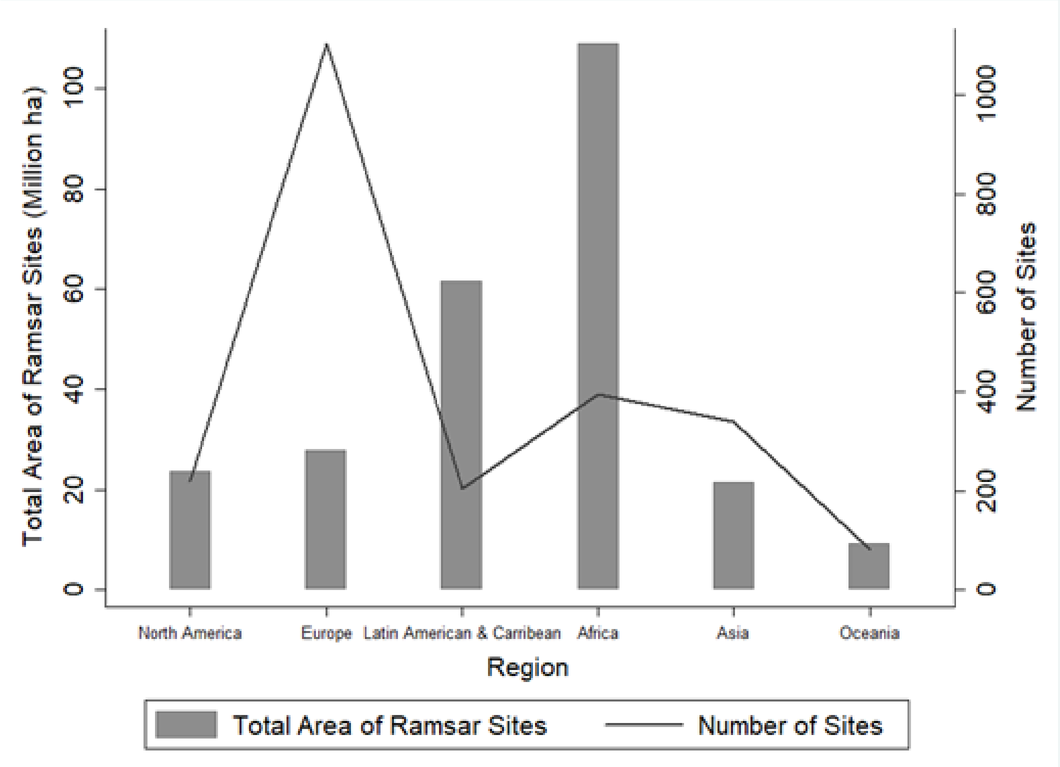


Figure 2.2: Regional variation of number of Ramsar Sites and area covered Data set extracted from Ramsar Sites Information Service (https://rsis.ramsar.org)

2.4 Ecosystem Health Concept

The fundamentals of ecosystem health concept was set in the eighteenth century with the ideas of James Hutton, who described the earth as an integrated system (Burkhard, Müller, & Lill, 2008). The concept is now extensively used and forms the basis for several national and international programs, especially regarding the management of many ecosystems (Rapport et al., 1999). It encompasses biophysical, socioeconomic, cultural, and human dimensions of the environment (Burkhard et al., 2008).

Costanza & Mageau (1999) stated that an ecological system is healthy and free from distress syndrome if it is stable and sustainable that is, if it is active and maintains its organization and autonomy over time and also resilient to stress. Ecosystem health is made up of three components; vigour (function/productivity), organization (structure) and resilience (Costanza & Mageau, 1999). Ecosystem health has a direct link with sustainability (Burkhard et al., 2008; Costanza & Mageau, 1999; Rapport et al., 1999) which implies that a healthy ecosystem is the one that is able to maintain its original state (vigour and organization) over time after experiencing an external stress or perturbation.

2.4.1 Ecosystem Health Assessment

Ecosystem health assessment is an ecosystem management tool (Dai, Ma, & Zhang, 2013). The idea behind the ecosystem health assessment is parallel to human health assessment (Jörgensen, 2005; Rapport et al., 1999). Rapport (1989), stated three approaches in assessing ecosystem health. The first is by identifying key characteristics or vital signs that differentiate sick ecosystems from healthy ecosystems. The second approach measures the ability of the ecosystems to recover after stress. The last approach is by identifying the risk factors.

There are three things that are essential in ecosystem health assessment according to Costanza & Mageau (1999). The assessment should have a set of weighting factors to compare the different components of a system. The relative importance of constituents of an ecosystem is not the same, weighting should therefore be applied to reflect the value of different components. Secondly, scale or space is also important. Assessment of health of an ecosystem should be comprehensive enough to cover all components of the ecosystem.

Considering only one part implies that the remaining parts are not important. The assessment should be large enough to cover all the relevant parts. Lastly, time is also equally important in ecosystem health assessment. Some components of a system have longer life span than others but no component or the system itself has infinite life span. In summary, ecosystem health assessment should be comprehensive, multiscale, dynamic and hierarchical (Costanza & Mageau, 1999).

2.4.2 Geospatial Assessment of Ecosystem Health

Conventionally, ecosystem assessment is carried out using field data or models fed by field data. The traditional approach cannot be widely employed at a large spatial scale and difficult to be used in assessing ecosystem health at varying spatial and temporal scale (Kerr & Ostrovsky, 2003). However, there is a pressing need to understand and monitor the spatial heterogeneity of ecosystem health for better conservation strategies (Li, Xu, & Guo, 2014).

Geospatial technologies such as Remote Sensing and Geographic Information System (GIS) present immense potentials assessing the health of ecosystems at different spatio-temporal scales of large areas (Ludwig, Bastin, Chewings, Eager, & Liedloff, 2007). Global Positioning System (GPS) enables precise location of sampling points for repeated field measurements. GIS is a computer based system that provides enormous abilities to collect, organize, analyse and present geographic data over both space and time. Advancement in Remote Sensing has brought about finer resolution devices for collecting information on the earth surface. The Geospatial technologies present great opportunities in carrying out retrospective and prospective assessment of ecosystem health.

Up till now, most of the application of geospatial technologies in ecosystem health assessment has been on single ecosystem component such vigour (net/gross primary productivity) organization (species diversity) and resilience (response to stress like fire or climate change) (Ludwig et al., 2007). The challenge with geospatial technologies is that not all the ecosystem health indicators can be measured. Besides, geospatial assessment requires personnel with the technical know-how to execute.

2.4.3 Ecosystem Health Indicators

Ecosystem health is assessed using surrogate measures called indicators (Burkhard et al., 2008). An indicator is defined as a variable that describes the state of a system (Walz, 2000). The choice of indicators are backed by ecological principles and systems theory and must be suitable for assessment on varying temporal and spatial scales (Burkhard et al., 2008). The choice of indicators also depends on the goals, and objectives of the assessment. The indicator should be sensitive enough to react to a detectable level at slight changes in the ecosystem and should be predictable in an unperturbed system (Niemi & Mcdonald, 2004). Ecosystems are complex and single indicator cannot effectively diagnose the status of an ecosystem. Different suites of indicators are used in practice to evaluate different ecosystems. The ecological indicators have been at the gene level through to the landscape level (Niemi & Mcdonald, 2004). Climatic conditions are not used as indicators for ecosystem health assessment because they are natural conditions (Jørgensen, Xu, & Costanza, 2010).

In the time past, the selection of ecological indicators were predominantly based on parameters related to individual species or community metrics but, most of them could not give comprehensive representation of biological community of organisms present (Niemi & Mcdonald, 2004). Multi-metric indices such as Index of Biological Integrity (IBI) were later introduced. Currently, multivariate indexes of the biological community are analysed using multivariate statistical techniques such as principal components analysis (PCA) canonical correspondence analysis (CCA) (Niemi & Mcdonald, 2004).

The goal of this study is to evaluate the ecosystem health of coastal urban wetland employing geospatial techniques. It implies that all the indicators selected should be measured and analysed using geospatial technologies. The ecosystem health indicators adopted for this study were ecosystem structure, ecosystem function and resilience. These indicators were derived from the ecosystem health components postulated by Costanza & Mageau (1999) thus, vigour, organization and resilience. Vigour and organization were modified into function and structure respectively.

Ecosystem Structure: National Research Council (2005) defined ecosystem structure as both the composition of the ecosystem and the physical and biological organization defining how those parts are organized. Skidmore et al. (2015), proposed ten variables that can be monitored by satellite towards the tracking of Aichi biodiversity targets. Under ecosystem structure, four variables were proposed; ecosystem distribution, fragmentation and heterogeneity, land cover and vegetation height.

Ecosystem function: it refers to the process that takes place in an ecosystem as a result of the interactions of plants, animals, and other organisms or their environment (National Research Council, 2005). The study considered two of the four variables proposed by Skidmore et al. (2015). The variables are vegetation phenology (variability) and inundation.Vegetation phenology is a key indicator for observing changes in the natural environment (Richardson et al., 2013). Vegetation phenology is commonly detected from multispectral remote sensing data by computing for the Normalized Difference Vegetation Index (NDVI) (Wu, 2018). NDVI indicates plant vigour and potential productivity (Walters & Scholes, 2017).

Among all wetland indicators, hydrology is a critical factor because, it affects the formation and functions of wetlands (Wu, 2018). Inundation was estimated using the Normalized Difference Water Index (NDWI). NDWI is efficient in detecting surface water and is used in delineating open water features and enhancing their presence in satellite images (McFeeters, 1996).

Ecosystem Resilience: it refers to the the capacity of an ecosystem to withstand external pressures and return to its pre-disturbance state over time (Yan, Zhan, Liu, Huang, & Li, 2014). Resilience can be assesed by quantifying the extent of wetland loss. Lein (2014) estimated wetland loss by estimating the extent of impervious surface. Man-made structures such as roads, pavements and roof tops that are made up of impervious materials are indicative of built environment. The extent of impervious surface is useful indicator of development intensity and human induced modification of the wetland landscape (Lein, 2014).

CHAPTER THREE

MATERIALS AND METHODS

The goal of the study is to assess the ecosystem health of wetlands using geospatial techniques. In order to achieve this, ecological indicators that can be measured and analysed using Remote Sensing and Geographic Information Systems (GIS) techniques were selected based on literature and parsimony. The ecological indicators adopted for this study were primarily derived from the ecosystem health components postulated by Costanza & Mageau (1999). They suggested three components in their study; vigour, organization and resilience. In the present study, the components were modified into ecosystem structure, ecosystem function and resilience. The main thrust of the methodology for this research is the use of remotely sensed data and techniques in evaluating wetland ecosystem health. The chapter begins with description of three Ramsar sites that jointly constitute the study area. Ecological indicators as well as the data collection and analyses are then presented.

3.1 Study Area

The study was carried out in three coastal urban wetlands; Muni-Pomadze, Densu Delta and Sakumo II Ramsar Sites. The three study sites are among the six wetlands designated as wetlands of International Importance in Ghana. Based on the criteria of the Ramsar Convention, the three wetlands are classified as marine/coastal wetlands (Ministry of Lands and Forestry, 1999). All three Ramsar Sites are located in or close to urban settlements.

3.1.1 Densu Delta Ramsar Site

The Densu Delta Ramsar Site is found in the south-western part of Accra, about 11km from the capital city. The Ramsar Site constitutes the lower reaches of the Densu River water course and its confluence with the Atlantic Ocean and occupies an area of about 46.2 km^2 (Gbogbo & Attuquayefio, 2010). It is located between latitude 5^{0}31'N and longitude 0^{0}20'W (Figure 3.1). The wetland consists of open lagoon, salt pans, sand dunes, marsh and scrub, which serve as favourable grounds for feeding, roosting and nesting of seashore birds (Ntiamoa-Baidu & Gordon, 1991). The area has bimodal rainfall pattern with mean annual rainfall of about 800 mm and mean temperature ranges from 24.2^{0}C to 31^{0}C (Denutsui et al., 2012).

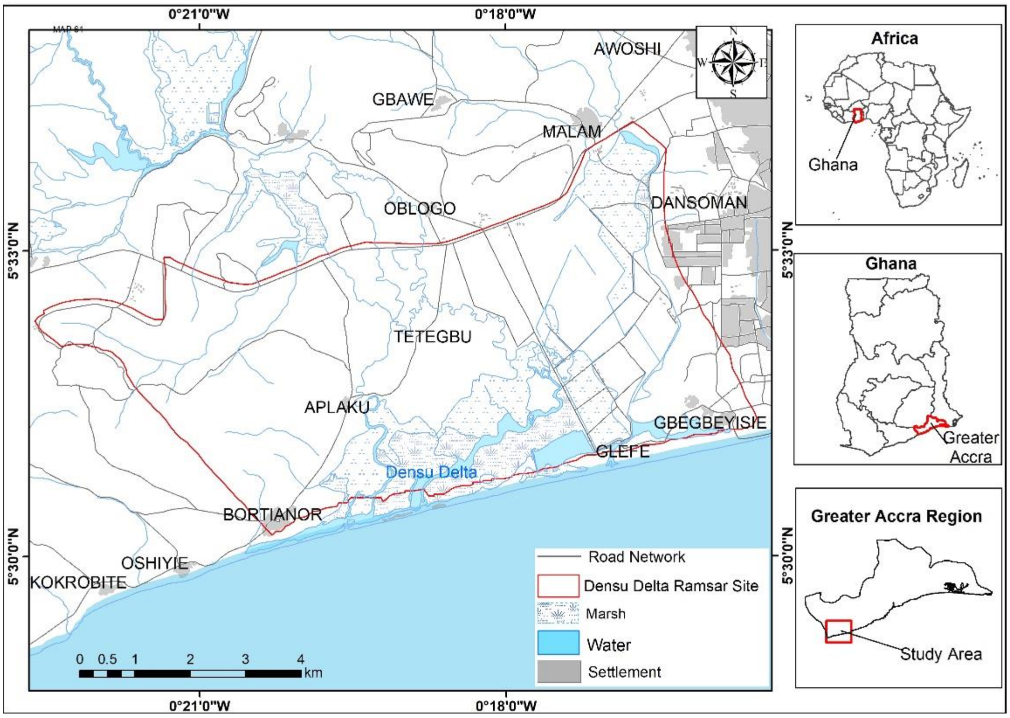


Figure 3.1: A Map Showing the Location of Densu Delta Ramsar Site

According to Ntiamoa-Baidu & Gordon (1991), there are five major habitats found in the Ramsar Site ; freshwater marsh, brackish lagoon, sand dunes, salt pans, coastal savanna grassland and thickets. The wetland is predominantly occupied by shrub and grassland. Some of the common vegetation found in the wetland are *Sporobolus virginicus, Avicennia africana, Paspalum vaginatum, Sesuvium portulacastrum, Cyperus articulatus* and *Imperata cylindrica* (Gbogbo & Attuquayefio, 2010). The Densu Delta Ramsar Site is a habitat for several species of resident and migratory birds. It serves as home for about 57 species of seashore birds with an estimated population of 35000 and about 15 species of finfish belonging to 14 genera and 9 families with *Sarotherodon melanotheron* and *Tilapia zilli* as the predominant fish species (Denutsui et al., 2012). The main livelihood activities of the people in the surrounding communities are fishing , large scale commercial salt extraction and peasant farming (Ntiamoa-Baidu & Gordon, 1991; Denutsui et al., 2012).

3.1.2 Sakumo II Ramsar Site

Sakumo II Ramsar Site is located in the Tema Metropolitan Assembly, about 15km East of Accra. It is situated between latitude 5^{0}37'N and longitude 0^{0}30'W (Figure 3.2). The Ramsar Site covers a total area of 13.4km^2 (Gbogbo, Langpuur, & Billah, 2012). According to Ntiamoa-Baidu & Gordon (1991), the mean monthly temperature ranges from 24^{0}C (minimum) in August to 29^{0}C (maximum) in March. And the mean annual rainfall is 578.5 mm. The main livelihoods of the surrrounding communities are fishing, large scale commercial salt extraction and peasant farming (Ntiamoa-Baidu & Gordon, 1991; Denutsui et al., 2012).

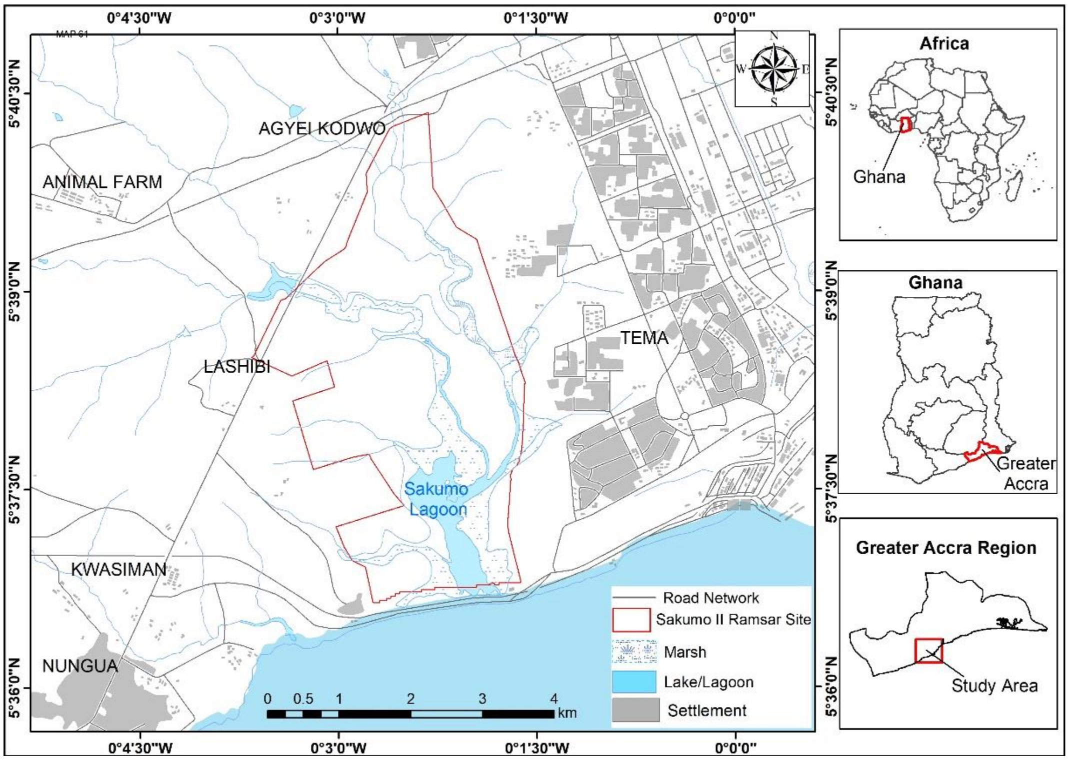


Figure 3.2: A Map Showing the Location of Sakumo II Ramsar Site

The wetland comprises an open lagoon, a floodplain and a freshwater marsh. The lagoon, depending on the season, covers an area of 1-3.5 km^2 and the flood plain surrounding the lagoon is about 7 km^2 (Ntiamoa-Baidu & Gordon, 1991). A narrow sand dune separates the lagoon from the Atlantic Ocean. The lagoon used to be a closed lagoon until a sluice was constructed in 1953 to link it to the sea during the construction of the Accra-Tema Beach Road (Ofori-Danson & Kumi, 2006). Two main rivers flow into the Sakumo II lagoon; Gbagbla Ankonu and Mamahuma, with an estimated catchment of about 222 km^2 (Ntiamoa-Baidu & Gordon, 1991).

There are four main types of habitats in the Sakumo II Ramsar Site as identified by Ntiamoa-Baidu & Gordon (1991); the freshwater marsh, open lagoon, coastal savanna grasslands and the surrounding floodplain. The dominant plant species in the Ramsar Site are *Bothriochloa bladhii Sesuvium portulacastrum Imperata cylindrica* and *Typha domingensis*. The open water is periodically covered with floating water lettuce, *Pistia stratiotes*. Sakumo II Ramsar Site provides habitat for about 57 species of seashore birds with an estimated population of 35000 and about 15 species of finfish belonging to 14 genera and 9 families with *Sarotherodon melanotheron* and *Tilapia zilli* as the predominant fish species (Ntiamoa-Baidu & Gordon, 1991).

Owing to the fact that the Ramsar Site is sandwiched between two major cities (Accra and Tema), the threats to the site are urban related activities (Gbogbo et al., 2012). The wetland is threatened by pollution from domestic and industrial solid/liquid wastes; overexploitation and urbanization are also major threats to the wetlands as a result of rapid human population growth.

3.1.3 Muni-Pomadze Ramsar Site

The Muni-Pomadze Ramsar Site is situated to the west of Winneba in the Central Region of Ghana, about 55 km from Accra and occupies an area of approximately 95 km^2 (Gordon, Ntiamoa-baidu, & Ryan, 2000). It encompasses the catchment of three seasonal streams, Pratu, Boaku and Muni which drain into the Muni lagoon. The Muni Lagoon covers an area of 3 km^2. It is located between latitude 5^{0}190-5^{0}270 N and longitude 0^{0}370-0^{0}410 W. This Ramsar Site is bounded by the Gulf of Guinea at the south, to the west by the Yenku Forest Reserve and to the East by Winneba Township (Figure 3.3). The Muni-Pomadze Ramsar Site was designated as a Ramsar Site due to its importance as a breeding and nesting site for migratory and resident waterbirds, insects, and terrestrial vertebrates (Ryan & Attuquayefio, 2000). It also serves as the traditional hunting grounds for the annual '*Aboakyir*' festival of the Efutu people (Ntiamoa-Baidu & Gordon, 1991)

The Muni-Pomadze Ramsar Site is generally a low lying undulating plain with two prominent isolated hills; the Ejisimanku Hills located at the south west and the Yenku Hills to the north east (Gordon et al., 2000). The parent rock at the Ramsar Site is generally Upper Birimian (Greenstone) at the western part and Tarkwaian quartzschists and biotite-hornblende at the eastern part with clay being the predominant soil (Gordon et al., 2000). The mean annual bimodal rainfall is about 854mm and mean temperature ranges from 24^0C in August to 29^0C in March; and relative humidity ranges between 75–80% (Wuver & Attuquayefio, 2006).

The Muni-Pomadze Ramsar Site falls within the coastal savanna vegetation zone. It has four main habitat types; the floodplain grassland, open water, degraded forest and scrubland (Ntiamoa-Baidu & Gordon, 1991). The banks of the lagoon are occupied by *Sesuvium portulacastrum, Paspalum virginicum* and *Sporolobus virginicus* and the sand bar vegetation is dominated by *Alternanthera maritima, Canavalia rosea, Cyperus maritimus* and *Remirea maritima*(Gordon et al., 2000). *Cocos nucifera* has been planted on the sand bar. The predominant grass species include *Andropogon gayanus, Hetero-pogon contortus, Panicum maximum,* and *Sporobolus pyramidalis* and portion the falls within the Yenku Forest Reserve was converted into Eucalyptus, Neem, and Teak plantations (Wuver & Attuquayefio, 2006).

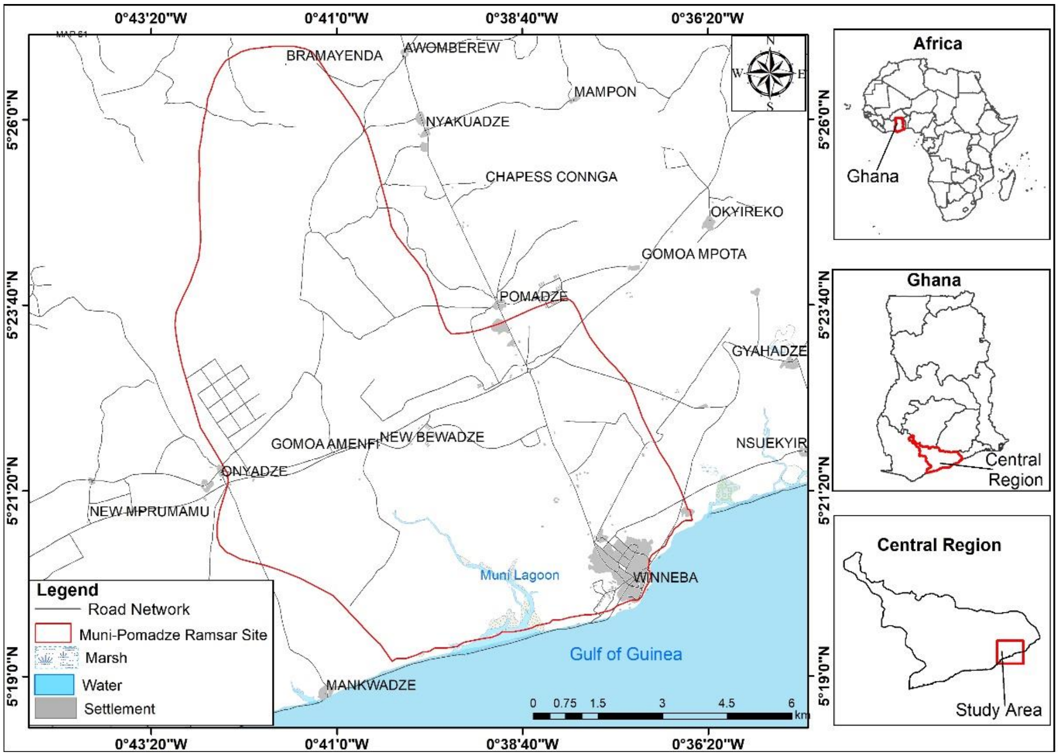


Figure 3.3: A Map Showing the Location of Muni-Pomadze Ramsar Site

The Muni-Pomadze Ramsar Site serve as abode for an estimated population of 23,000 waterbirds including waders, terns and herons/egrets (Ntiamoa-Baidu & Gordon, 1991). According to Amatekpor (1994) cited in Gordon et al. (2000), there are five main land use/land cover categories in the Ramsar site (i) Built-up areas (1197ha), (ii) Agricultural lands (3084ha), (iii) Natural vegetation (5038ha), (iv) Water bodies/floodplain (114ha) and (v) Salt pans and salt flats (25ha). For management purpose, the site is divided into five zones comprising; core area, traditional hunting grounds, controlled zone, land use management area and settlements.

3.2 Ecosystem Health Indicators

A plethora of indicators have been used to assess wetland ecosystem health for different purposes. The goal of this study was to evaluate the ecosystem health of coastal urban wetland employing geospatial techniques. It implies that all the indicators selected should be measured and analysed using geospatial technologies. The ecosystem indicators adopted for this study were ecosystem structure, ecosystem function and resilience. These indicators were derived from the ecosystem health components postulated by Costanza & Mageau (1999) thus, vigour, organization and resilience. Vigour and organization were modified into function and structure respectively.

In this study, LULC change and fragmentation were considered under ecosytem structure. Landscape Deviation Degree (LDD) was computed to represent LULC change. LDD quantifies the extent at which anthropogenic activities have changed the natural landscape (Chunxiao, Zhiming, & Nan, 2008). The formula for calculating LDD is:

LDD = the sum of all artificial surfaces/ total area of land (1)

Fragmentation refers to the breaking up of a habitat or land use type into small parcels (Cairns, McCormick, & Niederlehner, 1992). It is either caused by natural processes or anthropogenic activities. Fragmentation has ill-effects on the ecosystem including loss of habitat area. In the study, fragmentation of the wetlands was assessed using the retained class indices from the Principal Component

Analysis (PCA). Land use/land cover types were quantified after satellite image classification.

The study considered two of the four variables proposed by Skidmore et al. (2015) for ecosystem function. The variables are vegetation phenology (variability) and inundation. Vegetation phenology is commonly detected from multispectral remote sensing data by computing for the Normalized Difference Vegetation Index (NDVI) (Wu, 2018). NDVI indicates plant vigour and potential productivity (Walters & Scholes, 2017). The formula for calculating NDVI is:

$$NDVI = (NIR - Red) / (NIR + Red) \qquad (2)$$

NIR and Red represent the spectral reflectance values acquired in the near-infrared and red portion of the electromagnetic spectrum, respectively. NDVI values range from −1 to +1. NDVI values from -1 to 0 indicate no vegetation whereas values close to +1 indicate the highest concentration of green vegetation.

Inundation was estimated using the Normalized Difference Water Index (NDWI). NDWI is efficient in detecting surface water and is used in delineating open water features and enhancing their presence in satellite images (McFeeters, 1996). The formula for computing NDWI is:

$$\text{NDWI} = (\text{Green}-\text{NIR}) / (\text{Green}+\text{NIR}) \qquad (3)$$

NIR and Green represent the spectral reflectance values acquired in the near-infrared and green portion of the electromagnetic spectrum, respectively. NDWI values range from −1 to +1. Positive values indicate water features whilst negative to zero values indicate soil and terrestrial vegetation features.

Resilience was assesed by quantifying the extent of wetland loss. The wetland loss was quantified by estimating the impervious surface using Lein (2014) method. Impervious surface was computed from the area covered by built-up. Another variable considered under Resilience was persistence of the wetland LULC. Persistence was computed by subtracting the areas of the wetland that experienced changes from the total area of the wetland.

3.3 Data Collection and Analysis

The study employed both primary and secondary data to achieve the intended objectives. The primary data consist of Unmanned Aerial Vehicle (UAV) images of the three study locations, Global Position System (GPS) coordinates and expert knowledge on wetland ecosystem health. The UAV images and the GPS coordinates were used in the classification and validation of the satellite images. The expert knowledge was used to weight the three main criteria and indicators used in assessing the ecosystem health of wetlands.

The secondary data comprise multi-year (1985, 2002 and 2017) satellite images of the study area, Google Earth images of the three Ramsar Sites, rainfall data from 1982-2012 and population data of the cities in which the Ramsar Sites are located (Accra, Tema and Winneba). The ecological indicators were extracted from the satellite images after they had been subjected to image processing and analysis. The maps of the Ramsar Sites were digitized from the coastal wetland management plan and were used to clip out the study areas from the satellite images. The Rainfall data were obtained from Ghana Meteorological Authority. The population data were obtained from the 2010 Population and Housing Census National Analytical Report (Ghana Statistical Serice, 2013) was also examined to observe any population trend that could be relevant to the study. Figure 3.4 is a flow chart that illustrates how the data collected were analysed to achieve the objectives of the study.

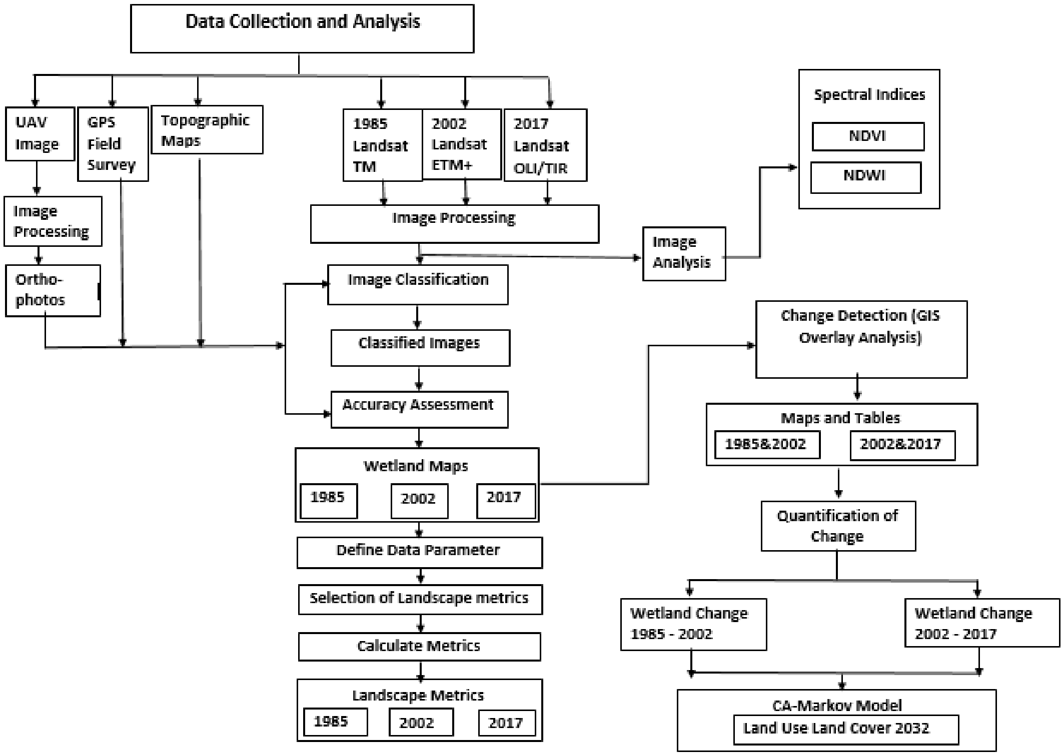


Figure 3.4: Flow Chart of Data Collection and Analysis

3.3.1 Expert Knowledge on Wetland Ecosystem Health Assessment

Ecosystem health assessment requires social and biophysical considerations. However, it is extremely problematic to accurately evaluate and quantify changing social preferences and also aggregate conflicting opinions of different stakeholders. The relative importance that the various stakeholders place on the indicators will definitely differ. In view of this, the indicators used in assessing ecosystem health should be weighted as suggested by Costanza & Mageau (1999).

The Analytic Hierarchy Process (AHP) is a multi-dimensional, multi-level and multifactorial decision-making method (Pecchia et al., 2013) that provides a systematic and robust means of eliciting and quantifying subjective judgments (Schmoldt, Peterson, & Smith, 1995). AHP is an effective mechanism for quantifying opinions of experts that are based on knowledge and personal experience to develop a consistent decision framework (Pecchia et al., 2013). In solving a particular problem or making a decision, pairwise comparisons are performed between criteria and sub criteria at each level of the hierarchy and also between the possible alternative decisions.

In this study, AHP was employed to design a decision framework for assessing ecosystem health wetlands (Figure 3.5). The first level of the hierarchy represents the goal; wetland ecosystem health assessment. The second level is the criteria which are the three ecological indicators considered in this study (structure, function and resilience). The third level of the hierarchy represents the sub criteria which are a set of variables that feed into a specific criterion. In all, 20 experts with diverse backgrounds were interviewed. A copy of the questionnaire used in collecting the experts' opinions is found in Appendix A. The weights of the criteria and sub criteria were calculated using the steps stated in Saaty (1987). The consistency ratio was also computed. The weighting values were defined according to Saaty (1987).

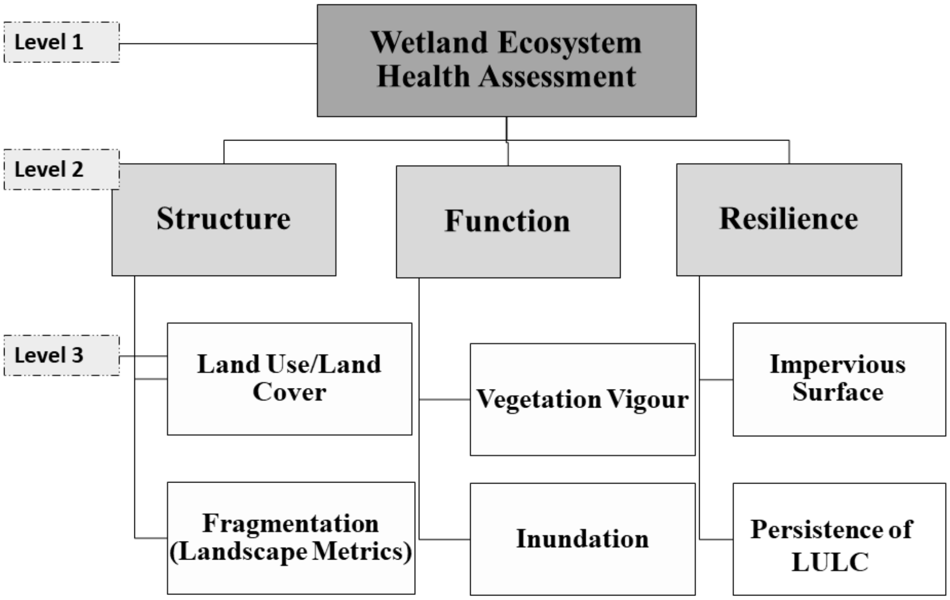


Figure 3.5: Analytic Hierarchy Process for Wetland Ecosystem Health Assessment

3.3.2 UAV Image Acquisition and Processing

Using Landsat satellite images for geospatial analysis requires ground referenced data which is often inaccessible or expensive to acquire high resolution satellite imagery. Studies have shown that UAV can equally provide high resolution data to serve the same purpose (Marx, McFarlane, & Alzahrani, 2017). In this study, some of the training samples for the Landsat satellite image classification and validation were selected from the UAV data.

DJI Phantom 3 Professional UAV from the Centre for Coastal Management was used to capture aerial photos of the Ramsar Sites. The onboard camera has a 1/2.3 inch sensor and 12 megapixels capable of performing programmed GPS missions with waypoints as well as fully autonomous flight missions. The images were captured at nadir view at an altitude of 150m above ground level (AGL) with ground sampling point of 1.5cm. Map Pilot v2.7 software was used to design the flight paths and also for controlling the autonomous flying of the UAV. The photos were taken at a frontal overlap (with respect to flight direction) of 80 percent and side overlap (between flight tracks) of 75 percent. After the images were captured, Pix4DMapper software was used to process the images at each Ramsar Site into seamless orthomosaic image. Appendix B show the orthomosaic photos.

3.3.3 Landsat Satellite Image Acquisition and Classification

The United States Geological Survey Department have produced and made available Landsat satellite data since 1972. Landsat satellite data have been used for historical study of land surface changes because of their continuous observation and free accessibility. In this study, Landsat satellite images for the years 1985, 2002, and 2017 were downloaded from the United States Geological Survey website (USGS EarthExplorer, 2019). The details of the Landsat satellite images are found in Table 3.1

Table 3.1 – *Landsat Satellite Images Used in the Study*

Satellite	Sensor	Path/Row	Spatial Resolution (m)	Acquisition Date	Source
Landsat 5	TM	193/56	30	06/03/1985	USGS 2018
Landsat 7	ETM+	193/56	30	26/12/2002	USGS 2018
Landsat 8	OLI/TIRS	193/56	30	11/12/2017	USGS 2018

The satellite images were classified using Supervised Classification with Maximum Likelihood Classifier in ENVI v.5.3. Radiometric and atmospheric corrections were done at the preprocessing stage. The individual bands of the satellite images were stacked and projected into the Universal Transverse Mercator (UTM) projection system (Zone: 30N, Datum: WGS84). The boundary of the wetlands were delineated using Ramsar Site maps from Ntiamoa-Baidu & Gordon (1991). Existing topographic maps and Google Earth images of the study areas were used as reference data for the classification of 1985 and 2002 Landsat images. Training samples collected from the processed UAV images and GPS coordinates served as reference data for the classification of the 2017 satellite image. Densu Delta and Sakumo II Ramsar Sites were classified into four LULC classes; marsh, thicket, water and built-up/bareland. Muni-Pomadze Ramsar Site had a different classification scheme. It was classified into six classes; Dense forest, shrub/grassland, water, built/bareland, burnt land and cultivated land. Even though burnt land is usually not regarded as LULC class, it was observed in all the study years. Cultivated land represented a mosaic of farm lands and fallow lands. UAV and Google Earth images and ground truthing data were used in the accuracy assessment.

3.3.4 Land Use Land Cover (LULC) Change

After the image classification, LULC maps of all the time periods (1985, 2002, and 2017) for the wetlands were developed. Post-classification comparison was carried out to estimate changes in the LULC classes and dynamism with the changes. Change detection statistics tool in ENVI 5.3 was used to quantify changes that occurred between the two time intervals in the wetlands.

3.3.5 Intensity Analysis of LULC Change

Intensity Analysis was carried out to understand the sizes and intensities of temporal changes among categories. Intensity analysis comprises three levels: Interval, Category, and Transition (Aldwaik & Gilmore, 2012; Gyöngyi, Pontius, Singh, & Szabó, 2019). The Interval level estimates the overall change during each time interval. This determines the time interval in which the overall annual rate of change was relatively slow or fast. The Category level assesses the gains and losses of each category during each time interval. The Transition level assesses how the gain of a category transitions from other categories during each time interval. The intensity was done using an open source Excel program from intensity analysis website (“Intensity Analysis,” n.d.). The formulae used in developing the software are in Aldwaik & Gilmore (2012).

3.3.6 Land Use Dynamic Degree

Land use dynamics describe the severity of change in land use and enable comparison of land use in different areas. The severity of LULC change of the wetlands was evaluated using integrated land use dynamic index and single land use dynamic degree.

The single land use dynamic degree (SLDD) of land-use/land-cover is used to quantitatively monitor the change in intensity of one land use type (Zhao, Zhang, Fu, & Zhang, 2012).

The degree of Integrated Land-Use Dynamic Degree (ILDD) is the integrated numeric changing of all the categories of land use during the study period in a defined area.

Zhao et al., (2012) formulae for computing SLDD and ILDD were used in this study.

3.4 Simulation of Built-Up/Bareland Growth in Coastal Urban Wetlands

The Markov Chain and Cellular Automata Analysis (CA-Markov) model was used to predict LULC change in the three Ramsar sites. CA-Markov models combine a Markov algorithm to simulate the quantity of change and a Cellular automata (CA) algorithm to simulate the allocation of change (Singh, Mustak, Srivastava, Szabó, & Islam, 2015). CA-Markov models have been used to simulate changes and estimate variations using satellite images (Arsanjani, Helbich, Kainz, & Boloorani, 2013). Cellular Automata (CA) employs proximity concept to show the regions which are closer to the existing areas of the same class are more likely to change to a different class. The transition probability matrix determines the likelihood that a cell or pixel will move from a land use category or class to every other category (Singh et al., 2015).

Land use land cover simulations for the study areas were carried out using the Land Change Modeler (LCM) in Terrset software. The purpose of the simulation was to predict the expansion of built-up/bareland, thus the transition of other LULC classes to built-up/bareland. Transition probability matrix were computed for the years 2017 (using LULC maps of 1985 and 2002) and 2032 (using LULC for 2002 and 2032). The transition probability matrix show areas that are likely to be transitioned to other classes. The driver variables included in the models were land cover map, distance to road, digital elevation model (DEM) and slope. The drivers were used to develop the transition potential models. Using the transition probability matrix and the transition potential model, 2017 maps were developed. The Kappa Components and Cramer’s V Statistics were used to validate the predicted maps for 2017 with 2017 LULC maps of 2017 serving as the reference. After the validation process, the predicted maps for 2032 were generated.

3.5 Wetland Landscape Fragmentation Analysis

The landscape pattern indices were computed to quantitatively describe the landscape structure transformations in the study areas. To identify the appropriate metrics for the study, thirty-nine (39) class metrics were calculated in FRAGSTATS v.4.2. Even though there are several software that can be used to compute landscape metrics, FRAGSTATS was selected because it provides comprehensive options of landscape metrics (Adade et al., 2017).

Spearman correlation was run to eliminate high correlating indices. One of the indices with Spearman’s Correlation Coefficient above 0.8 or less than -0.8 were eliminated to reduce redundancy. A Principal Component Analysis (PCA) was then carried out to determine the indices that explain much variance in the landscape indices dataset. Detailed descriptions of the landscape metrics and the formulae used in calculating them are found in the FRAGSTATS user’s guide (Mcgarigal, 2015). PCA was then carried out to determine the indices that explain much variance in the dataset. Detailed descriptions of the landscape metrics and the formulae used in calculating them are found in the FRAGSTATS user's guide (Mcgarigal, 2015). The indices that loaded highly in the components were selected to represent fragmentation in the ecosystem health analysis.

From the PCA, eleven (11) indices were selected; largest patch index (LPI), core area percentage of landscape (CPLAND), total edge (TE), landscape division index (DIVISION), splitting index (SPLIT), mean edge contrast (ECON_MN), edge density (ED), contrast-weighted edge density (CWED), patch density (PD), mean patch fractal dimension (FRAC_MN) and similarity index (SIMI_MN).

LPI quantifies the percentage of total landscape area occupied by the largest patch. It describes dominance of a particular class in the landscape. When LPI of a class is 100, it means the entire landscape is occupied by that class.

CPLAND is defined as the sum of all core areas of each patch of a class expressed as a percentage of the total landscape. When CPLAND is approaching 100, it implies that the landscape, as whole, is made of one patch type (class).

Total edge is a sum of all edge segments of a particular patch type (class). When TE is 0, it means that the landscape and its borders are of the same patch type (class).

DIVISION refers to the probability that two randomly selected pixels in a landscape are not found in the same patch of the corresponding patch type. When DIVISION is 0, then the entire landscape is made of on patch (class).

SPLIT is defined as number of patches with a constant patch size when the corresponding patch type is subdivided into S patches, where S is the value of the SPLIT. When the entire landscape is made up of a single patch type (class), the value of SPLIT is 1.

ECON_MN at the class level, it quantifies the average edge contrast for all patches in a landscape.

ED quantifies the sum of all edge segments of a particular patch type expressed as a percentage of the total area of the landscape. When ED is 0, it implies that there is no class edge in the landscape.

CWED standardizes edge to a per unit area basis to allow for comparison among other landscapes with varying sizes. When CWED is 0 it means there is no class edge in the landscape.

PD is the number of patches of a particular patch standardize by the total area of the landscape. The highest PD is recorded when every cell in the landscape becomes a patch.

FRAC_MN is a shape metric that quantifies the complexities of patch shape at the patch, class or landscape level. FRAC_MN for shape with simple perimeter approaches 1 and approaches 2 for more complex shapes. More complex shapes indicate the influence of anthropogenic activities in a landscape.

SIMI_MN is calculated at the class level. Similarity index is the sum of particular patch type in a specified radius divided by the number of patch type. A higher similarity index value indicates that there are more patches in the specified neighbourhood with greater similarity coefficient. A smaller similarity index shows a more fragmented landscape.

CHAPTER FOUR

RESULTS

The design and presentation of this chapter is informed by literature and similar studies that have been carried out. The chapter presents outputs from data analysis, comprising descriptive and inferential statistics. Besides, the results from the data analysis and observations have been organised into tables and charts. The data are both primary and secondary. The choice of software for different aspects of the study was based on the data type and the intended analysis. Confidence interval of 95 percent and probability value of 0.05 were used to test statistical significance. Some outputs of the data analysis that were not presented in this chapter have been provided in the Appendix and have been accordingly referenced where necessary.

4.1 Rainfall

The rainfall data for the study areas from 1982 to 2012 from Ghana Meteorological Authority (GMA) were analysed to determine if the amount of rainfall differs across Ramsar Sites and also, if there have been significant changes that could affect the health of the wetlands. The rainfall data for the cities in which the wetlands are located were used but for Muni-Pomadze, Winneba, which did not have GMA station, Saltpond GMA data were used because it was the immediate nearest station to Winneba. The results from ANOVA statistics (see Appendix C) indicated that the mean annual rainfall received in Accra and Tema from 1985 to 2012 were not statistically different but Saltpond received higher rainfall compared to the other two locations. Figure 4.1 shows the mean plot of annual rainfall in the study areas from 1982 to 2012. Anomaly plots of mean annual rainfall for the three GMA stations are provided in Appendix C. In addition, Mann Kendall Trend Test analysis was performed to examine the rainfall pattern in the study areas from 1982-2012. The results provided in Appendix C show that there was no trend.

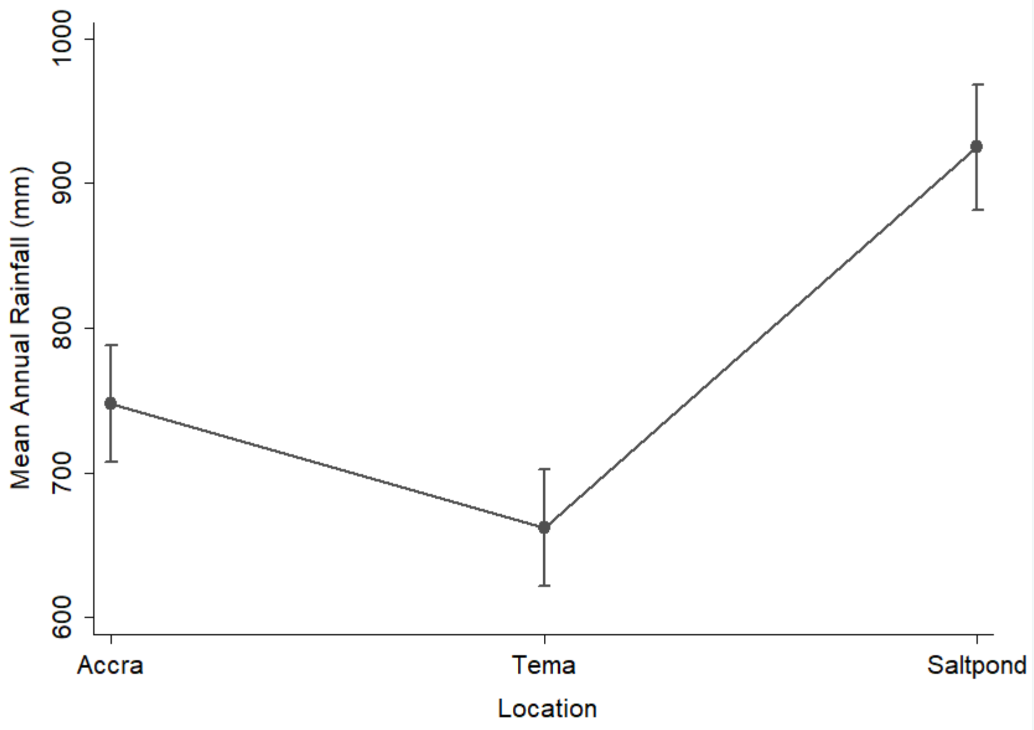


Figure 4.1: Mean plot of annual rainfall (1982-2012) of the Study Areas

4.2 Population

Population data for the three cities, Accra, Tema and Winneba were obtained from the Ghana Statistical Service 2010 Population and Housing Census National Analytical Report (2013). The population of the three cities has steadily progressed over the years from 1984 to 2010, when the last census was carried out. The line graph of population and growth rate between 1974 and 2017 of the study areas are provided in Appendix D. Winneba had a population of 27,105 in 1984 and 57,015 in 2010. Accra Metropolis population was 969,195 in 1984 and 2,070,463 in 2010. Tema had a population of 100,052 in 1984 and 139,784 in 2010. The population of Accra and Winneba doubled from 1984 to 2010 and that of Tema also increased significantly.

4.3 Land Use Land Cover Maps

The LULC maps for the three Ramsar Sites were developed from the Landsat satellite images of 1985, 2002 and 2017 using the supervised maximum likelihood classification method. The Classification schemes for Densu Delta and Sakumo II Ramsar Sites were the same but Muni-Pomadze Ramsar Site had a different classification scheme due to the prevailing LULC classes.

Densu Delta Ramsar Site had marsh as the largest LULC class in 1985 (17.49km^2, 37.05%) and 2002 (17.18km^2, 36.41%) but, built-up/bareland was the largest in 2017 (23.90km^2, 50.63%). The smallest LULC class for Densu Delta in 1985 (7.00km^2, 14.84%) was water and changed to thicket in 2002 (7.09km^2, 15.03%) and 2017 (3.48km^2, 7.38%). The details of the area covered by the various LULC classes for the respective years are found in Table 4.1 and the LULC maps for Densu Delta Ramsar Site are presented in Figure 4.2

Table 4.1 - *Land Use Land Cover of Densu Delta Ramsar Site from 1985 to 2017*

	1985		2002		2017		Change 1985-2002		Change 2002-2017	
Land Cover	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Thicket	10.88	23.05	7.09	15.03	3.48	7.38	-3.79	-8.02	-3.61	-7.65
Built-up/ Bareland	11.83	25.07	13.22	28.01	23.90	50.63	1.39	2.94	10.68	22.62
Marsh	17.49	37.05	17.18	36.41	9.84	20.85	-0.30	-0.64	-7.34	-15.56
Water	7.00	14.84	9.70	20.55	9.97	21.14	2.70	5.72	0.27	0.58
Total	47.20	100.00	47.20	100.00	47.20	100.00	8.18	17.32	21.90	46.41

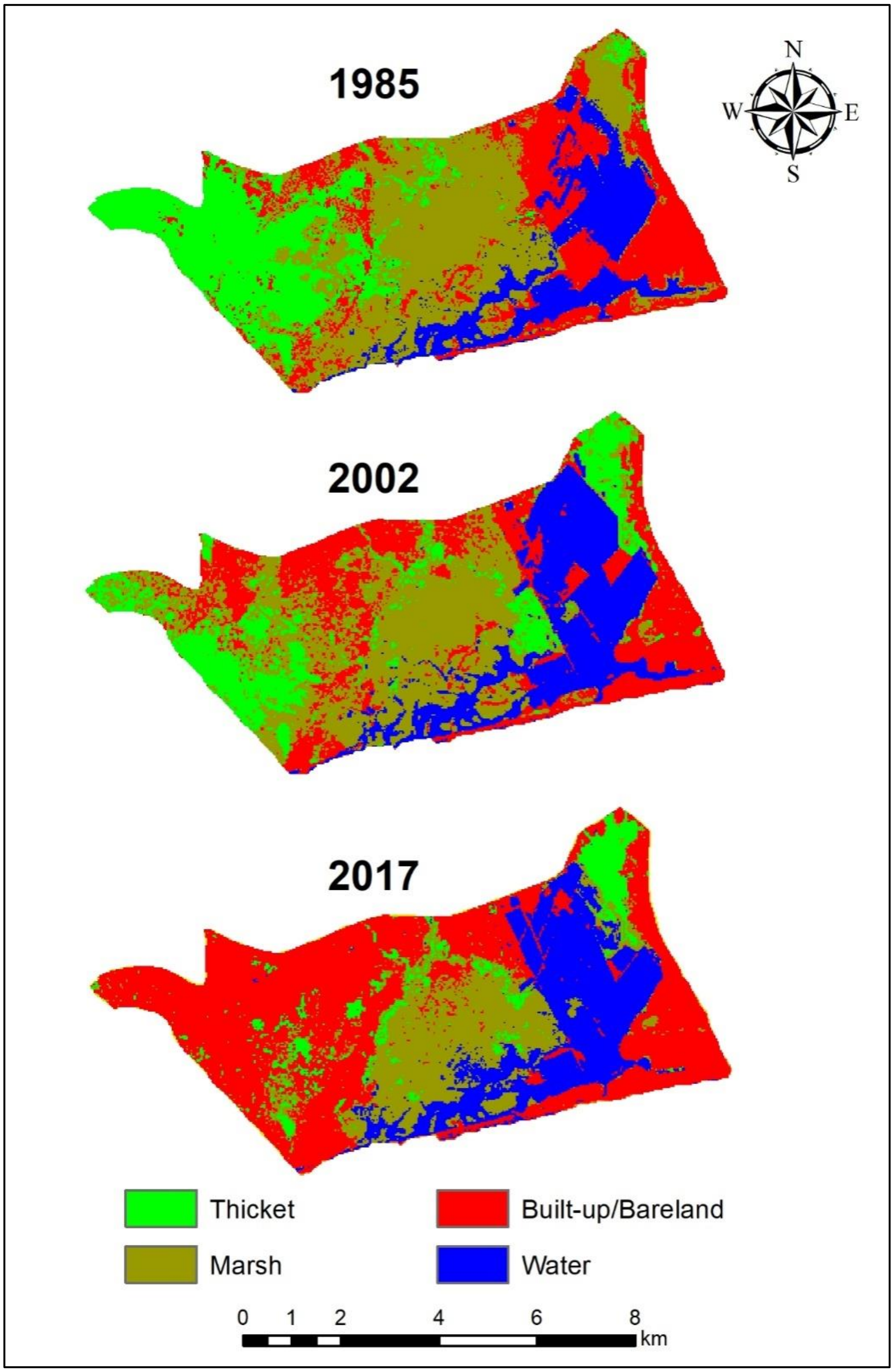


Figure 4.2: Changes in LULC in the Densu Delta Ramsar Site from 1985 to 2017

Marsh was the largest LULC class for Sakumo II Ramsar Site in 1985 (9.13km^2, 63.60%) and 2002 (8.18km^2, 56.95%). As it was observed in Densu Delta Built-up/Bareland became the largest LULC class in 2017 (4.88km^2, 33.98%). The smallest LULC class for Sakumo II was water in all the years; 1985 (1.19km^2, 8.26%), 2002 (0.81km^2, 5.67%) and 2017 (1.61km^2, 11.19%). Table 4.2 gives the details of the area covered by the various LULC classes for the respective years and the LULC maps for SakumoII Ramsar Site are in Figure 4.3.

Muni-Pomadze Ramsar Site had shrub/grassland as the largest LULC class in 1985 (41.35km^2, 43.03%) and 2002 (30.12km^2, 31.35%) however, cultivated land became the largest in 2017 (30.81km^2, 32.06%). The smallest LULC class for Muni-Pomadze in 1985 (1.39km^2, 1.44%) and 2002 (1.20km^2, 1.25%) was water and changed to burnt areas in 2017 (2.97km^2, 3.09%). The area covered by the various LULC classes in all the three study years for Muni-Pomadze are in Table 4.3 and the LULC maps are presented in Figure 4.4.

Table 4.2 - *Land Use Land Cover of Sakumo II Ramsar Site from 1985 to 2017*

	1985		2002		2017		Change 1985-2002		Change 2002-2017	
Land Cover	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Thicket	2.60	18.12	3.01	20.99	3.52	24.49	0.41	2.87	0.50	3.50
Built-up/ Bareland	1.44	10.02	2.35	16.39	4.88	33.98	0.91	6.37	2.53	17.59
Marsh	9.13	63.60	8.18	56.95	4.36	30.34	-0.95	-6.65	-3.82	-26.61
Water	1.19	8.26	0.81	5.67	1.61	11.19	-0.37	-2.59	0.79	5.52
Total	14.36	100.00	14.36	100.00	14.36	100.00	2.67	18.48	7.64	53.22

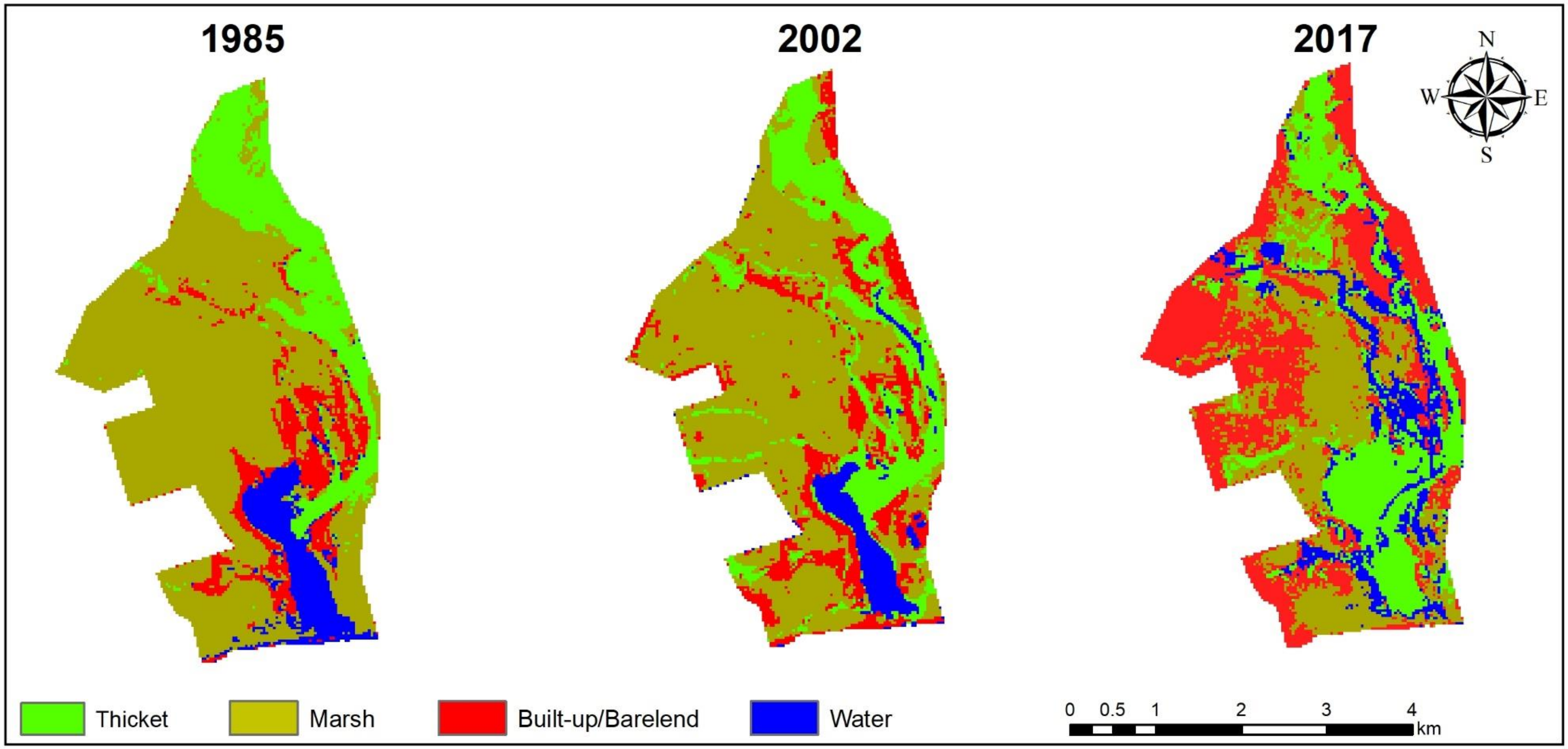


Figure 4.3: Changes in LULC in the Sakumo II Ramsar Site from 1985 to 2017

4.3.1 Land Use Land Cover Changes

Post classification analyses were carried out after the satellite images were classified into the various LULC classes. The quantum of changes that occurred in the period 1985-2002 and 2002-2017 indicate the dynamic states of the Ramsar Sites. Densu Delta Ramsar Site experienced the least change (17.32%) from 1985-2002 compared to the other two wetlands and became the second highest (46.41%) in 2002-2017 period. In Densu Delta, thicket had the highest change in the 1985-2002 period, losing 8.02 percent whereas marsh recorded the least change, losing 0.64 percent in the same period. Built-up/Bareland was the LULC class that changed most in the 2002-2017 period, gaining 22.62% percent. Water experienced the least change, gaining 0.58 percent. The changes that happened in Densu Delta Ramsar site in the two study periods are presented in Table 4.1 and the evaluation of gains and losses of all the LULC classes are in Figure 4.5A.

Among the three wetlands, Sakumo II Ramsar Site was the second wetland in terms of changes that occurred between 1985 and 2002 (18.48%) but changed most (53.22%) in the 2002-2017 period. In both 1985-2002 and 2002-2017 periods, marsh changed the most, losing 6.65 percent and 26.61 percent respectively. Water experienced the minimal change, losing 2.59 percent in the 1985-2002 period whereas thicket experienced the least change, gaining 3.5 percent in the 2002-2017 period. The details of the changes that occurred in Sakumo II Ramsar site with respect to the various LULC classes are in Table 4.2 and the evaluation results of gains and losses are presented in Figure 4.5B.

Table 4.3 - *Land Use Land Cover of Muni-Pomadze Ramsar Site from 1985 to 2017*

	1985		2002		2017		Change 1985-2002		Change 2002-2017	
Land Cover	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Cultivated land	17.13	17.83	21.07	21.92	30.81	32.06	3.93	4.09	9.74	10.14
Dense forest	21.48	22.36	19.62	20.42	10.17	10.58	-1.86	-1.94	-9.45	-9.84
Water	1.39	1.44	1.20	1.25	4.27	4.45	-0.19	-0.19	3.07	3.20
Built-up/ Bareland	11.01	11.45	16.66	17.34	25.26	26.29	5.65	5.88	8.60	8.95
Shrub/ Grassland	41.35	43.03	30.12	31.35	22.61	23.53	-11.23	-11.68	-7.51	-7.82
Burnt	3.73	3.88	7.42	7.72	2.97	3.09	3.69	3.84	-4.46	-4.64
Total	96.08	100.00	96.08	100.00	96.08	100.00	26.55	27.62	42.83	44.59

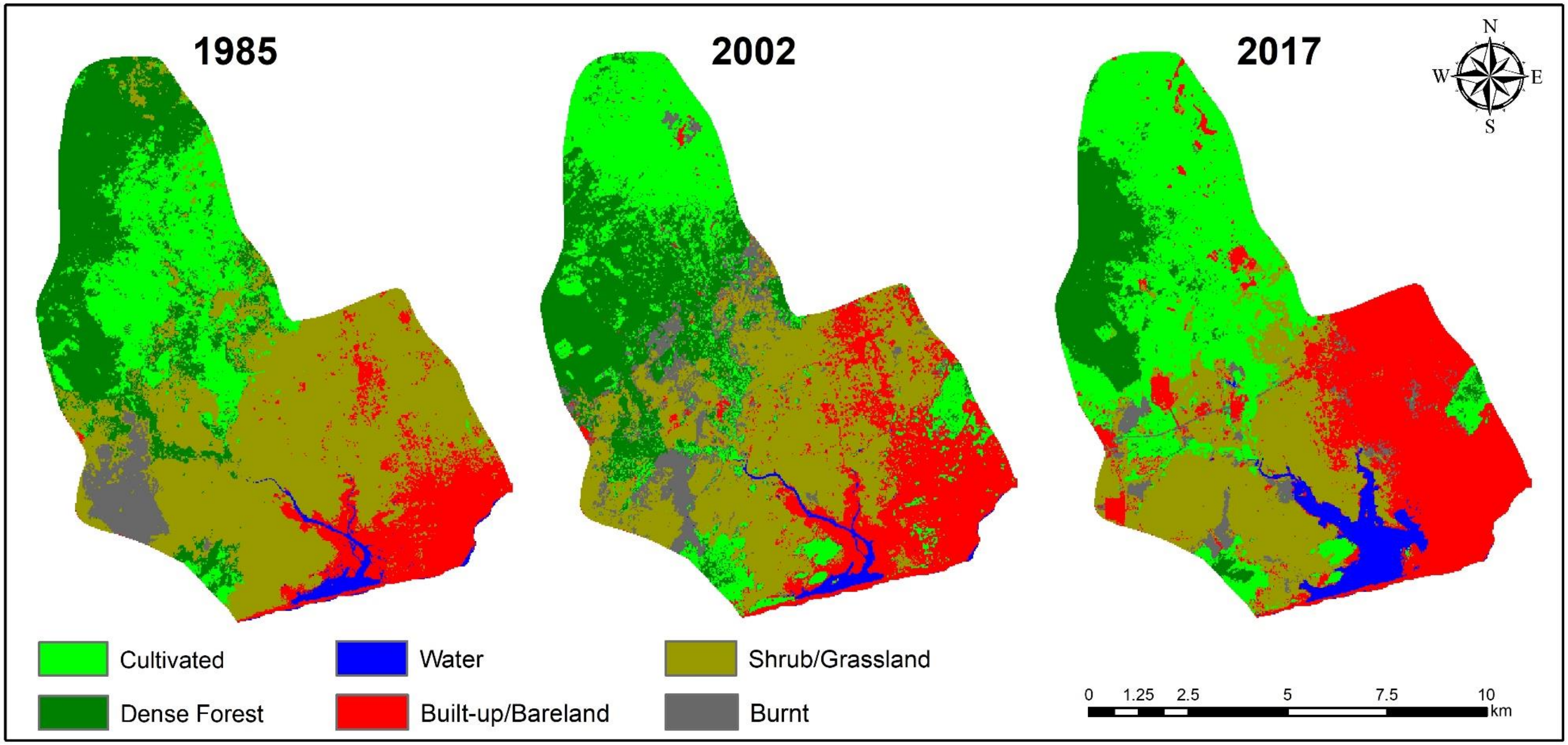


Figure 4.4: Changes in LULC in the Muni-Pomadze Ramsar Site from 1985 to 2017

Muni-Pomadze Ramsar Site changed most (27.62%) in the period 1985-2002 compared to the other two wetlands in the same period but dropped to the second highest (44.59%) in the 2002-2017 period. Shrub/Grassland class recorded highest change, losing 11.68 percent in 1985-2002 period and it was overtaken by cultivated land which experienced the highest change in 2002-2017 period, gaining 10.14 percent. Water as observed in Sakumo II Ramsar Site experienced the least change in both study periods, losing 3.07 percent in the first time interval and gaining 3.20 percent in the second time period. The changes that occurred in Muni-Pomadze Ramsar Site are presented in details in Table 4.5 and the evaluation results of gains and losses of all classes are provided in Figure 4.5.

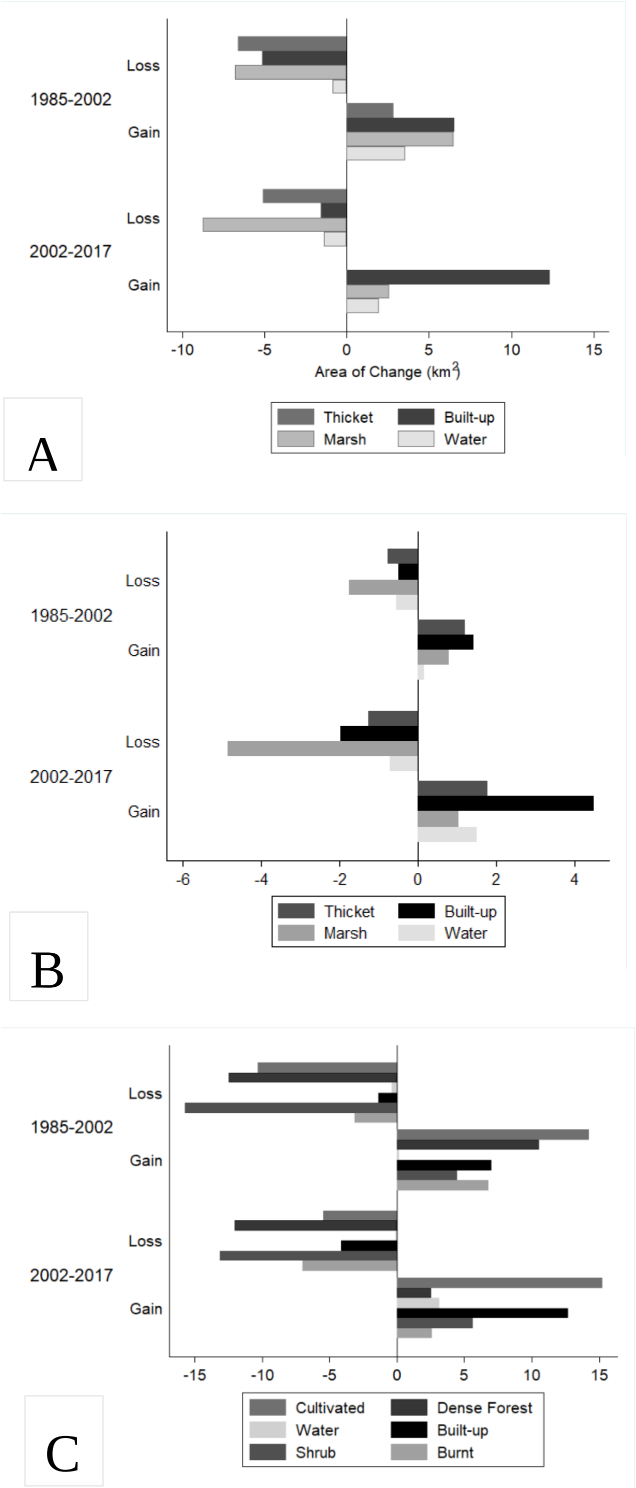


Figure 4.5: Gains and Losses of LULC Classes between 1985-2002 and 2002-2017

A. Densu Delta B. Sakumo II C. Muni-Pomadze

4.4 Intensity Analysis for Densu Delta Ramsar Site

Table 4.4 is a transition matrix for Densu Delta Ramsar Site for the two study periods. It gives detailed information about the annual area of gross loss and gain, and net for each category and the overall change. Thicket and marsh show net loss in both time intervals. Built-up/Bareland and water show a net gain in both time intervals. The gross gain for the first time interval for all categories with the exception of built-up/bareland were greater than the gross gain for the second time interval. Built-up/bareland decreased in gross loss from first to second time interval. The numbers on the diagonal (bold face) indicate persistence.

Table 4.4 – *Land Transition Matrix (km^2) for Densu Delta Ramsar Site for 1985-2002 and 2002-2017*

		2002					
		Thicket	Marsh	Built-up/ Bareland	Water	Initial Total	Gross Loss
1985	Thicket	**4.26**	4.33	2.28	0.01	10.88	6.62
	Marsh	2.21	**10.70**	3.87	0.71	17.49	6.79
	Built-up/ Bareland	0.51	1.78	**6.69**	2.85	11.83	5.14
	Water	0.11	0.37	0.38	**6.14**	7.00	0.86
	Final Total	7.09	17.18	13.22	9.71	47.20	19.41
	Gross Gain	2.83	6.48	6.53	3.57	19.41	
		2017					
2002	Thicket	**1.97**	1.36	3.72	0.04	7.09	5.12
	Marsh	1.18	**7.26**	7.95	0.80	17.19	9.93
	Built-up/ Bareland	0.10	0.48	**11.54**	1.10	13.22	1.68
	Water	0.23	0.74	0.68	**8.04**	9.69	1.65
	Final Total	3.48	9.84	23.89	9.98	47.20	18.38
	Gross Gain	1.51	2.58	12.35	1.94	18.38	

Intensity analysis was carried out at three levels thus, interval, category and transition. Generally, the time interval level analysis in Figure 4.6 shows that the annual change (2.42%) in the first time interval was relatively slow whereas the annual change in the second time interval (2.60%) was relatively fast. The uniform annual change for the entire study period (1985-2017) was 2.5 percent.

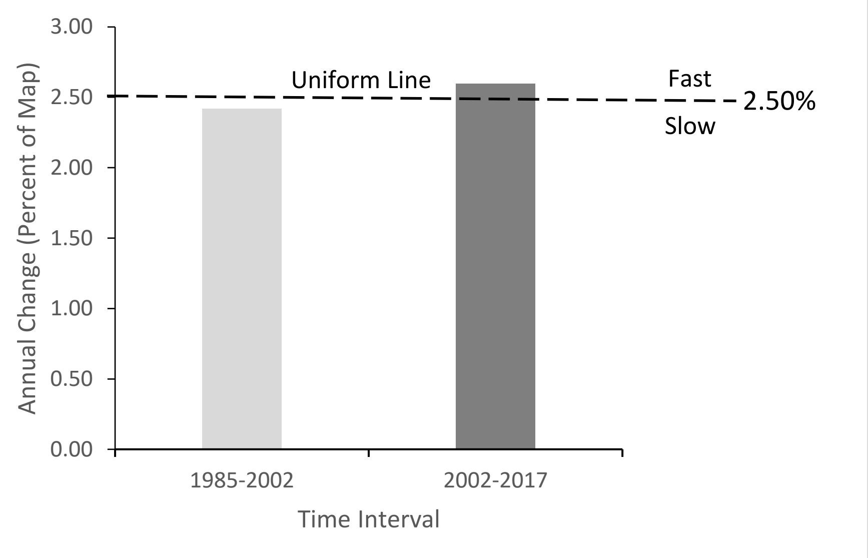


Figure 4.6: Interval level Intensity for 1985-2002 and 2002-2017 at Densu Delta Ramsar Site

The results for category level intensity analysis are provided in Figure 4.7 and 4.8. In the first time interval, the annual change intensity for thicket was relatively dormant in terms of gains but was actively losing. Marsh and water experienced relatively dormant annual change intensity for both gains and losses. The annual change intensity for built-up/bareland for both gains and losses was relatively active. In the second time interval, thicket experienced relatively active annual change intensity for both gains and losses. The annual change intensity for marsh was relatively dormant in terms of gain but experienced active loss. Built-up/bareland recorded active gains and dormant losses. Water experienced relatively dormant gains and losses in annual change intensity in the second time interval.

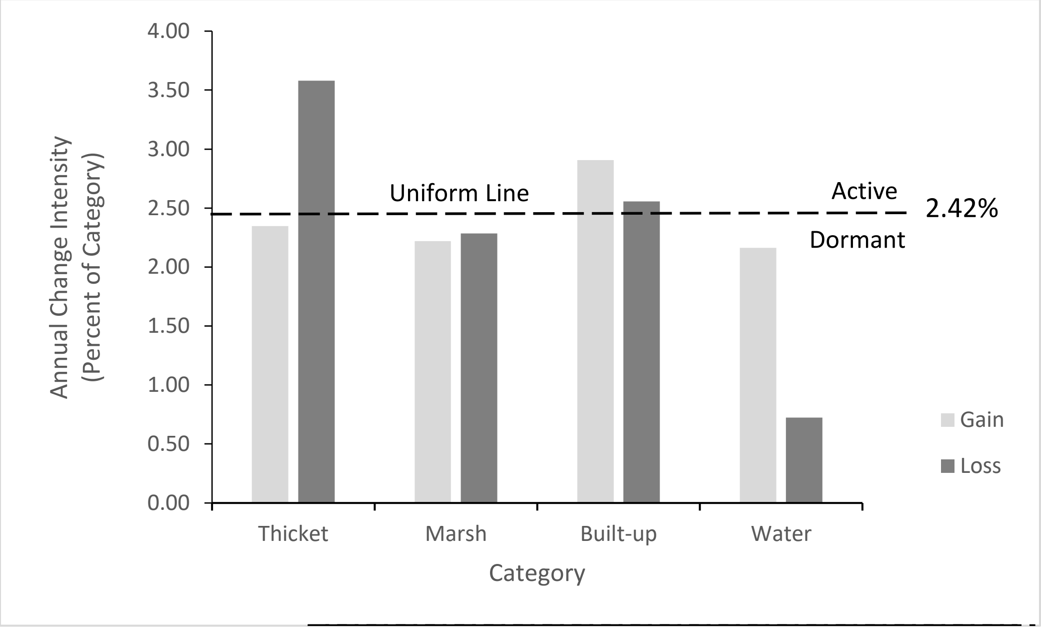


Figure 4.7: Intensity Analysis for 1985-2002 at Densu Delta

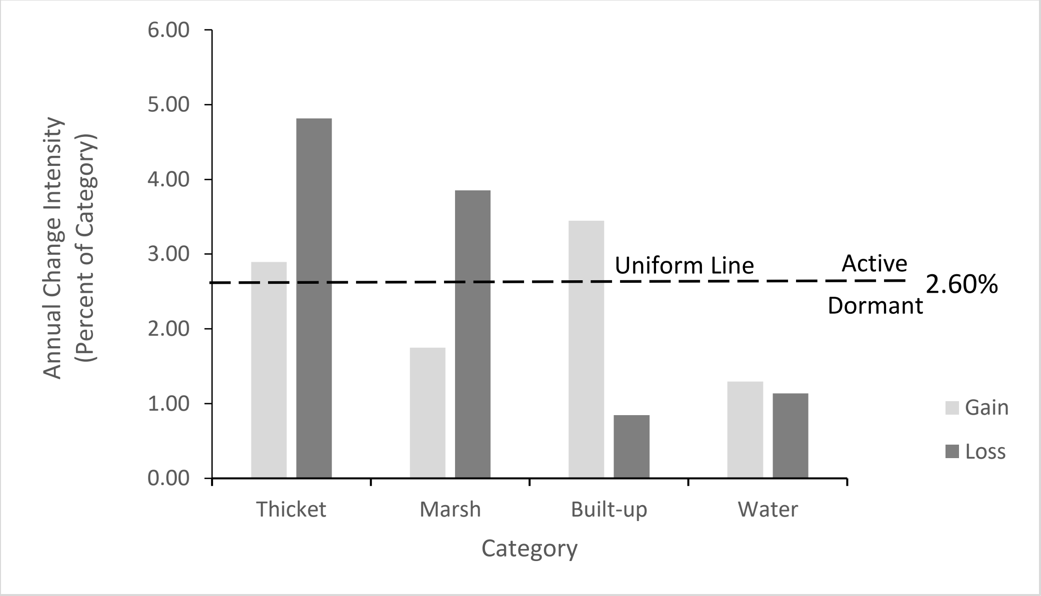
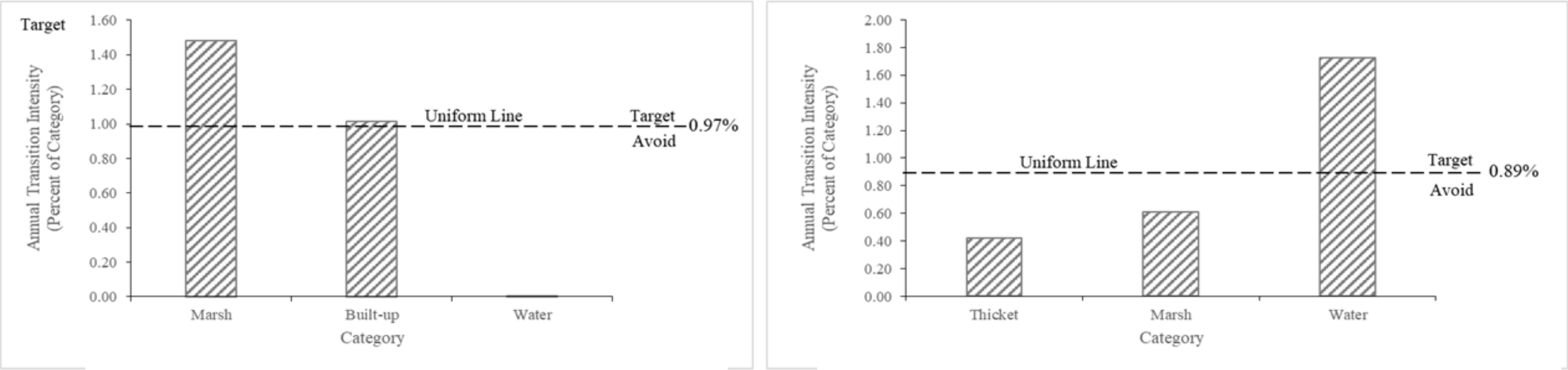


Figure 4.8: Category Intensity Analysis for 2002-2017 at Densu Delta

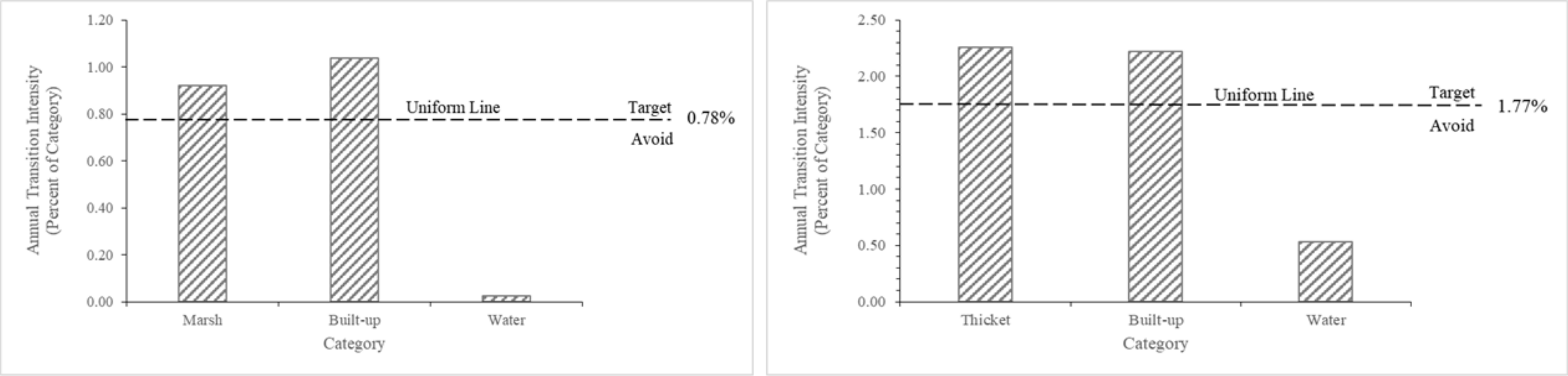
Figure 4.9 gives the results from the intensity analysis for the transition from active losing categories to the other categories in both time intervals. In the two time intervals, thicket tends to be targeted more intensively by marsh and built-up/bareland given loss of thicket. Built-up/bareland also tends to be targeted more intensively by thicket and marsh in the first time interval. Marsh was targeted more intensively by thicket and built-up/bareland resulting in loss of marsh in the second time interval.

Figure 4.10 shows the intensity analysis for the transition to active gaining categories from active losing categories in both time intervals. Built-up/bareland tends to target thicket and marsh intensively but avoids water in the two time intervals. Thicket tends to target marsh more intensively and avoids water and built/bareland, given in the second time interval.



From thicket to other categories (1985-2002)

From built-up/bareland to other categories (1985-2002)



From thicket to other categories (2002-2017)

From marsh to other categories (2002-2017)

Figure 4.9: Transition Intensity Analysis from Active Losing Categories for the Two Time Intervals at Densu Delta

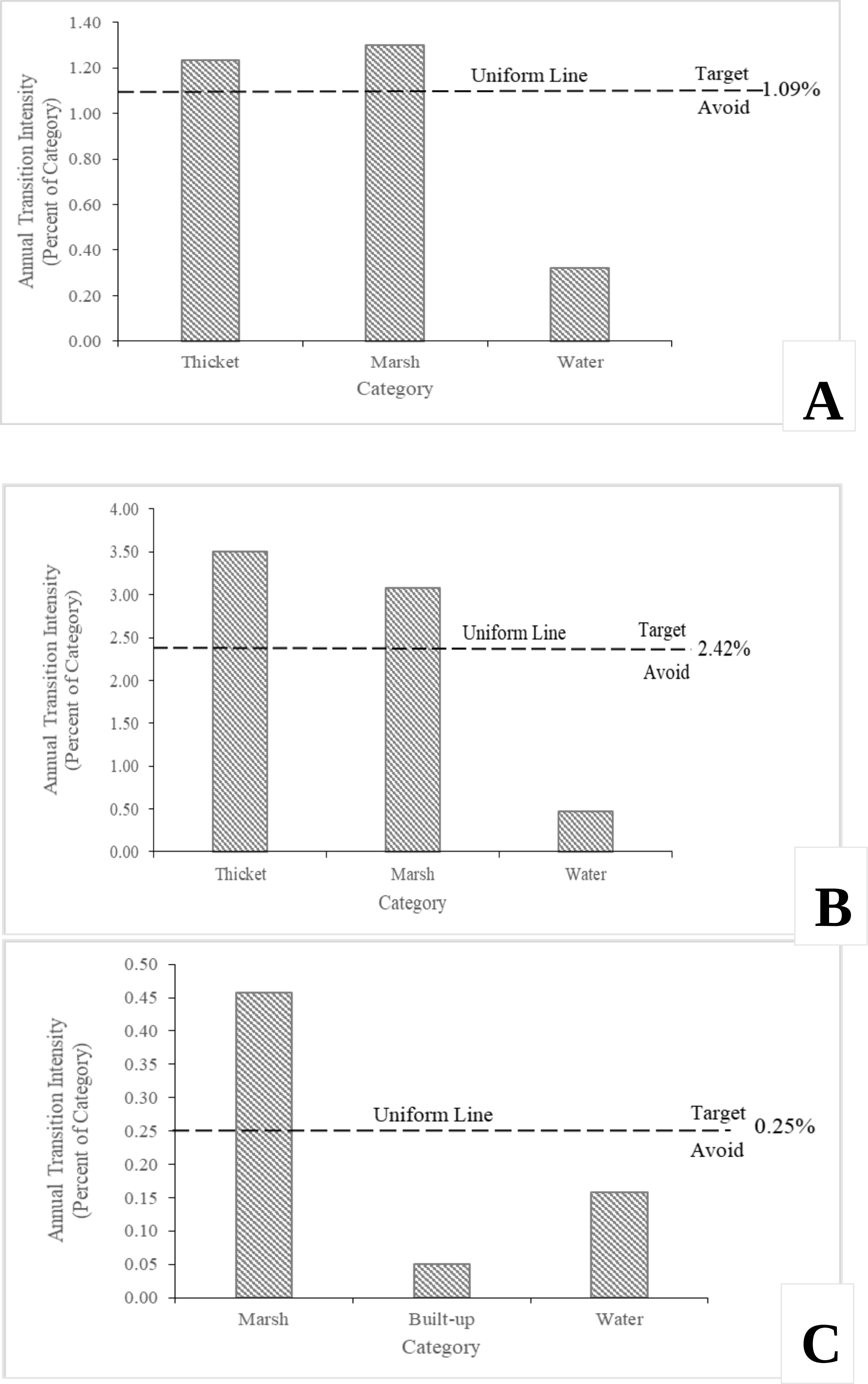


Figure 4.10: Transition Intensity Analysis for Active Gaining Categories at Densu Delta

A. Built-up/bareland (1987-2002) B. Thicket (2002-2017) C. Built-up/Bareland (2002-2017)

4.4.1 Intensity Analysis for Sakumo II Ramsar Site

Table 4.5 is a transition matrix for Sakumo II Ramsar Site for the two time intervals. Thicket and built-up/bareland show a net gain in both time intervals. Marsh shows net losses in both time intervals. Water recorded a net gain in the first time interval and then experienced a net loss in the second time interval. The gross gains in the second time interval for all categories with the exception of marsh were greater than the gross gains for the first time interval. Marsh was the only category that increased in gross loss from first to second time interval. The numbers on the diagonal (bold face) indicate persistence.

Table 4.5 – *Land transition matrix (km^2) for Sakumo II Ramsar Site for 1985-2002 and 2002-2017*

		2002					
		Thicket	Marsh	Built-up/ Bareland	Water	Initial Total	Gross Loss
1985	Thicket	**1.83**	0.41	0.29	0.08	2.61	0.78
	Marsh	0.77	**7.37**	0.94	0.05	9.13	1.76
	Built-up/ Bareland	0.16	0.3	**0.94**	0.04	1.44	0.5
	Water	0.26	0.1	0.18	**0.65**	1.19	0.54
	Final Total	3.02	8.18	2.35	0.82	14.37	3.58
	Gross Gain	1.19	0.81	1.41	0.17	3.58	
		2017					
2002	Thicket	**1.74**	0.23	0.4	0.65	3.02	1.28
	Marsh	0.74	**3.73**	3.31	0.39	8.17	4.44
	Built-up/ Bareland	0.37	0.38	**1.13**	0.47	2.35	1.22
	Water	0.67	0.01	0.03	**0.1**	0.81	0.71
	Final Total	3.52	4.35	4.87	1.61	14.37	7.65
	Gross Gain	1.78	0.62	3.74	1.51	7.65	

The results of interval level analysis are shown in Figure 4.11. Similar to Densu Delta, the annual change in first time interval (1.47%) was relatively slow whereas the annual change in the second time interval (3.55%) was relatively fast. The uniform annual change for the study period (1985-2017) was 2.44 percent.

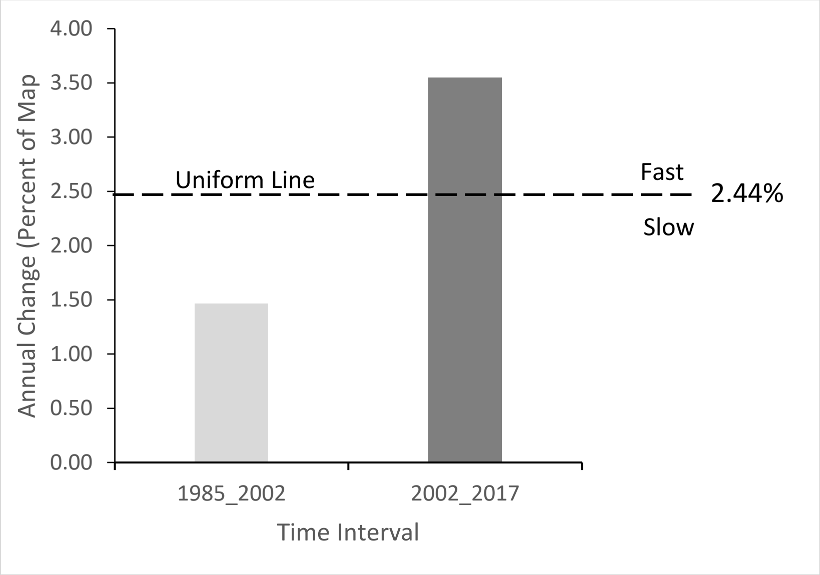


Figure 4.11: Interval level Intensity for 1985-2002 and 2002-2017 at Sakumo II Ramsar Site

The results for category level intensity analysis are provided in Figure 4.12 and 4.13. In the first time interval, the annual change intensity for thicket and built-up/bareland was relatively active for both gains and losses. Marsh experienced relatively dormant annual change intensity for both gains and losses. The annual change intensity for water was relatively dormant in terms of gains and relatively active in losses. In the second time interval, thicket experienced relatively dormant annual change intensity for both gains and losses. The annual change intensity for marsh was relatively dormant in gains but experienced active losses. Built-up/bareland recorded active gains and dormant losses. Water experienced active gains and losses in annual change intensity in the second time interval.

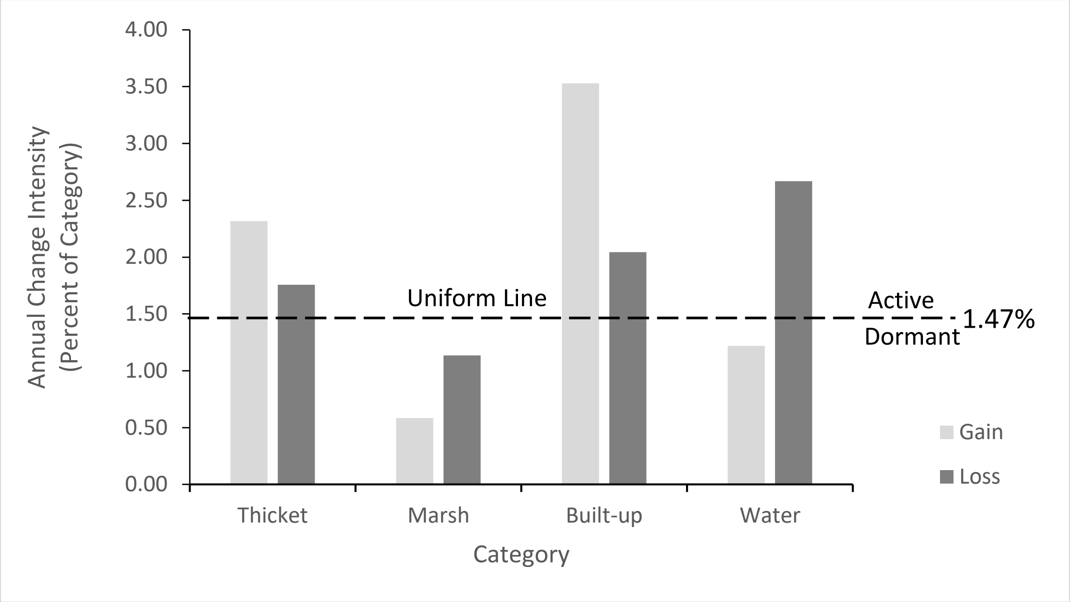


Figure 4.12: Category Intensity Analysis for Sakumo II Ramsar Site from 1985-2002

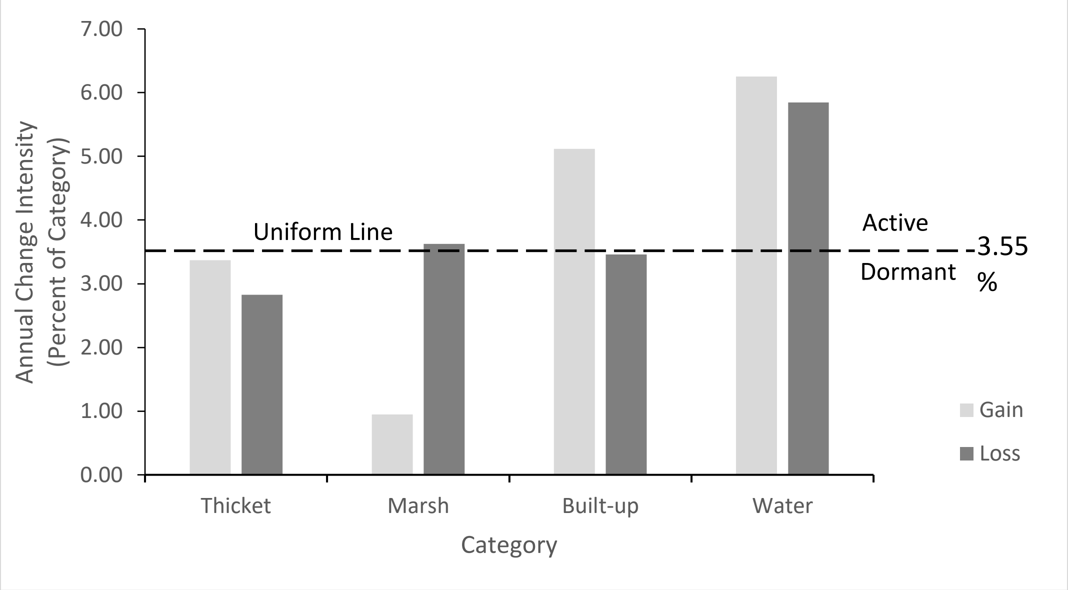


Figure 4.13: Category Intensity Analysis for Sakumo II Ramsar Site from 2002-2017

Figure 4.14 and 4.15 present the results from the intensity analysis for transition from active losing categories to other categories in the two time intervals. In the first time interval, thicket tends to be targeted more intensively by water and built-up/bareland given loss of thicket. Built-up/bareland also tends to be targeted more intensively by thicket and water. Water tends to be targeted more intensively by thicket and built-up/bareland resulting in loss of water. In the second time interval, marsh tends to be targeted intensively by built-up/bareland. Water tends to be targeted mainly by thicket.

Figure 4.16 shows the intensity analysis for the transition to active gaining categories in both time intervals. Thicket tends to target built-up/bareland and water more intensively and avoids thicket, given the gain of thicket in the first time interval. In the same time interval, built-up/bareland tends to target thicket and water intensively and avoids marsh. In the second time interval, built-up/bareland tends to target marsh intensively and avoids thicket and water. Water targets thicket and built-up/bareland intensively and avoids marsh

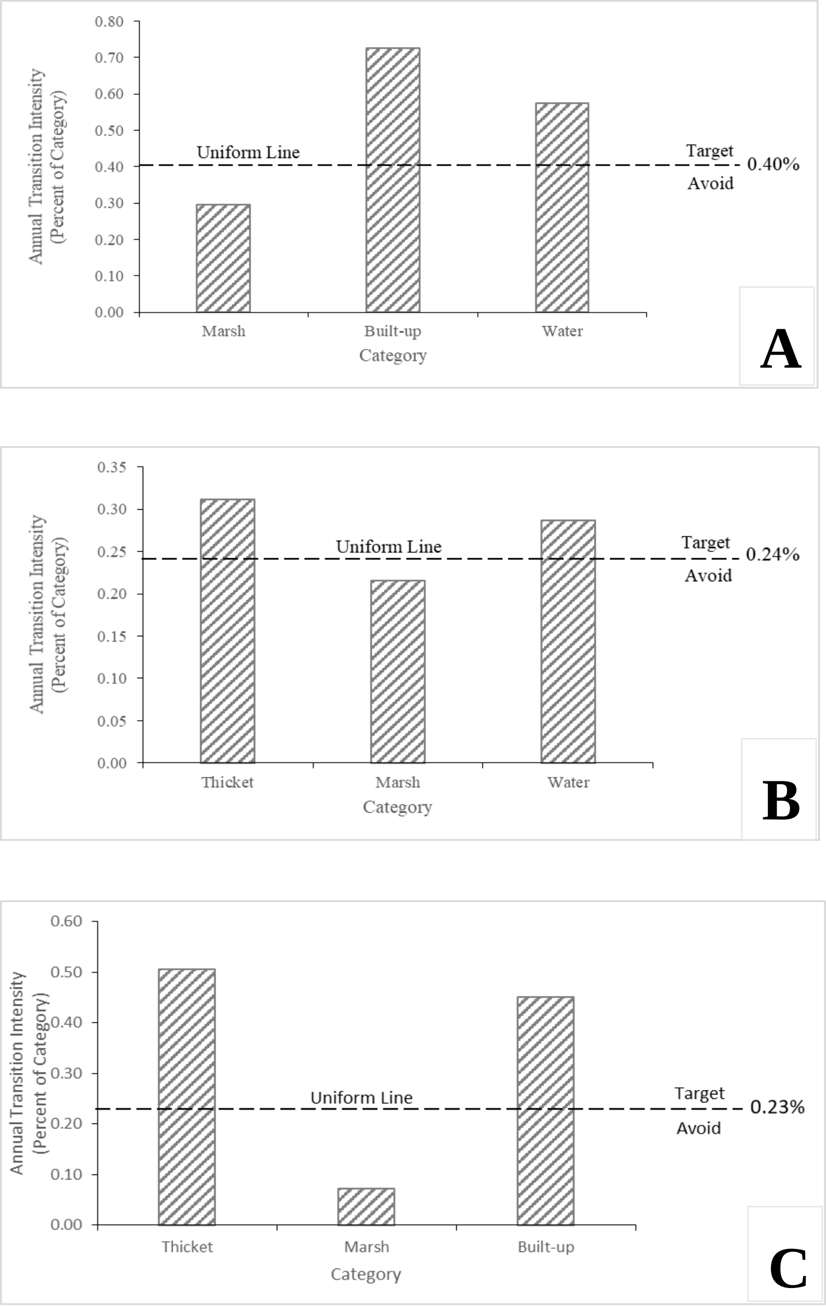


Figure 4.14: Transition Intensity from active losing categories for Sakumo II Ramsar Site (1987-2002)

A. From thicket to other categories
B. From built-up/bareland to other categories
C. From water to other categories

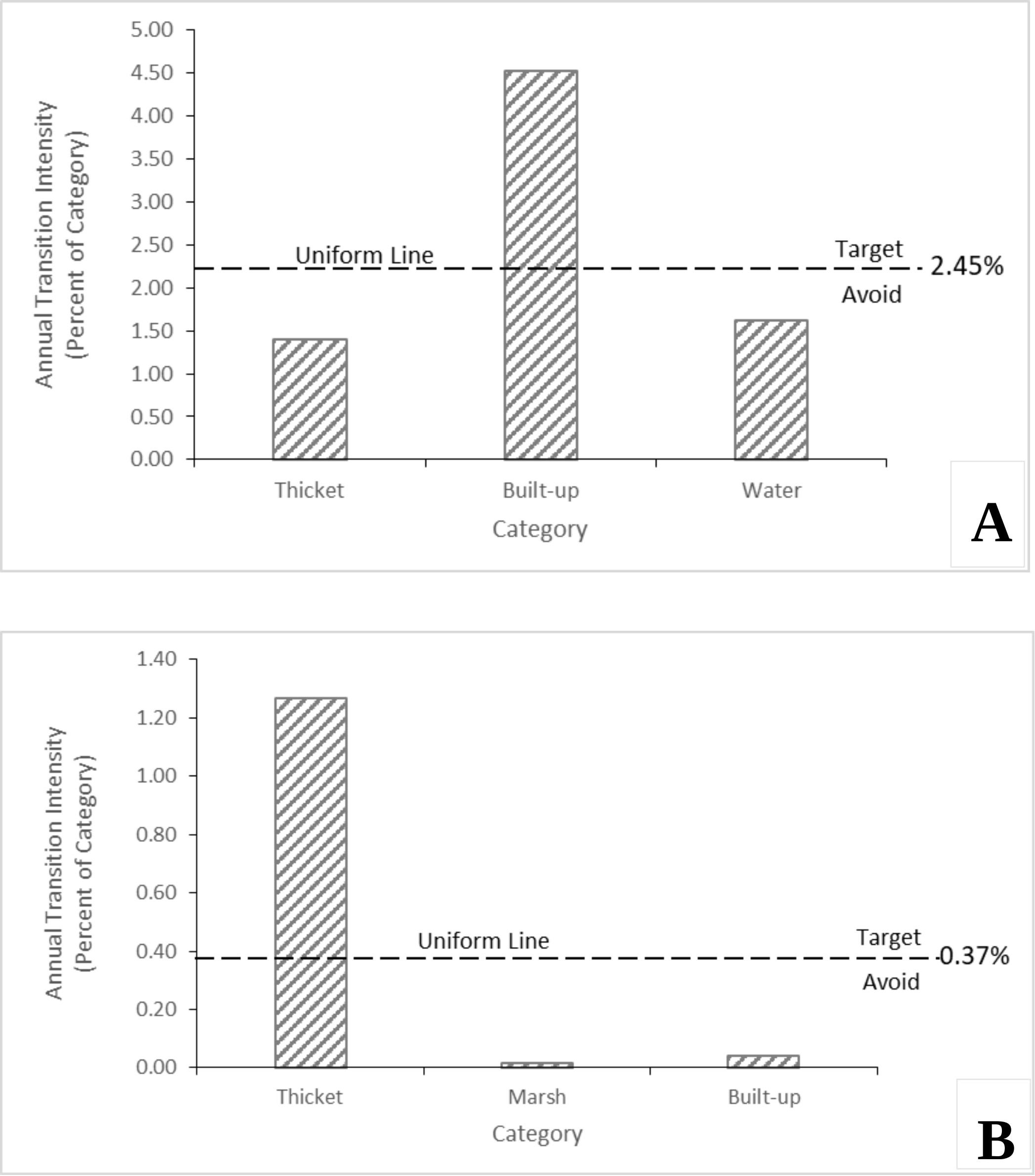
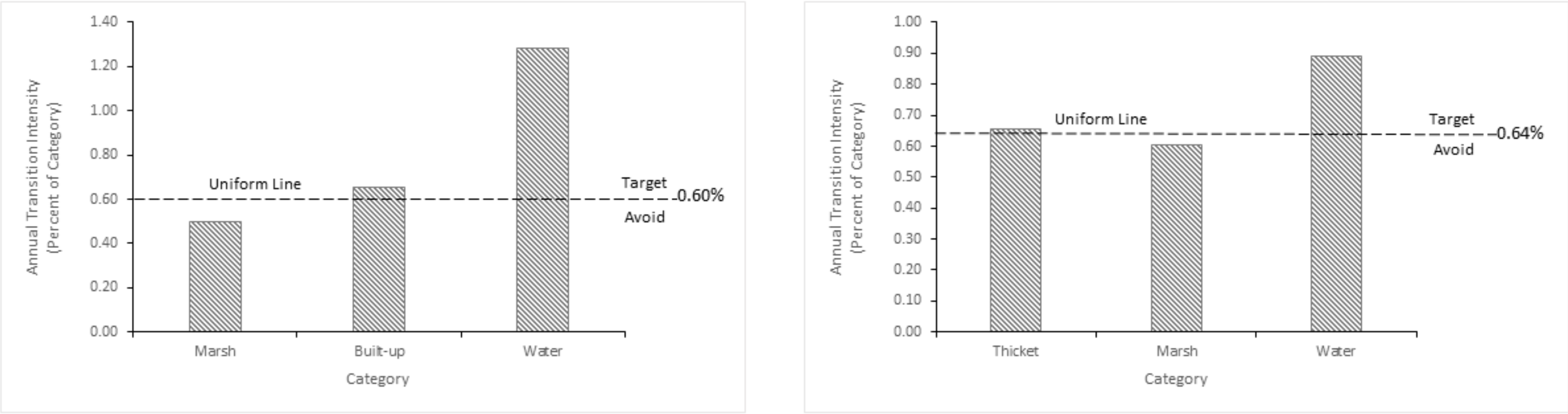


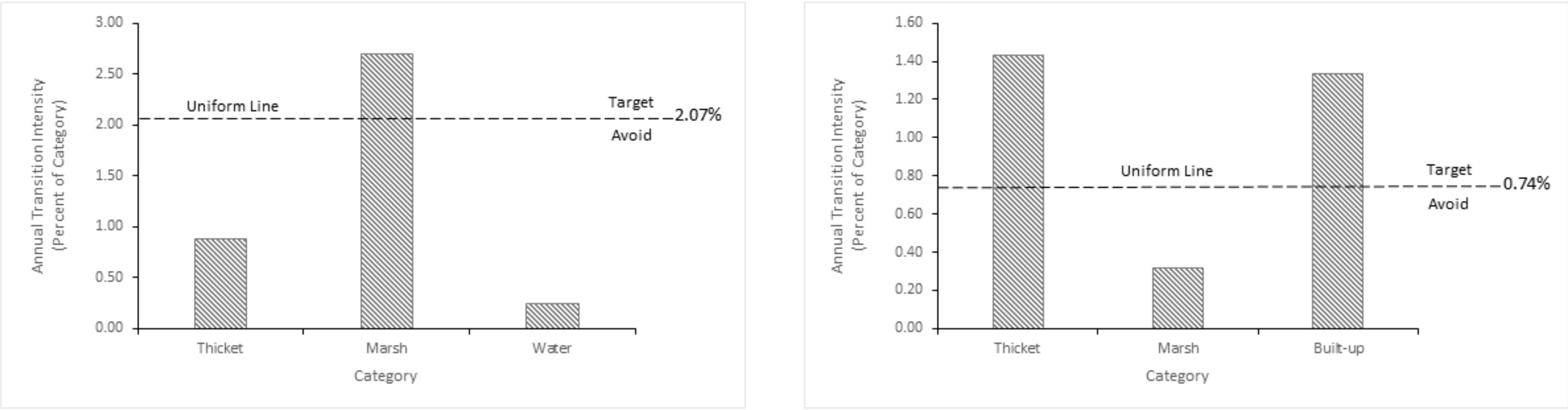
Figure 4.15: Transition Intensity from active losing categories for Sakumo II Ramsar Site (2002-2017)

A. From marsh to other categories
B. From Water to other categories



a. Other categories to thicket (1985-2002)

b. Other categories to built-up/bareland (1985-2002)



c. Other categories to built-up/bareland (2002-2017)

d. Other categories to water (2002-2017)

Figure 4.16: Transition Intensity Analysis for Active Gaining Categories for Sakumo II for the Two Time Intervals

4.4.2 Intensity Analysis for Muni-Pomadze Ramsar Site

Table 4.6 is a transition matrix for Muni-Pomadze Ramsar Site for the two time intervals. Cultivated land and built-up/bareland show a net gain in both time intervals. Dense Forest and shrub/grassland show a net loss in both time intervals. Burnt land shows a net gain in the first time interval and then shows a net loss in the second time interval whereas water shows a net loss in the first time interval and then shows a net gain in the second time interval. The gross gain for the second time interval for cultivated land, built-up/baeland, shrub/grassland and water were greater than the gross gain recorded in the first time interval. Dense forest and burnt land increased in gross loss from first to second time interval. The numbers on the diagonal (bold face) show persistence.

Table 4.6 – *Land transition matrix (km^2) for Muni-Pomadze Ramsar Site for 1985-2002 and 2002-2017*

		2002							
		Cultivated	Dense Forest	Burnt Area	Built-up/ Bareland	Shrub/ Grassland	Water	Initial Total	Gross Loss
1985	Cultivated	**6.84**	8.68	1.13	0.10	0.39	0.00	17.14	10.30
	Dense Forest	9.59	**9.05**	1.66	0.15	1.03	0.00	21.48	12.43
	Burnt	0.27	0.69	**0.61**	0.01	2.14	0.00	3.72	3.11
	Built-up/ Bareland	0.36	0.00	0.02	**9.64**	0.92	0.06	11.00	1.36
	Shrub/ Grassland	3.99	1.20	4.01	6.40	**25.63**	0.11	41.34	15.71
	Water	0.01	0.00	0.00	0.34	0.01	**1.03**	1.39	0.36
	Final Total	21.06	19.62	7.43	16.64	30.12	1.20	96.07	43.27
	Gross Gain	14.22	10.57	6.82	7.00	4.49	0.17	43.27	
		2017							
2002	Cultivated	**15.59**	2.50	0.30	1.73	0.91	0.04	21.07	5.48
	Dense Forest	10.58	**7.61**	0.25	0.52	0.65	0.01	19.62	12.01
	Burnt	2.87	0.05	**0.39**	0.82	3.29	0.01	7.43	7.04
	Built-up/ Bareland	0.30	0.01	0.15	**12.54**	0.77	2.89	16.66	4.12
	Shrub/ Grassland	1.47	0.00	1.87	9.57	**16.98**	0.23	30.12	13.14
	Water	0.01	0.00	0.01	0.08	0.01	**1.09**	1.20	0.11
	Final Total	30.82	10.17	2.97	25.26	22.61	4.27	96.10	41.90
	Gross Gain	15.23	2.56	2.58	12.72	5.63	3.18	41.90	

The results of interval level analysis are provided in Figure 4.17. As observed in Densu Delta and Sakumo II Ramsar Sites, the annual change in first time interval (2.65%) was relatively slow whereas the annual change in the second time interval (2.91%) was relatively fast. The uniform annual change was 2.77 percent.

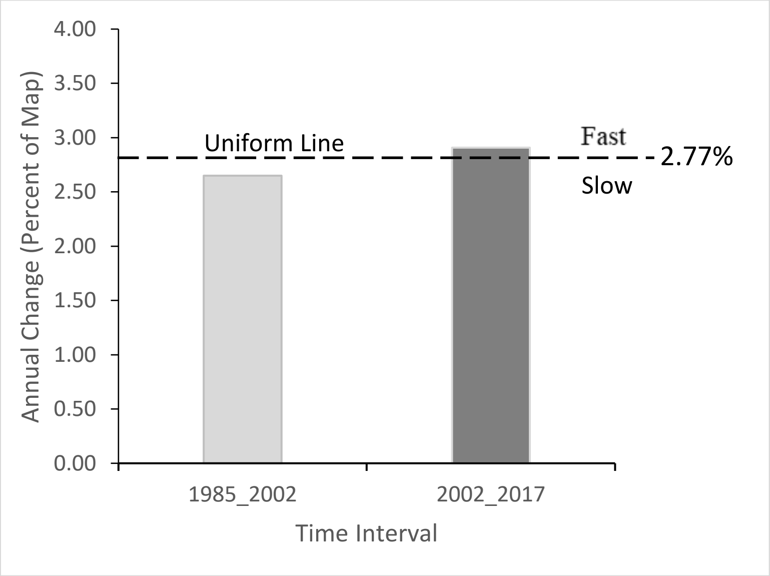


Figure 4.17: Interval Intensity Analysis for 1985-2002 and 2002-2017 at Muni-Pomadze Ramsar Site

The results for category level intensity analysis are provided in Figure 4.18 and 4.19. In the first time interval, the annual change intensity for cultivated land, dense forest and burnt land was relatively active for both gains and losses. Built-up/Bareland, shrub/grassland and water experienced relatively dormant annual change intensity for both gains and losses. In the second time interval, burnt land was the only category that experienced relatively active annual change intensity for both gains and losses. The annual change intensity for cultivated land, built-up/bareland and water recorded active gains and dormant losses. Dense forest and shrub/grassland recorded relatively dormant gains and active losses. Water recorded active gains and losses in annual change intensity in the second time interval.

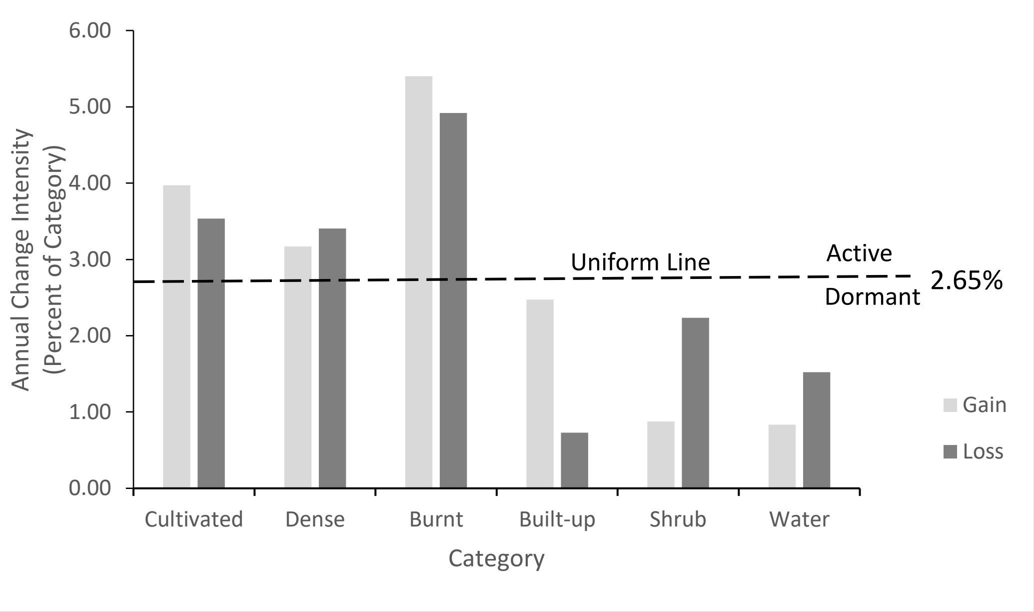


Figure 4.18: Category Intensity Analysis for Muni-Pomadze from 1985-2002

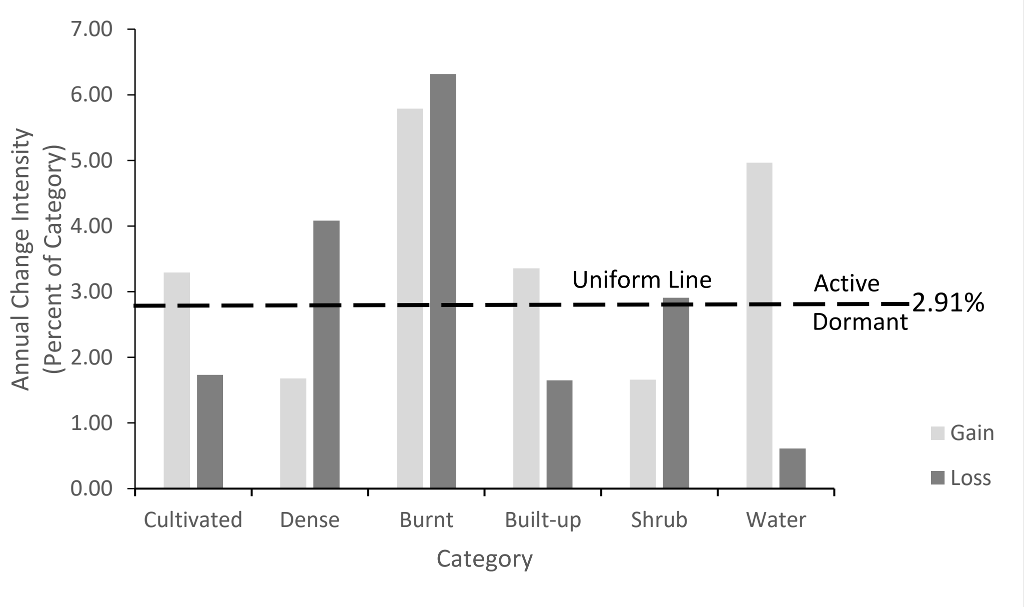


Figure 4.19: Category Intensity Analysis for Muni-Pomadze from 2002-2017

Figure 4.20 and 4.21 provide the results from the intensity analysis for the transition from active losing categories to other categories in both time intervals. In the first time interval, cultivated land tends to be targeted more intensively by dense forest and burnt land. Dense forest also tends to be targeted more intensively by cultivated land and burnt land. Burnt land tends to be targeted more intensively by shrub/grassland. With respect to second time interval, dense forest tends to be targeted intensively by cultivated land and burnt land. Burnt land tends to be targeted mainly by cultivated land and shrub/grassland. Shrub/grassland tends to be targeted intensively by burnt land and built-up/bareland.

Figure 4.22 and 4.23 present the results of the intensity analysis for the transition to active gaining categories from other categories in both time intervals. In the first time interval, cultivated land tends to target dense forest and avoids the other categories, given the gain of cultivated land. Dense forest targets cultivated land and burnt land to increase. Burnt land also tends to target dense forest and shrub/grassland, given the gain of burnt land. In the second time interval, cultivated land tends to target dense forest and burnt land intensively and avoids other categories. Burnt land targets mainly shrub/grassland to increase and avoids other categories. Built-up/bareland tends to target shrub/grassland intensively and avoids the other categories. Water targets built-up/bareland intensively to increase.

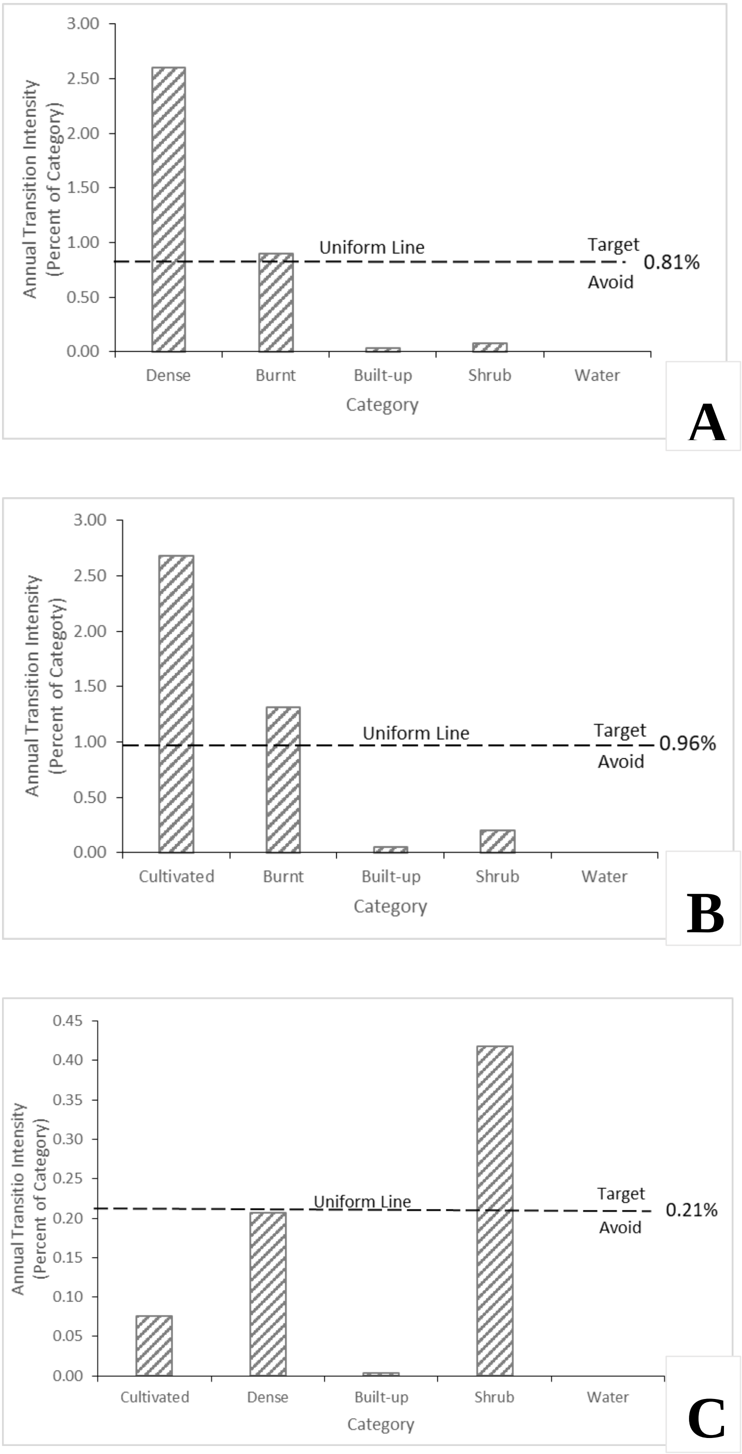


Figure 4.20: Transition Intensity from active losing categories for Muni-Pomadze (1985-2002)

(A) From cultivated land (B) From dense forest (C) From burnt land

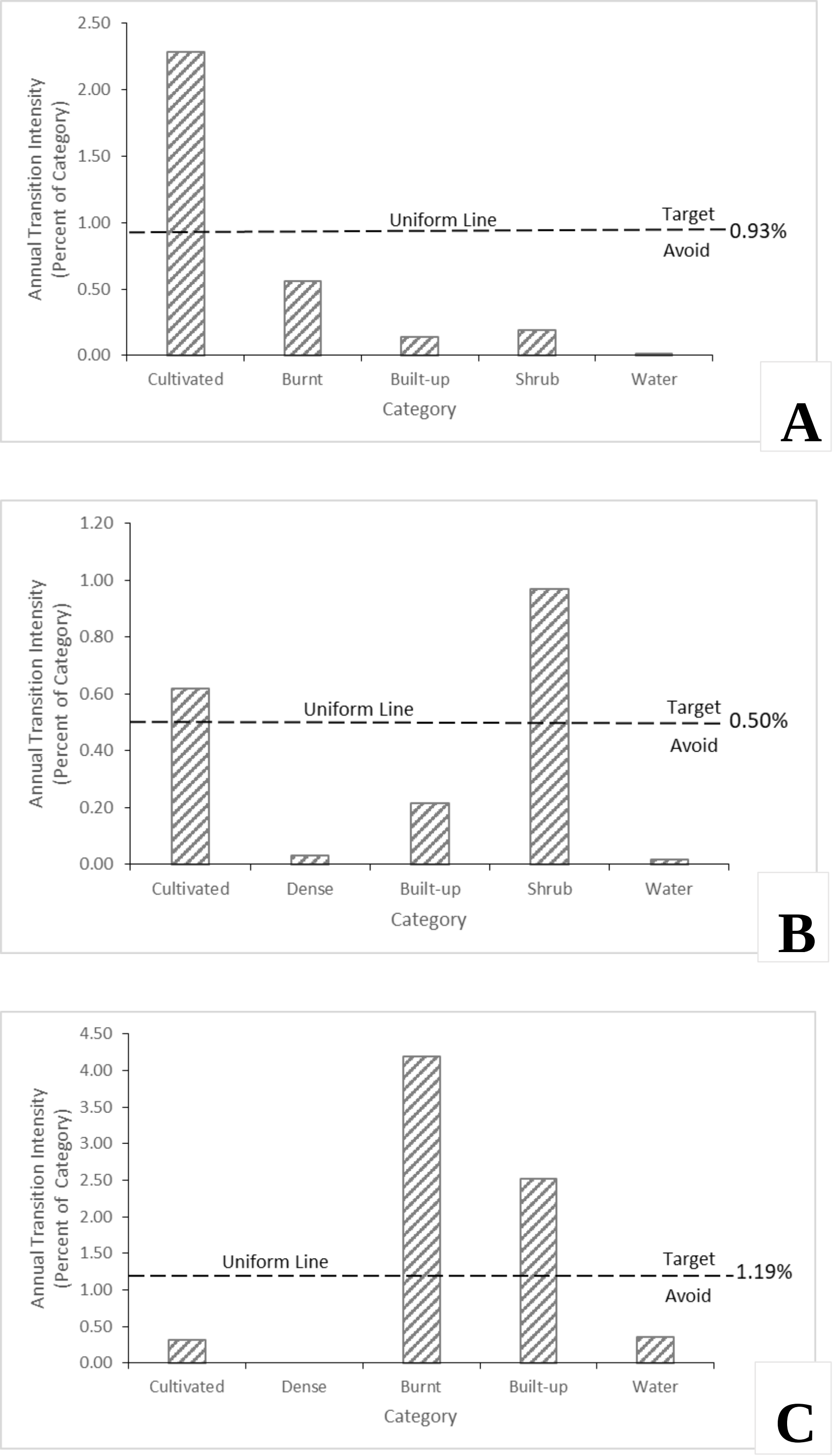


Figure 4.21: Transition Intensity from active losing categories for Muni-Pomadze Ramsar Site (2002-2017)

(A) From dense forest to other categories (B) From burnt land to other categories (C) From shrub/grassland to other categories

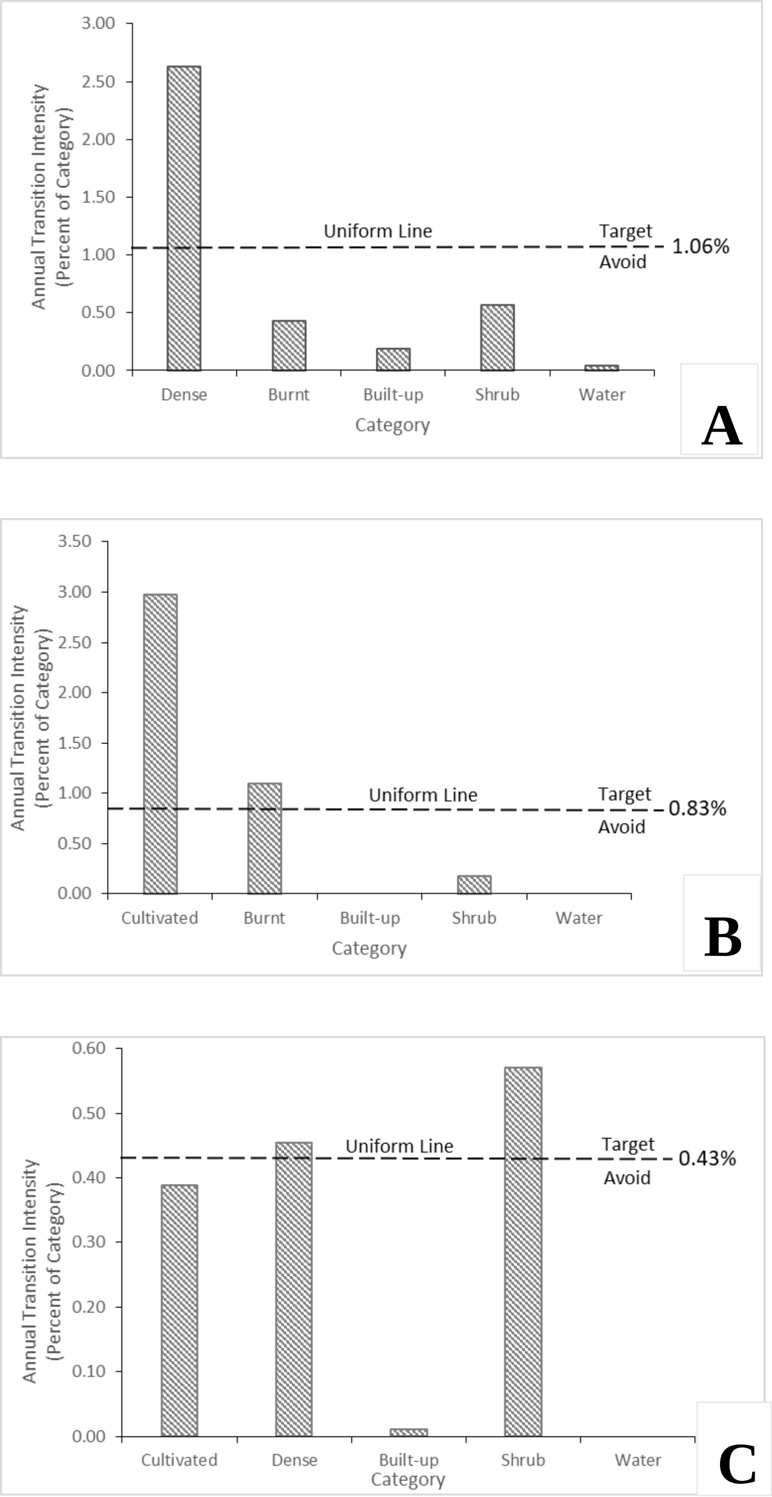
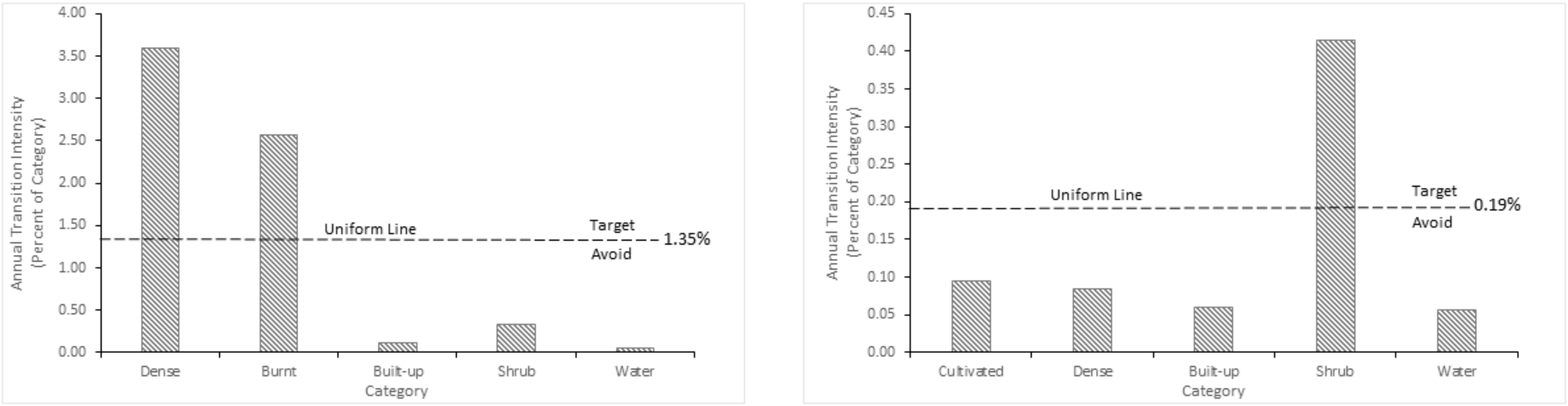


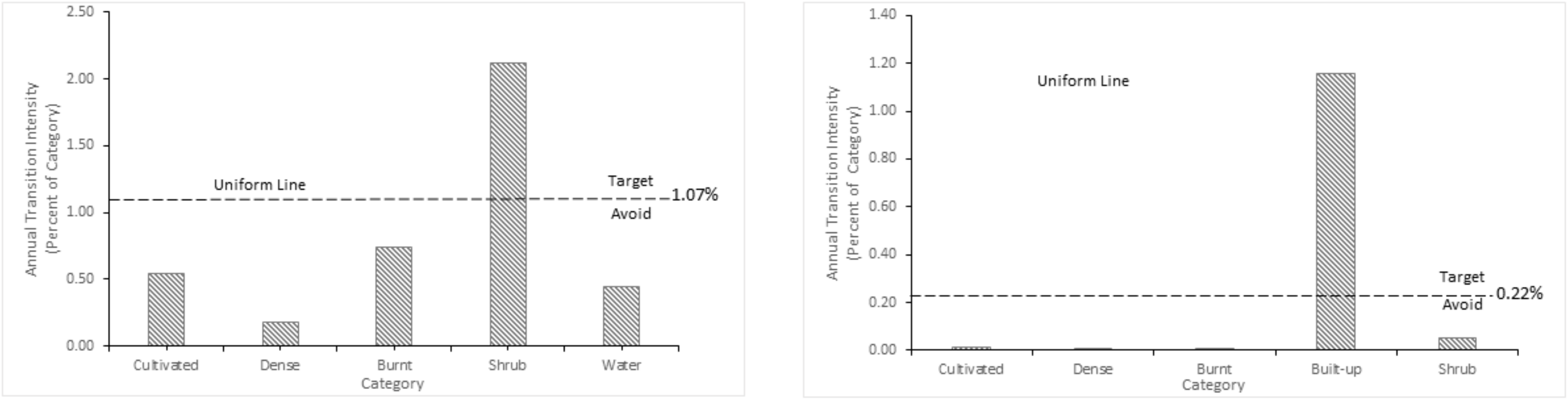
Figure 4.22: Transition Intensity to Active Gaining Categories for Muni-Pomadze Ramsar Site (1985-2002)

(A) Cultivated Land (B) Dense Forest (C) Burnt Land



a. Other categories to cultivated land

b. Other categories to burnt land



c. Other categories to built-up/bareland

d. Other categories to water (2002-2017)

Figure 4.23: Transition Intensity to Active Gaining Categories Muni-Pomadze Ramsar Site (2002-2017)

4.5 Land Use Change Dynamic Degree

Table 4.7 and 4.8 provide the results of the Single Land-Use Dynamic Degree (SLDD) for the three Ramsar Sites. A positive value indicates a LULC growth, while a negative value indicates a reduction. A larger absolute value means a faster changing speed. The results re-emphasize the outputs of the LULC change analysis as well as the intensity analysis. At Densu Delta, thicket and marsh decreased continuously in both time intervals whereas built-up/bareland increased significantly in both time intervals. Marsh recorded the least annual rate of reduction (0.10%) which occurred in the first time interval and built-up/bareland had the highest annual rate of increment (5.38%) in the second time interval.

At Sakumo II Ramsar Site, thicket and built-up/bareland experience continuous increase on the other hand, marsh recorded a continuous decrease. Water decreased in the first time interval and then increased during the second time interval. Marsh had the lowest annual rate of reduction (0.62%) which occurred in the first time interval and the highest annual rate (7.15%) being an increment was recorded by built-up/bareland in the second time interval.

With regards to Muni-Pomadze Ramsar Site, cultivated land and built-up/Bareland experienced continuous increment. Dense forest and shrub/grassland reduced continuously in both time intervals. Water had a negative rate (decreased) in the first time interval and changed to positive rate (increased) in the second time interval. Contrary to water, burnt land increased in the first time interval but decreased in the second period. Dense forest had the lowest annual rate of reduction

(0.51%) which occurred in the first time interval and the highest annual rate of increment (17.07%) was recorded by water in the second time interval.

The last role in Table 4.7 and 4.8 gives information on Integrated Land-Use Dynamic Degree (ILDD). ILDD is computed to quantify the overall change of all LULC classes through calculating the transfer rate among all LULC in landscape at a specified time period. The IDLD values show that the annual rate of change in the wetlands in the first time interval was smaller compared to the second time interval. It means that the wetlands are changing at a faster speed in the second time period. This finding is in consistent with the results of the interval level intensity analysis. Densu Delta had the smallest annual rate of change (0.51%) in the first time interval and Muni-Pomadze had the highest annual rate of change of 0.81 percent. In the second time interval, ILDD analysis indicated that Sakumo II changed at a much faster rate (1.77%) annually compared to the other wetlands. The speed at which Muni-Pomadze was changing was the least (1.55%) comparing it to the other wetlands.

Table 4.7 - *SLDD and ILDD (%) for Densu and Sakumo II Ramsar Sites*

	Densu Delta		Sakumo II	
LULC Class	1985-2002	2002-2017	1985-2002	2002-2017
Thicket	-2.05	-3.39	0.93	1.11
Built-up/ Bareland	0.69	5.38	3.74	7.15
Marsh	-0.10	-2.85	-0.62	-3.12
Water	2.27	0.19	-1.84	6.48
ILDD	0.51	1.55	0.55	1.77

Table 4.8 – *SLDD and ILDD (%) for Muni-Pomadze Ramsar Site*

LULC Class	1985-2002	2002-2017
Cultivated land	1.35	3.08
Dense forest	-0.51	-3.21
Water	-0.79	17.07
Built-up/ Bareland	3.02	3.44
Shrub/ Grassland	-1.60	-1.66
Burnt	5.83	-4.00
ILDD	0.81	1.49

4.5.1 Landscape Deviation Degree (LDD) of Wetlands

LDD quantifies the extent at which human activities have changed the natural landscape. The results of the deviation degree of the wetlands are provided in Table 4.9. In Densu Delta, Ramsar Site, saltpans areas which form part of the water class were considered as artificial surfaces. In Sakumo II Ramsar Site, portions of the water surface that were covered by Pistia plants were also considered as artificial surfaces. Sakumo II Ramsar Site had the lowest deviation throughout the three time points and Densu Delta had the highest deviation in 1985 and 2017 but had the same LDD with Muni-Pomade Ramsar Site in 2002. The deviation degree for all the three wetlands increased progressively over the study period.

Table 4.9 – *Landscape Deviation Degree of Wetlands*

	Degree of Deviation		
Ramsar Site	1985	2002	2017
Densu Delta	0.39	0.47	0.71
Sakumo II	0.10	0.18	0.39
Muni-Pomadze	0.33	0.47	0.61

4.6 Simulation of Built-up/Bareland Growth in Coastal Urban Wetlands

Land use land cover simulations for the study areas were carried out using the Land Change Modeler (LCM) in Terrset software. The purpose of the simulation was to predict the expansion of built-up/bareland, thus the transition of other LULC classes to built-up/bareland. Transition probability matrix were computed for the years 2017 (using LULC maps of 1985 and 2002) and 2032 (using LULC for 2002 and 2032) presented in Appendix E.

The transition probability matrix show areas that are likely to be transitioned to other classes. The driver variables included in the models were land cover map, distance to road, digital elevation model (DEM) and slope. These drivers were used to generate transition potential maps. The LULC of 2017 were predicted using the transition probability matrix and the transition potential models. Figure 4.24, 4.25 and 4.26 show the classified LULC maps of 2017 and the simulated maps of 2017.

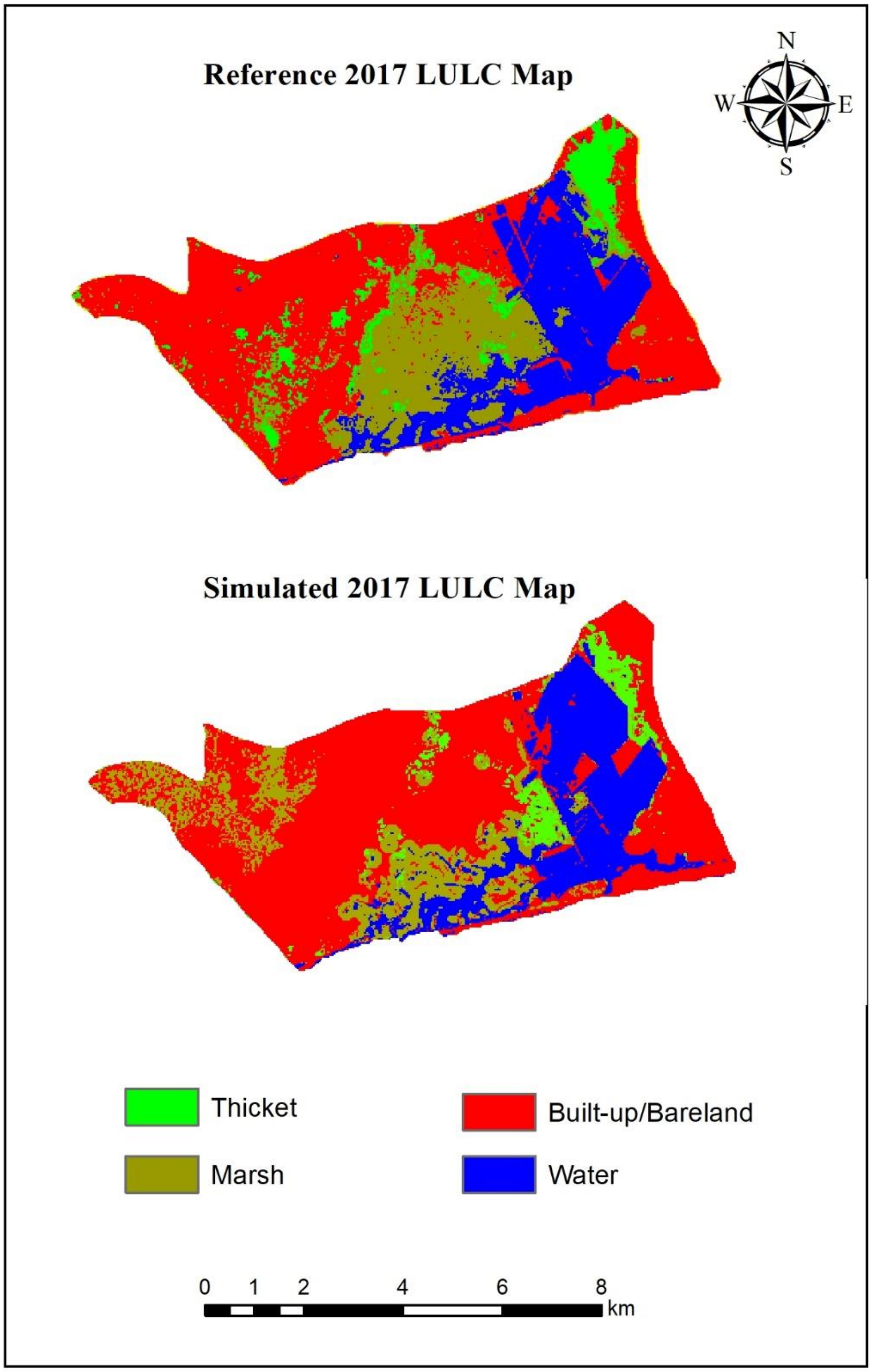


Figure 4.24: Densu Delta Reference and Simulated maps for 2017

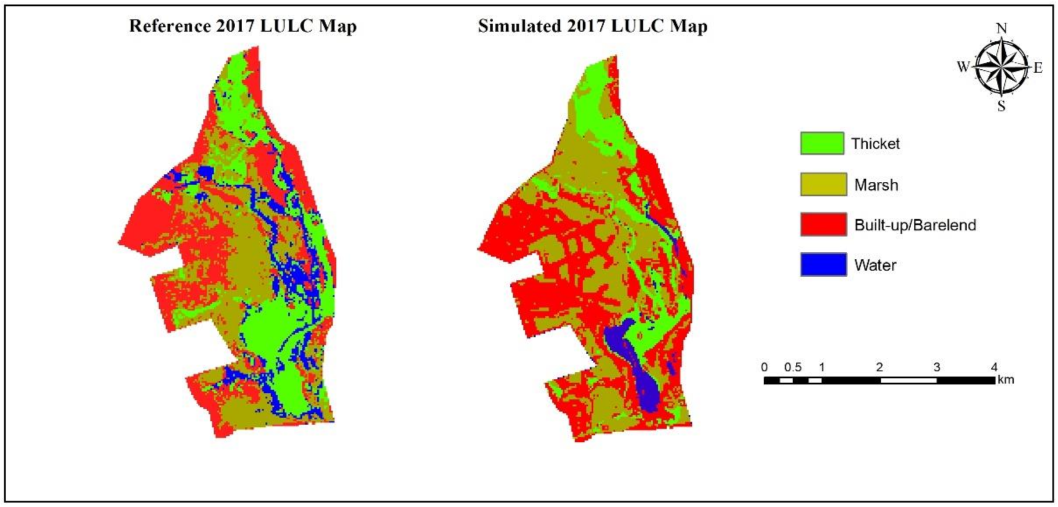


Figure 4.25: Sakumo II Reference and Simulated maps for 2017

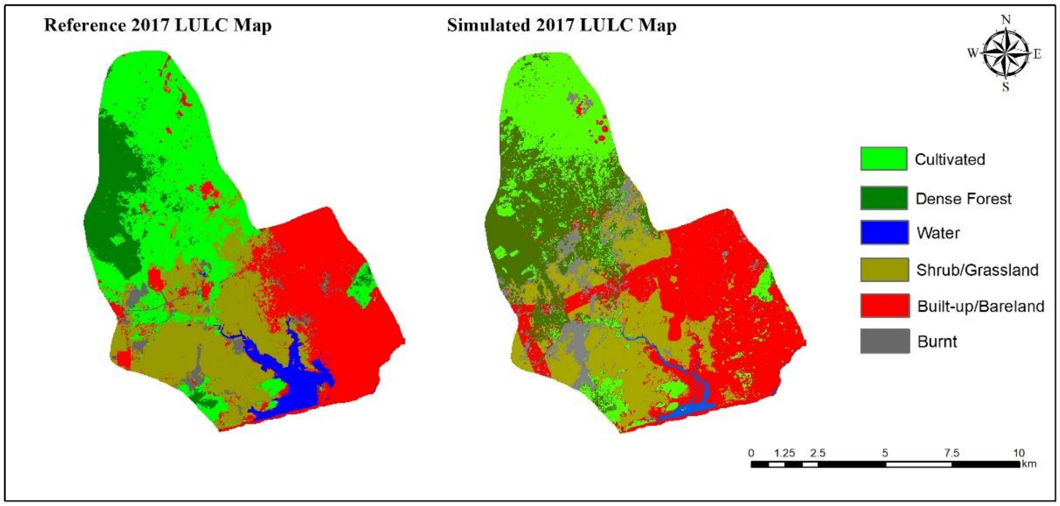


Figure 4.26: Muni-Pomadze Reference and Simulated maps for 2017

The predicted maps for 2017 were validated using the classified LULC maps of 2017. The Kappa Components and Cramer's V statistics results from the validation are provided in Appendix E. The validation results indicate that the reference LULC maps and the simulated maps are much similar. When values for Kappa Components and Cramer's V statistics reach 1, it indicates a perfect agreement between the reference LULC maps and the simulated maps. The overall accuracy of the predicted map is given by Kno value. From the validation results, the simulated map of Densu Delta Ramsar Site had the highest Kno value of 0.79, followed by the Muni-PomadzeRamsar Site (0.75) and Sakumo II had the least value of 0.67.

After the validation process, the predicted maps for 2032 were generated. Figure 4.27, 4.28 and 4.29 present the simulated maps, persistence maps and change maps for 2032 for all the study areas. Change analysis was carried out to determine the changes that were likely to occur and the results are presented in Appendix E. At Densu Delta Ramsar Site, area covered by built-up will increase from 23.90km^2 (50.63%) in 2017 to 30.98km^2 (65.64%) in 2032. The main target class will be marsh, losing about 4.55km^2 (9.65%). Thicket will reduced by 3.87 percent (1.83km^2). Water will be marginally affected by increase in built-up/bareland, it will reduce by 1.49 percent (0.70km^2) of its total area.

Built-up/Bareland in Sakumo II Ramsar Site was simulated to increase from 4.88km^2 (33.98%) in 2017 to 7.17km^2 (49.97%) in 2032. As observed in Densu Delta change analysis, marsh will be the main target for built-up/bareland expansion. Marsh will decrease by 12.30 percent (1.77km^2) whereas area covered by thicket will reduce from 3.52km^2 (24.49%) in 2017 to 3.05km^2 (21.27%) in 2032. Water will be least affected by expansion of built-up/bareland area, it will decrease by 0.47 percent (0.07km^2) of its total area.

The simulation analysis showed that built-up/bareland in Muni-Pomadze will increase from 11.01km^2 (11.45%) in 2017 to 16.66km^2 (17.34%) in 2032. Cultivated and burnt lands will also increase by 4.09 and 3.84 percent respectively. The main target class for the predicted increase will be shrub/grassland, losing about 11.23km^2 (11.68%). Thicket will reduced by 3.87 percent (1.83km^2). Water will be marginally affected by increase in built-up/bareland, it will reduce by 1.49 percent (0.70km^2) of its total area. Area covered by dense forest and water will decrease by 1.94 and 0.19 percent respectively.

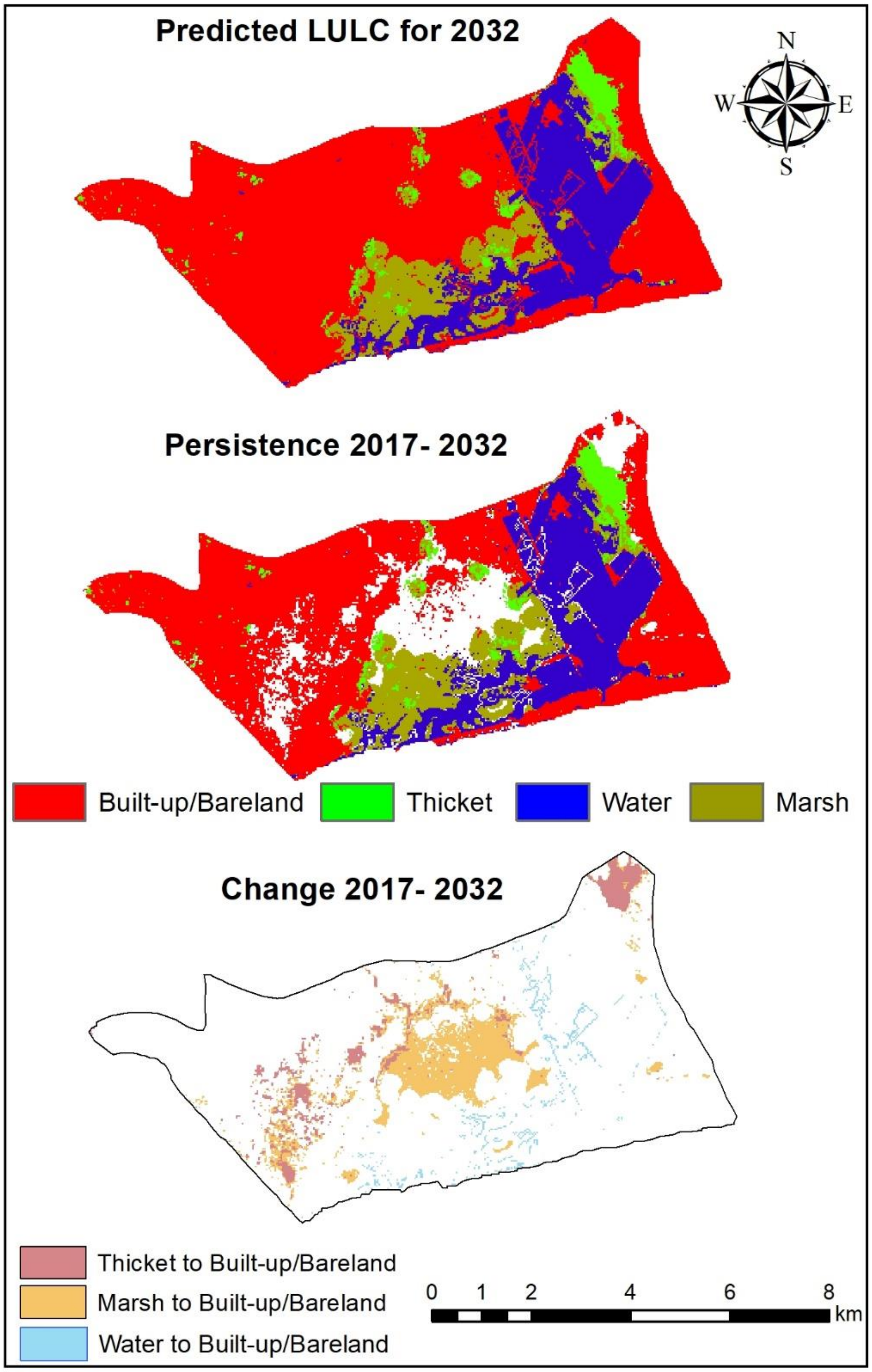


Figure 4.27: Densu Delta Ramsar Site Simulation Maps Showing Persistence and Change Areas in 2032

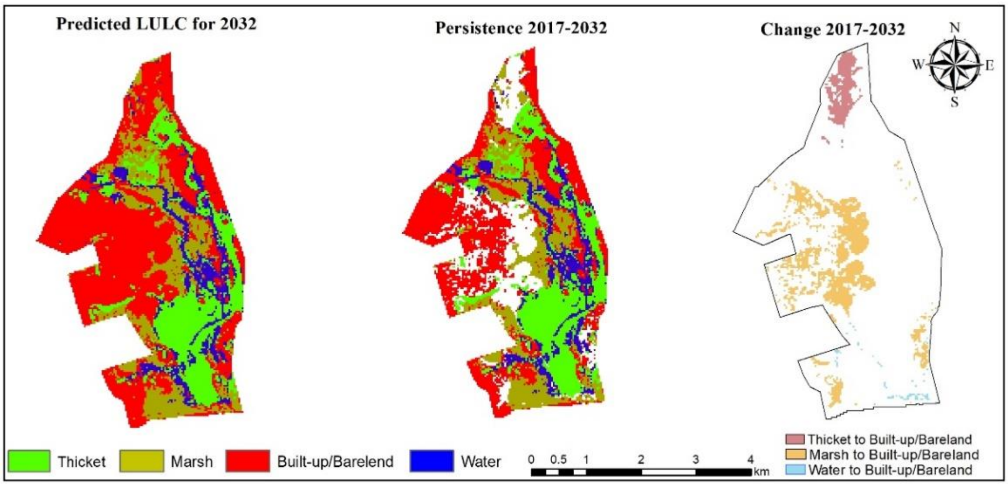


Figure 4.28: Sakumo II Ramsar Site Simulation Maps Showing Persistence and Change Areas in 2032

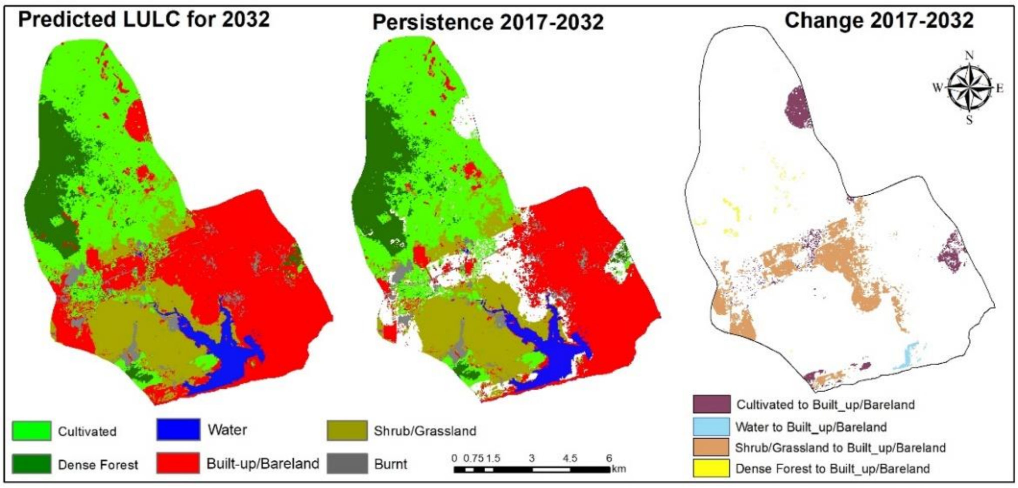


Figure 4.29: Muni-Pomadze Ramsar Site Simulation Maps Showing Persistence and Change Areas in 2032

4.7 Wetland Landscape Fragmentation Analysis

The landscape pattern indices were computed to quantitatively describe the landscape structure transformations in the study areas. To identify the appropriate metrics for the study, thirty-nine (39) class metrics were calculated. Spearman correlation was run to eliminate high correlating indices. One of the indices with Spearman's Correlation Coefficient above 0.8 or less than -0.8 were eliminated to reduce redundancy. A Principal Component Analysis (PCA) was then carried out to determine the indices that explain much variance in the landscape indices dataset. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy value was 0.61 indicating the appropriateness of the datasets for PCA analysis. Among the twenty-three (23) components generated, six (6) were retained at eigen value of 1 and more (see Figure 4.30).

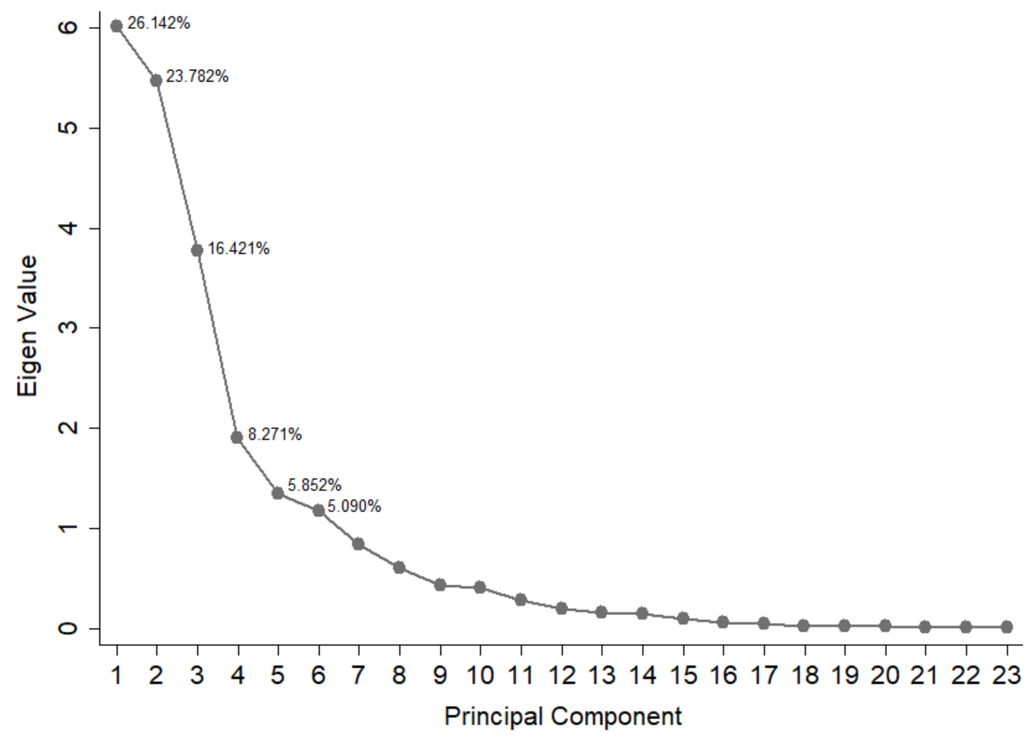


Figure 4.30: Scree Plot Showing Retained Components and their Corresponding Eigen Value

The 6 retained components explain 85.56 percent variance in data (Figure 4.30). For each retained component, high loading index (absolute score of 0.8 and above) were selected. In all, eleven (11) indices were selected; largest patch index (LPI), core area percentage of landscape (CPLAND), total edge (TE), landscape division index (DIVISION), splitting index (SPLIT), mean edge contrast (ECON_MN), edge density (ED), contrast-weighted edge density (CWED), patch density (PD), mean patch fractal dimension (FRAC_MN) and SIMI_MN. These landscape indices change with activities that increase fragmentation. The definitions of the retained indices are found in chapter 3, section 5 (3.5). This implies that fragmentation was very high in the study landscapes. The rotated component matrix is found in Appendix F. A biplot showing the orthogonal direction of the selected indices are shown in Figure 4.31.

Indices close to each other have high positive correlation and indices that are far apart have weak relationship.

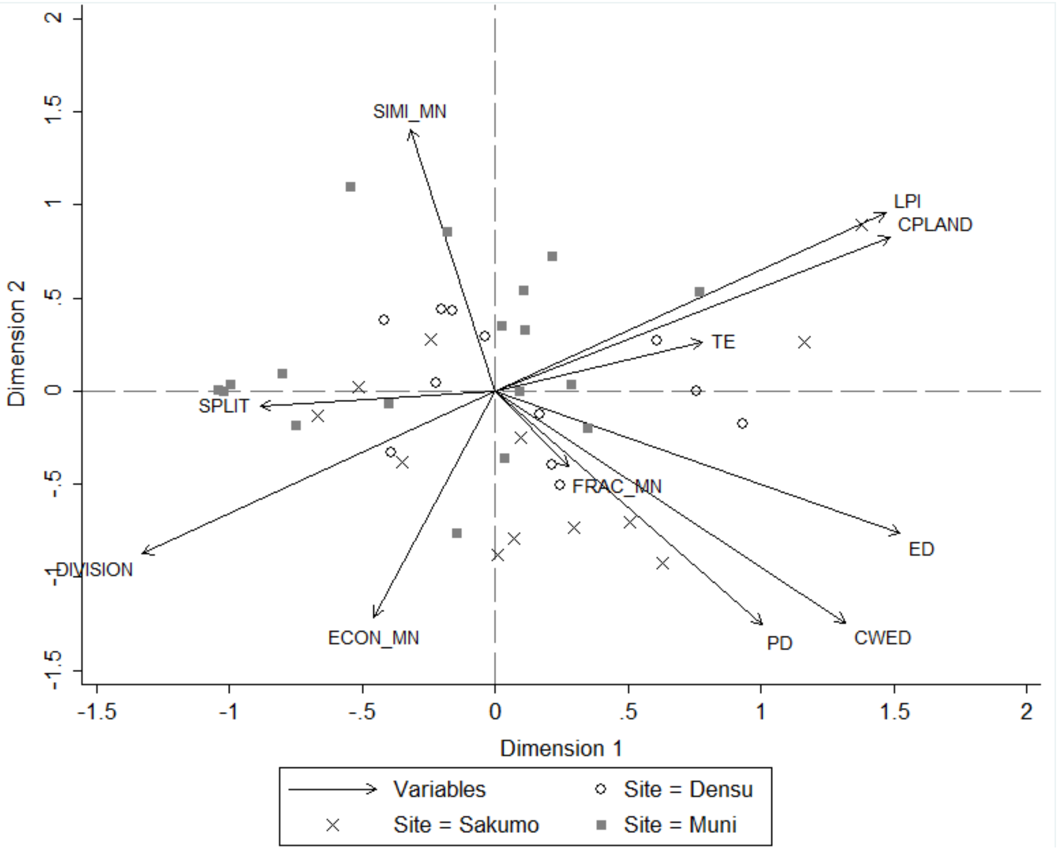


Figure 4.31: A Biplot of Retained Class Indices

For instance, CPLAND and LPI have high correlation and this explains why they were found in the same principal component (PC 2). LPI and SIMI_MN have weak relationship and that is why they were in different principal components. LPI, CPLAND, and TE have inverse relationship with DIVISION, SPLIT, and ECON_MN. This is because the latter indices increase with increase in fragmentation while the former indices decrease with fragmentation increase. On the other hand, natural classes values for DIVISION, SPLIT, ECON_MN, CWED, ED and FRAC_MN increased with time while that of built-up/bareland and cultivated values decreased with time indicating a continuous rise of fragmentation activities. There is also negative relationship between SIMI_MN and CWED, ED, FRAC_MN and PD. As observed in the earlier comparison, SIMI_MN decreases with fragmentation while CWED, ED, FRAC_MN and PD increase with fragmentation. In the biplot, ED, LPI, CPLAND and DIVISION had the largest variance and FRAC_MN and TE had the least variance. In all the wetlands, artificial classes (built-up/bareland and cultivated) values for the landscape indices showed a negative relationship with that of the natural classes like marsh, thicket dense forest and shrub/grassland decreased (see Appendix F).

4.8 Spectral Indices

Normalized difference vegetation index (NDVI) and normalized difference water index (NDWI) were computed to estimate vegetation vigour and inundation respectively for the study areas. NDVI maps are provided in Figure 4.32, 4.34 and 4.36. NDWI maps are presented in Figure 4.33, 4.35 and 4.37. There were some disparities in the values which could be attributed to the differences in the sensors used for the three study years. The maps were reclassified to quantify the extent of vegetation and water expressed as percentage of the total area of the wetlands (see Table 4.10). NDVI value of 0.2 and above were classified as vegetation and positive NDWI values were classified as water. Areas of high NDVI values at Densu Delta significantly reduced over the study period. In Sakumo II and Muni-Pomadze, areas of high NDVI values reduced in 2002 and increased in 2017. The increase observed in 2017 at Sakumo II could be largely attributed to the taking over of the Sakumo II lagoon by weeds. The gains made in 2017 at Muni-Pomadze could be as a result of plantation activities by the Forest Service Division and Wildlife Division offices at Winneba.

Areas of high NDWI values at Densu Delta significantly increased over the study period. Construction of saltpans accounted for the increase. Part of the wetland has been given out for commercial salt production. Sakumo II and Muni-Pomadze, experienced similar trend, areas of high NDWI values reduced in 2002 and increased in 2017.

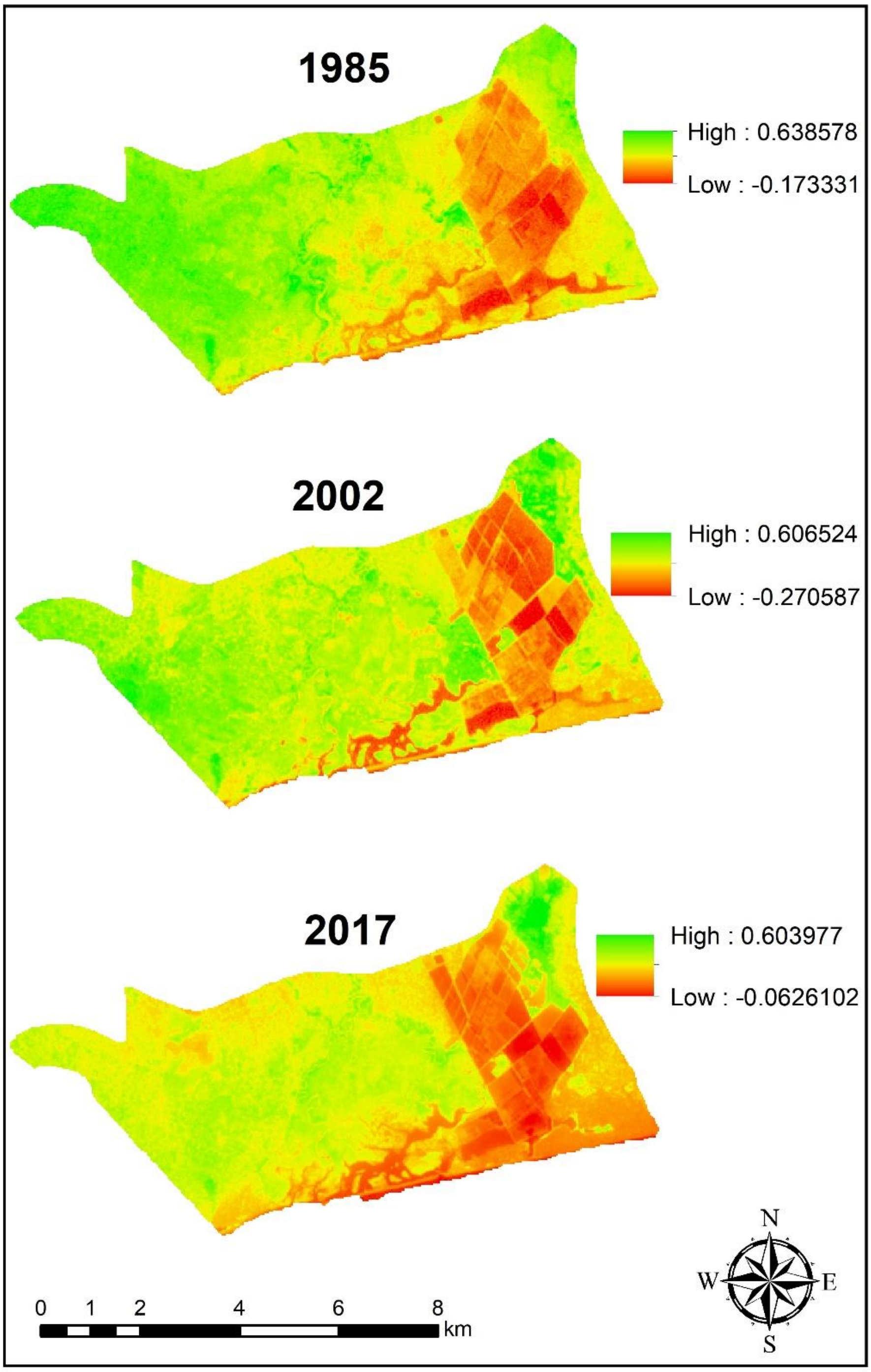


Figure 4.32: NDVI Maps of Densu Delta Ramsar Site for 1985, 2002 and 2017

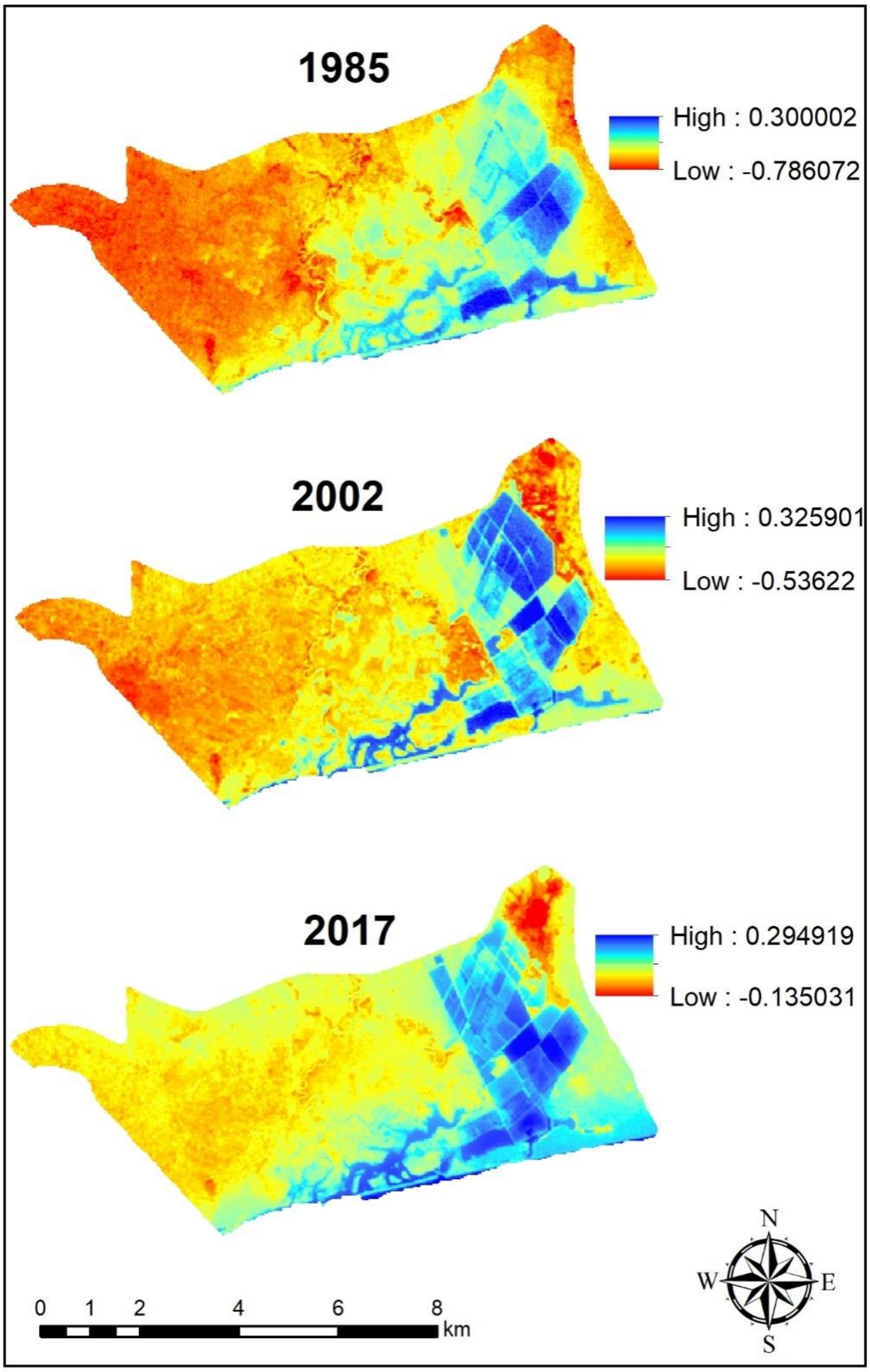


Figure 4.33: NDWI Maps of Densu Delta Ramsar Site for 1985, 2002 and 2017

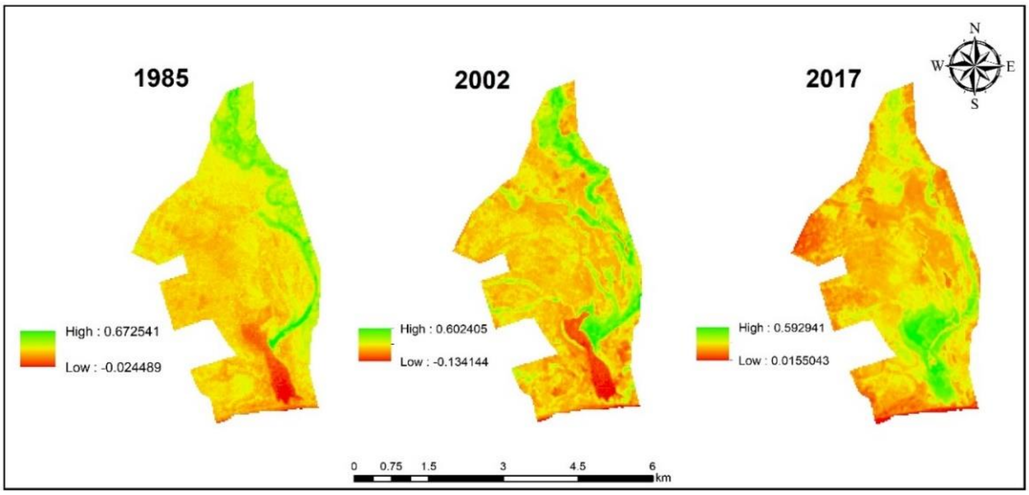


Figure 4.34: NDVI Maps of Sakumo II Ramsar Site for 1985, 2002 and 2017

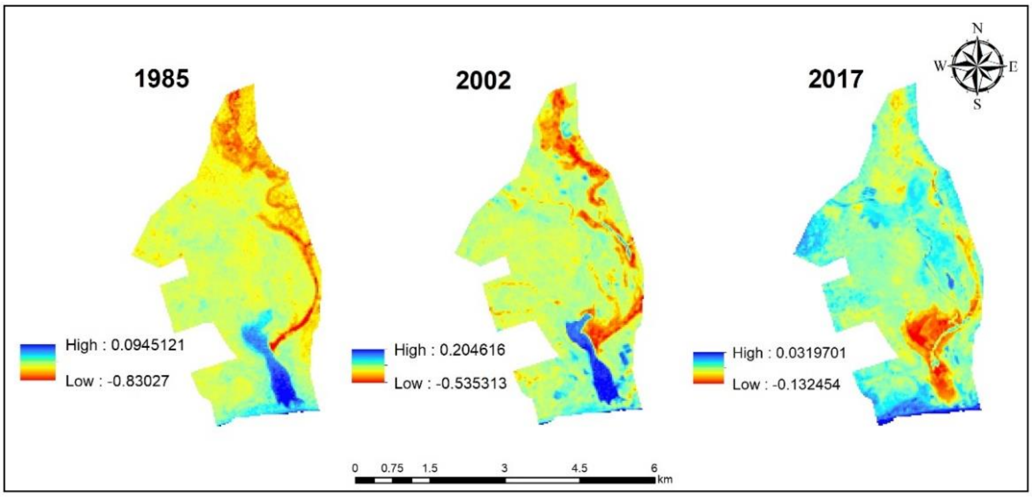


Figure 4.35: NDWI Maps of Sakumo II Ramsar Site for 1985, 2002 and 2017

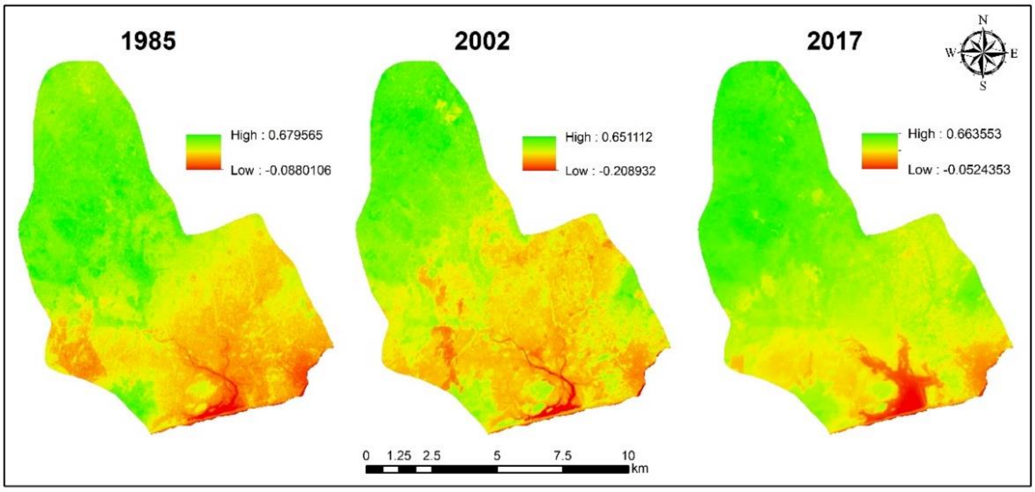


Figure 4.36: NDVI Maps of Muni-Pomadze Ramsar Site for 1985, 2002 and 2017

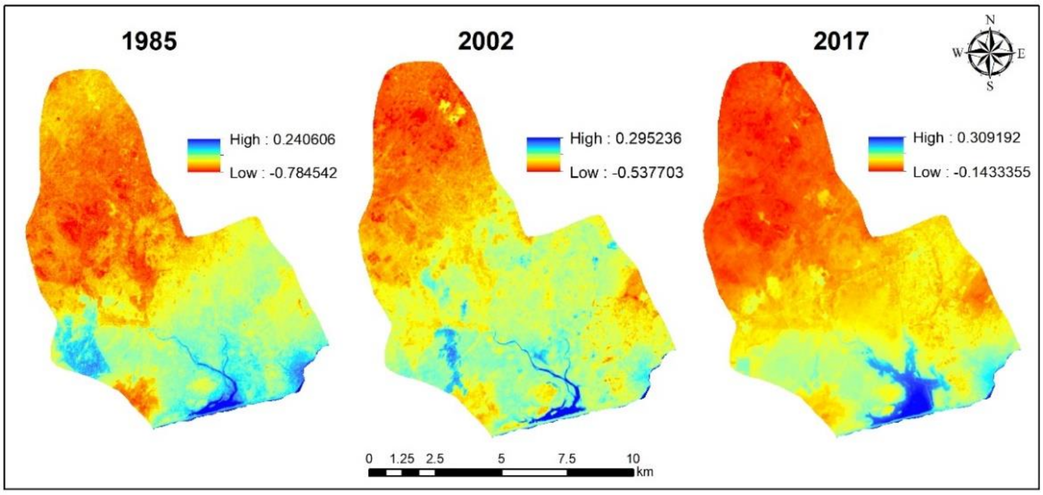


Figure 4.37 NDWI Maps of Muni-Pomadze Ramsar Site for 1985, 2002 and 2017

Table 4.10 – *NDVI and NDWI Area Coverage (%) of Study Areas*

	Densu		Sakumo II		Muni-Pomadze	
Year	NDVI	NDWI	NDVI	NDWI	NDVI	NDWI
1985	54.62	8.7	80.13	3.99	83.81	1.39
2002	45.91	16.16	59.88	3.85	62	1.66
2017	30.23	17.1	65.33	4.59	65.1	4.59

4.9 Wetland Ecosystem Health Assessment

In this study, wetland ecosystem health was assessed using three indicators; structure, function and resilience. The sub-indicators for structure were LULC change and fragmentation. LDD was the measured variable for LULC. Fragmentation was assessed using the eleven landscape class metrics that loaded strongly in the PCA. Each index was given equal share of the weight assigned to fragmentation from the AHP. The sub-indicators for function were NDVI and NDWI. Impervious surface and persistence of LULC were sub-indicators for resilience. Total area of built-up was the variable evaluated to represent impervious surface. Persistence of LULC was calculated by subtracting the sum of areas that experienced change from the total area of wetland. The change for 1985 was not measured in this study. A change value of 16 percent reported by Hu et al (2017) for wetlands in Africa was used. The state of the wetlands in 1985 was considered healthy to which the state of the wetlands in the other years were compared thus, 1985 values of the indicators were the reference values.

Among the sub-indicators, LULC and impervious surface were considered negative thus, an increase in their values deteriorate the health of wetland ecosystem. NDVI, NDWI and persistence were regarded positive sub-indicators, increase in their values improve the health of wetland ecosystem. With regards to fragmentation, LPI, CPLAND and SIMI_MN were positive and the remaining eight indices were negative. From the AHP, structure was assigned the greatest weight among the indicators and function had the least weight. Table 4.11 presents the weight of the wetland ecosystem health indicators evaluated using AHP method.

Table 4.11 – *Computation results of evaluating weight of wetland ecosystem health indicators by AHP method*

Goal	Indicator	Weight	Sub-indicator	Relative Weight	Overall Weight
Wetland Ecosystem Health	Structure	0.381	LULC	0.833	0.281
			Fragmentation	0.167	0.099
	Function	0.246	NDVI	0.875	0.156
			NDWI	0.125	0.090
	Resilience	0.374	Impervious Surface	0.200	0.111
			Persistence	0.800	0.263

Table 4.12 provides the health status of the three Ramsar Sites in 2002 and 2017 as compared to 1985.The values range from 0, being the worst state and 1, the healthiest state. The health status value in 1985 was regarded as 1. From the evaluation results (see Table 4.6), the health of all the wetlands deteriorated with time. In terms of magnitude, in 2002, Densu Delta experienced the least decline from 1985 state among the three wetlands and Sakumo II recorded the highest deterioration. Contrary to 2002, in 2017 the health of Densu Delta experienced the worst deterioration whereas Sakumo II recorded the least decline.

Table 4.12 - *Ecosystem Health Status of the Three Ramsar Sites*

Ramsar Site	Year		Change	
	2002	2017	1985-2002	2002-2017
Densu Delta	0.882	0.419	-0.118	-0.463
Sakumo II	0.620	0.358	-0.380	-0.262
Muni-Pomadze	0.730	0.438	-0.270	-0.291

CHAPTER FIVE

DISCUSSION

The results presented in Chapter four are discussed here. The discussion covers four main themes; assessment of LULC changes in coastal urban wetlands, landscapes fragmentation of wetlands, simulation of built-up growth in coastal urban wetlands and assessment of ecosystem health of coastal urban wetlands. For each theme, the discussion begins with a general perspective that covers all the three study areas and then narrows to examine specific issues peculiar to each of the wetlands.

5.1 Assessment of LULC Change in Coastal Urban Wetlands

In recent times, LULC change is increasingly acknowledged as a critical subject that needs to be addressed (Hu et al., 2019), especially in the era where global environmental change is an issue of concern to academia and policy makers. This study assessed LULC changes in three Ramsar Sites that are located within or close to urban settlements in the coastal zone of Ghana over thirty-two (32) year period. The results (Table 4.1-4.3) indicate that between 1985 and 2002 about 21.14 percent of the total area of the wetlands was subjected to changes and close to half of the total area (48.07%) of the wetlands experienced changes in 2002-2017 period. This means that processes that led to changes in the wetlands increased over the years. These processes could be linked to anthropogenic activities because, in 1985 and 2002, the largest LULC class for the wetlands were natural categories but in 2017, man-made LULC class became the largest. The deviation degree analysis (Table 4.9) which quantifies the extent at which human activities have changed the natural landscape showed a higher magnitude of anthropogenic disturbances over the study period. This implies that vegetated surfaces have been replaced with impervious surfaces which have adverse effects on the wetland ecosystem (Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005).

The results of the interval level intensity analysis (Figure 4.6, 4.11 and 4.17) and integrated land-use dynamic degree (Table 4.7 and 4.8) point to the fact that the speed with which the wetlands are changing is becoming intense in recent times, which means human activities in the wetlands is increasing in magnitude and at a faster pace. The increasing activities in the Ramsar Sites is as a result of rapid growth of human population in the cities in which the Ramsar sites are located. The human population of Accra and Winneba doubled between 1984 and 2010 according to the 2010 Population and Housing Census National Analytical Report (Ghana Statistical Service, 2013). This is in tandem with the LULC changes that also doubled in the second time interval.

The findings from the category intensity analysis of the wetlands (see Figure 4.7-4.8, 4.12-4.13 and 4.18-4.19) provide information on the gains and losses of the various LULC categories in the Ramsar Sites. At Densu Delta, thicket and built-up/bareland experienced the most significant losses in the first time interval. The transition intensity analysis indicated that the rise in physical developments such as residential facilities and commercial salt production accounted for the losses. Built-up/Bareland was the only category that gained significantly in the first time interval. The gains were made mainly at the expense of thicket and marsh. Similar pattern was observed in the second time interval however, Built-up/Bareland continued to expand at the expense of thicket and marsh. The changes in LULC at Densu Delta in both time intervals were driven by two main activities, urbanization and commercial salt production.

The LULC changes at Sakumo II wetland in both time intervals had a similar trend like the Densu Delta. Thicket and marsh were intensely lost due to the expansion of built-up. Thicket and marsh were also cleared as a result of agricultural activities. The catchment of the Sakumo lagoon was dominated by human activities such as arable farming, livestock rearing and industrialization during the first time interval (Amatekpor, 1998 cited in Nartey, Edor, Doamekpor, & Bobobee, 2011). The loss of water to thicket could be attributed to invasion of *Pistia stratiotes* plants on the surface of the lagoon caused by discharge of effluent from agricultural runoff, industrial wastewater and sewage from residential areas. During image classification, because parts of the lagoon were covered by the *Pistia stratiotes* plants, they were classified as thicket due their spectral signatures. LULC changes at Sakumo II Ramsar site in both time intervals were driven by urbanization, agricultural activities and pollution of the water bodies by agricultural runoffs, wastewater from industrial activities and sewage from residential areas as reported by Nartey et al. (2011).

LULC changes in Muni-Poamdze Ramsar Site did not follow similar trend like what occurred in Densu Delta and Sakumo II Ramsar Sites. Even though burnt areas are usually not regarded as a LULC class, they persisted in significant extent in all the three study years. Wildfires are common in the Ramsar Sites especially during the dry season (Attuquayefio, D. K., & Wuver, 2003). In essence, this study included burnt land as a LULC class in the image classification scheme of Muni-Pomadze Ramsar Site in order to assess how it changes over the period. In the first time interval, the active losing categories were cultivated land, dense forest and burnt land and they were the same categories that had significant gains. These changes were primarily driven by agricultural activities. The Ramsar Site is surrounded by eleven communities whose main occupation is farming and the site is their main source of farmlands (Gordon et al., 2000). This accounts for the reason why dense forest was intensely converted into cultivated lands. Besides, large areas of the Ramsar Site is occupied by shrub and grassland which serve as range land for some herdsmen and hunting grounds for hunters (Attuquayefio, Wuver, & Enu-Kwesi, 2003; Gordon et al., 2000). During the dry season, portions of the shrub/grassland are burnt by the herdsmen to enable fresh foliage to grow to serve as forage for their cattle.

In the second time interval, the active losing categories were dense forest, burnt land and shrub/grassland whilst the active gaining categories were cultivated land, built-up/bareland and water. Apart from the gains observed in the water category, all the changes were caused by increase in human population. The rise in farming population put more pressure on the dense forest and shrub/grassland and this explains the massive reduction experienced by the two categories. The remaining dense forest is largely the Yenku Forest Reserve which is a protected area. Cultivated land expanded at the expense of dense forest and built-up/bareland increased at the expense of shrub/grassland. The reduction in burnt land is largely due to the effort of the staff of Forestry Commission at the Winneba District. They embark on wildfire management campaign in collaboration with the Ghana Fire Service annually during the dry season to educate the communities and besides, the Forest Guards patrol along the boundaries of Yenku Forest Reserve to protect it against wildfire (A. Agyekumhene, personal communication, May 16, 2019). In 2016, the delay in opening the mouth of the Muni lagoon during the raining season forced it to overflow its banks. This incident has permanently increased the surface area of the lagoon and also modified the shape (A. Agyekumhene, personal communication, May 16, 2019). This explains expansion of water in the second time interval. In addition, some saltpans were constructed and this could also partly increase the water category.

5.3 Simulation of Built-Up/Bareland Growth in Coastal Urban Wetlands

It has been predicted that the growth of urban areas will lead to loss of natural wetlands (Yuanbin et al., 2012). A study has shown that urban growth also reduces water quality (Frumkin, 2015). The findings of this study indicate that built up/bareland growth will affect the other LULC classes in 2032. The simulation estimated that about 30 percent of the total area of the wetlands will be subjected to changes as a result of built-up/bareland expansion. Comparing the study areas maps (Figure 3.1-3.3) with the 2032 simulated maps (Figure 4.24-4.26), it was observed that built-up expansion will occur along the road network within the wetlands. This implies that accessibility is a major driving force to built-up expansion in the wetlands.

It was observed that in fifteen (15) years, built-up/bareland in Densu Delta Ramsar Site will increase by 15.01 percent occupying 65.65 percent of the total are of the wetland (see Appendix E). The main LULC targeted for this growth will be marsh, losing about 9.05 percent of its total area. Water will not be affected by the expansion of built-up/bareland. This will likely increase flooding incidence in the flood prone residential areas such as Glefe and Dansoman (Amoako, Kweku, & Inkoom, 2018) since marsh receives the spill over water from the estuary during raining season. In addition, the health of the estuary will deteriorate with the expansion of built-up/bareland growth. Studies have shown that urban growth has adverse effects on water bodies (Rashid et al., 2018).

Built-up/Bareland in Sakumo II Ramsar Site is predicted to expand by 15.98 percent in 2032, occupying almost half (49.97%) of the total area of the Site. Marsh will be the main category that will contribute to the growth leading to reduction of area by 12.30 percent in 2032. Area covered by water is likely to be maintained because it will not contribute to the growth of built-up/bareland. The expected growth will worsen the health of the Sakumo lagoon and other streams in the catchment area (Nonterah et al., 2015) and likely exacerbate flooding incidence in flood prone areas such as Lashibi and Ashiaman residential areas.

In 2032, built-up/bareland in Muni-Pomadze Ramsar Site is expected to increase by 5.88 percent which is far less than the growth predicted for Densu Delta and Sakumo II Ramsar Sites because of differences in human population. Interestingly, cultivated land will also increase by 4.09 percent even though transition sub-models were not developed for cultivated land. This indicates that agriculture activities in the Ramsar Site will also increase significantly mainly because the farming population in the surrounding communities is projected to increase. Shrub/grassland will be the category that will be affected most, losing about 11.68 percent of its total area recorded in 2017. The closest LULC category to the Muni lagoon is the shrub/grassland. This implies that the simulated growth pattern will have adverse effects on lagoon. As observed in the other two Ramsar Sites, the size of the lagoon may not be affected significantly by the predicted changes, even if it does, it might be very minimal.

5.2 Landscape Fragmentation of Coastal Urban Wetlands

Fragmentation analysis was carried out to examine and quantify the extent of fragmentation accompanied with the LULC changes. Fragmentation is regarded as one of the important drivers of biodiversity loss (Cosentino & Schooley, 2018). It decreases the size and increases the isolation of habitats and population (Lienert & Fischer, 2003). Principal Component Analysis was carried out at the class level and eleven class indices were identified as the indices that explains the variance in the indices computed. The results (Appendix F) show that the wetlands are becoming more fragmented with time. Out of the eleven indices, eight of them were indices that described disaggregation of the wetlands and the remaining three were aggregation indices. The values for the disaggregation indices for natural classes increased with time whilst the aggregation indices decreased with time. This implies that the natural classes became more fragmented over the study period. Fragmentation of natural habitats is an indication of urbanization (Liu et al., 2016) which leads to the expansion of artificial surfaces. This explains the reason why the values for aggregation classes for built-up/bareland increased with time. In effect, whilst the natural classes were being broken into smaller patches and isolated, built-up/bareland was expanding.

5.4 Assessment of Ecosystem Health of Coastal Urban Wetlands

The health of the wetland ecosystem was assessed using three ecosystem indicators; structure, function and resilience. Analytic Hierarchy Process method was used to assign weight to the indicators. From the AHP results provided in Table 4.11, ecosystem structure received the highest weight followed by resilience. Ecosystem function was assigned the lowest weight. Bofu et al. (2016), also assigned a higher weight to ecosystem structure than function however, resilience was assigned the highest weight in their work unlike in this study. The differences may be attributed to the different variables considered under each ecosystem indicator and the method used in weighting the indicators.

The reference health state for this study was the state of the wetland ecosystem in 1985. The results of the evaluation (Table 4.12) show that the health of the wetlands has deteriorated in recent times compared to the health of the wetlands in 1985. The extent of deterioration in the first time interval was far less than that of the second time interval with the exception of Sakumo II Ramsar Site where health deterioration in the second time interval was lower than that of the first time interval. The primary cause of the health deterioration of the wetlands is the expansion of the built environment. Both the intensity analysis and LULC change dynamic index showed that the magnitude and the pace at which built-up is increasing in the Ramsar Sites is progressively high. Built-up expansion is a result of urbanization and this eventually leads to the replacement of vegetated surfaces with impermeable surfaces (Shuster et al., 2005). Expansion of impervious surfaces substantially reduces the infiltration capacity of landscapes which results in increase in the production of runoff (Hsu, Chen, & Chang, 2000). This eventually leads to flooding in the affected areas. Expansion of built environment also pollutes the wetlands through the discharge of effluents into the waterbodies and dumping of solid waste. For instance, the Sakumo lagoon has been invaded by Pistia plants because of discharge of domestic and waste water in the waterbody (J. Selormey, personal communication, May 28, 2019). The reduction in NDVI values of the Ramsar Sites across the two time intervals could be attributed to the replacement of vegetated surfaces with built surfaces.

Densu Delta and Muni-Pomadze Ramsar sites had some commercial salt production activities on-going during the study period. Saltpans were not identified in the first time interval at Muni-Pomadze wetlands but were present in the second time interval. Area covered by saltpans in Densu Delta was larger in the second time interval than the first. This accounted for the increase in water category in 2002 for Densu Delta and 2017 for both Muni-Pomadze and Densu Delta. This is an indication of increasing salt production activities in recent times on the wetlands. Gbogbo (2009), found out that population densities of water birds feeding exclusively on benthic macroinvertebrates were significantly lower in the salt production wetlands than wetlands which had no saltpans. This means that salt production affects the ecosystem functions of wetlands.

Agricultural activities had significant contribution to the decline of the health of Muni Ramsar Site in both time intervals. In the first time interval, cultivated land and burnt land recorded an exponential increase and this accounts for the substantial deterioration of the health of the wetland. Attuquayefio & Wuver (2003) found out that burnt areas in Muni-Pomadze recorded lower relative abundance and species diversity of small mammals compared to unburnt areas. Wildfires have been reported to affect diversity and abundance of floral species, plant life-forms and soil seed bank in the Ramsar Site (Attuquayefio et al., 2003). Among all the anthropogenic activities carried out in the Ramsar Site, Wuver & Attuquayefio (2006), reported that farming, wildfires and hunting posed significant threats to the wetland ecosystem. The pressure on the wetland was compounded in the second time interval when in addition to the agricultural activities, physical development activities also became injurious to the health of the wetland. Urbanization and agricultural activities will continue to increase in magnitude and pace so far as the population of Winneba and the surrounding farming communities continue to grow rapidly.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The conventional methods of assessing ecosystem health of wetlands largely depend on field observation data which cannot be employed in studies of large areas at different times to provide spatio-temporal perspective. Geospatial techniques have proven to be effective in this regard. The purpose of the present study was to employ geospatial techniques to assess the ecosystem health of coastal urban wetlands over the past 32 years and simulate the probable changes that will occur in 2032 based on the changes observed in the study period.

The results indicated that between 1985 and 2002 about 21.14 percent of the total area of the wetlands were subjected to LULC changes and close to half of the total area (48.07%) of the wetlands experienced changes in 2002-2017 period. The findings indicated that processes that led to the changes in the wetlands progressively increased in magnitude and pace with time. Anthropogenic activities were primarily, the cause of the changes and this was evident in the result. Vegetated surfaces were rapidly replaced with impervious surfaces.

The fragmentation results indicated that the natural classes in the wetlands were increasingly being broken into smaller patches and becoming more isolated. On the other hand, built-up/bareland expanded and became more aggregated over the study period. In essence, as human activities in the wetlands increases, the natural habitats become more fragmented.

Built-up expansion simulation in the wetlands estimated that about 30 percent of the total area of the wetlands will be subjected to LULC changes as a result of built-up/bareland expansion in 2032. Natural LULC classes were predicted to be the main target categories for the built-up growth.

The health of the wetlands has deteriorated in recent times compared to the health of the wetlands in 1985. The extent of deterioration in the first time interval was far less than that of the second time interval with the exception of Sakumo II Ramsar Site where health deterioration in the second time interval was lower than that of the first time interval. The primary cause of the health deterioration of the wetlands is the expansion of the built environment but for Muni-Pomadze, agricultural activities significantly contributed to the worsening health status.

6.2 Conclusions

The following conclusions are made from the study:

LULC of Muni-Pomadze Ramsar Site changed most in the first time interval, 1985-2002, compared to the other two wetlands this was mainly caused by agricultural activities. Densu Delta Ramsar Site experienced the least LULC change in the same period.

LULC of Sakumo II Ramsar Site experienced the highest change in the second time interval (2002-2017), as a result of expansion of built environment. Muni-Pomadze Ramsar Site recorded the least LULC change in the same period.

Generally, annual change rate in the first time interval was relatively slow whereas the annual change in the second time interval was relatively fast. Rapid human population growth in the cities where the wetlands are located accounted for the fast annual changes in the second period.

Built-up/Bareland expanded at the expense of marsh and thicket in both Densu Delta and Sakumo II Ramsar Sites for the two study periods. Dense forest and shrub/grassland were targeted by cultivated land and built-up/bareland to increase in Muni Pomadze Ramsar Site.

The fragmentation of the wetlands could be attributed to increased human activities in the wetlands. The natural LULC classes progressively became more fragmented over the study periond due to the expansion of built up/bareland. In Muni-Pomadze Ramsar Site, the growth of cultivated land and burnt areas also contributed to the fragmentation of the natural LULC classes.

Built-up/Bareland in Densu Delta Ramsar Site was simulated to increase from 50.63 percent in 2017 to 65.64 percent in 2032 and that of Sakumo II Ramsar Site was predicted to increase from 33.98 percent in 2017 to 49.97 percent in 2032. The simulation analysis also predicted that built-up/bareland in Muni-Pomadze will increase from 11.45 percent in 2017 to 17.34 percent in 2032. Built-up/Bareland expansion was predicted to occur along the road network in the Ramsar Sites.

Among all the three ecosystem health indicators considered in this study, ecosystem structure received the highest weight followed by resilience. Ecosystem function was assigned the lowest weight. Ecosystem health of all the wetlands deteriorated progressively throughout the study period. In terms of magnitude, in 2002, Densu Delta experienced the least decline (11.8%) from 1985 state among all the three wetlands and Sakumo II recorded the highest deterioration (38%). Contrary to 2002, in 2017, the health of Densu Delta experienced the worse deterioration (46.3%) whereas Sakumo II recorded the least decline (26.2%). Ecosystem health of Muni-Pomadze Ramsar Site deteriorated at a similar magnitude, 27 percent and 29.1 percent for 2002 and 2017 respectively.

6.3 Recommendations

Based on the findings of this study, the following recommendations are suggested to protect coastal urban wetlands:

1. Forestry Commission should put in place a comprehensive plan to monitor Ramsar Sites regularly and document the observed changes in a database that provides data for retrospective studies, to guide formulation of long term management strategies.
2. There should be deliberate and concerted effort among the relevant government agencies for effective implementation and enforcement of laws and regulations that protect urban wetlands.
3. The Forest Commission should strictly prohibit the construction of roads in urban wetlands since access drives built-up expansion.

4. Land use and spatial planning authority should consult Forestry Commission before zoning out new residential areas to avoid giving out wetlands for physical development.

The present study was not able to address some pertinent issues which required attention. Further studies are recommended to address the following issues:

1. Incorporate social and economic indicators in assessing ecosystem health of coastal urban wetlands
2. Employ high resolution satellite images that will enable the disaggregation of some LULC classes such as built-up/bareland and cultivated land.
3. A comprehensive approach that assesses pollution of wetland soil, water and ambient air in addition to the variables that were measured by this study.

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APPENDICES

APPENDIX A – ANALYTIC HIERARCHY PROCESS QUESTIONNAIRE

Dear Participant,

Thank you for accepting to participate in this survey.

My name is Bernard Ekumah and I am a graduate student of University of Cape Coast, Department of Environmental Science. I am currently working on a research entitled "Geospatial Assessment of Ecosystem Health of some Coastal Urban Wetlands in Ghana". As part of the research, I am conducting a multi-criteria analysis to elicit expert knowledge in order to prioritise the criteria and sub-criteria for evaluating ecosystem health of wetlands.

This survey is designed to collect and analyse judgments from people with in-depth knowledge in wetlands. The questionnaire is in two (2) sections (section 1- General Information about you, section 2 - will assess wetland health indicators). The approach uses the Analytic Hierarchy Process (AHP), a multi-criteria decision-making method to assess ecosystem health of wetlands. AHP uses a pairwise comparison method to generate weightings (ratio scales) for criteria or options.

As shown in Figure 1, the first level of hierarchy is the ultimate goal of the research (wetland ecosystem health assessment); the second level represents the criteria (indicators) on the basis of which the goal is to be evaluated and, finally, the third level presents the sub-criteria which feed into each criteria.

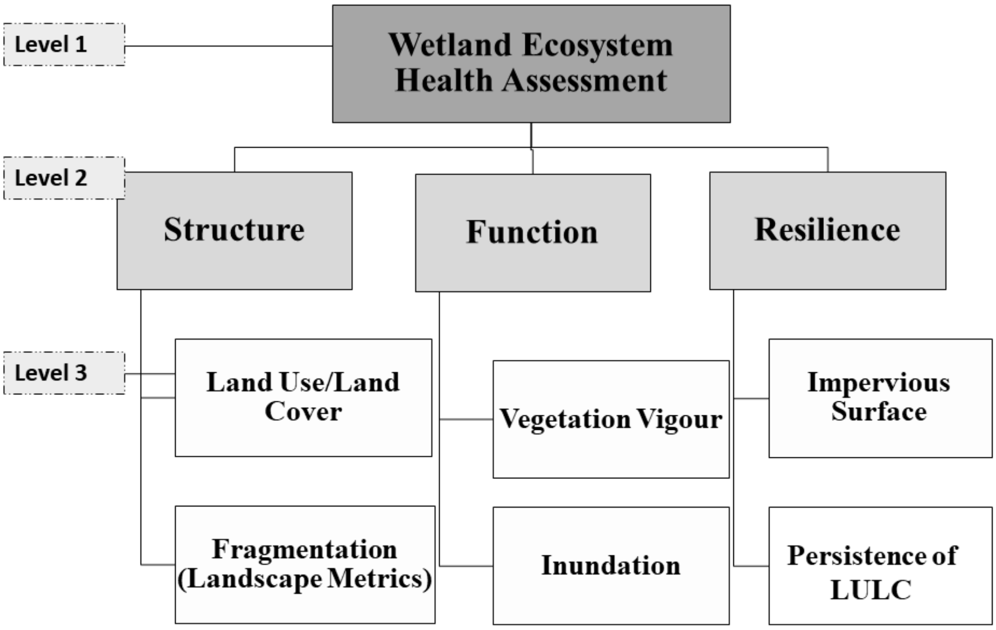


Figure 1. Analytic Hierarchy of the Decision

This document provides explanations to instructions for completing the comparison matrices. In the following pages we would like to obtain your opinion as an expert through a survey questionnaire. The information you provide will be of great value for this research, and accordingly, your participation is anticipated and very much appreciated.

I value your participation and thank you for your commitment of time, energy and effort.

Thank you once again for your help

Bernard Ekumah

Definition of Key Terms

i. **Ecosystem structure:** the composition of the ecosystem and the physical and biological organization defining how those parts are organized.
ii. **Ecosystem function:** the process that takes place in an ecosystem as a result of the interactions of plants, animals, and other organisms in the ecosystem with each other or their environment
iii. **Resilience:** the capacity of an ecosystem to withstand external pressures and return to its pre-disturbance state over time.
iv. **Fragmentation**: the breaking up of a habitat or land use type into small parcels
v. **Vegetation vigour:** defined as active, healthy, well-balanced and robust growth of plants.
vi. **Inundation:** the condition when land is covered with water, thus the wetness of the land.
vii. **Persistence of land cover:** the land cover class that does not change from time 1 to time 2.
viii. **Impervious Surface:** are mainly artificial structures that do not allow penetration of water.

PART I

Background of respondents *(Please tick as appropriate)*

1. Sex	Male ( )	Female ( )			
2. Where do you work?	University/ Research Institution ( )	Forestry Commission ( )	MMDAs ( )	NGO/ CSO ( )	Others………
3. What is your highest level of education?					
4. What is your area of expertise?					
5. How long have you been working?					

In the following sheets, we would like to elicit your opinion in order to select amongst the alternatives. The pairwise comparison scale is used to express the importance of one element over another. The weighting values are defined in the table below.

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed

PART II: Wetland Ecosystem Health Indicators

6. Using a scale of 1 to 9 please, indicate the relative importance (pairwise comparison) of the three wetland ecosystem health indicators. Any value selected in the left column rates option A item more important than the option B item and vice versa.

OPTION 'A'	Extreme Importance		Very Strong Importance		Strong Importance		Moderate Importance		Equal Importance		Moderate Importance		Strong Importance		Very Strong Importance		Extreme Importance	OPTION 'B'
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Structure																		Function
Structure																		Resilience
Function																		Resilience

SUB-CRITERIA

a. Structure criteria

7. Using a scale of 1 to 9 please, indicate the relative importance (pairwise comparison) of the two sub-criteria under ecosystem structure; Land Use/Land Cover Types and fragmentation. Any value selected in the left column rates option A item more important than the option B item and vice versa.

OPTION 'A'	Extreme Importance		Very Strong Importance		Strong Importance		Moderate Importance		Equal Importance		Moderate Importance		Strong Importance		Very Strong Importance		Extreme Importance	OPTION 'B'
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Land Use/Land Cover Types																		Fragmentation

b. Function criteria

8. Using a scale of 1 to 9 please, indicate the relative importance (pairwise comparison) of the two sub-criteria under ecosystem function; vegetation vigour and inundation. Any value selected in the left column rates option A item more important than the option B item and vice versa.

OPTION 'A'	Extreme Importance		Very Strong Importance		Strong Importance		Moderate Importance		Equal Importance		Moderate Importance		Strong Importance		Very Strong Importance		Extreme Importance	OPTION 'B'
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
Vegetation vigour																		Inundation

c. Resilience criteria

9. Using a scale of 1 to 9 please, indicate the relative importance (pairwise comparison) of the two sub-criteria under ecosystem resilience; impervious surface and persistence of land cover. Any value selected in the left column rates option A item more important than the option B item and vice versa.

OPTION 'A'	**Extreme Importance**		**Very Strong Importance**		**Strong Importance**		**Moderate Importance**		**Equal Importance**		**Moderate Importance**		**Strong Importance**		**Very Strong Importance**		**Extreme Importance**	**OPTION 'B'**
	9	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Impervious Surface																		Persistence of land cover

APPENDIX B – UAV ORTHOMOSAIC IMAGES COVERING PARTS OF THE STUDY AREAS

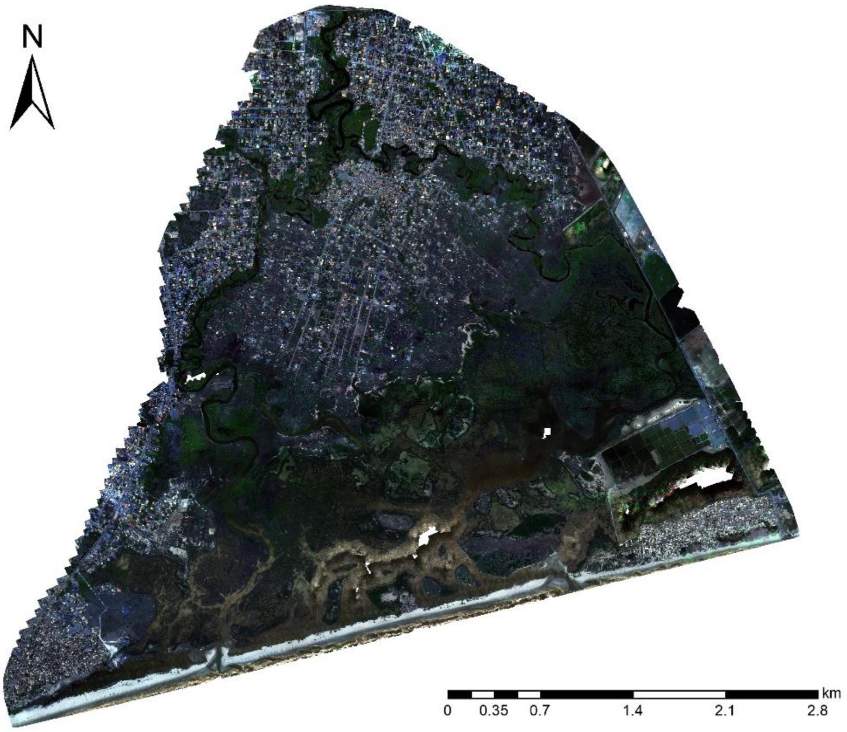


Figure B1: UAV Orthomosaic Image of Part of Densu Delta Ramsar Site

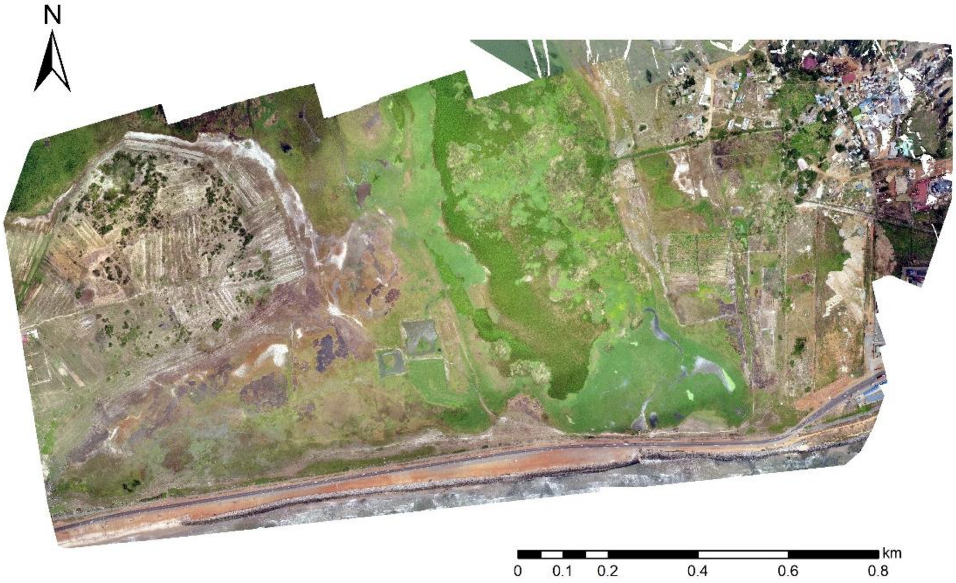


Figure B2: UAV Orthomosaic Image of Part of Sakumo II Ramsar Site

Figure B3: UAV Orthomosaic Image of Part of Muni-Pomadze Ramsar Site

APPENDIX C: SUPPORTING RESULTS FOR RAINFALL ANALYSES

Table C1 – ANOVA Results of Mean Annual Rainfall for Accra, Tema and Saltpond from 1982-2012

Source	SS	df	MS	F	P-Value
Between groups	1113507	2	556753.638	10.53	0.0001
Within groups	4758528	90	52872.5303		
Total	5872035	92	63826.4674		

Table C2 – *Post Hoc (Tukey) Results of Mean Annual Rainfall for Accra, Tema and Saltpond from 1982-2012*

Rainfall	Contrast	Std. Err.	t	P>t	Conf. Interval	
Tema vs Accra	-85.435	58.405	-1.46	0.314	-24.62	53.75
Saltpond vs Accra	177.293	58.405	3.04	0.009	38.11	316.48
Saltpond vs Tema	262.729	58.405	4.5	0.000	123.54	401.91

Table C3 – *Mann Kendall Trend Test Results*

	Accra	Tema	Saltpond
Tau	0.20	0.21	0.17
P-value	0.12	0.10	0.18
Score	93	99	79
Denominator	465	465	465
Variance (Score)	3461.667	3461.667	3461.667

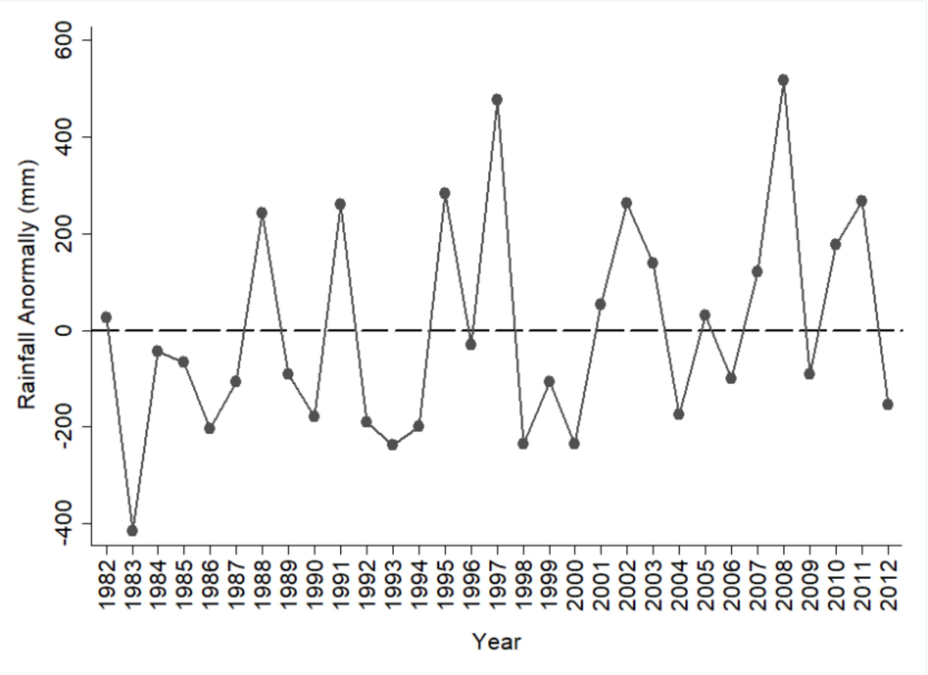


Figure C1: Mean annual rainfall anomaly plot for Accra

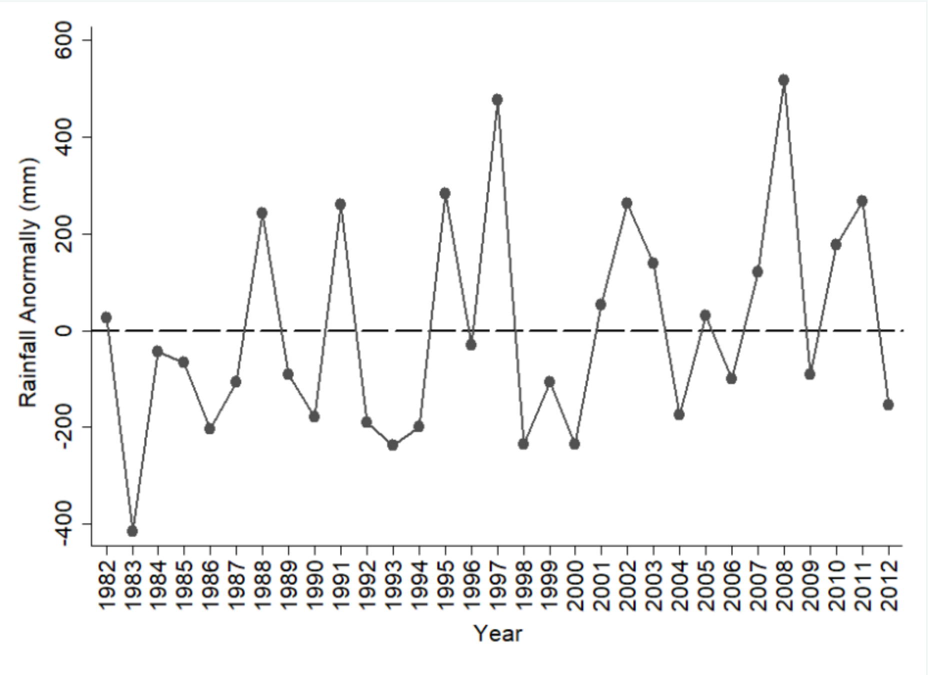


Figure C2: Mean annual rainfall anomaly plot for Tema

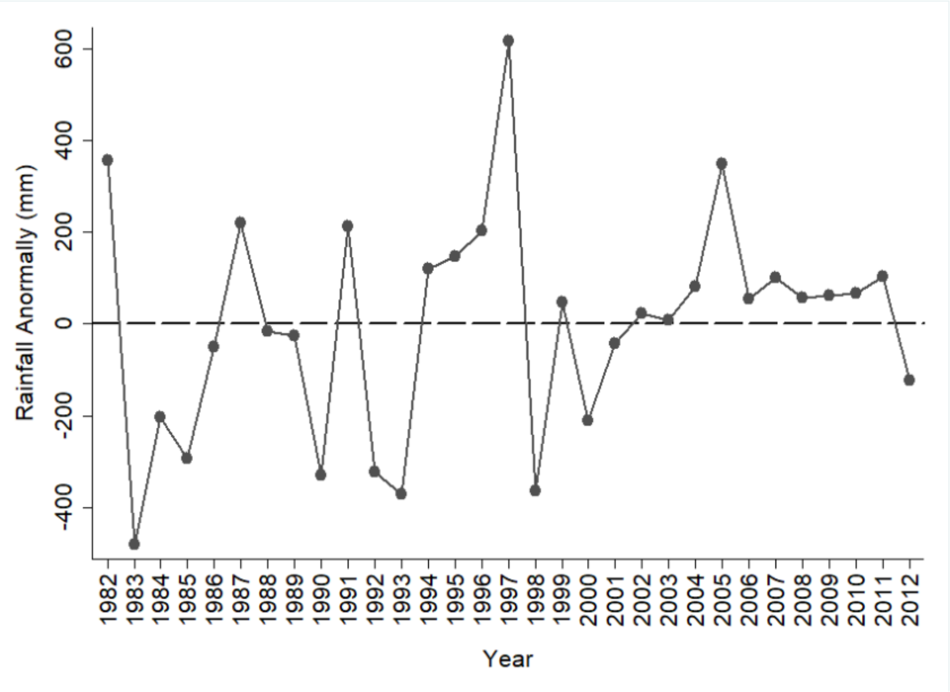


Figure C3: Mean annual rainfall anomaly plot for Saltpond

APPENDIX D: HUMAN POPULATION GROWTH

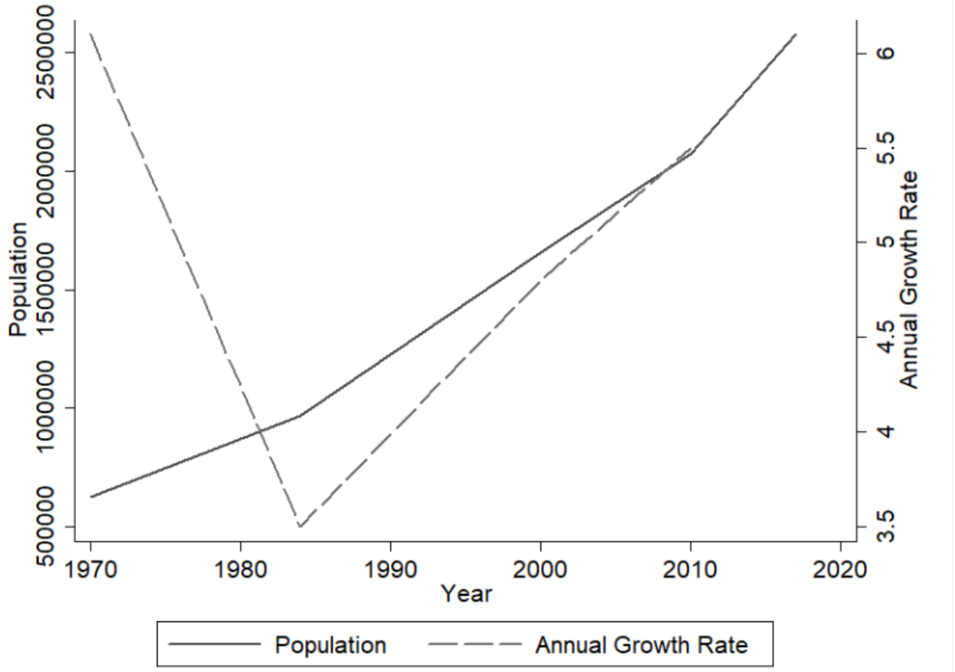


Figure D1: Line Graph of Human Population and Growth Rate of Accra

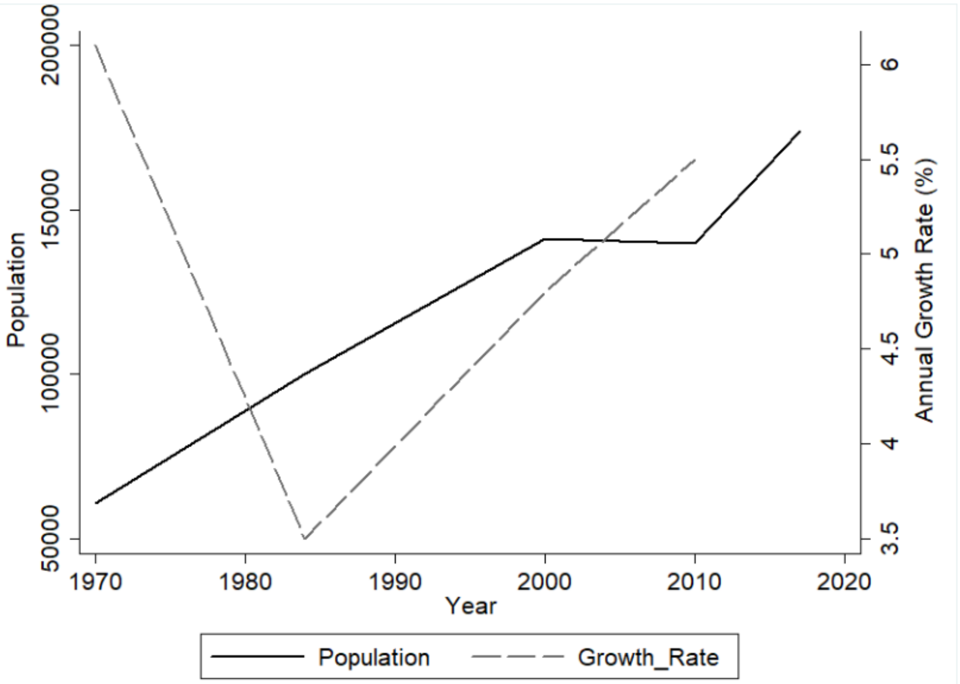


Figure D2: Line Graph of Human Population and Growth Rate of Tema

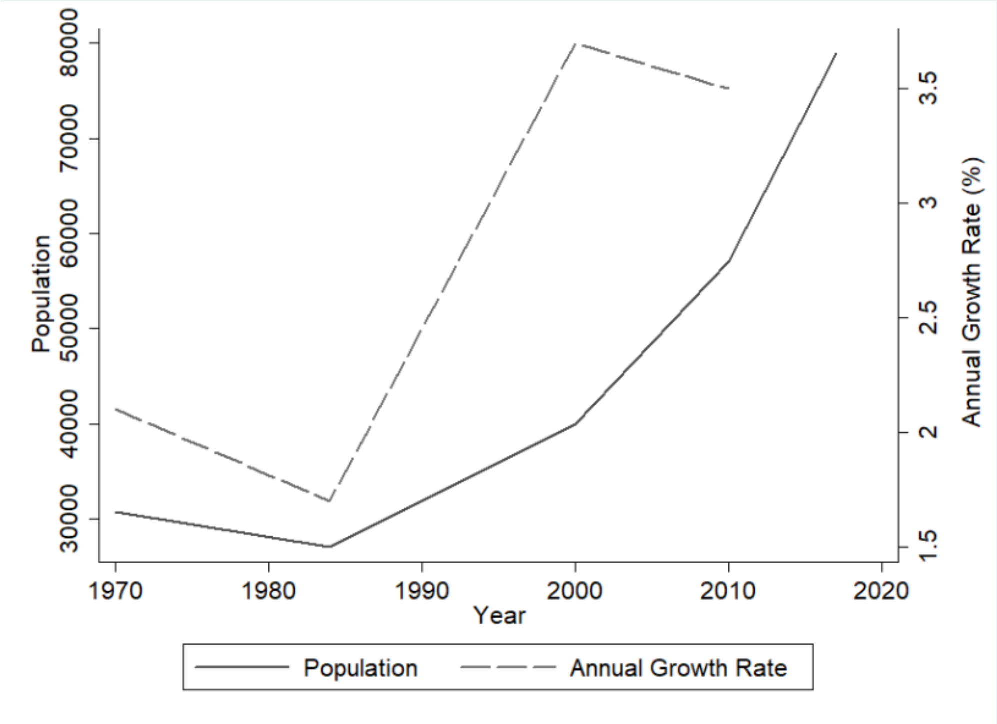


Figure D3: Line Graph of Human Population and Growth Rate of Winneba

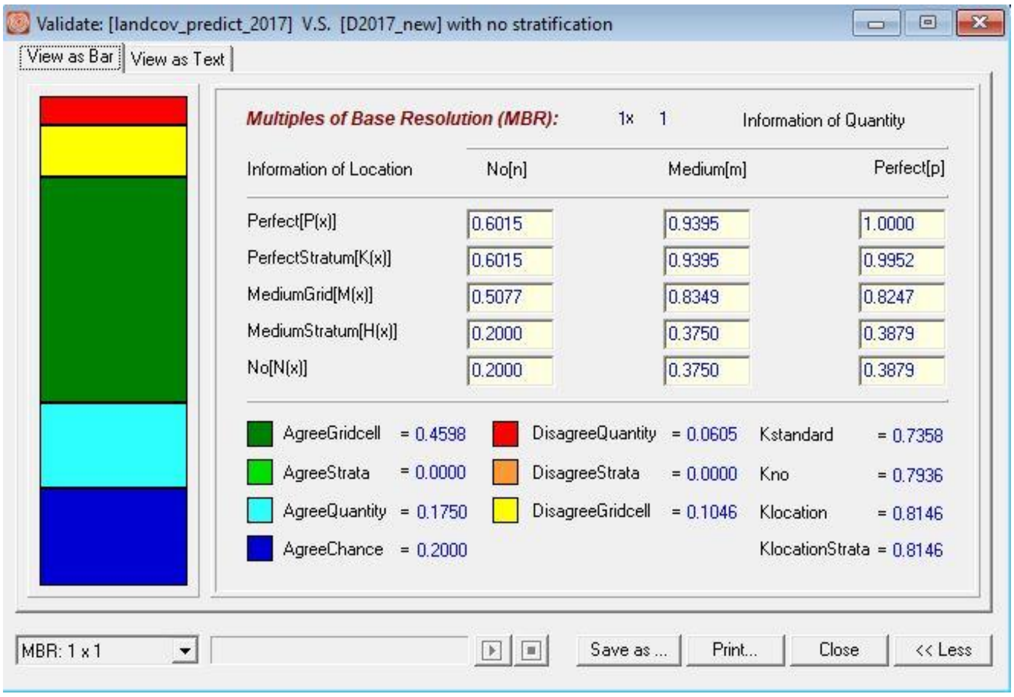
APPENDIX E: LAND USE-LAND COVER CHANGE MODELS

Table E1 – *Transition Probability Matrix for Densu Delta 2002-2017 and 2017-2032*

		2017			
		Thicket	Marsh	Built-up	Water
2002	Thicket	0.1636	0.3073	0.4114	0.1177
	Marsh	0.0716	0.3090	0.2242	0.3952
	Built-up	0.1308	0.3020	0.4050	0.1622
	Water	0.0365	0.1138	0.1138	0.7359
		2032			
2017	Thicket	0.2775	0.1924	0.5246	0.0055
	Marsh	0.0685	0.4225	0.4626	0.0464
	Built-up	0.0077	0.0363	0.8731	0.0829
	Water	0.0242	0.0760	0.0706	0.8292

Table E2 – *Predicted LULC changes 2017-2032 for Densu Delta*

	2017		2032		Change 2017-2032	
Land Cover	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Thicket	3.48	7.38	1.66	3.51	-1.83	-3.87
Built-up/ Bareland	23.90	50.63	30.98	65.64	7.08	15.01
Marsh	9.84	20.85	5.29	11.21	-4.55	-9.65
Water	9.97	21.14	9.27	19.64	-0.70	-1.49
Total	47.20	100.00	47.20	100.00	8.18	30



Validate: [landcov_predict_2017] V.S. [D2017_new] with no stratification

Multiples of Base Resolution (MBR): 1x 1 Information of Quantity

Information of Location	No[n]	Medium[m]	Perfect[p]
Perfect[P(x)]	0.6015	0.9395	1.0000
PerfectStratum[K(x)]	0.6015	0.9395	0.9952
MediumGrid[M(x)]	0.5077	0.8349	0.8247
MediumStratum[H(x)]	0.2000	0.3750	0.3879
No[N(x)]	0.2000	0.3750	0.3879

🟩 AgreeGridcell = 0.4598	🟥 DisagreeQuantity = 0.0605	Kstandard = 0.7358
🟩 AgreeStrata = 0.0000	🟧 DisagreeStrata = 0.0000	Kno = 0.7936
🟦 AgreeQuantity = 0.1750	🟨 DisagreeGridcell = 0.1046	Klocation = 0.8146
🟦 AgreeChance = 0.2000		KlocationStrata = 0.8146

Figure E1: Results of Model Validation of Predicted 2017 LULC for Densu Delta Ramsar Site

Cross tabulation results of reference LULC map and the simulated map

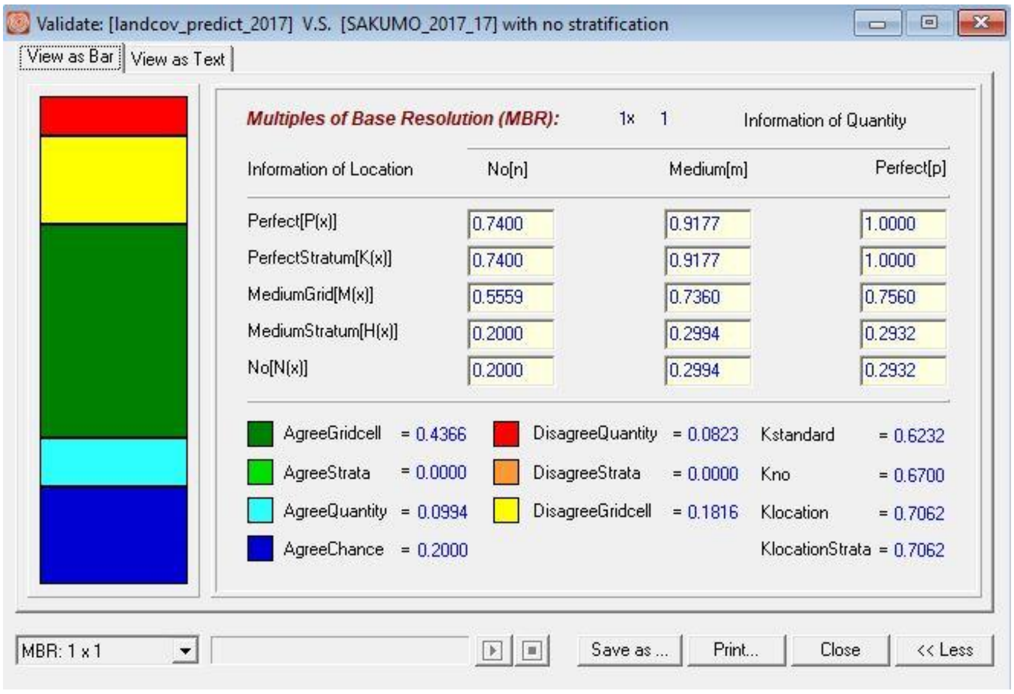
Chi-square = 168933.0938, df = 12, P-Level = 0.0000, Cramer's V = 0.7179, Overall Kappa: 0.7358

Table E3 – Transition Probability Matrix for Sakumo II for 2002-2017 and 2017-2032

		2017			
		Thicket	Marsh	Built-up	Water
2002	Thicket	0.6572	0.2427	0.2411	0.0009
	Marsh	0.5568	0.7744	0.3607	0.1841
	Built-up	0.1902	0.1506	0.9109	0.1583
	Water	0.9847	0.0056	0.2054	0.0001
		2032			
2017	Thicket	0.5771	0.0768	0.1314	0.2148
	Marsh	0.0905	0.4565	0.4054	0.0477
	Built-up	0.1564	0.1621	0.4818	0.1996
	Water	0.8221	0.0133	0.0420	0.1227

Table E4 – Predicted LULC changes 2017-2032 for Sakumo II Ramsar Site

	2017		2032		Change 2017-2032	
Land Cover	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Thicket	3.52	24.49	3.05	21.27	-0.46	-3.22
Built-up/ Bareland	4.88	33.98	7.17	49.97	2.30	15.98
Marsh	4.36	30.34	2.59	18.04	-1.77	-12.30
Water	1.61	11.19	1.54	10.72	-0.07	-0.47
Total	14.36	100.00	14.36	100.00	2.67	31.97



Validate: [landcov_predict_2017] V.S. [SAKUMO_2017_17] with no stratification

Multiples of Base Resolution (MBR): 1x 1

Information of Location	No[n]	Medium[m]	Perfect[p]
Perfect[P(x)]	0.7400	0.9177	1.0000
PerfectStratum[K(x)]	0.7400	0.9177	1.0000
MediumGrid[M(x)]	0.5559	0.7360	0.7560
MediumStratum[H(x)]	0.2000	0.2994	0.2932
No[N(x)]	0.2000	0.2994	0.2932

(Information of Quantity: No[n], Medium[m], Perfect[p])

🟩 AgreeGridcell = 0.4366
🟩 AgreeStrata = 0.0000
🟦 AgreeQuantity = 0.0994
🟦 AgreeChance = 0.2000
🟥 DisagreeQuantity = 0.0823
🟧 DisagreeStrata = 0.0000
🟨 DisagreeGridcell = 0.1816
Kstandard = 0.6232
Kno = 0.6700
Klocation = 0.7062
KlocationStrata = 0.7062

Figure E2: Results of Model Validation of Predicted 2017 LULC for Sakumo II Ramsar Site

Cross tabulation results of reference LULC map and the simulated map

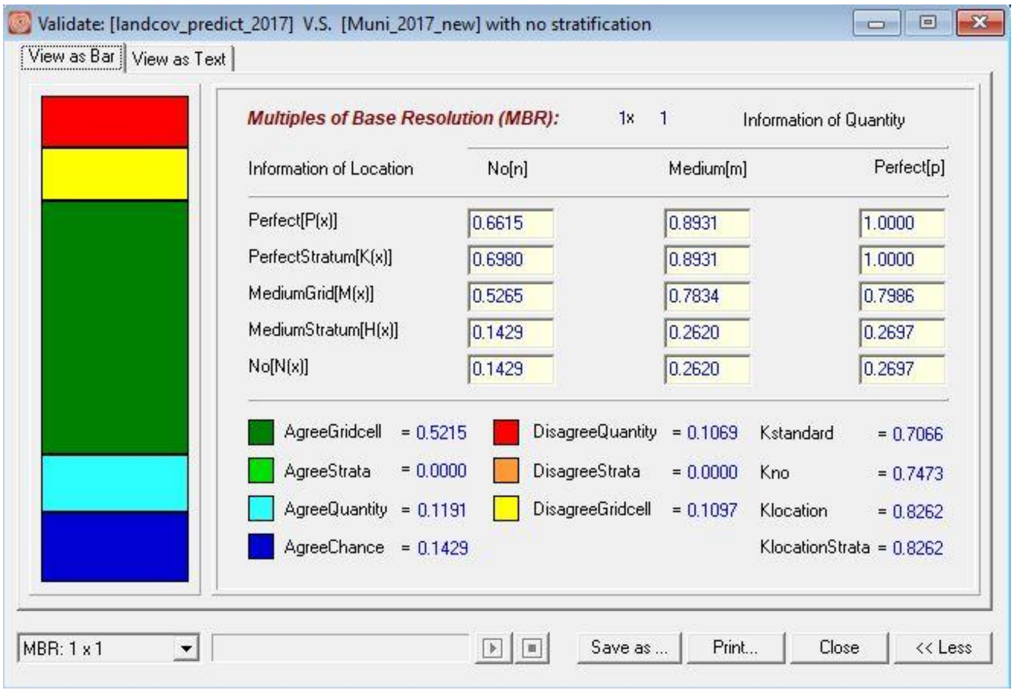
Chi-square = 42094.6328, df = 16, P-Level = 0.0000, Cramer's V = 0.5969, Overall Kappa: 0.6232

Table E5 – Transition Probability Matrix for Muni-Pomadze for 2002-2017 and 2017-2032

		2017					
		Cultivated	Dense Forest	Water	Built-up	Shrub/ Grassland	Burnt
2002	Cultivated	0.9486	0.0985	0.0050	0.0852	0.0940	0.0137
	Dense Forest	0.9478	0.0592	0.0001	0.0092	0.0401	0.0077
	Water	0.0005	0.0000	0.9959	0.0094	0.0002	0.0000
	Built-up/ Bareland	0.0103	0.0000	0.2052	0.9685	0.0758	0.0082
	Shrub/ Grassland	0.1032	0.0000	0.2553	0.3734	0.3735	0.1087
	Burnt	0.0540	0.0008	0.0055	0.0590	0.8819	0.0005
		2032					
2017	Cultivated	0.7399	0.1188	0.0018	0.0820	0.0433	0.0142
	Dense Forest	0.5391	0.3880	0.0003	0.0267	0.0331	0.0128
	Water	0.0068	0.0000	0.9100	0.0668	0.0090	0.0075
	Built-up/ Bareland	0.0179	0.0004	0.1738	0.7529	0.0462	0.0089
	Shrub/ Grassland	0.0488	0.0000	0.0076	0.3178	0.5637	0.0621
	Burnt	0.3863	0.0063	0.0018	0.1099	0.4433	0.0524

Table E6 – Predicted LULC changes 2017-2032 for MMuni-Pomadze Ramsar Site

	1985		2032		Change 2017-2032	
Land Cover	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Cultivated land	17.13	17.83	21.07	21.92	3.93	4.09
Dense forest	21.48	22.36	19.62	20.42	-1.86	-1.94
Water	1.39	1.44	1.20	1.25	-0.19	-0.19
Built-up/ Bareland	11.01	11.45	16.66	17.34	5.65	5.88
Shrub/ Grassland	41.35	43.03	30.12	31.35	-11.23	-11.68
Burnt	3.73	3.88	7.42	7.72	3.69	3.84
Total	96.08	100.00	96.08	100.00	26.55	27.62



Validate: [landcov_predict_2017] V.S. [Muni_2017_new] with no stratification

Multiples of Base Resolution (MBR): 1x 1 Information of Quantity

Information of Location	No[n]	Medium[m]	Perfect[p]
Perfect[P(x)]	0.6615	0.8931	1.0000
PerfectStratum[K(x)]	0.6980	0.8931	1.0000
MediumGrid[M(x)]	0.5265	0.7834	0.7986
MediumStratum[H(x)]	0.1429	0.2620	0.2697
No[N(x)]	0.1429	0.2620	0.2697

🟩 AgreeGridcell	= 0.5215	🟥 DisagreeQuantity	= 0.1069	Kstandard	= 0.7066
🟩 AgreeStrata	= 0.0000	🟧 DisagreeStrata	= 0.0000	Kno	= 0.7473
🟦 AgreeQuantity	= 0.1191	🟨 DisagreeGridcell	= 0.1097	Klocation	= 0.8262
🟦 AgreeChance	= 0.1429			KlocationStrata	= 0.8262

Figure E3: Results of Model Validation of Predicted 2017 LULC for Muni-Pomadze Ramsar Site

Cross tabulation results of reference LULC map and the simulated map

Chi-square = 459589.3438, df = 36, P-Level = 0.0000, Cramer's V = 0.6335, Overall Kappa: 0.7066

APPENDIX F: FRAGMENTATION ANALYSES

Table F1 - *Rotated Component Matrix of Class Indices from PCA*

Variable	PC1	PC2	PC3	PC4	PC5	PC6
NP	0.29	-0.07	0.78	-0.18	0.06	-0.06
PD	**0.93**	-0.08	0.13	-0.10	-0.05	0.09
LPI	0.18	**0.94**	-0.01	0.00	0.21	-0.08
TE	0.27	0.23	**0.82**	-0.10	0.27	-0.13
ED	**0.90**	0.31	0.06	0.03	0.11	0.02
FRAC_MN	0.16	0.02	-0.19	**0.92**	0.02	0.03
CONTIG_MN	0.31	0.03	-0.61	0.44	0.23	-0.10
PAFRAC	0.27	-0.14	0.74	-0.20	-0.31	0.00
CORE_MN	-0.49	0.53	-0.09	0.51	0.34	0.11
DCORE_MN	-0.61	0.48	-0.21	0.01	0.42	0.07
CAI_MN	0.14	0.19	-0.63	0.65	0.15	0.03
PROX_MN	-0.18	0.64	0.36	0.04	0.30	-0.12
SIMI_MN	-0.29	-0.01	0.33	-0.03	0.10	**-0.81**
ENN_MN	-0.65	-0.28	-0.33	-0.19	0.07	0.28
CWED	**0.87**	0.19	0.07	0.04	0.10	0.33
ECON_MN	-0.13	-0.24	0.13	0.20	-0.10	**0.86**
IJI	0.41	0.45	0.02	-0.41	-0.03	0.53
CONNECT	-0.39	-0.03	-0.37	0.72	0.03	0.23
COHESION	-0.17	0.47	0.19	0.06	0.72	-0.12
DIVISION	-0.14	**-0.93**	0.12	-0.06	0.01	0.02
SPLIT	-0.31	-0.09	0.11	-0.07	**-0.87**	0.06
NLSI	0.48	-0.43	0.12	-0.10	-0.68	0.14
CPLAND	0.21	**0.92**	-0.06	0.02	0.23	-0.03

Table F2 – *Class Indices for Densu Delta Ramsar Site*

	Marsh			Built-up/Bareland			Thicket			Water		
Index	1985	2002	2017	1985	2002	2017	1985	2002	2017	1985	2002	2017
PD	7.70	8.29	8.61	8.38	7.10	3.16	3.69	6.21	7.08	3.01	2.16	2.69
LPI	28.65	30.68	15.93	10.74	9.33	32.10	18.87	5.27	2.91	6.96	18.77	20.46
TE	383070	456150	266220	282120	284190	215940	167490	189090	137940	106950	107880	124650
ED	81.24	96.73	56.46	59.83	60.27	45.79	35.52	40.10	29.25	22.68	22.88	26.43
FRAC_MN	1.04	1.05	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.03	1.04	1.03
CPLAND	22.98	19.01	11.96	14.66	16.29	40.06	16.42	8.03	3.14	10.73	16.25	16.26
SIMI_MN	3179	2568	3572	1822	2723	1405	5566	6620	1430	6127	5141	3086
CWED	38.00	45.64	24.16	40.88	39.53	33.46	18.71	17.37	17.40	10.74	11.98	12.97
ECON_MN	44.54	47.49	49.80	67.42	62.31	69.82	48.92	43.61	64.64	38.98	46.20	47.33
DIVISION	0.92	0.91	0.97	0.98	0.99	0.88	0.96	1.00	1.00	0.99	0.96	0.96
SPLIT	12.03	10.61	39.25	61.45	79.89	8.55	27.86	244.16	1120.62	112.27	28.36	23.90

Table F2 – *Class Indices for Sakumo II Ramsar Site*

	Marsh			Thicket			Built-up/Bareland			Water		
Index	1985	2002	2017	1985	2002	2017	1985	2002	2017	1985	2002	2017
PD	5.922	7.0368	10.5203	2.5778	5.713	8.9179	4.3196	10.9383	11.1473	4.3196	2.0901	9.8933
LPI	55.9882	43.5227	12.3464	17.3313	16.9175	13.0298	2.4078	3.5365	14.7103	7.1796	4.4206	4.383
TE	85770	113550	131400	35010	76320	93690	52350	89100	127650	26490	17250	84780
ED	59.7567	79.1113	91.5475	24.3918	53.1728	65.2746	36.4727	62.0767	88.9349	18.4558	12.0182	59.067
FRAC_MN	1.0475	1.0471	1.0506	1.0465	1.0505	1.047	1.0556	1.0428	1.047	1.0334	1.041	1.0444
CPLAND	50.5455	40.7449	14.4156	13.011	11.4372	13.3873	3.5616	5.1104	16.6165	5.2797	3.5051	2.3138
SIMI_MN	1512.99	1118.94	527.934	2936.56	1887.29	408.524	1489.35	809.297	218.543	2342.69	886.302	237.281
CWED	27.2552	40.3938	45.3139	11.5061	31.4961	48.8964	23.9842	41.1086	61.1675	9.5979	10.3775	43.414
ECON_MN	42.2554	49.2784	49.7706	45.7359	55.681	71.5125	62.5131	59.9981	66.7753	57.6508	75.7913	71.4529
DIVISION	0.685	0.8077	0.9813	0.97	0.9713	0.9802	0.9984	0.9979	0.9744	0.9948	0.998	0.9978
SPLIT	3.1748	5.1994	53.5048	33.2878	34.7996	50.5449	618.877	485.884	38.99	193.767	506.879	460.442

Table F3 – Class Indices for Muni-Pomadze Ramsar Site

	Dense Forest			Shrub/Grassland			Cultivated Land		
Index	1985	2002	2017	1985	2002	2017	1985	2002	2017
PD	5.8725	4.394	2.4469	4.3211	4.1545	3.4465	3.4985	11.1723	2.2386
LPI	17.2258	18.0167	8.8565	38.4334	17.6081	19.4542	15.2673	13.1335	28.7016
TE	436230	458100	139860	462390	515850	341550	326610	537390	346260
ED	45.4213	47.6985	14.5626	48.1452	53.7115	35.563	34.0074	55.9543	36.0534
FRAC_MN	1.0458	1.0418	1.0399	1.0403	1.0355	1.042	1.0333	1.0407	1.0405
CPLAND	14.8793	12.0165	8.1275	34.2183	21.2881	17.1068	11.6913	13.4024	24.7001
SIMI_MN	13881.5	5643.08	22535.8	6950.37	3126.16	11583.5	15114.4	10777.7	8954.2
CWED	16.2931	17.3951	2.9437	34.2561	44.8712	25.4985	8.1309	24.0254	15.8583
ECON_MN	34.7198	36.6183	20.3783	64.9739	81.1963	65.5659	24.3644	45.1375	48.3667
DIVISION	0.9702	0.9675	0.9921	0.852	0.9633	0.9618	0.9767	0.9824	0.9175
SPLIT	33.5205	30.7868	127.119	6.7568	27.2251	26.1731	42.8328	56.8216	12.1186

Table F4 – Class Indices for Muni-Pomadze Ramsar Site

	Built-up/Bareland			Burnt Land			Water		
Index	1985	2002	2017	1985	2002	2017	1985	2002	2017
PD	2.7697	6.7992	5.6226	0.177	9.7667	4.0191	0.8434	0.5727	0.354
LPI	8.5923	13.3987	22.6938	3.7925	1.9332	0.4779	1.1948	1.1039	4.3482
TE	214020	385200	287820	39150	381270	150600	40890	34860	44280
ED	22.2843	40.108	29.9685	4.0764	39.6988	15.6808	4.2576	3.6297	4.6105
FRAC_MN	1.0417	1.0305	1.0336	1.0783	1.0352	1.0361	1.0359	1.0364	1.0383
CPLAND	7.5202	10.578	21.0726	3.0821	2.3334	1.0102	0.7403	0.6101	3.5619
SIMI_MN	4307.45	1700.47	2804.99	3329.62	1526.83	7376.98	3242.59	2401.28	3226.28
CWED	18.0826	34.0993	23.0836	3.6688	35.7204	10.5058	3.7431	3.1765	4.032
ECON_MN	79.3746	81.2178	84.5859	89.1593	89.4385	66.0178	76.4587	78.2308	78.0432
DIVISION	0.9925	0.9819	0.9484	0.9986	0.9994	0.9999	0.9999	0.9999	0.9981
SPLIT	133.107	55.1983	19.3983	695.19	1738.65	18071.4	6987.06	8195.92	528.899