THE IMPACT OF HUMAN POPULATION ON LAND COVER CHANGES IN GWASSI HILLS WATER TOWER, HOMABAY COUNTY

BY

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DECLARATION

This project report is my original work and to the best of my knowledge has not been previously presented for a degree in this University or any other.

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DEDICATION

I dedicate this work to the Almighty God for His grace, provision and strength. Secondly to my beloved parents who have always believed in my abilities and have kept cheering me in this journey of life. I am who I am because of the values you have instilled in me.

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ACRONYMS AND ABBREVIATIONS

CGH	County Government of Homabay
ESDA	Exploratory Spatial Data Analysis
FAO	Food Agricultural Organization
GDP	Gross Domestic Product
GHFMP	Gwassi Hills Forest Management Plan
GIS	Geospatial Information System
ha	hectare
IPCC	Intergovernmental Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change
KIPPRA	Kenya Institute for Public Policy Research and Analysis
km^2	square kilometres
KNBS	Kenya National Bureau of Statistics
KWS	Kenya Wildlife Service
KWTA	Kenya Water Towers Agency
L	Landsat
m	metres
OSIENALA	Friends of Lake Victoria
RF	Random Forest
RS	Remote Sensing
SDG	Sustainable Development Goal
sf	simple features
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environmental Programme
USGS	United States Geological Survey
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

ABSTRACT

Population growth has been pointed out as a main driving factor for land cover changes, mainly in developing countries. About 80% of Kenya's economy is sustained by land-based resources, implying that as population increases there is likelihood of over-exploitation of these resources leading to massive land cover changes. Information on agents causing land cover changes is key during decision making on sustainable conservation of natural ecosystems. In this regard, this research sought to examine the impact of population density and urban sprawl on land cover changes in Gwassi hills water tower located in Suba South Sub-county, Homabay County. The research used data from satellite imageries downloaded from Unites States Geological Survey and population census from Kenya National Bureau of Statistics as well as 100 square kilometre gridded population from Worldpop Open Spatial Demographic Data and Research. The data acquired were for years 1989, 1999, 2009 and 2019. Random forest algorithm method was used to generate supervised land cover classification in R-studio. The data was processed and analysed in ArcGIS 10.8 and presented inform of tables, maps and graphs. Overlapping Neighbourhood Pearson correlation coefficient analysis was used to determine the relationship between population density and land cover changes. Chi-square was used to assess the influence of urban sprawl on land cover changes within ten towns in the study area.

The study findings showed that population density in Gwassi hills water tower had risen from 89 persons/km^2 in 1989 to 229 in 2019. Land cover in the study area has also been changing over time where area under forestland, grassland and built-up areas increased while bareland declined between 1989 to 2019. In addition, urban sprawl has also been witnessed in the water tower with built-up areas within towns expanding by 93% between 1989 and 2019. These land cover changes were attributed to devolution of Government services, restoration efforts and improved infrastructure. The study established that there was significant relationship between population growth and land cover changes in Gwassi hills water tower. It also found out that land cover changes in the urban areas was significantly influenced by urban sprawl. Thereafter, the study concluded that land cover changes in the water tower is expected to continue happening in favour of cropland and built-up areas to meet demands of the ever-increasing population and urban areas. It is recommended that there is need to promoting sustainable land management and conservation of water catchment to mitigate land cover changes related to anthropogenic factors.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

In the 21st century, land cover changes on the earth's landscape have been happening at a faster rate with population growth pointed out as one of the main factors causing this change (Addae & Oppelt, 2019). The world population has also grown rapidly to stand at 7.7 billion in 2019 and is expected to reach 8 billion by 2025 (PRB, 2020). It is projected that more than half of the world's population growth will be in Africa (United Nations, 2019). Therefore, this exponential growth is expected to heightened utilization of natural resources leading to unprecedented change in ecosystem's land cover. Rural and peri-urban areas are projected to experience the greatest impact. According to United Nations (UN) and Food Agriculture Organization (FAO) (2020), population increase has propelled demand of more land for agriculture, urban growth and settlement thus leading to deforestation. It was estimated that 420 million hectares of world forest has been lost since 1990 due to changes in land uses (UN & FAO, 2020). On the other hand, United Nations Environment Programme, UNEP (2016) pointed out that forestlands are expeditiously being converted to agricultural land and settlement thus accounting for more than 60% forest cover loss worldwide.

Globally, there has been concerns of heightened land cover changes being experienced in water catchment areas (UNEP, 2016; Osaliya et.al, 2019; Sugianto et.al, 2022). Water towers, commonly known as water catchment areas are fragile ecosystems which supports countries drainage basins. It is estimated that 42% of the world's population live in catchment basins hence affecting their land cover (Ngeno, 2012). Rapid population growth in water towers especially in Africa have led to exponential expansion of agricultural land and built-up areas into these ecosystems (Osaliya et.al, 2019;). In addition, increased urbanization has led to conversion of forestland to settlement leading to loss of forest cover (Sugianto et.al. 2022). The impact of modification of land cover in water towers has been reduced the rate of water infiltration and percolation (Osaliya et.al, 2019). In East Africa, land cover changes is manifested through loss of natural vegetation such as forests and grasslands thus hindering ecological potential of water towers (Sugianto et.al, 2022) by interfering with water flows into rivers.

In Kenya, rapid population growth has been reported to alter land cover within water towers which are fragile ecosystems that supports the country's drainage basin (Kenya Water Towers Agency-KWTA, 2020; Onyango et.al, 2019). Kenya's population has increased from 21.4 million in 1989 to 47.6 million in 2019 (KNBS, 2019). In Homabay County, where Gwassi hills water tower is located, the population is increasing at a growth rate of 2.7% per annum which is higher than the national rate of 2.2% (County Government of Homabay-CGH, 2018; KNBS, 2019). Impacts associated with population growth coupled with changes in economic status of the people have resulted in decline of the country's natural resource base causing land cover changes (Ibrahim, 2017). This has in turn put pressure on available land, forests and water resources thereby posing a threat to sustainable development agenda. Kenya being a natural resource dependent economy, it is postulated that the more its population grows the higher the pressure exerted on land leading to massive change in land cover. This in turn has a negative impact on the economy since Kenya's GDP is largely dependent on land resources. Therefore, exponential population growth will continue to cause unprecedented land cover changes in natural ecosystems. This leads to rising environmental problems such as encroachment, loss of fertile agricultural land, drying of rivers, and landslides, loss of forest cover and fragmentation of large forests into smaller forested areas (KWTA, 2020; Ibrahim, 2017).

In Gwassi hills water tower, local communities mainly depend on small scale agriculture and fishing for sustenance. According to a study conducted by KWTA (2020) more than 89% of the people in Gwassi hills water tower practice farming as a source of livelihood with an average land holding of between 1-3 acres. In addition, almost half of the population in the study area are youths, implying that the numbers of young families in the area is higher hence resulting into more utilization of ecosystem resources (KNBS, 2019; CGH, 2018). This is witnessed through expansion of land under cultivation and settlement. In addition, most households in Homabay County including Gwassi hills upholds the tradition where sons inherit land from their parents (CGH, 2018). This practice of sub-division of ancestral land among sons is a common tradition in the area contributing to reduced land sizes and increased land fragmentation. It has negatively impacted on livelihoods of communities as less land is available per households for farming yet this is their main source of income. Additionally, it has rendered sections of land in the water tower uneconomical mainly in terms of farming (KWTA, 2020; Gitau, 2018). This has forced local communities to move to other areas thus altering of land cover in favour of agriculture, grazing, settlement and town centres.

To demonstrate the relationship between population and land cover changes, Remote Sensing (RS) and Geospatial Information System (GIS) techniques and tools are used during data processing and analysis. Information on population-land cover interactions ensures proper measures are put in place to enhance sustainable development. Selection of land cover classes in Gwassi hills water tower was done in accordance to 2006 land cover classification guidelines by the Intergovernmental Panel on Climate Change (IPCC). The classes are Forestland, Grassland, Cropland, Waterbody, Built-up areas and Bareland. Therefore, it enabled generation and analysis of land cover changes within Gwassi hills and relating it to population density and urban sprawl. The information generated will be useful in guiding decision making towards conservation of Gwassi hills ecosystem since understanding underlying factors is a key in consideration for promotion of sustainable land management.

1.2 Statement of Research Problem

Most communities in Kenya rely on land-based resources mainly agriculture, wood and non-wood products as their source of livelihood (KIPPRA, 2020). Population increase has intensified demand placed on land leading to its over-exploitation and unsustainable utilization (Briassoulis, 2020). Additionally. population in Suba South sub-county where Gwassi hills falls has been rising with statistics showing an upward trend from 103,054 in 2009 to 122,382 in 2019 (KNBS, 2019; KNBS, 2009). In addition, communities within the study area depends on resources from Gwassi hills water tower for sustenance.

Rapid population growth has led to unsustainable use of ecosystem resources and poor land management practices with aim of increasing household income (CGH, 2018). The outcome has been changes in land cover in the water tower through expansion of agricultural land and built-up areas at the expense of forestland and grassland resulting to land cover changes (Briassoulis, 2020; KWTA, 2020). These have led to land degradation and environmental related impacts experienced in Gwassi hills water tower. They include encroachment, deforestation, soil erosion, landslides, poor agricultural yield, loss of income, drying of rivers and springs during dry season.

Continuous utilization of resources from Gwassi hills water tower to meet population needs further threatens the ecological functions and integrity of this ecosystem. In addition, Gwassi hills is an important ecosystem sustaining Ruma National Park, the only park hosting endemic Roan Antelope (KWS, 2020). The study area also hosts gazetted forest reserve delineated at peak of the hills and is also the main source of water and livelihood for communities in Suba South sub-county (Friend of Lake Victoria-OSIENALA, n.d; KWTA, 2020). It is estimated that almost 24% of the forest and grassland in the area has been lost mainly due to agricultural expansion and settlement (Gwassi Hills Forest Management Plan-GHFMP, 2013). In addition, there are increased number of springs and rivers drying up during dry season while intensity of floods and landslides has also risen (KWTA, 2020). The dwindling forest cover and poor land management practices has reduced land productivity affecting community livelihoods (OSIENALA, n.d). These changes have been exacerbated by reduced land sizes due to sub-division leading to increased fragmentation causing ecosystem degradation in Gwassi hills water tower. Therefore, if mitigation measures against land degradation triggered by land cover changes in Gwassi hills water tower are not deduced and implemented, the magnitude of the impact will keep rising affecting the already declining living standards of the people.

In this regard, this study sought to assess the impact of population on land cover changes in Gwassi hills water tower between 1989 and 2019. The findings and outcome of this study will play a critical role in providing pertinent information that decision and policy makers require to inform on measures to halt environmental impacts resulting from land cover changes occurring in Gwassi hills water tower. This is especially important as this is a key ecosystem to Ruma National Park and Homabay County at large. Hence the study will significantly contribute towards achieving the targets set in the sustainable development goals 6 (Clean water and sanitation), 11(Sustainable cities and communities) and 15 (Life on land).

1.3 Research Questions, Objectives and Hypothesis

1.3.1 Research questions

1. What has been the change in population density and land cover in Gwassi hills water tower?
2. What is the relationship between population density and land cover changes in Gwassi hills water tower?
3. What is the effect of urban sprawl on land cover within towns in Gwassi hills water tower?

1.3.2 Research objectives

General objective

To assess the impact of human population on status of land cover in Gwassi hills water tower between 1989 and 2019.

Specific objectives

1. To determine the relationship between population density and land cover changes in Gwassi hills water tower.
2. To examine the effect of urban sprawl on land cover within towns in Gwassi hills water tower

1.3.2 Research hypothesis

H_0: There is no significant spatial relationship between population density and land cover changes in Gwassi hills water tower.

H_1: There is significant spatial relationship between population density and land cover changes in Gwassi hills water tower.

H_0: There is no significant effect of urban spawl on land cover within towns in Gwassi hills water tower after ten years.

H_1: There is significant effect of urban sprawl on land cover within towns in Gwassi hills water tower after ten years.

1.5 Justification of the Study

The landscape of Gwassi hills water tower has undergone changes in its bio-physical characteristics over the years. Changes occurring in such ecosystem largely impacts on its land cover distribution whose drivers are associated with pressure from socio-economic factors especially population growth (Addae & Oppelt, 2019; Ogola 2018). With population increase reported in the study area, land cover changes is expected to continue occurring due over-exploitation of ecosystem resources. Gwassi hills water tower plays a significant role in provision of ecosystem services ranging from provisioning, regulatory, supporting and cultural. These include microclimatic conditions for agriculture production, water supply, climate regulation, river flow regulation, grazing ground for animals, control of soil erosion, nutrient cycling, timber and non-timber products among others. Communities living in this water tower depends on Gwassi hills ecosystem for livelihood hence are key beneficiaries of the goods and services it provides.

Gwassi hills lies within Lake Victoria catchment area. It comprises the Lake Victoria, Lambwe Valley, Gwassi Forest and Ruma National Park. The forested ecosystem that provides invaluable services and benefits to communities, wildlife and economy hence creating opportunities for poverty alleviation and economic development (OSIENALA, n.d; CGH, 2018). In addition, the water tower controls flooding in the Lambwe Valley as well as sustains and supports key biodiversity habitats in the nearby Ruma National Park (KWS, 2020). The Park is known as the "last retreat" and only home for remaining population of the endemic and critically endangered Roan Antelope in Kenya (KWS, 2020). On the other hand, rivers emanating from Gwassi hills water tower drain into Lake Victoria which is a regional water body traversing Kenya, Uganda and Tanzania. The Lake is the origin of the Nile River that passes through Egypt before draining in the Mediterranean Sea.

Noting the importance and strategic location of Gwassi hills water tower, changes in its land cover at the expense of forest and grassland would affect the functions of this ecosystem. Therefore, rising population in this area should be a factor of concerns as the communities mainly depend on natural resource-based products hence demand for more land for agriculture, settlement as well as logging activities. This has led to continuous encroachment into the forest leading to fragmentation, land sub-division, and over-extraction of wood and non-wood products. Hence, negative land cover changes in this area are likely to affect the capacity of an ecosystem to reach its full potential in provision of the required goods and services. Observed land cover changes are detected through assessment of land cover conversions from one type to the other due to intensification of a certain land use practices over the time. They include conversion of forestland to cropland or settlement and vice versa. It can also be seen through increased degradation levels.

Although most of studies on analysis of population on land cover changes are done at the national scale, rapid changes amalgamate from local levels. For better decision making on sustainable management of country's natural resources, it is paramount to assess the population impact on land cover changes at local level for proper decision making and sustainable management of country's natural resources. Therefore, studying the relationship between population and land cover changes in Gwassi hills water tower will help understand its effects to the ecosystem functions. Analysis done in this study has brought out such attributes as well as enabled recommendations on sustainable conservation and management of Gwassi hills water tower. It thus helped bring such issues to attention of decision makers and policy makers on the need to move with speed in conserving this significant ecosystem. The information can also be integrated in development of spatial land use plan for Homabay as well as create a platform for discussion on the need to promote sustainable livelihood options in the area that will not only diversify household's sources of livelihood but also promote conservation

1.6 Scope and Limitation of the Study

This research study focuses on impact of population growth on land cover changes that have occurred in Gwassi hills water tower from 1989 to 2019. The study only assessed population as driver of land cover changes. Therefore, other factors such as rainfall variability, relief and land uses practices suggested to likely impact on land cover changes are beyond the scope of this study. Assessment of population growth in this study only focussed on population density in the water tower in addressing the research problem. Therefore, other components of population growth such as age, mortality, migration, fertility rate, education levels, affluence among others were not considered. Assessment of urban sprawl in this study only focused on size of built-up areas within towns in the water tower. Other factors of urban sprawl such as transportation, continuity, development with low housing density were not examined. On land cover analysis, the study also analysed the changes in terms of six main classes: forestland, cropland, grassland, water body, built-up areas and otherland. Thus, any other land cover and land uses classifications are beyond the scope of this study.

During the study period, the first limitation faced was on data acquisition. The census population data acquired from Kenya Bureau of Statistic were in vector format hence could be used to perfume the correlation analysis since land cover data was raster based. To address this limitation, gridded population data for years 1999, 2009 and 2019 were obtained from Worldpop Open Spatial Demographic Data and Research by University of Southampton. The two datasets had insignificant variation hence provided the confidence to use gridded data to run correlation analysis to determine the relationship between population density and land cover changes. Second limitation was due to financial constraints and timing for data collection being in the wet season thus groundthruth data could not be collected. Therefore, this research validated the generated supervised land cover classes using from Google Earth imagery embedded in a random forest algorithm script in R-studio as well as comparison with maps published in the KWTA (2020) report and leveraged on the researcher being conversant with landscape features in the study area.

1.7 Definition of Operational Terms

Bareland: Land covered by bare soil, rock, ice, and all land areas that do not fall into the other five categories of IPCC classification.

Built-up areas: All developed land including settlement and infrastructure

Confusion matrix: Special form of a contingency table that is used to demonstrate the performance of classification algorithm by assessing if the system is confusion two or more land cover classes.

Cropland: All cultivated land covered by annual and perennial crops, either harvested or planted.

Forestland: All land with woody species ranging comprise dense, moderate and open forest cover.

Geographical Information Systems (GIS): A computer system that is designed for capturing, storing, manipulating, analyzing, managing and displaying geo-referenced information.

Grassland: Land covered with wooded grassland or open grassland including rangeland and pastureland that is not considered as cropland.

Human population: the number of people occupying an area**.**

Land cover changes: Spatial and temporal changes occurring on land cover class and are derived using satellite imageries.

Land cover: the bio-physical characteristics of the earth's landscape, in terms of distribution of area covered by forests, wetlands, bare surfaces, including those created by human such as croplands and built-up areas among other types.

Landsat: Satellites that gather imageries of a specific area on the earth's landscape.

Population density: number of persons per square kilometre.

Remote sensing: Process of acquiring data of physical characteristic of a specific area without being in physical contact with the object, by use of satellites to produce satellite imageries of the earth's features.

Spatial autocorrelation: Geostatistical method that measures the degree in which an object is similar to the nearby objects by assessing whether they are clustered, depressed or random due to their relative geographical location.

Urban sprawl: Uncontrolled and unplanned spatial growth of towns characterized by low density built-up areas that significantly contributes to conversion of rural land use to urban land use.

Water body: An area covered with lakes, rivers, dams or having open water.

Water tower: A geographically elevated area encompassing hills, mountains and plateaus where the bio-physical features support reception, retention and infiltration of precipitation that allows ground water storage and slowly releasing through springs, streams and rivers recharging swamps, lakes and oceans while sustaining the bio-diverse ecosystem and livelihood.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter explored literature on the impact of human population on land cover changes in Gwassi hills water tower. The literature review adopted a thematic approach in discussing the relationship between population and urban sprawl on land cover changes at global, national and local level. This section also highlighted research gaps and provided discussion on theoretical and conceptual framework for the study.

2.1 Literature Review

2.1.1 Population growth and land cover changes

The United Nations (2019) pointed out population as one of the main driving factors of land cover changes in an ecosystem. It revealed that world population will keep rising to reach 8 billion by 2025 from 7.7 billion recorded in 2019 (United Nations, 2019). It further pointed out that highest percentage of population increase will happen in Africa at a growth rate of 2.5% per annum (United Nations, 2019). Therefore, as global population is rising at unprecedented rate, there is also increased demand placed on natural resources especially land, water and biodiversity to meet basic needs for the ever-growing population. This has contributed to 30% loss of wetlands and a decline of more than 75% of forest cover in the world (United Nations (2019). The United Nation (2019) also revealed that these impacts will be highest in Africa whose economy is highly fuelled by land-based resources. In addition, concerns have been raised on how fast tropical mountainous forests, which play vital role in water catchment protection, are being destroyed. Whereas the study by the United Nations (2019) was done at global scale, it affirmed the objectives of this research study. It also created a platform on to cascade such studies to assess the concurrence of discussed behavioural pattern between population and land cover changes at local scale.

Rawat & Kumar (2015) discussed the importance of using GIS and remote sensing techniques in assessing and monitoring land cover changes. The study used Landsat imageries to detect land cover changes and maximum likelihood method to generate supervised land cover classification. Their findings revealed that built-up areas increased at the expense of vegetation cover and agricultural land due to population pressure. They also noted that in addition to population contributing to land cover changes, various policies and economic factors could also play a significant role in altering land cover at regional and global levels. Therefore, Rawat & Kumar (2015) concluded that it essential for research to be conducted to provide detailed information to enable proper sustainable land management decision making. Thus, the argument and recommendation made by Rawat and Kumar (2015) provided this researcher with better understanding and mechanisms in assessing the association between population and land cover changes in Gwassi hills water tower. Although, the method used by Rawat and Kumar (2015) was maximum livelihood to generate supervised land cover classification, this research study has employed the use of random forest algorithm method.

Further, a report done by Briassoulis (2020) also supported research work done by Rawat and Kumar (2015) by upholding that the analysed information on land cover changes is necessary. This provides a platform for understanding the nexus of spatio-temporal interactions between bio-physical and socio-economic characteristics in an ecosystem. Briassoulis (2020) further highlighted that population elements such as size, density, age, sex, composition, migration, fertility and mortality rate had significant influence on distribution of land cover types in an ecosystem over time. The researcher also strengthened the findings of the study by inter-linking various theories and approaches on "how well they reflected drivers, processes and implications of population-land cover change" (Briassoulis, 2020). However, it was noted data to facilitate such analysis was scattered among disciplines which made the process of data collection time consuming (Briassoulis, 2020). Although, this research study has assessed population growth in terms of population density, the challenge encountered by Briassoulis (2020) was also experienced during data collection stage. In this study, data on census population was obtained from Kenya Bureau of Statistics, gridded population from Worldpop Open Spatial Demographic Data and Research and land cover from United States Geological Survey.

Yaser and Saba (2016) found out that increased human population had intensified utilization of natural resources. This led to growing demand for basic needs such as shelter and food thus exerting more pressure on the ecosystem leading to land cover changes. Despite land cover changes being influenced by a combination of several factors, population growth was noted as a major driving force (Yaser and Saba, 2016). The study postulated that changes in land cover patterns in an ecosystem can either be positive or negative depending on natural successions and human activities. For instance, population pressure had been attributed to be the largest driver force causing agricultural and urban expansions. Therefore, Yaser and Saba (2016) findings are in line with this research study which sought to examine the impact of population on land cover changes in Gwassi hills water tower.

Additionally, a research study by Tobar (2012) in Komadugu-Yobe River Basin in Nigeria analysed trends in land cover changes and population growth. Data analysis undertaken was to ascertain the relationship and level of influence of each variable. This was done using spatial autocorrelation, overlapping neighbourhood Pearson correlation, variogram, rose diagram, and histogram (Tobar, 2012). Spatial autocorrelation analysis was used to examine if variables distribution were clustered or dispersed due to spatial influence. On the other hand, overlapping neighbourhood Pearson correlation analysis was done to establish if there is strength and direction of relationship between population and land cover changes in the study area. The results by Tobar (2012) revealed that there was strong and direct correlation between population and land cover changes in densely settled areas while forest and grassland had an inverse relationship. The two discussed methods used by Tobar (2012) for data analysis were also employed in data analysis for this research study to determine the relationship between population density and land cover changes.

The assessment by Borrelli et. al. (2017) looked into what could be causing land cover changes in an ecosystem. In their findings, they posited that rapid population growth was the main factor that affected earth's landscape system. They further noted that the intensity and magnitude on land cover changes was greatly increased in the 21st century with more land being placed under agriculture and built-up areas. In addition, high rate of conversion of forest and rangeland ecosystems to agricultural land were extensively witnessed in developing countries since their livelihood depends on natural resources (Borrelli et. al. 2017). These findings concurred with the argument by Deng et al. (2015) which showed that conversion of forests into grazing lands and farmlands were happening at an unprecedented rate across the globe. For instance, forests in the Amazon are rapidly being converted to grasslands while in Central Asia grasslands are being converted to barren lands and shrublands whereas in Eastern Africa forestland are fast changing to farmlands (Deng et al. 2015). These heightened changes in land cover were attributed to unsustainable utilization of forest resources, overgrazing, unsuitable agricultural practices and urban sprawling spurred by rapid population increase. Although, this research study focused on local scale analysis, its approach corresponds with the discussion made by Borrelli et. al. (2017) and Deng et al (2015) that population is an integral factor of land cover changes in any ecosystem.

In Africa, increased population exerts more pressure on available natural resources such as land, water and biodiversity thus affecting countries' economy. Kirui & Mirzabaev (2014) recorded that approximately 65% of Eastern Africa population are in rural areas with main source of livelihood being 90% dependant on agriculture. In the last three decades, East Africa has experienced rapidly growing economic and environmental changes that have led to exponential conversion of arable land to farmlands and settlement. On the other hand, findings by Bullock (2021) revealed that population growth has resulted to 17% decline in forest cover in East Africa. Effects of these negative changes are being witnessed through environmental degradation as more land is placed under cropland and settlement. Therefore, to mitigate these impacts and ensure sustainable development, there is need to conduct thematic study for drivers of land cover changes to inform decision making and policy development.

Gitau (2018) examined the implication of land cover changes on agriculture in the peri-urban areas of Kiambu county. Using GIS and remote sensing techniques, the study findings revealed that 38% of agricultural land in the peri-urban areas of Kiambu county had been converted to built-up areas (Gitau, 2018). This was attributed to exponential population increase that has heightened demand of land for settlement. Despite the existence of a national land use policy, development of local spatial plans, its implementation and enforcement in the country are still weak hence most counties and sub-counties have not domesticated it. In this regard, Gitau (2018) recommended on need for domestication and implementation of land use plan to mitigate rapid land cover changes. The recommendations provided a niche for investing in assessing drivers of land cover changes. This research study fitted well in this niche as it sought to look into the relationship between population and land cover changes in a different geographical area.

Ogola (2018) conducted a study in Migori county to establish if there is significant impact of population growth and land resources. The findings revealed that forest and water resources in Migori county had declined at the expense of cropland. These was attributed to increasing demand for food to sustain the growing household sizes which led to farmland expansion into forest and wetlands (Ogola, 2018). In addition, the study used world gridded data which is raster based to spatially correlate population with land cover. Similar method was adopted in this study where gridded population data was downloaded from Worldpop Open Spatial Demographic Data and Research.

The Homabay County Integrated Development Plan 2018-2022 pointed out that population of Homabay County has been growing at unprecedented rate of 2.7% per annum (CGH, 2018). This is higher than that of country which is estimated at 2.2% per annum (KNBS, 2019). According to the Plan, the largest proportion of population in Homabay county are youths at 49.1% population in 2019 and is projected to increase to 69% by 2030. CGH (2018) indicated that this is the bracket with highest percentage of working population coupled with high dependency ratio of 107 in 2019 compared to 88 in 2009. This puts more pressure on limited natural resources for sustenance of livelihood leading to farming and settlement expansion into forested and grassland area. The level of exploitation of natural resource especially for fuel wood continues to rise with national level estimated at 80% (AFIDEP & PAI, 2012). It has led to indiscriminate harvesting of more trees for charcoal production without sparing ecologically sensitive areas such as wetlands and riparian zones. These statistics shed light in the discussion of parameters assessed in this study.

Kenya Water Towers Agency (KWTA) developed Gwassi hills water tower status report which assessed the overall condition of Gwassi hills water tower. The report pointed out that the water tower had experienced ripple effects of population growth (KWTA, 2020). In addition, it revealed that the water tower had witnessed changes in land cover between 1990 and 2018 with cropland and otherland showing an increasing trend while grassland had decreased in coverage (KWTA, 2020). These changes were postulated to be caused by human induced pressure such as population growth. The study also used IPCC classification for land cover classes. The same guidelines were adopted in categorizing land cover classes in this research. Whereas KWTA

(2020) also provided time series analysis of land cover changes in the water tower between 1990 and 2108, the study did not go further to demonstrate the relationship between population as driving factor for land cover changes. In this regard, this research study has built on KWTA (2020) argument by providing an in-depth analysis that has deduced whether population had significant impact on land cover changes in Gwassi hills water tower.

2.1.2 Urban sprawl-and land cover changes

Addae and Oppelt (2019) conducted a study on land cover analysis and urban growth modelling in Accra Metropolitan Area in Ghana. In their report, the authors pointed out that by early 1990s human influence on natural environment had been established through changes in land cover, land use and industrial metabolism (Addae & Oppelt, 2019). In addition, exponential growth in human population is mentioned as a major driver altering bio-physical landscapes across the globe leading to expansion of urban areas at expense of vegetation cover. The study established that built-up areas in Accra Metropolitan Area had increased by 277% over the 24-years with forest cover declining from 34% in 1991 to 6.5% in 2015 (Addae & Oppelt, 2019). It concluded that with increasing population, urban areas are expected to continue extending to natural ecosystems. Therefore, to mitigate the impact of occasioned by urban growth, there is need to generate information key in guiding strategies, policies and decision making on management of urban environment. Thus, these recommendations affirmed the objective of this research study.

According to UNDP (2016), global urban land will continue increasing to cover an area of 1.2 million km^2 by 2030. Africa and Asia were projected to experience the largest growth in their urban areas coupled with the rapid population growth. In addition, massive land cover changes would occur in growing towns occasioned by faster and uncontrolled land conversions to meet the growing needs of urban population (UNDP, 2016). Urbanisation brought about by rapid population growth has led to proliferation of towns at the expense of land considered fertile for crop production and livestock rearing (UNDP, 2016). Therefore, rapid growth of urban areas would put more pressure on rural landscapes due to increased demand for food and shelter. The impact will largely be experienced in peri-urban areas whose population has been growing at a faster rate than in the established towns (UNDP, 2016). Therefore, land available for agricultural activities in peri-urban areas are likely to be reduced thus forcing farmland to be shifted other areas covered by forests, wetland and grasslands. This study would assess if the highlighted outcome would concur with findings on effects on urban sprawl on land cover changes.

Arifeen et. al. (2021) noted that developing countries are experiencing rapid urbanization which significantly impacts on land cover in urban areas. The rate of urbanization was ascribed to exponential population growth. This is due to increased movement of people to urban areas in search of better opportunities especially employment and trade leading to urban sprawling. According to United Nations (2019), urban growth has led to rapid transformation of towns rural areas in favour of into built up land thus impacting on pristine and peri-urban areas which act as transitional zones. Hence, increased conversion of more agricultural land to high density built-up areas. It has also led farmlands to be receded to areas that covered by grasslands, forests and riparian land. Furthermore, Arifeen et. al (2021) found out that urban areas Gazipur district in Bangladesh had expanded by more than 500% between 1990 and 2020 with major expansion witnessed along roads. They recommended that for realization of achievement of SDG 11 on sustainable cities and communities, there is need to develop concrete policies and strategies for management of urban growth. This will require detailed assessments such as the one done in this research study to be conducted in urban areas to guide land use planning and management.

Yiran et. al. (2020) reviewed various literature on urban sprawl in Sub-Saharan Africa. The review revealed that there is rapid urbanization in most Sub-Saharan countries due to exponential population growth. The researchers also noted that studies done on urban sprawl in Africa were mostly generic and focused on broad outlook on causes and effects with little information on the relationship between specific drivers and impacts (Yiran et. al. 2020). In their recommendation, they pointed out that future research should pay attention to urban ecosystems found in rural settings due to fast mushrooming of settlements leading to uncontrolled urban growth. These have led to rapid destruction of natural ecosystems hence affecting community livelihoods. Research by Yiran et. al. (2020) is in line with the objective of this study which is to assess effects of urban sprawl on land cover changes.

A study by Fura (2013) analysed urban land cover changes in Upper Lubigi catchment area in Kampala, Uganda. It revealed that built-up and bare areas in the Upper Lubigi catchment increased at rate of 6.85% per annum at the expense of vegetation cover between 2004-2010 (Fura, 2013). Additionally, infrastructural development in urban areas created more impervious areas leading to loss of wetlands, forests and open areas that played important role in provision of ecosystem services. Since urban areas and population were rapidly growing, sustainable land management and planning of urban areas needs to be prioritized at micro-scale. This will improve decision making in urban planning and promote sustainable development. Although, this research was done in Upper Lubigi catchment area in Kampala, the conclusion drawn and recommendation are relevant to rural setting in Gwassi hills water tower, a catchment area for Lake Victoria.

Njiru (2016) posits that urban areas are fast expanding into peri-urban environment. This is because of increased demand of land for commercial and residential use by the ever-growing urban population. Using GIS and remote sensing, Njiru (2016) investigated the extent of loss of rural land to urban land and its effects on land cover changes in Kiambu county between 1986 to 2014. The study found out that 61.5% of agricultural land in Kiambu county has been converted to built-up areas hence farming had to be moved to pristine areas such as forest and wetland. The findings were also supported by a study done by Abuya & Oyaro (2019) who assessed effects of land use on urban infrastructure in Ruaka town, Kiambu county. In addition, both Njiru (2016) and Abuya & Oyaro (2019) agreed with AFIDEP & PAI (2012) that Kenya’s urban areas are growing at a fast rate with estimated urban growth rate of 4.4% per annum. They concluded that majority of urban centres are still unprepared and ill-equipped to manage urban growth and its impacts on land cover resulting to unorganized and unsustainable towns (Njiru, 2016; Abuya & Oyaro, 2019). These finding supports the investigation of this research objective that examines effect of urban sprawl on land cover changes. Therefore, significant in shading light to discussion of results obtained from data collection.

Rapid population growth has largely been witnessed in urban areas; cities and towns. As population and urbanization increases most rural towns in Kenya are undergoing adjustment and tend to grow either radially or laterally. In a study conducted by Ochola et. al. (2018), they found out that establishment of Rongo University spurred rapid expansion of settlements and hence emergence of towns in Rongo sub-county. It further revealed that cropland, grassland and bareland were largely converted to built-up areas. This led to haphazard development of settlement and destruction of fertile agricultural land (Ochola et. al. 2018). In addition, devolution of government services to rural towns has played significant role in growth of these urban areas. However due to lack of information to guide proper urban planning structures especially those targeting agricultural-based towns, urban sprawling has caused massive deforestation and draining of wetlands. The findings aligned with that of Njiru (2016) and Abuya & Oyaro (2019) where demand from ever-expanding town areas have shifted agricultural areas into pristine ecosystem mainly forests and grassland areas.

Onyango et.al. (2021) indicated that Lake Victoria watershed is increasingly experiencing land cover changes due to rapid urbanization. The researcher reported that about 80% of deforested areas in the watershed is utilized for agricultural purposes. Furthermore, land in Lake Victoria basin has been indiscriminately converted to built-up areas and agriculture by the ever-increasing population over the last three decades (Onyango et.al, 2021). Therefore, expansion and emergence of towns in Lake Victoria watershed has been on the rise. This coupled with rapid urban sprawl contribute to land cover changes areas under vegetation cover are being transformed to shopping centres and administrative towns (Onyango et.al, 2021). Additionally, Onyango et. al (2021) recommended on the need to understand the impact of urban growth on land cover changes and in development of an integrated watershed management plan. In line with the findings, this research looked into the effects of urban sprawl on land cover changes in Gwassi hills which is one of the ecosystems within Lake Victoria watershed.

2.1.6 Research Gaps

The research gaps identified are:

1. There are very few studies attempting to bring out empirical relationship between population growth and land cover changes is ecosystems located in rural areas. Most studies focus on broad scale land cover changes and hence many small ecosystems have been overlooked.

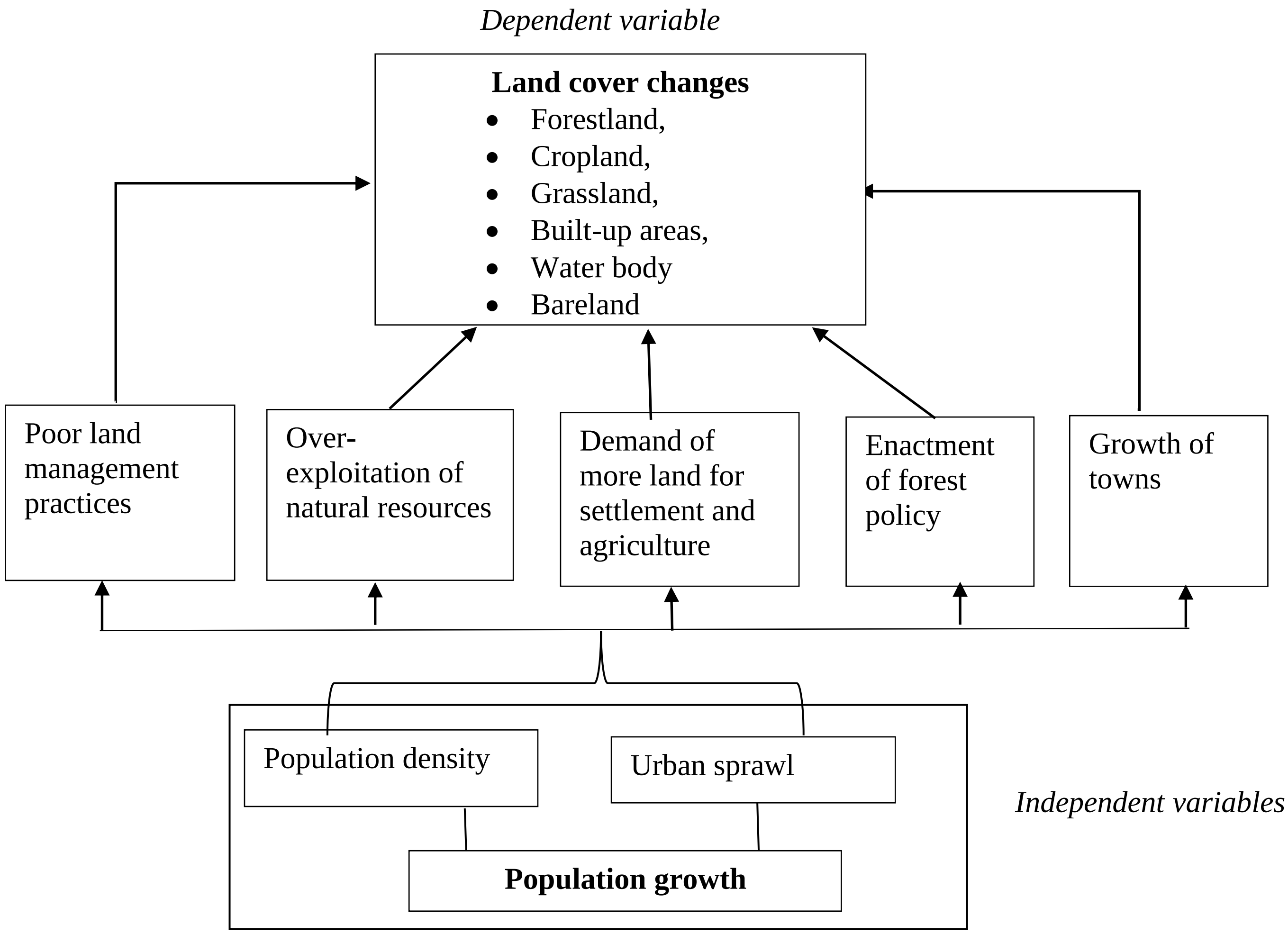
2. Population growth as one of the factors that could be influencing land cover changes in the study area by KWTA (2020). Therefore, leaving a research gap that requires undertaking an in-depth analysis to examine the empirical relationship between population and land cover changes. This research addresses this gap by providing empirical evidence linking the two factors, population and landcover changes relationship.
3. Onyango *et. al.* (2021) recommends that conservation measures proposed to be implemented within the Lake Victoria landscape should be done holistically by considering ecological, social and political aspects. This will ensure that an integrated watershed conservation of the Lake Victoria basin is achieved.
4. There is need for more expanded research on relationship between socio-economic factors and land cover changes in rural ecosystems to inform devolved strategic land use plans and sustainable conservation practices in the country.

2.2 Theoretical and Conceptual Framework

Theories relating to land cover and land use changes are pertinent when it comes to discussing human interactions with nature including their role in causing global environmental changes (Briassoulis, 2020; Hersperger *et.al*, 2010; Yuting *et al*, 2019). Studies linking humans and land cover land use dates back to Malthusian theory of population in the 18th Century whose concern was relationship between exponential population growth and fixed natural resources availability especially food (Briassoulis, 2020). Due to growing need to curb global environmental problems relating to rapid population increase, Briassoulis developed the nature-society theory. It focusses on analysis of the role of population as a driving force to land cover changes being experienced in ecosystems worldwide. It provides the best approach that can be used to examine the impact of population growth on land cover changes compared to other theories such as urban and regional economic theory and sociological and political economy. Urban and regional economic theory looked into inequitable growth of urban areas based on space, transportation cost, production and consumption decisions while sociological and political economy theory provided a framework focusing on impact of ecosystem changes in regards to interrelationships between people, government, and public policy (Briassoulis, 2020; Hersperger *et.al*, 2010; Yuting *et al*, 2019). Among these three theories, nature-based theory was the best suited to provide the theoretical focus and relevance of this study.

The nature-society theory by Briassoulis is a holistic and multi-disciplinary in assessing and analysing the role of human to global environmental changes (Briassoulis, 2020). The theory promotes ecological equilibrium approach in addressing changes in land cover by looking into the interactions in environment, economy, politics, institutions and culture sectors (Hersperger *et.al*, 2010). It also uses humanity-based, natural and social sciences approaches in establishing the relationship pressures arising from population dynamics on land cover and land use changes. In addition, it provides a platform that supports decision and policy making, assessment of the spatial-temporal relationships between the drivers and resultant land cover/land use changes and enables development of scenarios in forecasting future land use patterns with changes in bio-physical and socio-economic characteristics (Briassoulis, 2020; Hersperger *et.al*, 2010). It also plays a significant role during impact assessment of environmental, social and economic activities and when it comes in proposing the optimum land use for sustainable utilization of land (Briassoulis, 2020; Hersperger *et.al*, 2010; Yuting *et. al*, 2019).

In consideration of the aforementioned, the nature-society theory helped in the development of conceptual framework for this research on the impact of human population on land cover changes in Gwassi hills water tower between 1990 and 2020 (Figure 1). The dependent variable is land cover change and independent is population density and expansion of built-up areas in towns (urban sprawl).



Source: Researcher

Figure 1: Conceptual framework on impact on population on land cover changes

On operationalization of the conceptual framework, the arrows point to the direction of influence. The independent variable in this study is population growth which was assessed in terms of population density and urban sprawl (extent of built-up areas within towns). The dependent variable is land cover changes in Gwassi hills water tower. The population growth is likely to cause significant changes on land cover types in the study area due to due to poor sustainable land management practices, over-exploitation of natural resources, expansion of towns, enactment of forest policy and increased land under settlement. For instance, the enactment of forest policy led to evictions of those who had settled in the forest hence cropland and built-up areas were converted to grassland or forestland. Therefore, land cover changes play a critical role in determining the land cover distribution observed in an ecosystem at any given time.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

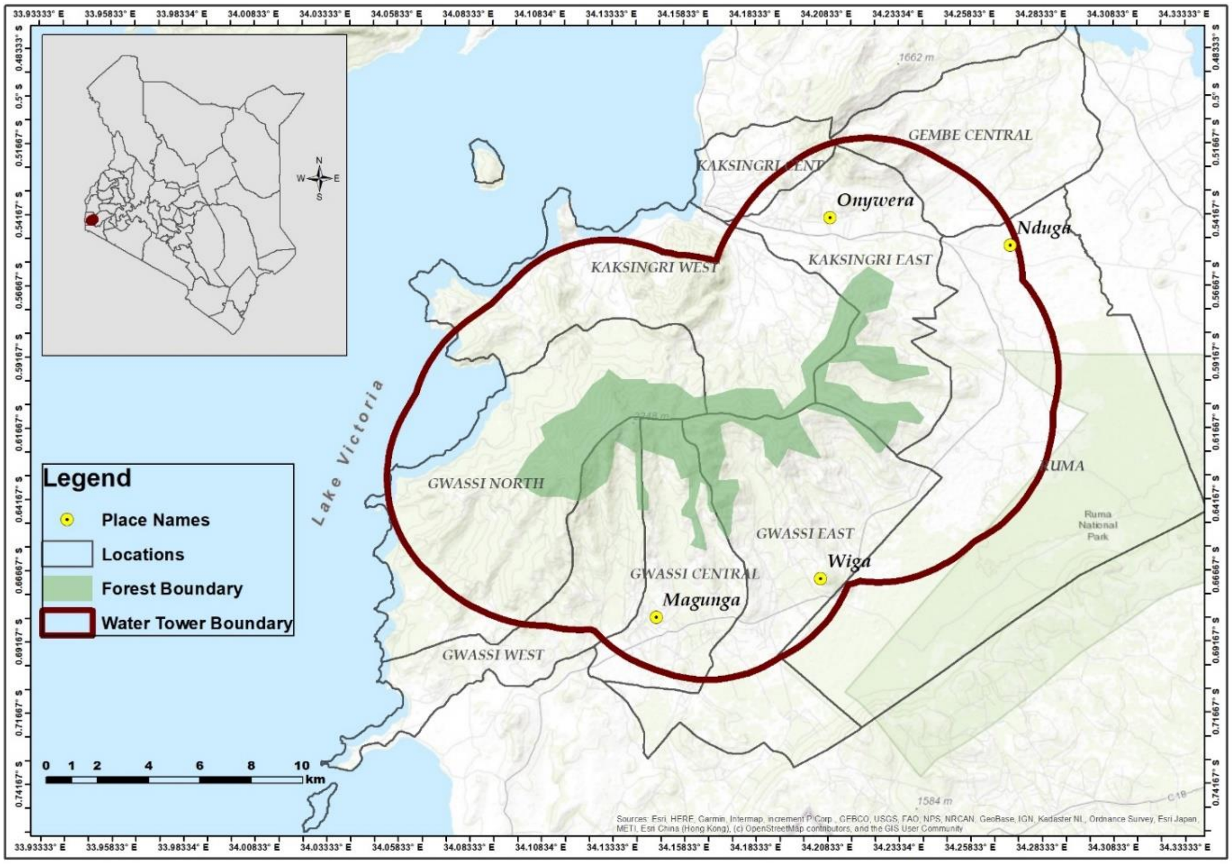
This chapter provides a description of the study area and methods used to meet the research objectives. It is composed of study area, research design, data collection methods, processing, analysis and presentation.

3.2 Description of the Study Area

This section provides information on the geographical location, size, bio-physical and socio-economic characteristics of Gwassi hills water tower.

3.2.1 Location and Size

Gwassi hills water tower lies in Suba South sub-county in Homabay County. It is located about 40km to the South-west of Homabay town and 20km South-east of Mbita town (KWTA, 2020). The water tower is a conglomeration of small hills located near Ruma National Park, Kanyamwa Escarpment and Lambwe Valley in the south-west of Lake Victoria (OSIENALA, n.d; KWTA, 2020). It traverses Gwassi North, Gwassi West, Gwassi East, Kaksingri East, Kaksingri West, and Ruma locations (Figure 2). It covers an area of 37,484 ha (374km^2).



Source (Researcher)

Figure 2: Gwassi hills water tower

3.2.2 Physiographic conditions

Gwassi hills water tower falls at elevation of between 1000m to 2275m above sea level (KWTA, 2020). It also hosts a gazetted forest reserve located at the peak of hills which is mainly dominated by indigenous trees and grass species (OSIENALA, n.d). The hillslope and the base of the hills are characterized by a flat terrain extending to Lambwe Valley and Lake Victoria. These areas are mainly covered with farmlands and settlement.

3.2.3 Climate

Climate of Gwassi hills is influenced by altitude and proximity to Lake Victoria. The area receives bimodal rainfall with an annual range of 700-1200mm (KWTA, 2020). Short rains are experienced from September to December and long rains in March to May. Rainfall reliability of about 60% is experienced in the high-altitude areas, basically the hills compared to the lowlands at the lakeshore side which is characterized as a rain shadow zone (CGH, 2018; KWTA, 2020). Annual average temperatures in this areas range between 17.1°C to 18.6°C to with hot months from December to March with February being the hottest (CGH, 2018).

3.2.4 Geology and Soils

Gwassi hills are part of an old, dissected volcano that is made up of tertiary Kaksingri lava and lateritic layers (Egis, 2017). The hill slopes are steep crossed by numerous gullies and in part forest (Egis, 2017). The rocks of Gwassi area comprises of Precambrian lava and sediments of an extensive series of volcanic and intrusive rocks, sediments of Tertiary and Pleistocene age (Egis, 2017). The hills are rich in alluvial volcanic soils while Lambwe valley is characterized by black cotton and clay soils

3.2.5 Drainage and hydrology

Gwassi hills water tower falls within Lake Victoria South catchment area (OSIENALA, n.d). Most rivers from the hills flows eastwards into the Lambwe River while only Misare and Taronegi river flows north-west into Lake Victoria (KWTA, 2020). The Lambwe River flows through the Lambwe Valley and Ruma National Park hence sustaining agricultural activities and biodiversity respectively (KWS, 2020).

3.2.6 Agro-ecological zone

Gwassi hills falls within two main agro-ecological zones which are upper midland (UM3) and lower midland (LM4) (MoALF, 2016). Upper midland zone dominates most part of Gwassi hills and Suba south sub-county supporting the growing of maize, millet, sorghum pineapples, soya beans, tomatoes and sunflower (CGH, 2018). The lower midland is located in the north-section of Gwassi hills in Kaksingri with mainly millet, cotton and livestock production (CGH, 2018).

3.1.7 Population

The 2019 population within the study area is 112,295 of which 54,676 are males and 57,616 are female (KNBS, 2019). The population growth rate in this area is estimated at 2.7% per annum. More than 47.6 percent of the population in the area is characterized as labour force (CGH, 2018).

3.2.8 Biodiversity

Vegetation in the area is characterized by dense forest at the peak of the hills to semi-deciduous wooded grasslands found along the forest boundary and the Ruma National Park (GHFMP, 2013). Open grasslands are mainly at Lambwe valleys and farmlands (GHFMP, 2013). The dominant tree species are *Euphorbia candelabrum, Acacia sp. Grewia sp., Euclea divinorium, Balanites sp.* and *Rhus natalensis* (GHFMP, 2013; KWTA, 2020). The common grasses found in the area are *Hyparrhenia fillipendila, Themeda triandra* and *Setaria spacelata* (GHFMP, 2013; KWTA, 2020). Gwassi hills ecosystem is also a key habitat for the endemic and threatened Roan Antelope which is only found in the Ruma National Park (KWS, 2020). Other fauna in the area are Gazelles, Vervet monkeys, Warthogs, Hyena, Dik-dik, birds, snakes among others (GHFMP, 2013)

3.2.9 Socio-economic activities

Agriculture is the main source of livelihood in the area. A study undertaken by KWTA (2019) indicated that agriculture is practiced by approximately 89% of the population in the areas. About 7% of the population are engaged is small scale business and the remaining 4% is shared among other socio-economic activities such as fishing (KWTA, 2019). The main crops grown are maize, beans sorghum, cassava, sweet potatoes and millet (GHFMP, 2013). The land holding in the area is averagely 1-3 acres with average households having 6-8 members (KWTA, 2019).

3.3 Research Methods

This section describes methods used to collect and analyse data to determine the impact of human population on land cover changes that have occurred in Gwassi hills water tower. Data collection techniques employed use of satellite imageries, population census data recorded in 1989, 1999, 2009 and 2019 as well as documented literature from previous studies

3.3.1 Research design

The study used descriptive design where quantitative and qualitative data collection methods were adopted. This allowed assessment of population density and expansion of built-up areas in towns on land cover changes in Gwassi hills water tower. The design adopted 1989 as the base year of because this is when population of Kenya started blooming as well as Landsat satellite imageries indicated pronounced land cover changes in the area with rising population. The designed allowed to conduct spatial analysis on relationship between population density and land cover data to determine how the variable relate with each other. In addition, it supported help examine the impact of urban sprawl on land cover distribution and presentation as well as discussion of the research findings.

3.3.2 Target Population

The study targeted human population and land cover in entire of Gwassi hills water tower for years 1989, 1999, 2009 and 2018. For urban sprawl the target population were 10 towns found in the study area each covering a radius of 500m.

3.2.5 Population Data Acquisition and Processing

The decadal population data for 1989, 1999, 2009 and 2019 were acquired from Kenya National Bureau of Statistics. These covered Gwassi North, Gwassi West, Gwassi East, Kaksingri East, Kaksingri West, Lambwe East, Gembe Central and Ruma locations (Table 1).

Table 1: Population in Gwassi hills water tower

Population size in Gwassi hills water tower from 1989 to 2019					
Location	**1989**	**Location**	**1999**	**2009**	**2019**
Gembe	14290	Gembe Central	4,559	5,756	7,022
Gwassi Central	4071	Gwassi Central	5,305	7,052	8,456
Gwassi East	6852	Gwassi East	8,180	10,032	11,111
Gwassi North	15134	Gwassi West	12,098	15,042	19,380
		Gwassi North	9,869	15,556	18,436
Kaksingri	6873	Kaksingri West	3,533	17,223	15,123
		Kaksingri Central	7,125	6,594	13,033
		Kaksingri East	12,778	7,029	8,129
Lambwe	8468	Ruma	4,028	4,843	5,157
Total	**65,688**	**-**	**67,475**	**89,127**	**105,847**

The spatial population for locations in Gwassi hills water tower were processed in ArcGIS 10.8 for analysis of change in population density. Gridded population raster data for generation of Pearson correlation was also downloaded from Worldpop Open Spatial Demographic Data and Research managed by University of Southampton (https://www.worldpop.org). It provided a pixel size of 100km^2 hence produced a better correlation analysis. It was noted that the population variation between census data and Worldpop was insignificant because of rasterization process

3.3.6 Land Cover Data Acquisition and Processing

Satellite imageries and ancillary data was used to examine historical land cover changes in Gwassi hills water tower over a period of 30 years with epoch 1989, 1999, 2009 and 2019. A subset of Landsat (L) satellite imageries was downloaded from the United States Geological Survey (USGS) database using Google Earth Engine script. The script code incorporated L5 - Thematic Mapper (TM), L7 - Enhanced Thematic Mapper Plus (ETM+) and L8 - Operational Land Imager (OLI)/ Thermal Infrared Sensor (TIRS)

To achieve the best comparison of the acquired satellite data, images captured during dry season was used. This is because the season was best suited in acquiring cloud-free imageries with good visibility on ground features since the sky is mostly clear throughout the day. Validation of imageries was through visulation interpretation of land cover classes using Google Earth Pro and comparison of land cover classes publised in the KWTA (2020) report before processing of land cover classification. Land cover data was processed using ArcGIS 10.8 and R Studio 1.4.1106 to deduce land cover changes that have occurred in an interval of 10 years between 1989 and 2019 as described below.

i. Image pre-processing

Google Earth Engine script was used to pre-process the images in the USGS database before the images were downloaded. Inbuilt in the script were radiometric and geometric correction, de-stripping Landsat 7, image subsetting as well as mosaicking of the images. To achieve the best comparison of the acquired satellite data for the two time periods, images captured during dry season was used with relatively dry and cloud free period falling on 0 to 90 julian days (January to March). The landsat satellite pre-processing was carried out before image classification and land cover change detection in the study area. This was to minimize errors arising from image distortion, noise, scale uncertainities and geometric conditions as well as to build association between acquired satellite imageries and observed ground features from the four satellites (Alawamy, 2020). The bands used during the analysis were Near Infrad Red, Red, Green and Blue. The imageries were then projected to the UTM coordinate system, Datum Arc1960, Zone 36 North.

ii. Image processing and classification

Pixel-based supervised classification was executed using Random Forest (RF) classifer in R-Studio 1.4.1106. The packages used included sf, maptools, snow, raster, randomforest, lwgeom and rgdal, which are all available in R environment. The advantage of using random forest was due to ability to limit overfitting without significantly increasing error due to bias (Kulkarni & Lowe, 2016; Rotich et. al, 2022). Also running RF in R-Studio is faster, easy to integrated validation data and generate confusion matrix within the model (Kulkarni & Lowe, 2016; Scharsich 2019; Rotich et. al, 2022). Delienation of polygon training sites and coding was done where a polygon represented areas of each landcover class: forestland, grassland, cropland, water body, built-up areas and bareland. Goolge Earth imageries and secondary data, visual interpretation of the satellite imageries were used to guide generation of polygon training samples for each landcover classes for epoch 1989, 1999, 2009 and 2019 (Appendix I). Guided by Rotich et. al. (2022) and Shelestov et al. (2017) recommedations,the training samples for land cover classs were generated using defined number of pixels that are based on proportion of polygons per class in Appendix I. Thereafter, RF classifier was applied to conduct a stratified random pixel classification in an image and total of 1070 pixels were colleceted for 1989, 1240 for 1999, 1140 for 2009 and 1140 for 2019 as taining sites in R studio (Appendix I).

iii. Accuracy assessment

Using defined training samples generated by RF script in the R-environmnet, a random stratified sampling procedure was applied per land cover class to validate the image classification (Appendix I). The validation samples for the imageries were interpreted visually on composite Landsat and high-resolution Google Earth images (Appendix II). Thereafter, accuracy assessment confusion matrices indicating the Kappa coefficient, overall accuracy, producer and user errors for 1989, 1999, 2009 and 2019 were generated in R-studio as follows:

Producer error:

The producer error only gives the probability of correctly classified pixels in an image. It is generated by the formular:

$$\text{Producer error} = \frac{\text{Number of pixels correctly classified per class}}{\text{Total number of pixels in the class column}} \times 100$$

User error

User error indicates the probability that pixels used to generate the classified image reflects the class on the ground. These was derived using the formula:

$$\text{User error} = \frac{\text{Number of pixels correctly classified per class}}{\text{Total number of pixels in the class row}} \times 100$$

Kappa coefficient (K)

Kappa coefficient (K) is used to demonstrate the proportion of reducing errors during classification in comparison with error from random image classification. A value of less than or equal to 0 indicates no agreement and +1 as perfect agreement. The classification value of the image is generated by formula:

$$K = \frac{N \sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} \times x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} \times x_{+i})}$$

Where,

N = total number of training sites in the matrix

r = the number of rows in the matrix

i= row or column in the matrix

xii = the number of training sites in row i and column i

xi+ = total training sites for row i

x+I = total training sites for column i

Statistically, overall accuracy of more than 80% and kappa coefficient of 0.4 to 0.75 is termed as almost perfect classification agreement (Alawamy,2020). This allowed the training pixels to be used to process land cover classification from acquired satellite imagery

iv. Land cover change detection

Post-classification comparison of processed imageries was carried out to detect land cover changes through assessing conversions of thematic land cover classes that have occurred in Gwassi hills water tower. Corresponding time series thematic land cover maps and tables between interval period of 1989, 1999, 2009 and 2019 were generated. This helped to further explain the obtained results on land cover changes that have occurred in Gwassi hills water tower.

3.3.7 Data Analysis

Data on decadal population census obtained from KNBS and land cover changes from satellite imageries between 1990 and 2019 was used to determine relationship. Exploratory spatial data analysis (ESDA) was employed in ArcGIS 10.8 to investigate the spatial relationship between land cover changes, which is the dependent variable and population and built-up densities, the independent variables under study and how they affect each other. Spatial autocorrelation was conducted for 1989, 1999, 2009 and 2019 to establish the degree of spatial variation between variables and its neighbouring environment in ArcGIS 10.8. The test assumes that the variables being examined are randomly distributed in the study area. The spatial autocorrelation tool in ArcGIS 10.8 enabled the analysis of this assumption by generating values on Moran I index, expected index, variance and z-score. The Moran I index indicates the level of distribution of variable under study and whether they are clustered, dispersed or random. The values range from +1 meaning perfect clustering and -1 perfect dispersal. The expected index shows the anticipated value required for no spatial autocorrelation, variance is the deviation from the mean and z-scores provides the statistical significance of variables distribution patterns.

Despite ESDA analysis being able to graphically show the spatial relationship between the independent variables (population density) and land cover change (dependent variable) within the study area, there was need to undertake statistics analysis to firm up the study hypothesis tests. In this regard, Pearson correlation coefficient was generated with incorporating overlapping neighbourhood statistic components so that effects associated with spatial correlation of variables under study would be addressed. The formula for generating Pearson correlation coefficient between population density and land cover changes was:

$$\rho_{X,Y} = \frac{\text{cov}(X, Y)}{\sigma_X \sigma_Y}$$

where;

ρ is the Pearson's correlation coefficient

X = land cover for 1989, 1999,20009 and 2019

Y = population density for 1989, 1999,2009 and 2019

cov (X, Y) = covariance value of X and Y

σ_X =standard deviation of X

σ_Y =standard deviation of Y

An Overlapping Neighbourhood Statistics Toolbox Model was developed in ArcGIS 10.8. The four-step module was guided by study by Tobar (2012) which used the same model in assessing the impact of population density on land cover changes. The step-by-step modelling of Overlapping Neighbourhood Statistics Toolbox statistic is described in Table 2 below and its visual presentation in Appendix III.

Table 2: Pearson correlation coefficient in overlapping neighbourhood statistic model

Module 1:	The raster images for population and land cover were standardized. The rasterized unconstrained population data with cell size 100m was obtained from Worldpop Open Spatial Demographic Data and Research by University of Southampton (https://www.worldpop.org/) for 1999, 2009 and 2019 to allow undertaking of this analysis. In comparison with census data obtained, there was negligible as it accounted to less than 1% difference. Thereafter, land cover raster was renamed as X and population as Y for ease of manipulation.
Module 2:	Computed the squares of X and Y raster images and their product.
Module 3:	Computed focal statistics of the outputs generated from first and second modules. As recommend by Tobar (2020), a cell size of 10by10 was used since

focal statistics of a cell are calculated from the values within a specified neighbourhood around it

Module 4: Produces the standard deviation and covariance of the X and Y raster images and uses these values to calculate the Pearson's correlation coefficient of the variables.

To test the second hypothesis on significant effect of urban sprawl within towns in Gwassi hills water tower after every ten years, Chi-square was used. This test allows test of significant difference between categorical values, which is increased size of built-up areas over time (!989-1999, 1999-2009 and 2009-2019). The calculated chi-square (χ^2) to the critical value (α) at 0.05 significance level was generated in R-studio using the formula:

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

χ^2 = chi squared
O_i = observed value
E_i = expected value

The results from the analysed data were presented using tables, maps and figures thereafter, conclusion was drawn and recommendations made.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This chapter presents research findings and discussions on impact of population on land cover changes in Gwassi hills water tower between 1989 and 2019. This is in terms of population growth, land cover distribution and changes over time, land cover conversions and an analysis of relationship between population on land cover changes. Further discussion was done in assessing the magnitude of urban sprawl on land cover changes within towns in Gwassi hills water tower.

4.1 Population in Gwassi Hills Water Tower

Trends in human population growth in Gwassi hills water tower was assessed in a decadal interval which was 1989, 1999, 2009 and 2019. This was informed by timing of population census in Kenya. From the overall assessment, the population in Gwassi hills water tower has grown exponentially between 1989 and 2019. Analysis of population size and density within the study area are detailed below.

4.1.1 Population size

Population size recorded in 1989 in Gwassi hills water tower was 65,688 with Kaksingri and Gwassi North locations having highest numbers of 16,873 and 15,131 people respectively (KNBS, 1989). Growth in population experienced in Suba District (now renamed Suba South sub-county) in years preceding 1999 led to Government of Kenya decision to sub-divide various locations in the Sub-county affecting three locations in the study area. This was to facilitate efficient and effective administration of services. The locations included Kaksingri which was divided into: Kaksingri West, Kaksingri East and Kaksingri Central locations; Gwassi North split to Gwassi North and Gwassi West locations; Gembe to Gembe Central while Lambwe was renamed to Ruma because of the Ruma National Park. Therefore, impacting on the number of persons in study area within this period mainly in areas of Kaksingri Central and Gembe Central In the succeeding years, population continued to grow exponentially to reach 105,847 in 2019 from 89,127 people recorded in 2009.

During the 30-year study period, it was noted that Gwassi North and Gwassi West locations recorded the highest population throughout followed by Kaksingri West and Kakasigri Central (Figure 3). On the other hand, Ruma location had lowest population across the years from 1989 to 2019 since the largest section of this location falls within the protected Ruma National Park.

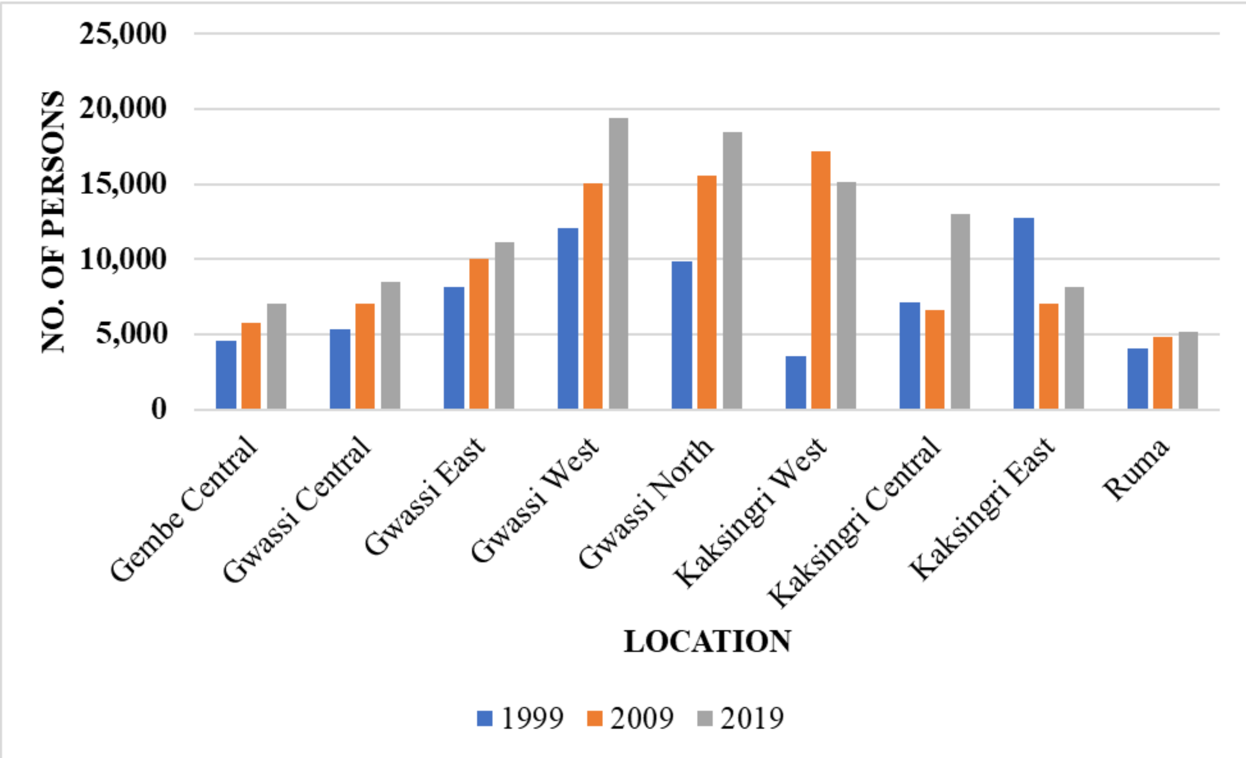


Figure 3: Population size per locations in Gwassi hills water tower in 1999, 2009 and 2019

4.1.2 Population density

Population increased between 1989 and 2019 as shown by the population census records. From this data, it was important to assess population density pattern in the study area. Information on population density plays critical role in understanding impact of population to land cover changes since land is a fixed and limited resource and also depended upon as the main source of livelihood. The analysis indicated that population density in Gwassi hills water tower rose from 89/km^2 in 1989 to 229/km^2 by 2019 (KNBS, 1989; KNBS, 2019).

The densities per location were then evaluated and Kaksingri Central recorded the highest population density throughout the study period from 1989 to 2019 followed by Gwassi West and Kaksingri West (Figure 4). These was attributed to these locations hosting major town centres in Suba South sub-county as well as good road infrastructure such as roads and access to government services. Location with lowest density was Ruma since falls in the flooding Lambwe valley and borders the Ruma National Park which is a protected area. It was also noted that areas that there was a direct relationship between population and household densities. This means that areas with high population densities also recorded high household densities hence an indicator of high dependency levels which in turns puts more demand on the natural resources.

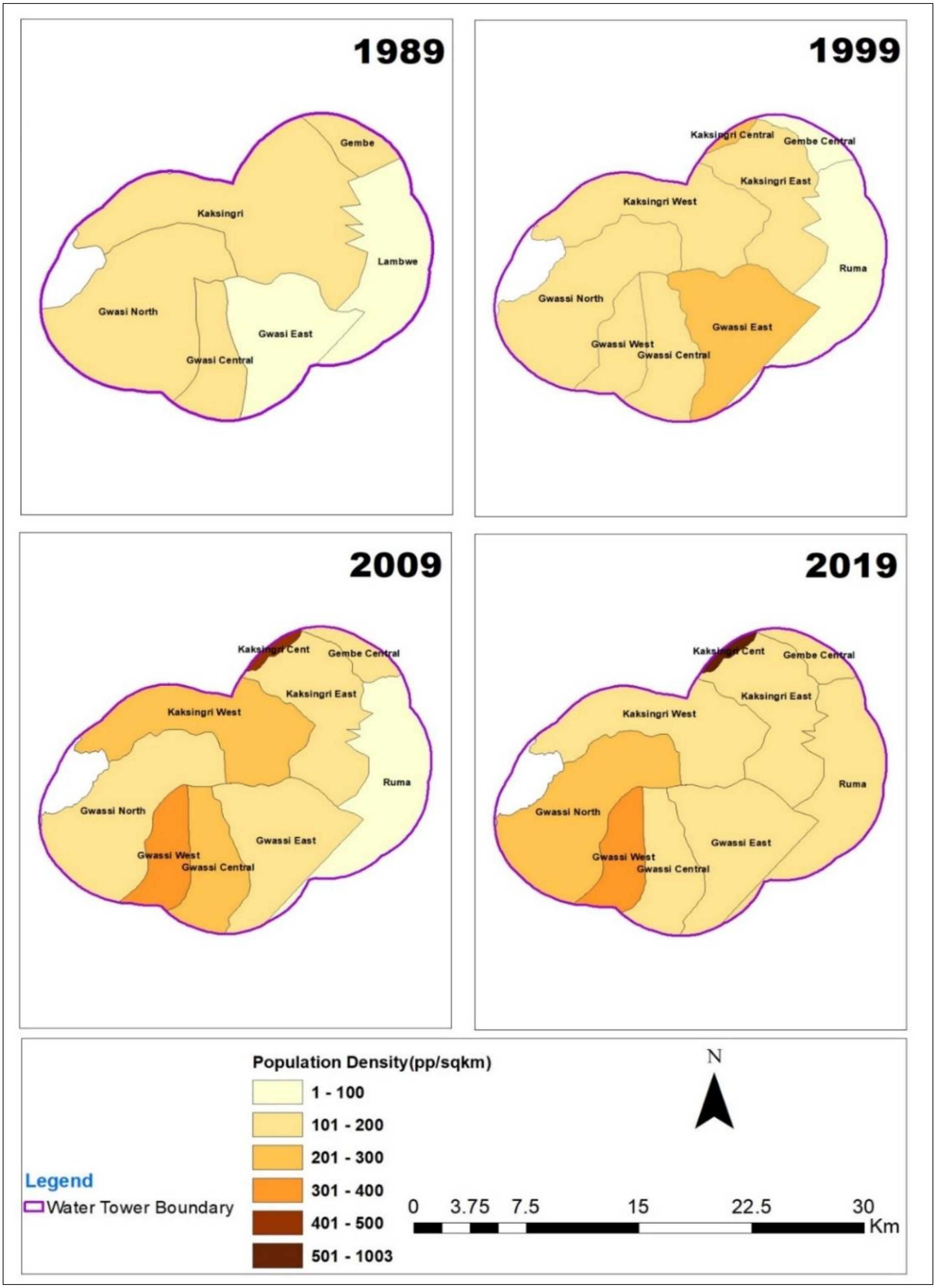


Figure 4: Population densities in Gwassi hills water tower from 1989 to 2019

4.2 Land Cover Analysis

Land cover classification in Gwassi hills water tower was conducted using the six classes: forestland, grassland, cropland, waterbody, built-up areas and bareland. The assessment was done in an interval of 10-year period of epoch 1989, 1999, 2009 and 2019. Classification accuracy for each epoch were generated using a confusion matrix which indicated overall accuracy and Kappa statistics for different LC classes as presented in table 2 and detailed confusion matrix in Appendix IV.

Table 3: Overall accuracy assessment for land cover classification

Year	Overall accuracy (%)	Kappa coefficient
1989	98.8	0.986
1999	99.4	0.993
2009	97.4	0.971
2019	99.4	0.993

These results were within the acceptable range which required the overall accuracy to be above 80% and kappa confident of not less than 0.40 (Alawamy, 2020). The co-efficient of above 0.75 is termed as almost perfect agreement. Hence, this allowed for generation land cover classification that was used to assess the impact of human population on land cover cover chnages in Gwassi hills water tower.

4.2.1 Distribution of Land Cover Classes

The dominant land cover class in Gwassi hills water tower was cropland covering 23,535ha in 1989 and 22,486 ha in 2019 out of the total area of 37,484ha (Table 3). This translated to between 63% and 60% of the size of water tower respectively which likely caused by seasonality and growth of towns. Agriculture was noted to be the main source of livelihoods of people in the area, which is practiced by 89% of the population (KWTA, 2019). Grassland covered an area of 3,693 ha in 1989 and 5,523 in 2019 while forestland increased from an area of 3,731 ha in 1989 to 4,928 ha in 2019 which was mainly observed in forest reserve and along riparian areas. Built-up areas class covered 20 ha in 1989 and increase 300 ha in 2019 (Table 3). With increase in built-up area and unsustainable land management practices, it has contributed to uneconomical parcels of land being since they have become unproductive (Onyango et. al, 2021; Scharsich et.al, 2019). The area under water bodies was dominantly covered by Lake Victoria.

Table 4: Land cover classes in Gwassi halls water tower between 1989 and 2019

Land Cover	**1989**		**1999**		**2009**		**2019**	
	Ha	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
Forestland	3731	10	2,354	6	3,956	11	4,928	13
Grassland	3693	10	9,975	27	4,745	13	5,523	15
Cropland	23535	63	22,800	61	22,241	59	22,486	60
Waterbody	1254	3	1,255	3	1,248	3	1,269	3
Built-up areas	20	0	58	0	212	1	300	1
Bareland	5250	14	1,042	3	5,082	14	2,979	8
Total	**37,484**	**100**	**37,484**	**100**	**37,484**	**100**	**37,484**	**100**

4.2.2 Assessment of Land Cover Changes in Gwassi Hills Water Tower

a) Land Cover Changes between 1989 to 1999

During this period, forestland decreased from 3,731ha to 2,354ha translating to 37% loss (Figure 5). The decline was as result of encroachment into the forest for agriculture and over-exploitation of forest resources such as logging. Areas that recorded the largest decrease in this class were Uregi and Kaksingri West. On the other hand, grassland increased by 170% to reach 9,975ha in 1999 which is attributed to massive vegetation clearance allowing grass growth while cropland showed insignificant decline accumulating to 3% loss, from 23,535ha in 1989 to 22,800ha in 1999 (Figure 5).

These changes were linked to after-effects of the 1997 EL Nino and unsustainable agricultural practices that led to reduced land productivity. Built-up areas increased by 38% that is from 20ha in 1989 to 58ha in 1999 due to increased population while bareland decreased by 4,208ha translating a decrease of 80% from 1989 to 2019. The decline in bareland was mainly occasioned by grass growth in areas where vegetation had been cleared and left bare either to pave way for farming or settlement. There were insignificant changes observed in water bodies class associated with tidal changes at the shoreline of Lake Victoria.

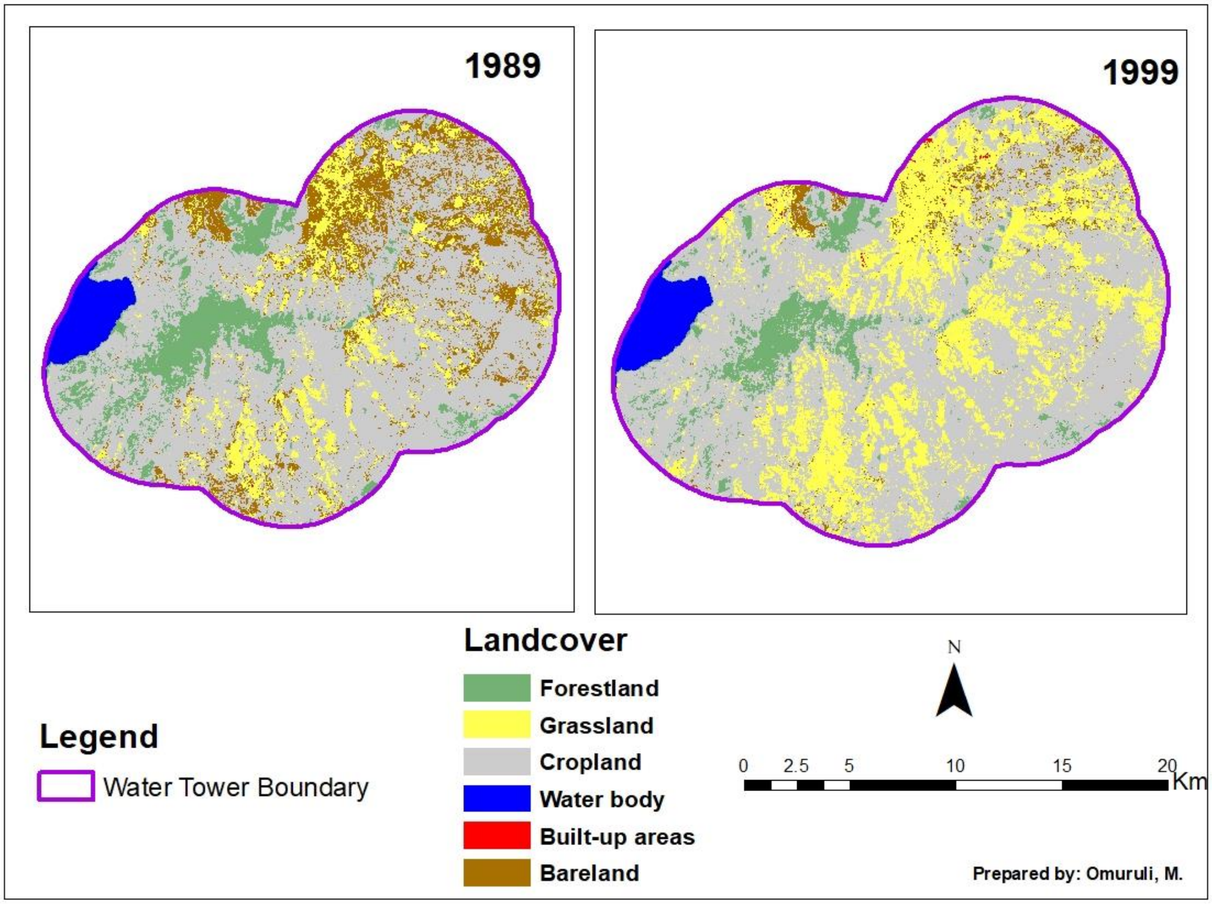


Figure 5: Land cover changes between 1989 and 1999 in Gwassi hills water tower

b) Land Cover changes between 1999 to 2009

Within the 10-year period from 1999 to 2009, there was significant increase in forestland by 1,602ha, accounting to 61%. During the same period, grassland and cropland decreased by 5,230ha (52%) and 559ha (2%) respectively (Figure 6). These changes were occasioned by gazettement of Gwassi forest as a national reserve in 2005 that led to people being evicted from the forest and farmed areas reclaimed hence allowing for reforestation and forest regeneration (GHFMP, 2013). In addition, changes in grassland also associated to after-effects El Nino rains that led to massive grass growth by the year 1999 in bareland and farmlands (GHFMP, 2013).

Increase in bareland observed in the classified satellite imageries was attributed to reclamation of forest lands due to gazettement leading to people clearing the area near forest boundary for cultivation. This is because the local communities considered areas fertile for crop production.

Thus, contributing to increase in bareland which rose by 4,166 ha between 1999 and 2009. On the other hand, built-up areas also increased by 154 ha translating to 266% from 58 ha recorded in 1999 due to increased population and expansion of towns (Figure 6). The change in the water bodies was insignificant and was due to tidal variations.

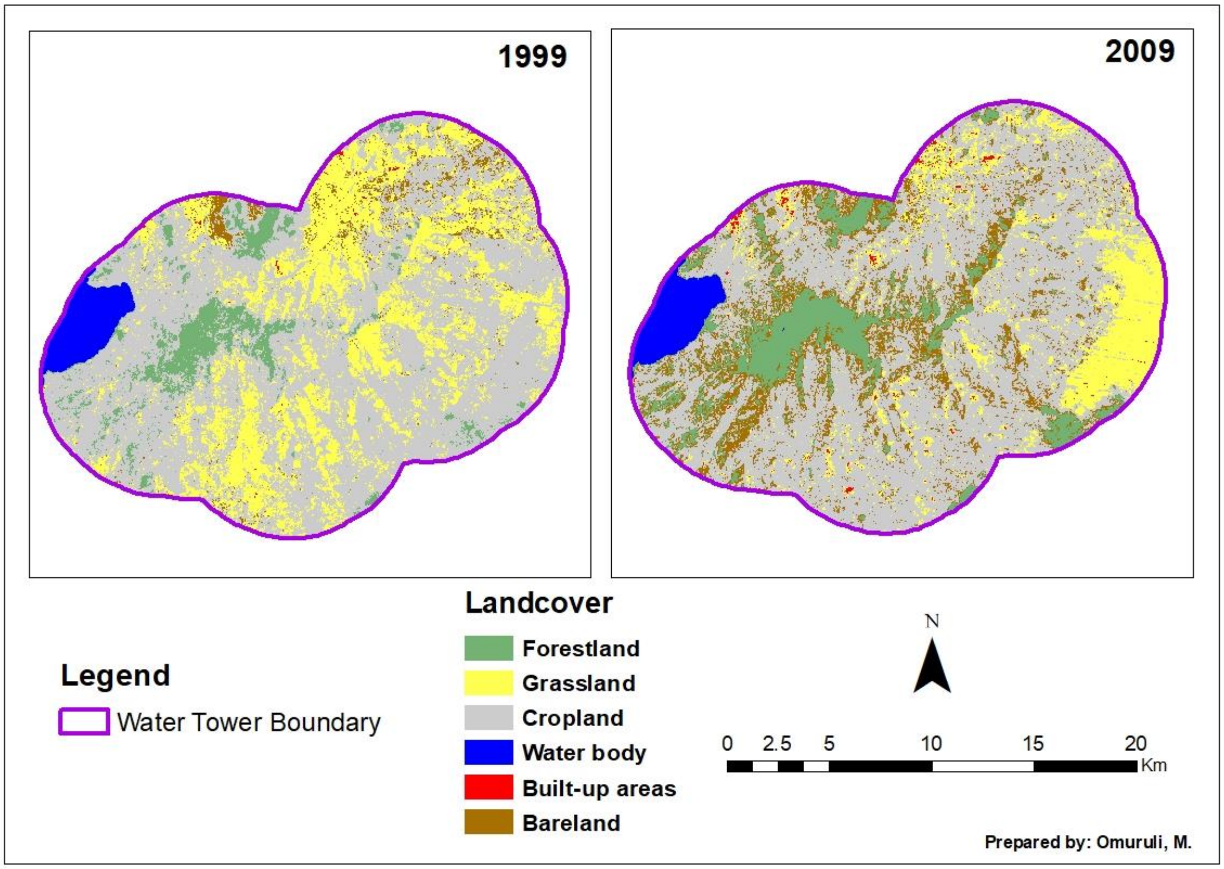


Figure 6: Land cover changes between 1999 and 2009 in Gwassi hills water tower

c) Land Cover changes between 2009 and 2019

During this period, forestland, grassland, cropland and built-up areas increased in coverage (Figure 7). Forestland and grassland significantly increased by 972 ha and 777 ha respectively while built-up areas rose by 42% between 2009 and 2019 translating to cover 300 ha in 2019 and cropland by 245 ha. Bareland is the only class that experienced a decline in coverage from 5,082 in 2009 to 2,979 ha in 2019, that is a decrease of 41% (Figure 7). These changes were associated with increased population leading to expansion of farmlands and settlement, growth of urban areas and their associated infrastructure, adoption of agroforestry and encroachment into the forest.

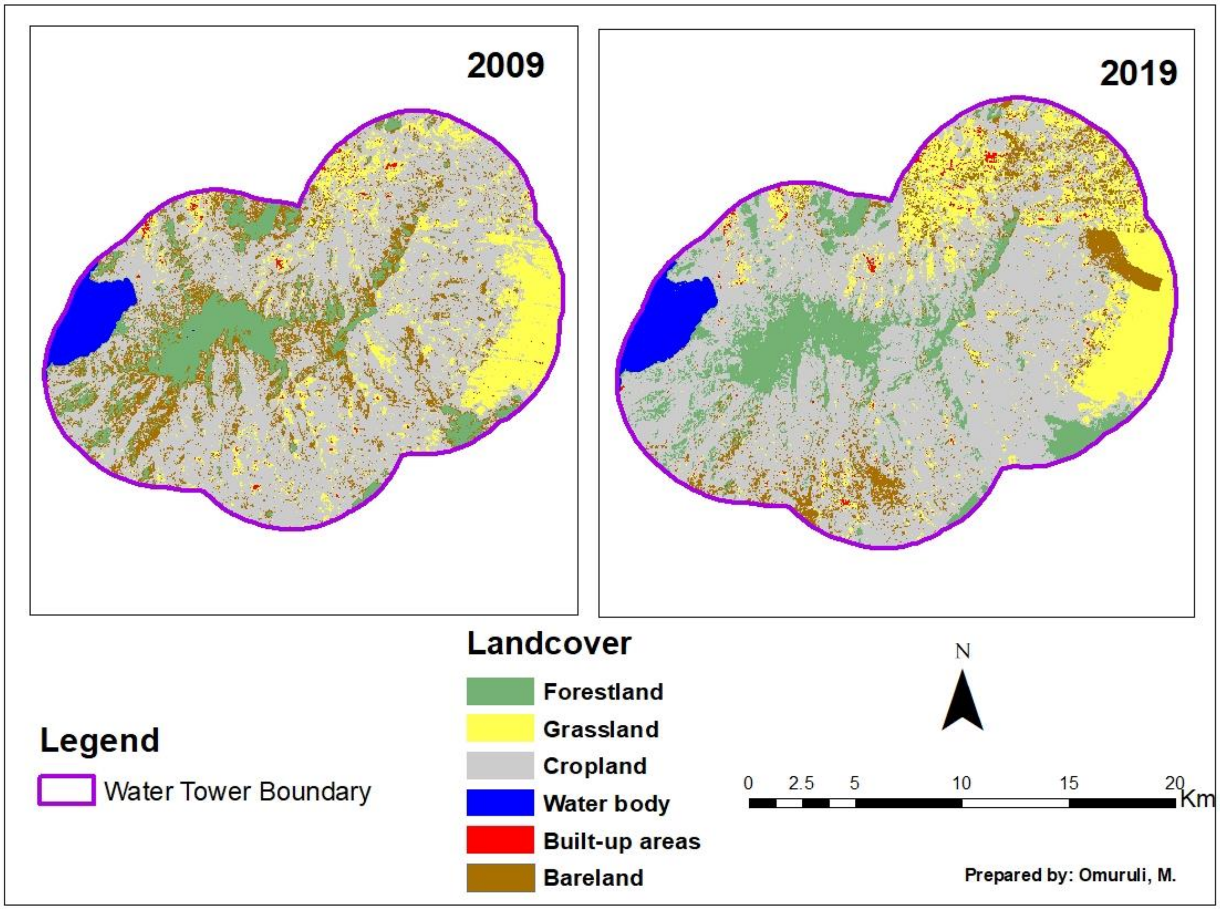


Figure 7: Land cover changes between 2009 and 2019 in Gwassi hills water tower

4.2.3 Trends in Land Cover changes in Gwassi hills water tower from 1989 to 2019

From 1989 to 2019, there was increase in area covered by forestland, grassland, built-up areas and waterbody (Figure 8). Built-up area was the class that experienced the greatest expansion as it grew by 93% (281 ha) translating to an annual increase of 3% (Figure 8). Areas under grassland also increased by 1,829 ha (33%) while bareland declined by 2,272 ha (76%) between 1989 and 2019 (Figure 8 and Figure 9). Overall percentage change in land cover pattern showed that increased or decreased forestland and otherland was accompanied by converse change in grassland (Figure 9). The trend indicated restoration efforts in gazetted forest such as gazettement of the Gwassi forest as nature reserve that led to evictions, massive rehabilitation and natural regeneration (KWTA, 2020). In addition, there was increased adoption of agroforestry practices in farmlands by the local communities. However, the largest class dominating the area was still cropland as farming is the main source of livelihood.

It was also noted that as people were moved from the forest, there was a pattern where they infringed into areas covered by grassland like Lambwe valley and colonized bareland to seek land for cultivation and settlement. In addition, the riparian areas were also affected with encroachment as they were seen suitable to increased agricultural yields. Statistical analysis on waterbody class revealed insignificant variation with less than 1% due to tides while cropland declined by 1,049 ha (5%) as shown in figure 8 and 9 below. Therefore, land cover conversions are expected to continue over the years in favour of arable land and built-up areas to meet the demand of the increasing population in the area.

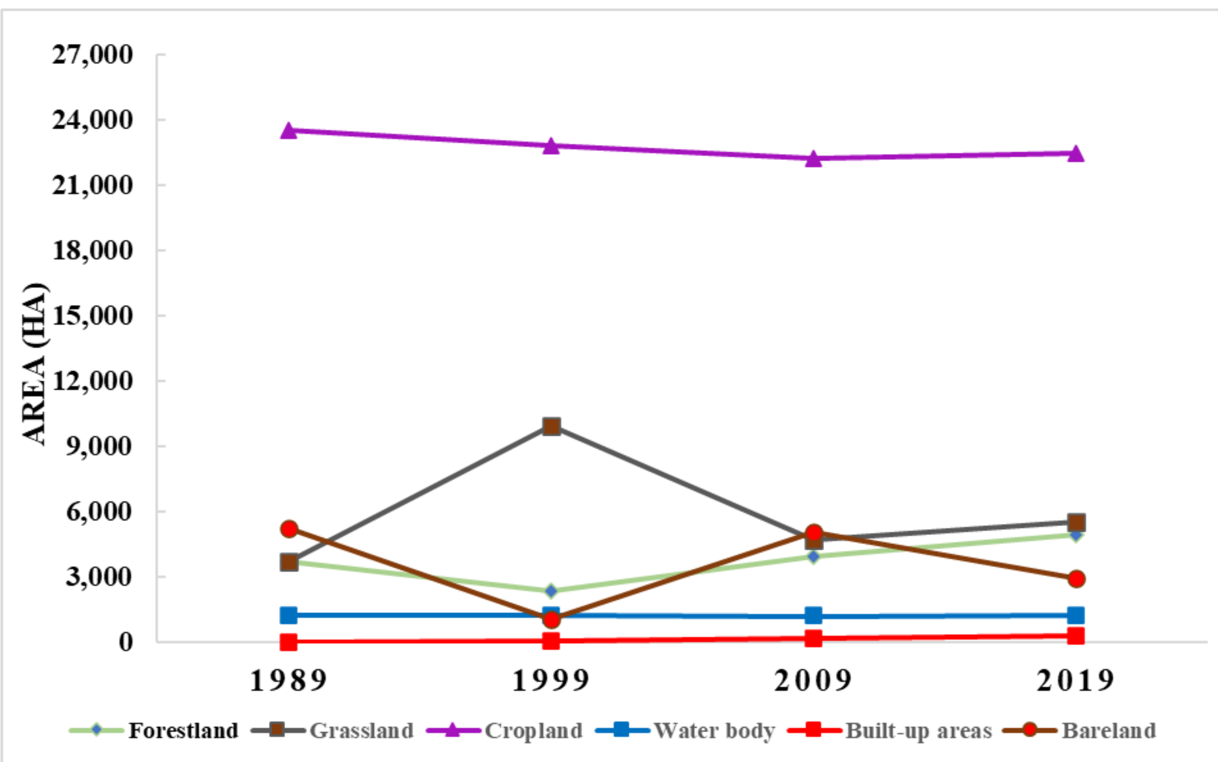


Figure 8: Land cover changes between 1989 and 2019 in Gwassi hills water tower

4.2.4 Thematic land cover conversions

Understanding thematic changes in land cover occurring in an ecosystem is crucial towards integration of land management and sustainable development. The assessment also is an indicator on how people exploit land resources over time. In this regard, this sub-section presents an analysis on land cover conversions experienced in Gwassi hills water tower from 1989 to 2019 and detailed matrix is attached in Appendix V.

Land cover	Description of conversion status
Forestland	The largest proportion of forestland was lost to cropland with the greatest impact recorded from 1989 to 1999 which accounted for 1,461 ha forest loss. Although conversions continued happening after 1999, the rate was minimal as area under forestland that had been encroached had been reclaimed and rehabilitate hence only 676 ha was recorded to have reverted back to cropland between 2009 and 2019.
Grassland	This class also recorded high percentage of conversions throughout the 30 years study period. The class experienced more gain than losses in its coverage compared to the other five classes. Loss of grassland area was mainly recorded between 2009 and 2019 in favour of cropland, otherland and built-up areas which cumulatively was 1,600ha.
Cropland	The class experienced both gain and loss over the 30-years period with the greatest gain recorded from 1989 to 1999 and the loss between 2009 and 2019.
Built-up areas	The gain in built-up area was experienced throughout the study period, from 1989 to 2019. Although, this class covered a small area in terms of hectares, it is direct indicator of population growth contributing immensely to human-induced impacts experienced in the ecosystem.
Water body	This class experienced insignificant changes associated with variation in the lacustrine buffer zone caused by tides.
Bareland	Between 1989 and 1999 this class was mainly converted to cropland while from 1999 to 2009 there was a gain of 4,051 ha. The largest loss in this

Land cover	Description of conversion status
	class was experienced between 2009 and 2019 where it was converted to cropland and forestland.

4.3 Assessing the Impact of Population on Land Cover Changes

Satellite imageries provides for spatial analysis and visualization of changes in land cover within an area. It was noted that as population in Gwassi hills water tower increased, land cover distribution in the area has also been changing (Figure 9).

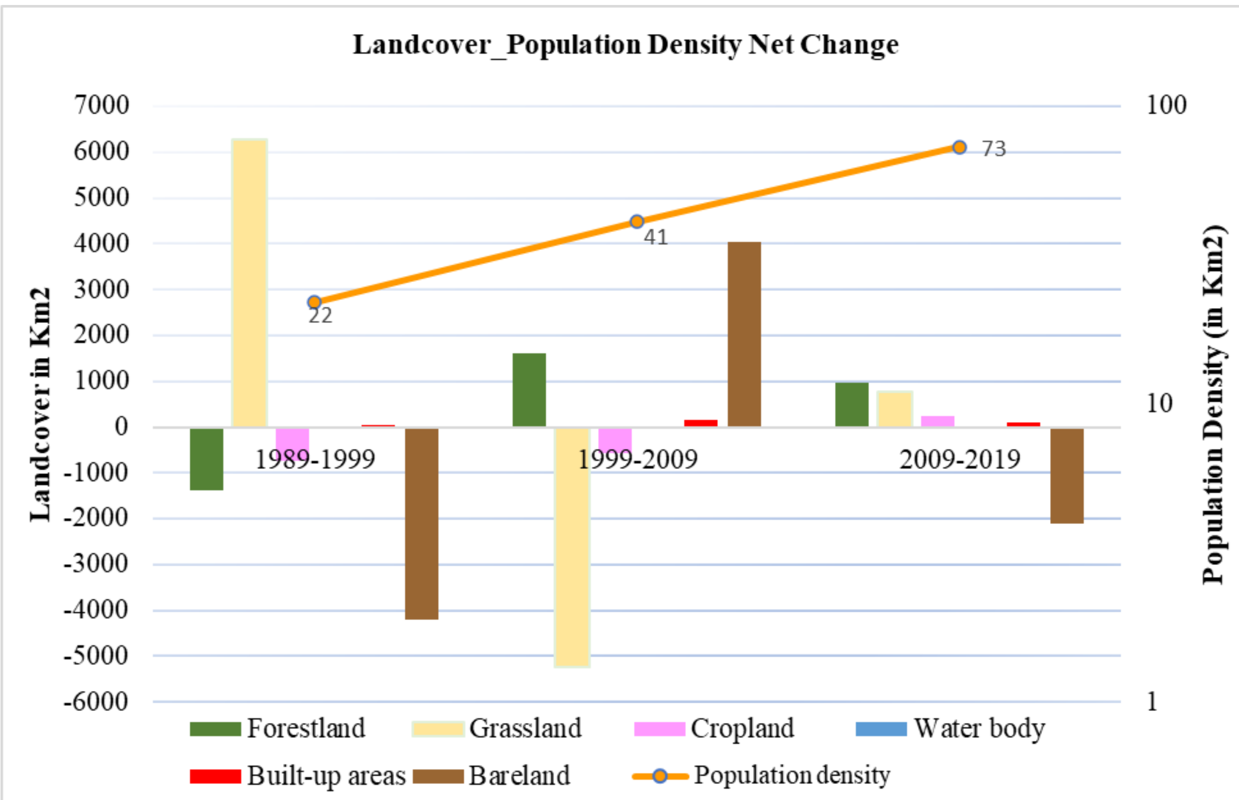


Figure 9: Net changes of population growth and land cover classes between 1989 and 2019

From statistical data generated, the rise in population led to increased demand for more land for cultivation and settlement. Hence people moved into the forestland and along the riparian areas as these areas were seen as suitable for crop production. They also colonized bareland to allow expansion of farmlands and settlement. This exacerbated loss of forest cover and increase in cropland and grassland inside the forest as presented in spatial satellite imageries of between

1989 and 1999 (Figure 9). With continuous destruction of the forest, the Government had to act fast as Gwassi hills is the main ecosystem that sustains the Ruma National Park which is the last retreat habitat for the threatened and endemic Roan Antelope. Therefore, these occasioned the gazettement of Gwassi forest as a national reserve which led to evictions of people and reclamation of encroached land back to forestland in 2005.

As noted by various scholars, population growth is one of main driving forces leading to land cover changes (Tobar, 2012, Onyango et.al, 2021; Briassoulis, 2020; UNEP, 2016). Assessment of historical outlook of land cover distribution in Gwassi hills water tower showed that the study area was least populated in years preceding 1970s due to Tsetse flies infestation (OSIENALA, n.d). Successful implementation of Tsetse flies control program by the Government of Kenya and World Health Organization led to reduction of Tsetse flies population in Gwassi hills which made the area habitable to humans hence rapid increase in cropland. Previous studies also showed that within a decade after the Tsetse flies had been controlled in Gwassi hills, human population tripled by the year 1980 (Scharsich, 2019). This population continued to rise and in 1989 locations in Suba sub-county where the water tower lies recorded the highest population increase in Homabay County with a density of 22 persons per km^2 (Figure 9).

The tremendous population growth rate in the Gwassi hills was estimated at 2.7 per annum which is higher than the country estimates of 2.2% per annum (KNBS 2019; AFIDEP & PAI 2012; CGH, 2018). With the rapid growth in population and approximately 89% of the local communities depending on farming as their source of livelihood (KWTA, 2019) it implies that, this exponential trend will continue to be witnessed hence heightening land cover changes in Gwassi hills water tower. This is evident through conversion of natural ecosystems forestland and grassland to man-made ecosystems mainly cropland and built-up areas. This condition is also worsened by reduced land holdings to approximately 1-3 acres among 6-8 members in a household (KWTA, 2019). Therefore, the tradition of continuous sub-division of land has exacerbated over-utilization of land leading to degradation forcing farmers to abandon the unproductive farms to colonized other land types for cultivation such as forestland, grassland and bareland (Onyango et al. 2021) (Figure 9). This had led to increased environmental degradation such as soil erosion, flooding, prolonged drought and crop failure.

Increased household density reflected in expansion of built-up areas over the 30 years period is also witnessed. This implies more pressures is placed towards land reallocation to cater for the growing population and their basic needs such as food and shelter. This has led to intensified altering of land in favour of agricultural and settled areas in Gwassi hills water tower (Briassoulis, 2020; UNEP, 2016). Therefore, exacerbating expansion of agriculture into unsuitable areas for cultivation such as wetlands, steep slopes and pristine areas like forest (Scharsich et.al, 2019; Onyango et.al, 2021). Since land suitable for farming is limited, agriculture expansion is often towards areas that noted as ecologically sensitive hence less favourable for cultivation which can lead to land degradation (Scharsich, 2019; Nkonya et.al, 2016). It has led to indiscriminate clearing of forests and conversion of grasslands to pave way for crop production and built-up areas that has led to environmental degradation.

4.4 Effect of Urban Sprawl on Land Cover Changes

Growth in towns informs urban expansion through coverage of built-up areas hence a key indicator used in measuring how land cover is impacted in urban zones. Expansion of built-up areas in ten towns in Gwassi hills water tower were assessed to demonstrated effect of urban sprawl on land cover distribution in the urban area. These town are (1)-Magunga, (2)-Wiga, (3)-Onywera, (4)-Sindo B, (5)-Malongo, (6)-Suba, (7)-Nyatoto, (8)-Nyamisra, (9)-Nyagwethe and (10)-Kwoyo. The geographical location of these towns in Gwassi hills water tower presented in Figure 10.

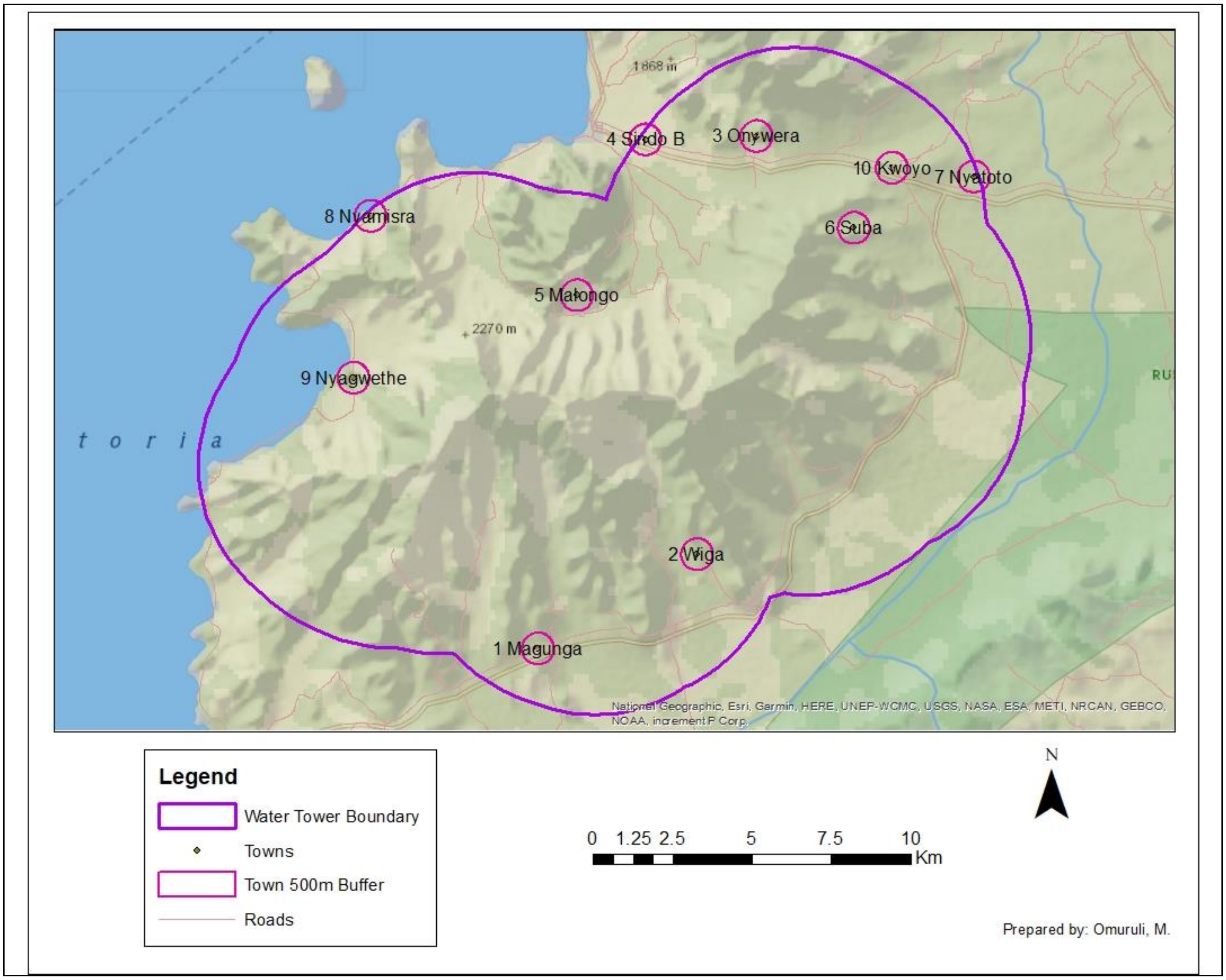


Figure 10: Towns assessed for urban sprawl in Gwassi hills water tower

Studies have shown that urban growth is a direct indication of population growth which plays a significant impact to urban sprawling especially in towns within rural settings such as in Gwassi hills. Therefore, in assessing urban sprawl in Gwassi hills water tower a buffer 500m from the centroid of the town was used. The extent of urban area was based on expert opinion when the coverage areas of built-up areas in the latest year (2019) was assessed and none within the 10 towns exceeded the set thresholds. In addition, the major activity in the town is manly based on small scale trading.

The assessment of decadal growth indicated sprawl of built-up areas between 1989 and 1999 was at expense of bareland and cropland. Built up areas increased from 12.3 ha in 1989 to 21.8 ha in 1999 and decline of cropland and bareland by 23.8ha and bareland by 149.2 ha respectively in the ten sampled town (Figure 11). Between 1989 and 1999, the study area had low population thus more land was either farmed or bare. As population continued to grow in towns due to improved infrastructures mainly road networks, these areas were converted to built-up areas with commercial building for small scale businesses. With population growing, there was rising demand for households to meet their basic needs through supplementing their income, thus leading to most areas previously under grassland at the town periphery to be converted to cropland. Thus, increase in built-up areas (by 41.1 ha) and cropland (by 171.6 ha) at the expense of grassland and bareland as revealed by land cover analysis between 1999 and 2009 (Figure 11).

Towards 2019, the infrastructure in the area had further been improved to allow quick movement of goods hence improved income from business largely spurred by devolution. Therefore, between 2009 and 2019 there was demand for more land for establishment of more business premises as well as settlement for people working in towns. Therefore, an increase in built-up areas by 25.5ha and adoption of zoning of green spaces within towns contributing to increase in grassland and forestland by 56.2ha and 4.3ha at the expense of cropland and bareland (Figure 11). The main socio-economic activities within the town had shifted from rural shopping centres to commercialized urban areas with better operational services due to improved road networks and service delivery in the region hence a pull factor for migration of people especially labour force into nearby and established towns.

As population continued to grow exponentially and with increased economic status in the towns leading to an urban spawl which is demonstrated by 93% in built up areas between 1989 and 2019. The areas under cropland were pushed to the town periphery to pave way for more land for towns expansion. Therefore, areas covered by bareland were the easiest target for urban expansion thus declining from 180.9ha in 1989 to 54.1ha in 2019. The pictorial spatial presentation of the urban sprawl happening are illustrated in Figure 12.

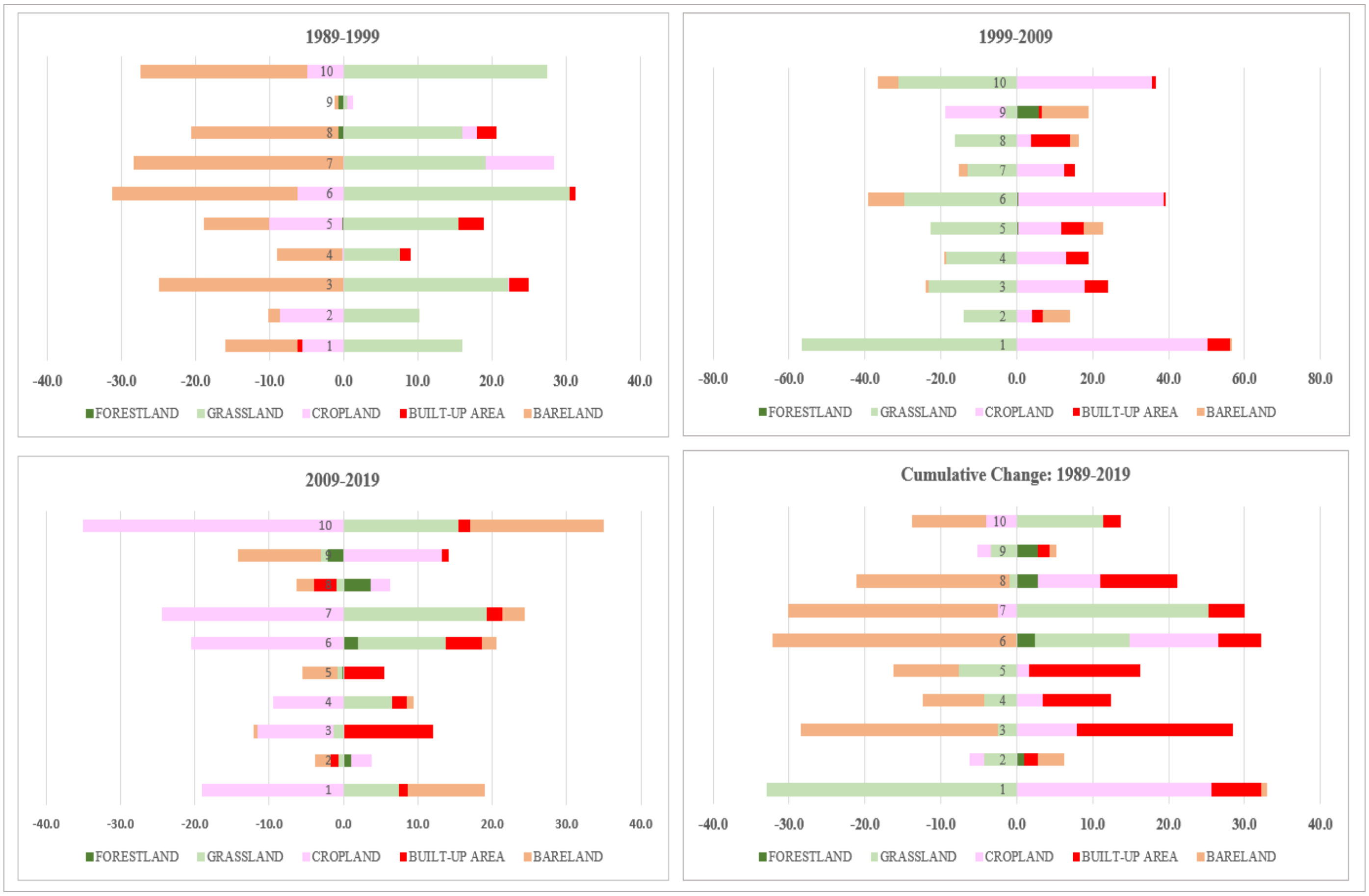


Figure 11: Behavioural spatial pattern of land cover changes within urban areas in Gwassi hills water tower between 1989 and 2019.

Overally, built-up areas in the ten towns were noted to be haphazard and mainly occurred along the road networks (Figure 12). The analysis on land cover changes across the towns revealed increase in built-up areas from 1989 to 2019 translating to growth of 76.1 ha (93%) growth. This expansion was at the expense of bareland and grassland (Figure 12). This means that as the towns sizes expanded, farming was pushed at the periphery in areas that had been previously dominated by bareland and grassland (Figure 12). These are also areas that were easily be colonized mainly to allow for establishment of towns.

Figure 12: Pictorial presentation on urban growth in Gwassi hills water tower

<table>
<tr><th>2001</th><th>2019</th></tr>
<tr><td colspan="2" align="center">Sindo</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2" align="center">Magunga</td></tr>
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</td><td>
</td></tr>
</table>

2001	2019
Nyatoto	
	
Nyagwethe	
	

Source: Google Earth

These finding pointed out that increase in built-up areas in Gwassi hills water tower is a factor of rapid population growth due contributed to improved infrastructure, better business condition and devolution of administrative services. For instance, small scale trading of goods is the second largest proportion on income generating activities being undertaken in the area estimated at 7% of the population (KWTA, 2019). This entailed commercial selling of farm produce and fish products in an urban setting that influenced growth of urban areas. The loss of forest cover was also noted to be due to indiscriminate harvesting of trees to meet the demand of the lucrative charcoal and timber business among the dwellers along the Lake Victoria shore (Onyango et al, 2021). The urban population in Kenya is estimated at 4.4% therefore is also reflected in urban areas located in rural towns such as those in Gwassi hills water tower. The results have also showed that areas within town in the study area are being converted to built-up areas and cropland is being pushed at the periphery implying that as year proceed if no measure is taken into consideration as towns expand then impact of such as trend is expected to continue to grow (Onyango et al. 2021).

4.5 Hypothesis Testing

4.5.1: Population growth and land cover changes

The study evaluated the relationship between population growth and land cover changes in Gwassi Hills Water Tower by testing the null hypothesis that:

> *H_o: There is no significant spatial relationship between population growth and land cover changes in Gwassi hills water tower*

Since the data subjected to hypothesis testing was spatially acquired, spatial autocorrelation with 95% confidence was performed to understand the type of association existing between variables. Thereafter a Pearson correlation coefficient was done using Overlapping Neighborhood Statistics to determine strength of the relationship between population growth and land cover changes.

a) Spatial autocorrelation

The metrics results from spatial autocorrelation analysis were summarized in Table 4.

Table 5: Spatial autocorrelation metrics

Year	Moran I Index	Expected Index	Variance	Critical Value (z-score)
1989	0.0392	-0.2000	0.0571	1.0009
1999	-0.0060	-0.2000	0.0382	0.9920
2009	-0.6626	-0.2000	0.0486	-2.0990
2019	-0.3277	-0.2000	0.0286	-0.7544

Moran I index in 1989 was positive indicating that land cover distribution against population density during this period was clustered. For the period covering 1999, 2009 and 2019 the Moran I indices were negative implying that land cover distribution against population were dispersed. With this assessment and Moran I indices obtained falling between -1 and +1, there was need to generate critical values (z-scores) to demonstrate if the spatial autocorrelation between variables were significant (Tobar, 2012).

The z-score at 95% confidence fell between -2.58 and +2.58 meaning that there was 5% likelihood chance that the pattern, either dispersed or clustered, could be as result of random chance. This means that result of spatial correlation of land cover distribution and population density demonstrated by Moral I index occurred randomly in the study area. Therefore, expansion of cropland, increase in settled areas and urban growth observed in the area tend to be significantly spatially distributed in a manner that there was encroachment into forestland and grassland as well as colonization of bareland. However, the Moran I index and z-score could not be able to demonstrate the strength and direction of association between population density and land cover changes. Therefore, spatial Pearson's correlation analysis embedded in overlapping neighbourhood statistics model was undertaken to examine the impact of population growth on land cover changes in Gwassi hills water tower to test hypothesis I as described below.

b) Pearson correlation in overlapping neighborhood statistics model

In order to test Hypothesis I, which is to examine the relationship between population growth and land cover changes in Gwassi hills water tower, the Pearson correlation coefficient was generated with incorporation of overlapping neighborhood statistics component in ArcGIS 10.8 by developing a four-stage model summarized in (Appendix II). This allowed for standardization of population density and land cover data to remove biasness arising from spatial association of variable hence complying with the statistical rules of using Pearson correlation analysis. The geostatistical analysis model adopted the 10x10 neighbourhood cell size as recommended by Tobar (2012). The 10 by 10 cell size is incorporated in factor analysis stage of the model to provide a more defined results of spatial correlation of variables between population density and land cover. The results of Pearson's correlation coefficients are presented in Table 5. The *p* (rho) for 1989 could not be generated since the $100m^2$ pixel size raster images obtained from Worldpop Open Spatial Demographic Data and Research dated back to 2000 while for 2000 was inferred as 1999 in this study considering population change within a year is very insignificant.

Table 6: Results of Pearson Correlation using Overlapping Neighborhood Statistics Tool

Year	**Min**	**Max**	**Mean**	*p* (rho)
1999	-1.0382	1.0773	-0.0021	0.0220
2009	-1.0013	1.1408	0.00384	0.0198
2019	-1.0011	1.0090	0.03489	0.0212

The Pearson's correlation coefficients generated were thereafter plotted in a time series map for 1999, 2009 and 2019 for visual analysis (Figure 13). The correlation values were presented using stretched colour ramp detecting correlation between land cover and population density variables where red colour indicated a strong direct correlation between the variables, green colour showed strong inverse correlation while the yellow colour was no correlation between the variables.

In comparison with land cover and population map generated, areas with increasing population and cropland such as towns in Magunga, Sindo, Nyagwethe, Onywer, Wiga, Kwoyo among others had direct correlation with land cover while those with low population like at Ruma and part of forest reserve have an inverse correlation (Figure 13). This means as population increases land cover is changing from forestland and grassland to built-up areas and farmlands. On the other hand, areas with low population land cover are mainly grasslands such as in Ruma National Park, forestland in the gazetted forest reserve and along the riparian. Therefore, the p(rho) results on the relationship between population and land cover implied that apart from population, other factors could also be influencing land cover changes in Gwassi hills water tower. Hence the need to do multiple regression to determine which of these factors have more influence the other.

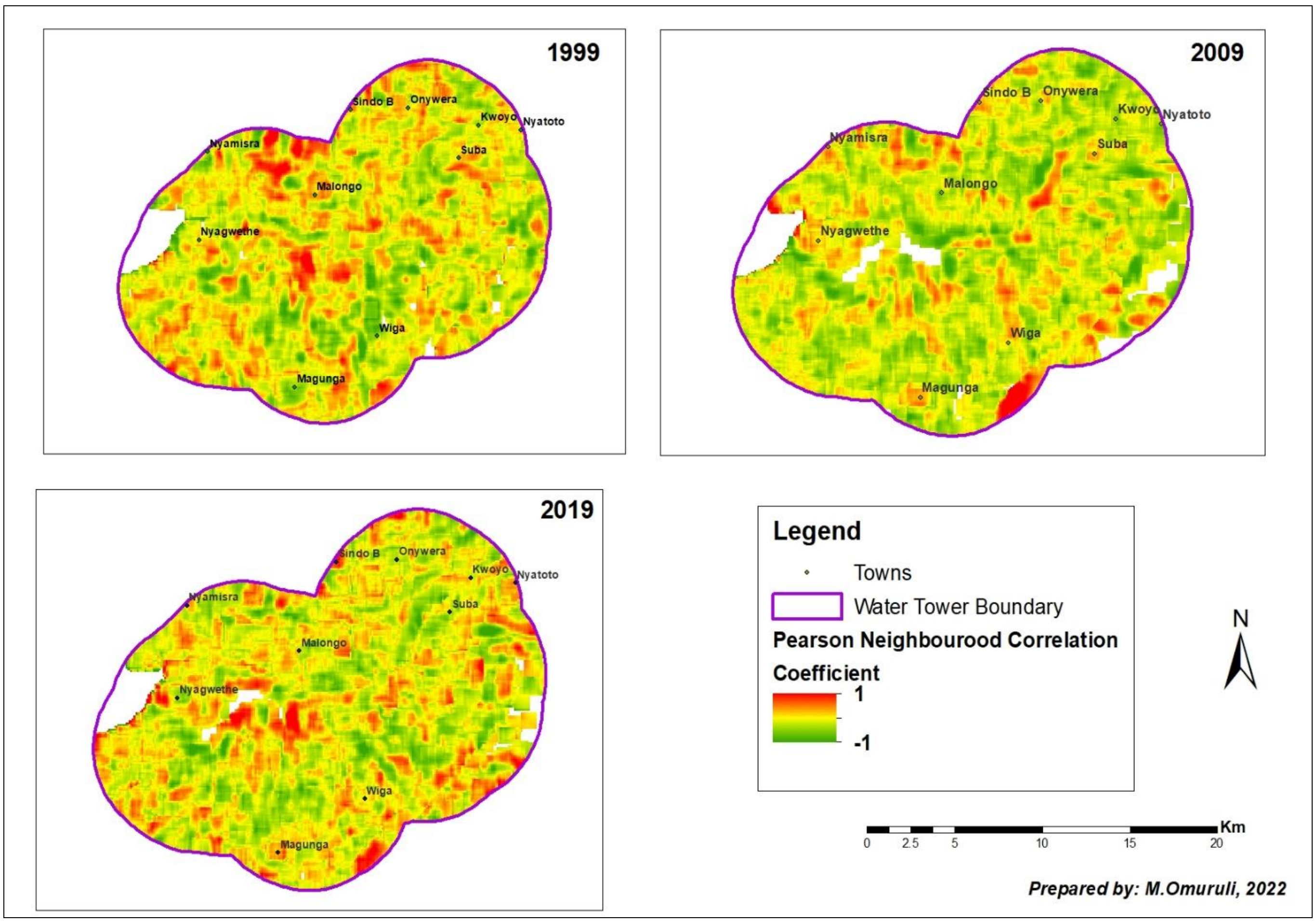

Figure 13. Pearson correlation coefficients in overlapping neighborhood statistical model

Based on the results of spatial Pearson correlation coefficient in overlapping neighbourhood statistics, it showed there is significant correlation between population growth and land cover changes occurring in Gwassi hills water tower between 1989 and 2019. Therefore, the null hypothesis is rejected.

4.5.2 Assessing the effect of urban sprawl on land cover changes

The research study assessed whether there was a significant effect of urban sprawl on land cover changes in Gwassi hills water tower. The null hypothesis tested was:

> *H_o: There is no significant effect of urban spawl on land cover within towns in Gwassi hills water tower after ten years*

The effect of urban sprawl in Gwassi hills water tower was done to test the significant associations between variables. The hypothesis was tested using Chi-square at 0.05 significance level and results obtained are shown table 7.

Table 7: Assessing effect of urban sprawl on land cover using Chi-square test

	Growth of towns in ha between from 1989 to 2019						
Towns	**1989-1999**	**1999-2009**	2009-2019	**Total**	**χ^2 Calculated value**	**p-value**	**χ^2 critical value** (α)
Magunga	-0.7	6.0	1.2	**6.5**	50.66	0.000	28.87
Wiga	0.0	2.9	-1.1	**1.8**			
Onywera	2.4	6.0	12.0	**20.4**			
Sindo B	1.3	5.7	1.9	**8.9**			
Malongo	3.3	6.0	5.2	**14.5**			
Suba	0.6	0.1	4.8	**5.5**			
Nyatoto	0.0	2.5	2.2	**4.7**			
Nyamisra	2.5	10.5	-3.0	**10**			
Nyagewethe	0.0	0.7	0.7	**1.4**			
Kwoyo	0.0	0.6	1.6	**2.2**			
Total	**9.4**	**41**	**25.5**	**75.9**			

Degrees of freedom=18; Significance level of 0.05

Based on the chi-square result, the calculated value of χ^2=50.66 is larger than critical value (α) =28.87 and $p<0.05$. Therefore, the null hypothesis stating that "There is no significant effect of urban spawl on land cover within towns in Gwassi hills water tower after *ever*y ten years" was rejected. The analysis indicated that there is significant effect of expansion of urban areas in Gwassi hills to land cover changes over the years. This means that as population continues to rise, urban sprawl in towns will continue happening leading to conversion of natural ecosystems and arable land.

CHAPTER FIVE:

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

This chapter summarizes the research findings which enable drawing of conclusion about the study and recommendation on policy and for future research.

5.1 Summary of Findings

The aim of the study was to assess impact of human population on land cover status in Gwassi hills water tower between 1989 to 2019. The summary of findings in this sub-section have adopted a thematic approach and following the order of the study objectives.

5.1.1 Population growth and land cover trends in Gwassi hills water tower

a) Population growth

The study found out that population in Gwassi hills water tower has been rising over the 30 years (1989 to 2019). The rapid population growth in the area begun from years dating back to 1970s when the Tsetse flies infestation in the area was brought under control. As of 1999, the population had increased exponentially that the Government had to sub-divide three location namely Kaksingri, Gwassi North and Gembe to form six new locations. Main factors that promoted population growth were improved road infrastructure and devolution. Overally, the locations that recorded the highest population between 1989 and 2019 were Kaksingri Central, Gwassi West and Kaksingri West. The Ruma location had the lowest population since it hosted the protected Ruma National Park.

b) Land cover trends

The dominant land cover observed in Gwassi hills water tower was cropland which covered the largest proportion of the study area and was due to agriculture being the main source of livelihood for the local communities. This was followed by grassland, forestland and bareland. Lake Victoria accounted for the largest area covered by waterbody in the area since most rivers are seasonal. The built-up areas had the least acreage.

On land cover changes, the study revealed that from 1989 to 2019, classes that experienced increased coverage were forestland, grassland and built-up areas while bareland recorded a decline. It was also noted that cropland experienced a steady change over the years as people were moved from the forest reserve or abandon the unproductive land, they sought for more land in other areas such as the Lambwe valley, along the riparian areas and colonized bareland to meet their household demands. Built-up areas experienced the greatest expansion as it grew by 93% over the 30-year period.

The overall percentage change in land cover showed a behavioral pattern either increased or decreased forestland and otherland with a converse change in grassland. Therefore, land cover conversions are expected to continue over the years in favour of arable land and built-up areas to meet the demand of the increasing population in the area

5.1.2 Relationship between population growth and land cover changes

Population in Gwassi has been growing exponentially with its density rising from $89/km^2$ to $229/km^2$. The increasing population has in turn put pressure on land resources causing change in land cover patterns recorded in the area. The study found out that the population in Gwassi hills had tripled by 1989 due to control of Tsetse flies in the areas that had made the area inhabitable. This led to more land being cleared for cultivation and settlement including within Gwassi forest and along riparian areas. The ever-increasing population is therefore altering natural ecosystems in favour of agricultural and built-up areas.

There was expansion of agriculture into unsuitable areas for cultivation such as wetlands, steep slopes and pristine areas like forest. This exacerbated loss of forest cover and increase in cropland and grassland inside the forest between 1989 and 1999. It was also noted that eviction of people and reclamation of forestland in gazetted nature reserve led to increased forest cover in the area. With increasing population, the land holding is also reducing due to continuous land sub-division attributed to local communities tradition of land inheritance from generation to generation. This has led to over-utilization of land and farming in areas unsuitable for crop production contributing to increasing environmental degradation such as soil erosion, flooding, prolonged drought and crop failure.

5.1.3 Effect of urban sprawl on land cover changes

The study found out that urban areas in Gwassi hills expanded in haphazard manner but majorly along road networks. The built-up areas increased by 93% from 1989 to 2019 which was at the expense of bareland and grassland. As the town sizes expanded, cropland was pushed at the periphery in areas that had been previously dominated by bareland and grassland. With improved infrastructure and devolution of services, there was intensified expansion of built-up areas and zoning of green spaces within towns contributing to increase in grassland and forestland at the expense of cropland and bareland between 2009 and 2019. Therefore, the main socio-economic activities within the town had shifted from rural shopping centers to commercialized urban areas with better operational services due to improved road networks and service delivery in the region hence a pull factor for migration of people especially labour force into nearby and established towns.

5.2 Conclusion

Based on the finding of the study, it was concluded that population growth impacted on land cover changes experienced in Gwassi hills water tower. The growing population also meant increased households demand to meet its basic need that heightened conversion of natural environment in favour of cropland and built-up areas. In addition, urban sprawl caused by population growth is considered as one of the main prime factors of land cover changes. Expansion of towns mainly growth of commercial areas in rural setting also impacts on water catchment areas as witnessed in the major towns in the water tower. This means that land cover conversion will continue to be witnessed in the area as long as agriculture and haphazard growth of towns is left unchecked. Therefore, Gwassi hills water tower remains highly susceptible to degradation from rapidly increasing population. This will at long-term negatively impact on existence of the water tower and Ruma National Park.

5.3 Recommendations

Information on land cover changes and its causal factors such as population and urban growth is important and of benefit to land planners and policy makers both at County and national Government. Therefore, with devolution there is need to devolve research activities to rural ecosystem to especially inform the County action plans and by-laws and promote sustainable development besides national plans. This will ensure that effective and efficient decision making are made as well as integration of science with policy making process. In addition, it will provide an avenue for diversification of livelihoods sources in such areas and proper management of urban growth.

For policy makers, the study recommends on the need for development and implementation of spatial local plans at sub-county level to ensure sustainable land management with population growth. This will promote conservation of critical catchment areas.

For further research, the study recommends an investigation be done on:

1. An analysis on the impact of various factors such as population and rainfall variability on land cover in Gwassi hills water tower.
2. A study on relationship between sustainable land management and economic development on land cover status in Suba-South Sub- County
3. A study to evaluate the role of land cover changes to environmental degradation experienced in the area and model future scenarios.

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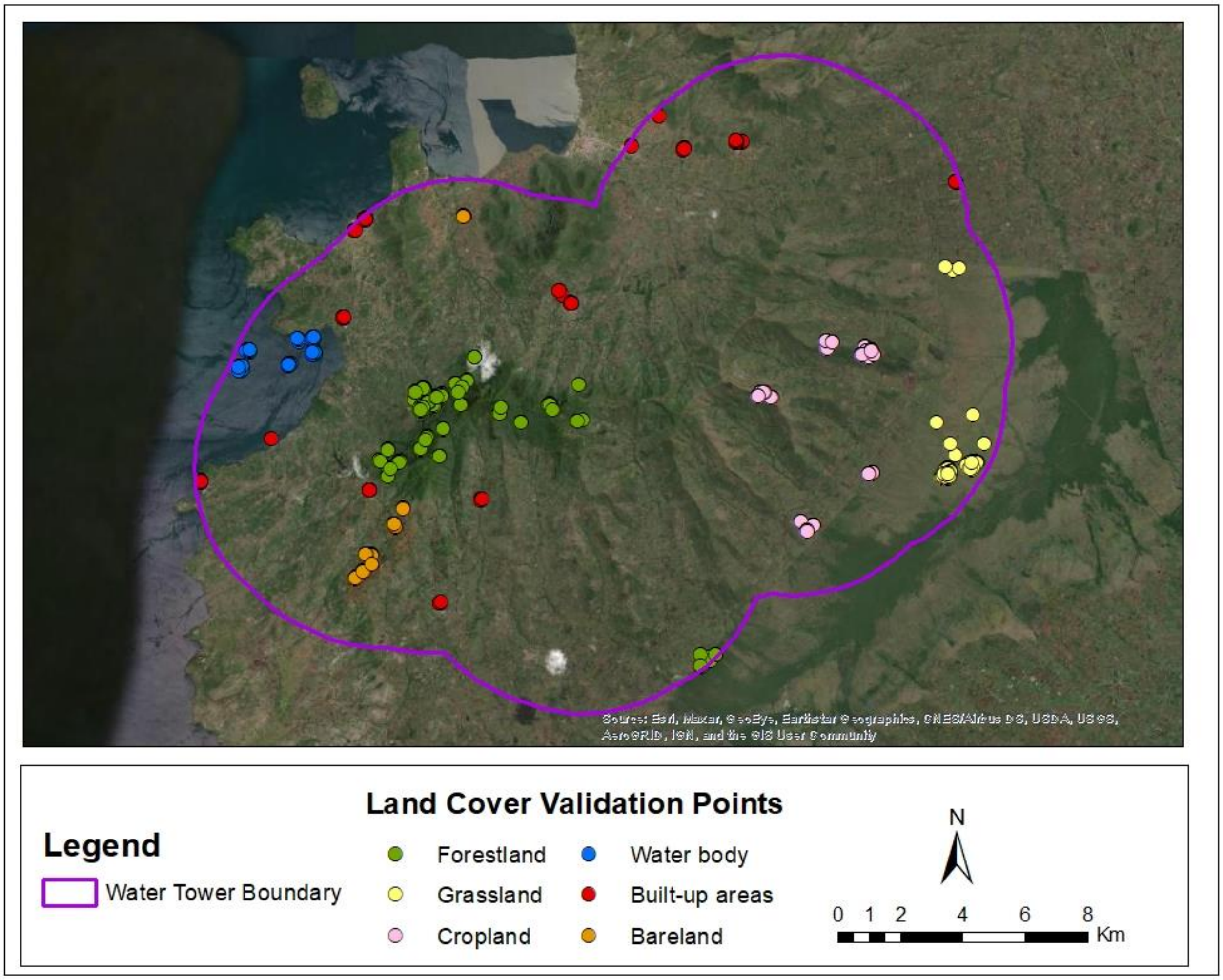
APPENDICES

Appendix I: Training Sites for Classification of Land Cover Classes in Gwassi Hills Water Tower

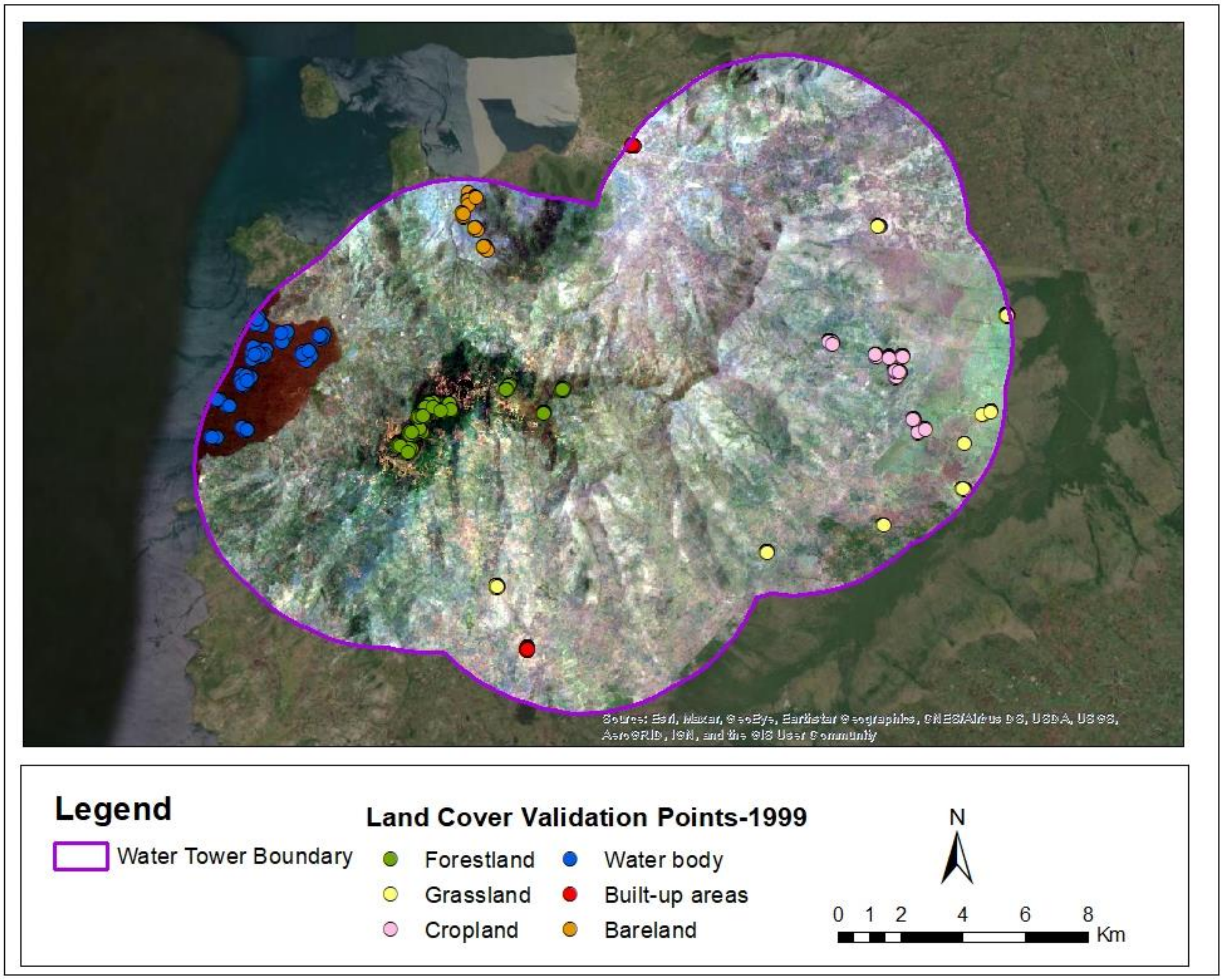
	1989		**1999**		**2009**		**2019**	
Landcover	**Polygon**	**Training pixel**	**Polygon**	**Training pixel**	**Polygon**	**Training pixel**	**Polygon**	**Training pixel**
Forestland	15	400	23	400	21	400	37	400
Grassland	8	300	10	300	10	200	18	200
Cropland	9	200	11	300	14	300	18	300
Water body	6	70	9	70	9	70	6	70
Built-up areas	8	50	10	70	9	70	19	100
Bareland	3	50	4	100	8	100	10	70
Total		**1070**		**1240**		**1140**		**1140**

Appendix II: Land Cover Validation Points in Gwassi Hills Water Tower

2019

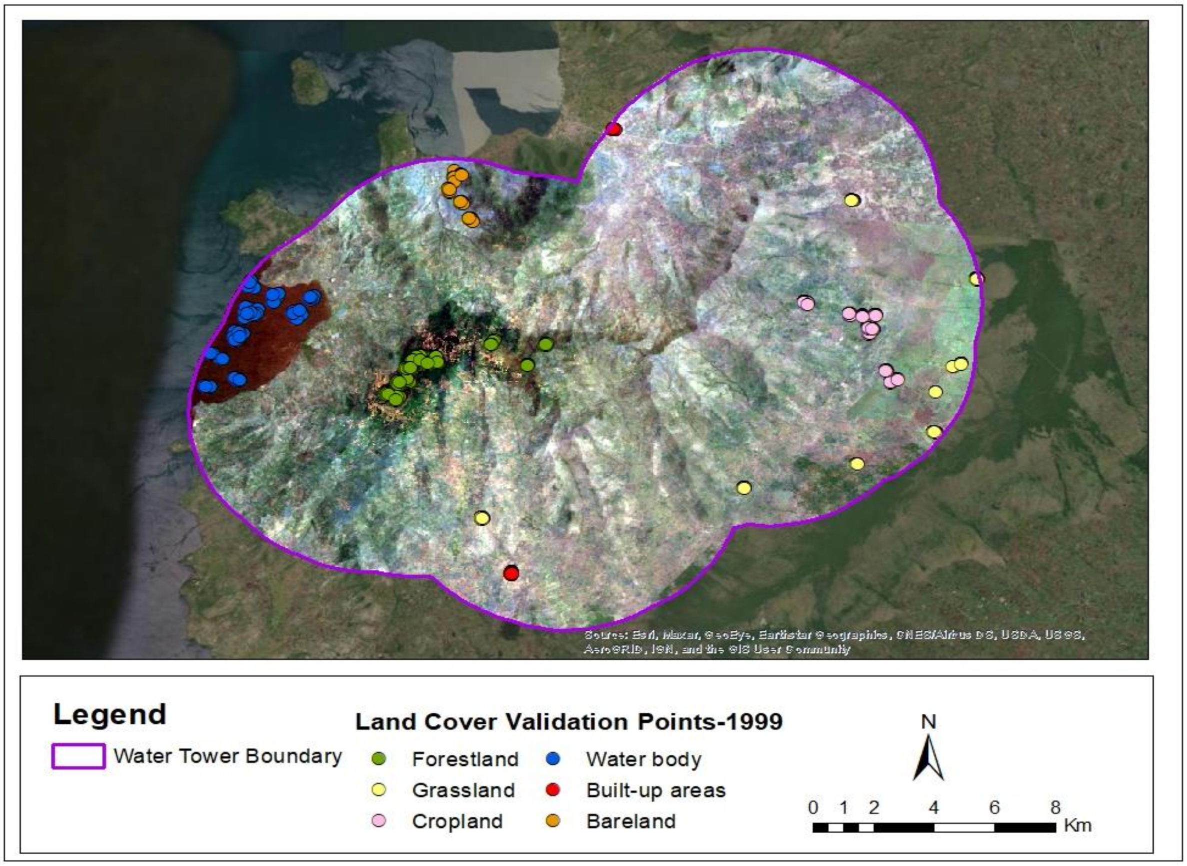


2009



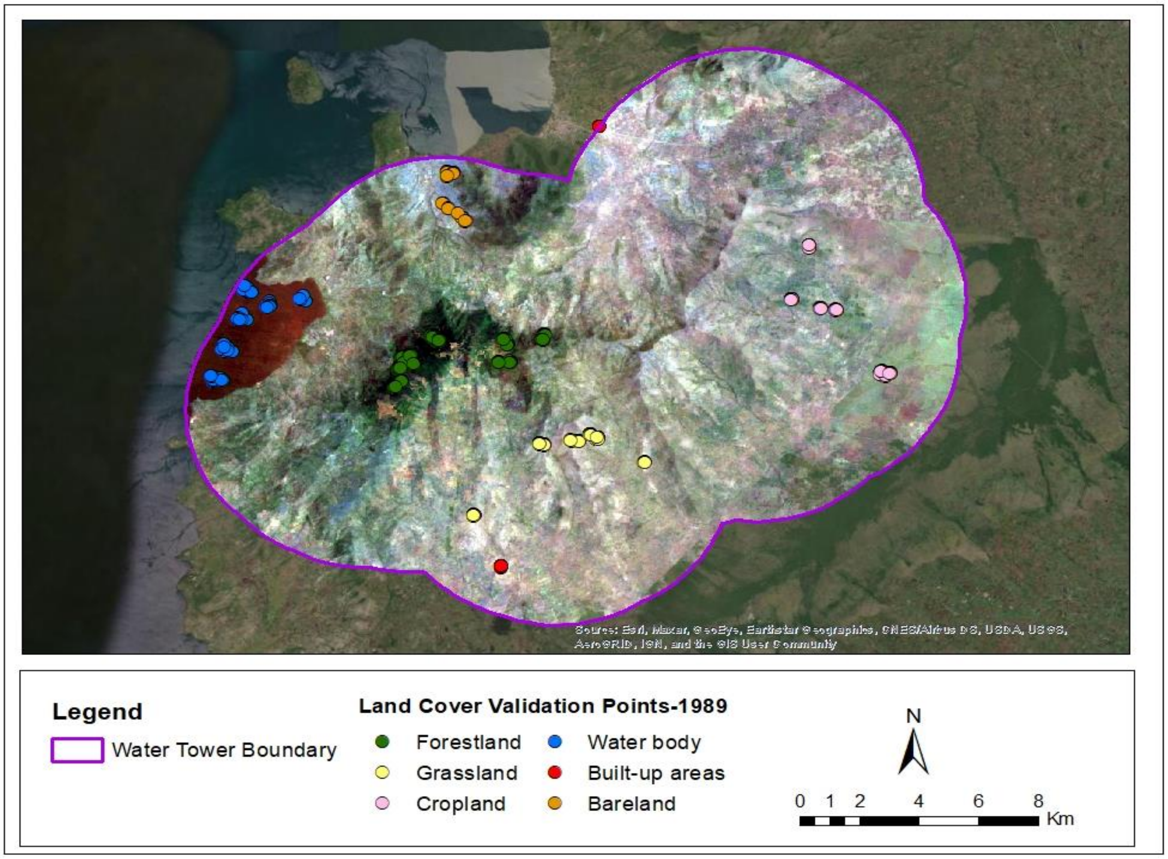
Sources: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Legend
Water Tower Boundary
Land Cover Validation Points-1999
Forestland
Grassland
Cropland
Water body
Built-up areas
Bareland
N
0 1 2 4 6 8
Km

1999



Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Legend
Water Tower Boundary
Land Cover Validation Points-1999
Forestland
Water body
Grassland
Built-up areas
Cropland
Bareland
N
0 1 2 4 6 8
Km

1989


Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community
Legend
Water Tower Boundary
Land Cover Validation Points-1989
Forestland
Grassland
Cropland
Water body
Built-up areas
Bareland
N
0 1 2 4 6 8
Km

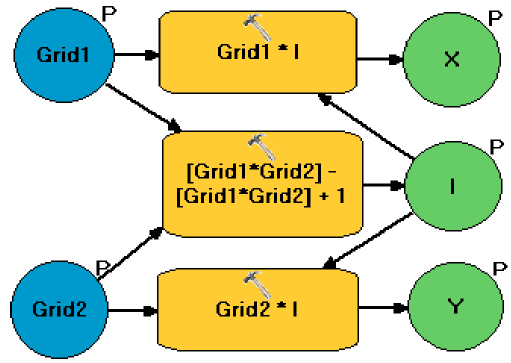
Appendix III: Overlapping Neighbourhood Statistics Toolbox Modules for Pearson Correlation Coefficient

Module Number and Name

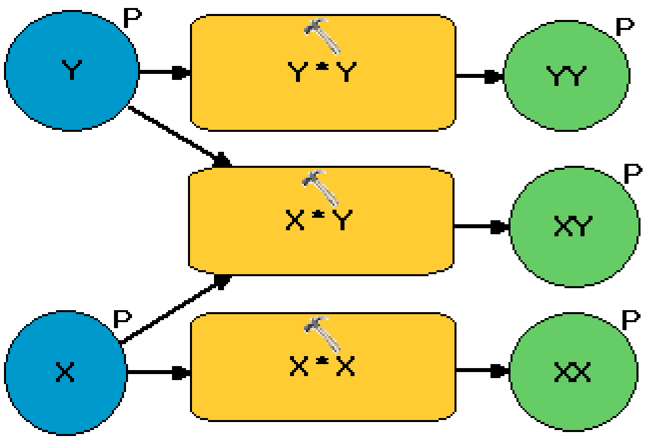
Overlapping neighbourhood statistics tool

- Standardize Grid X and Y
  - Grid 1: Land cover
  - Grid 2: Population
- Calculate Grid XX, YY, XY
- Focal Statistics10 by 10
- Pearson Correlation Coefficient

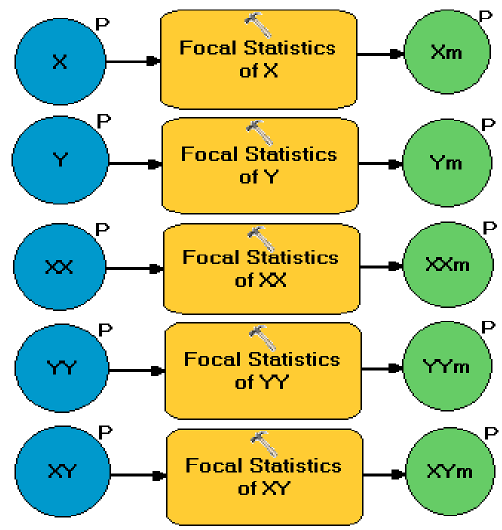
Module 1



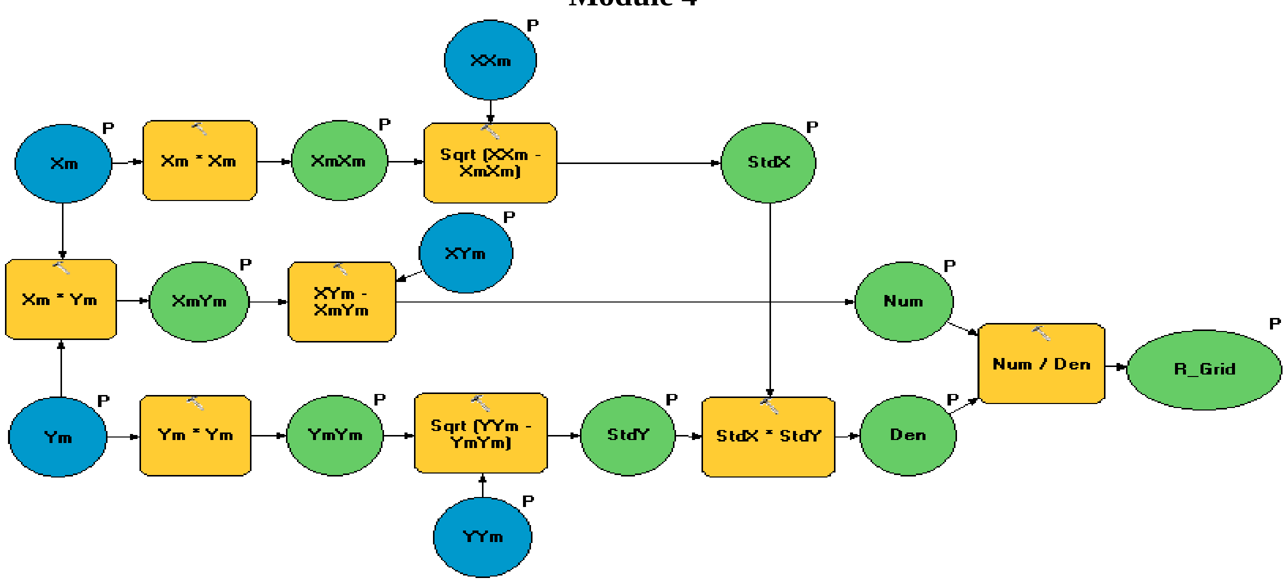
Module 2



Module 3



Module 4



Appendix IV: Confusion Matrix on Accuracy Assessment for Land Cover Classification 1989-2019

(a) 1989

Land cover 1989	Forestland	Cropland	Grassland	Water body	Bareland	Built up Areas	Total	User's Error	p
Forestland	**398**	0	0	1	0	0	399	**99.7**	0.235
Cropland	0	**300**	0	0	3	0	303	**99.0**	0.178
Grassland	2	0	**200**	2	0	0	204	**98.0**	0.120
Water Features	0	0	0	**66**	0	0	66	**100.0**	0.039
Bareland	0	0	0	1	**45**	2	48	**93.8**	0.028
Built up Areas	0	0	0	0	2	**48**	50	**96.0**	0.029
Total	**400**	**300**	**200**	**70**	**50**	**50**	**1070**		
Producer Error	**99.5**	**100.0**	**100.0**	**94.3**	**90.0**	**96.0**	**1057**		
Overall accuracy	**0.988**								
Kappa coefficient	**0.986**								

(b) 1999

Land cover 1999	Forestland	Cropland	Grassland	Water body	Bareland	Built up Areas	Total	User's Error	**p**
Forestland	400	0	0	0	0	0	400	**100.0**	0.235
Cropland	0	295	0	0	0	1	296	**99.7**	0.174
Grassland	0	0	300	0	0	0	300	**100.0**	0.176
Water body	0	0	0	70	0	0	70	**100.0**	0.041
Bareland	0	4	0	0	70	2	76	**92.1**	0.045
Built up Areas	0	1	0	0	0	97	98	**99.0**	0.058
Total	**400**	**300**	**300**	**70**	**70**	**100**	**1240**		
Producer Error	**100.0**	**98.3**	**100.0**	**100.0**	**100.0**	**97.0**	**1232**		
Overall accuracy	**0.994**								
Kappa coefficient	**0.993**								

c) 2009

Land cover 2009	Forestland	Cropland	Grassland	Water body	Bareland	Built up Areas	Total	User's Error	*p*
Forestland	397	2	1	2	0	1	403	**98.5**	0.237
Cropland	3	189	7	0	0	0	199	**95.0**	0.117
Grassland	1	3	288	0	0	0	292	**98.6**	0.172
Water body	0	0	1	68	0	0	69	**98.6**	0.041
Bareland	0	5	3	0	69	0	77	**89.6**	0.045
Built up Areas	0	1	0	0	0	100	101	**99.0**	0.059
Total	**401**	**200**	**300**	**70**	**69**	**101**	**1141**		
Producer Error	**99.0**	**94.5**	**96.0**	**97.1**	**100.0**	**99.0**	**1111**		
Overall accuracy	**0.974**								
Kappa coefficient	**0.971**								

d) 2019

Land cover 2019	Forestland	Cropland	Grassland	Water body	Bareland	Built up Areas	Total	User's Error	*p*
Forestland	400	0	0	0	0	0	400	**100.0**	0.235
Cropland	0	200	0	0	0	0	200	**100.0**	0.118
Grassland	0	0	300	0	0	0	300	**100.0**	0.176
Water body	0	0	1	70	0	0	71	**98.6**	0.042
Bareland	0	0	0	0	99	0	99	**100.0**	0.058
Built up Areas	0	0	0	0	0	70	70	**100.0**	0.041
Total	**400**	**200**	**301**	**70**	**99**	**70**	**1140**		
Producer Error	**100.0**	**100.0**	**99.7**	**100.0**	**100.0**	**100.0**	**1139**		
Overall accuracy	0.999								
Kappa coefficient	**0.999**								

Appendix V: Thematic land cover conversions in Gwassi hills water tower from 1989 to 2019

a) Between 1989 and 1999

		1999						
	Land Cover	Cropland	Forestland	Grassland	Water body	Bareland	Built-up areas	**Total**
1989	Cropland	20182.2	103	3341.1	0.2	253.2	0.3	**23880**
	Forestland	1460.8	2221.1	13.6	3.9	0.5	0	**3699.9**
	Grassland	137.7	0	3475.9	0	3.8	37.6	**3655**
	Water body	0.2	2.2		1280.2	0	0	**1282.6**
	Bareland	1313.1	0.1	3095.3	0	717.9	1.8	**5128.2**
	Built-up areas	0	0	5	0	0	12.6	**17.6**
	Total	**23094**	**2326.4**	**9930.9**	**1284.3**	**975.4**	**52.3**	**37663.3**

b) Between 1999 and 2009

		2009						
	Land Cover	Cropland	Forestland	Grassland	Water body	Bareland	Built-up areas	**Grand Total**
1999	Cropland	14,896	1,962	2,172	0	4,051	9	**23,090**
	Forestland	109	1,967	0	3	247	0	**2,326**
	Grassland	6,900	33	2,435		413	149	**9,930**
	Water body	0	10		1,274	1		**1,284**
	Bareland	737	1	80		157	1	**975**
	Built-up areas	1		12		0	39	**52**
	Total	**22,644**	**3,974**	**4,698**	**1,277**	**4,869**	**198**	**37,658**

c) **Between 2009 and 2019**

		2019						
	Land cover	Cropland	Forestland	Grassland	Water body	Bareland	Built-up areas	**Total**
	Cropland	18086.6	472.4	2137.3	0.3	1903.7	44.7	**22645.0**
	Forestland	676.3	3206.8	1.3	23.1	67.1	0.0	**3974.7**
	Grassland	1042.5	4.3	3092.3	0.0	425.0	135.3	**4699.3**
2009	Water body	0.0	4.1		1272.0	0.0	0.0	**1276.1**
	Bareland	2998.1	1194.7	219.7	1.0	450.2	4.6	**4868.4**
	Built-up areas	13.6	0.0	90.2	0.0	3.1	91.3	**198.3**
	Total	**22817.1**	**4882.3**	**5540.8**	**1296.5**	**2849.1**	**275.9**	**37661.8**

d) **Cumulative land cover conversion from 1989 to 2019**

		2019						
	Land cover	Cropland	Forestland	Grassland	Water body	Bareland	Built-up areas	**Grand Total**
	Cropland	17559.3	2091.5	2467.5	0.4	1730.4	28.9	23877.9
	Forestland	849.0	2748.3	0.6	17.6	84.7	0.1	3700.4
	Grassland	1938.7	8.5	1297.5	0.0	229.4	180.9	3655.0
1989	Water body	0.0	3.8	0.0	1278.5	0.1	0.0	1282.3
	Bareland	2470.2	29.7	1771.3	0.0	804.2	52.3	5127.7
	Built-up areas	0.4		3.1	0.0	0.3	13.8	17.6
	Total	**22817.7**	**4881.8**	**5540.0**	**1296.5**	**2849.0**	**275.9**	**37660.9**