SPATIAL ANALYSIS OF SIBBINDA RURAL SETTLEMENT DEVELOPMENT AND DEFORESTATION IN ZAMBEZI REGION, NAMIBIA

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Abbreviations

CA-Markov: Cellular Automata and Markov Chain

CBD: Central Business District

GIS: Geographic Information System

LULC: Land Use Land Cover

LUCCs: Land Use/Cover Changes

MLR: Ministry of Lands and Resettlement

MRLGHRD: Ministry of Regional and Local Government, Housing and Rural Development

NSA: Namibia Statistics Agency

OECD: Organisation for Economic Co-operation and Development

PCA: Principal Component Analysis

RS: Remote Sensing

SDG11: Sustainable Development Goal 11

UN: United Nations

UNDP: United Nations Development Programme

UNESC: United Nations Economic and Social Council

UN-HABITAT: United Nations Human Settlements Programme

Abstract

Spatio-temporal analyses using GIS and remote sensing techniques are tools used to model rural settlement development as a catalyst of deforestation. Spatial analyses were performed using IDRISI 17.0 software. A supervised classification-maximum likelihood algorithm was applied to detect land cover/land use changes observed in the study area. Study land cover was classified into four major land use classes, vegetation, land cleared for settlement purposes, dwelling units/buildings and bare land. Linear and multiple regression were applied to predict and quantify the contribution of roads, building construction and land clearing to deforestation.

Past, present and future land use and land cover changes due to Sibbinda rural settlement development favour deforestation. In a rural settlement setup with no major road network development; deforestation is positively associated with road networks for a limited time period, and thereafter as deforestation moves towards saturation stage, it becomes negatively associated with road networks. Vegetated areas that are easily accessible to humans are more likely to be initially deforested.

At the early stage of deforestation, the distance of an area from a road network is the most important factor of deforestation in that specific area. As deforestation increases in the area, the distance from buildings becomes the most significant factor of deforestation. Deforestation hotspots at Sibbinda are expected in the northwest direction, in areas far from roads, yet more densely vegetated.

Reforestation is very low at the Sibbinda settlement, as it is mainly a result of natural processes. To minimise the extent of deforestation, future settlement development projects need to correspond to the aims of SDG11, so that forests are effectively preserved. There is a need to draw future settlement land-use plans depicting the future growths of the settlement and forestry conservancy areas (mainly in the northwest of Sibbinda). It is recommended to promote rotational crop farming system(s) among residents so that unproductive agricultural land can be given enough time to covert to forests. There is a need to explore the possibility of implementing renewable energy projects, to enhance environmental quality and reduce deforestation at the Sibbinda settlement.

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Chapter 1: Introduction

1.1. Orientation of the Study

Rural settlement development has a great potential to generate deforestation (FARIAS, BELTRÃ, SANTOS & CORDEIRO 2018; BADRELDIN, FRANKL & GOOSSENS 2013). This occurs when residents in rural settlements utilises forest resources such as trees and grasses to build their houses or when they secure their income from farming activities and selling of forest products such as timber/trees and grasses. WU, DE PAUW and ZUCCA (2008: 847) established that, deforestation is produced by human activity, particularly overgrazing, land clearing for cultivation purposes and timber harvesting. The later stated deforestation drivers are catalyzed by human culture and unreasonable land use policies. Deforestation can lead to desertification that undermines the land's productivity and contributes to poverty (BADRELDIN, FRANKL & GOOSSENS 2013). This is due to the elimination of fertile topsoil and vegetation cover resulting in people unable to easily meet their survival needs through for instance farming activities (ANH, WILLIAMS & MANNING 2006).

Although, rural settlement development is positive correlated to deforestation (ASSUNÇÃO & ROCHA 2016), there is still a need for settlement development to occur through sustainable practices. The demand for rural settlement development is high especially in the developing countries such as Namibia. For instance, the Namibian government intends to accomplish the realisation of improved and enhanced livelihoods for the people in the Zambezi sub-growth points through rural settlement development (THE MINISTRY OF LANDS AND RESETTLEMENT [MLR] 2015). Such rural settlement development activities will be associated with negative impacts on the natural environment in the form of deforestation (EHRHARDT-MARTINEZ 1998). To reduce deforestation around those rural settlements in Namibia, there is a need to draw future settlement land-use plans depicting the future growths of settlements and forestry conservancy areas.

In Namibia, deforestation is more likely to be triggered by the need to improve service provision in rural settlement by the government through the construction of roads, houses, health and education facilities (MLR 2015). MLR (2015) encourages settlement administrators to allocate more land to be used for ervens, agriculture and housing (dwelling units). The latter activities will result in the clearing of land by cutting trees and removing grasses leading to deforestation. Sibbinda (also known as Sibinda) was identified as one of the most suitable sub-regional growth points for rural settlement development in the Zambezi region (MLR 2015: 22;28). Settlement development at Sibbinda and other regional sub-growth points needs to be based on the Sustainable Development Goal 11 (SDG11). SDG11 aims to make cities and human settlements inclusive, safe, resilient and sustainable by the year 2030 (UNITED NATIONS ECONOMIC AND SOCIAL COUNCIL [UNESC] 2017: 13).

SDG11 also aims to minimise negative environmental impacts such as deforestation caused by urbanisation and rural settlement development (UNESC 2017: 13). The unprecedented increase in population and rapid rate of urbanisation has led to extensive land use changes. Settlement development needs to integrate residential areas, offices, light manufacturing, service centres and recreational areas to reduce travel distances, and encourage environmentally friendly modes of transport (HUSSIN, MOHAMMED, OMAR, SAMAT & SANUSI 2014: 1; VAN WYK 2017).

PARSA and SALEHI (2016: 44) assert that there is a need for up-to-date, adequate and reliable Land Use/Cover Changes (LUCCs) information from the past to present. The past, present and future plausible changes are needed to understand and evaluate social, economic and environmental consequences of these changes (PARSA & SALEHI 2016: 44) (cited in FOLEY et al. 2005; GIRI, ZHU & REED 2005; WILLIAMS & SCHIRMER 2012; WILSON & CHAKRABORTY 2013). Spatial tools such as Geographic Information System (GIS) and Remote Sensing (RS) can be applied to generate Land Use/Cover Changes (LUCCs) Spatial-temporal models that quantify environmental damage as a result of rural settlement development (ANH et al. 2006: 2). Grainger (as cited in ANH et al. 2006: 1) reinforce that, the most effective way to improve the accuracy of deforestation monitoring would be to employ remote sensing data such as Landsat imageries, which are designed to survey ground condition over a larger area and longer period.

1.2. Problem Statement

In Namibia, the percentage of people living in urban areas increased from 33% in 2001 to 43% in 2011 (NAMIBIA STATISTICS AGENCY [NSA] 2012: 8). This increase of population in urban areas has and continues to challenge town councils in developing countries such as that of Katima Mulilo to provide residents with serviced land and housing (UNITED NATIONS HUMAN SETTLEMENTS PROGRAMME [UN-Habitat] 2005: 24-25). An example is that of the Bukalo area, in the Zambezi region, which was speedily transformed to a village council in 2015. The settlement developments at Bukalo are likely to reduce the pressure of urbanisation in Katima Mulilo. At the same, deforestation is expected to increase at the Bukalo settlement due to the clearing of land for construction of houses and offices. Equally, GMAC INVERSTMENT CC (2019: 68) recognised that the proposed construction and operation of a fuel retail station and truck depot at Ngoma settlement in the Zambezi region is more likely to cause degradation of the local environment.

During the transition of Bukalo area to a government settlement status, people who were residing around and close to the Central Business District (CBD) of Bukalo were forced to move to close by forest areas to establish new homes and farming units. Such human activities have led to a high rate of deforestation at Bukalo (FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS [FAO] 2020), similar deforestation trends are expected at other Zambezi sub regional growth points such as Chinchimane, Kongola, Lusese, Ngoma, Sangwali and Sibbinda (MLR 2015; GMAC INVESTMENT CC 2019). This highlights that, the Zambezi region is likely to experience a large scale of deforestation due to settlement development. Hence the need to establish environmental damages because of Settlement development at those localities.

Spatio-temporal models are tools that support sustainable settlement development without encroaching on productive agriculture land and forests which habitats biodiversity (SALAME, QUEIROZ, ROCHA, AMIN & ROCHAL 2016; AHMED, ACHOUR, SAMI & SAMI 2020). This study seeks to model deforestation in relation to settlement development to areas within 15-20 km from the Central Business District (CBD) of Sibbinda settlement. The effects of future settlement development on the land uses and land cover at Sibbinda will be quantified and shared with local communities and the Zambezi Regional Council.

1.3. Research Aims, Objectives, Hypothesis and Questions

The main aim of this study is to conduct Spatio-temporal analyses using GIS and remote sensing techniques to analyse Sibbinda rural settlement development. The study will quantify the past, current and future impact of Sibbinda settlement development on deforestation.

The study intends to achieve the following specific objectives

- To design a conceptual framework of understanding deforestation drivers because of rural settlement development using the GIS and RS based Spatial-temporal models and regression analysis.
- To predict the dynamics of land use and land cover changes using Spatio-temporal model.
- To conduct past, present and future deforestation analysis.
- To analyse the relationship between road networks, construction of dwelling units, clearing land for settlement purposes and deforestation.
- To quantify the contribution of road networks and human activities (e.g., construction of dwelling units and clearing land for settlement purposes) in promoting deforestation.
- To predict future deforestation hotspots using multi-regression analysis.
- To conduct past, present and future reforestation analysis.

Hypothesis

- There are no land use and land cover changes taking place at Sibbinda due to rural settlement development.
- There is a positive correlation between road networks and deforestation at Sibbinda.
- There is a positive correlation between clearing land for settlement purposes and deforestation at Sibbinda.
- There is a positive correlation between dwelling construction and deforestation at Sibbinda.
- There is a positive correlation between rural settlement development and reforestation at Sibbinda.
- Past, present and future land use and land cover changes support deforestation at Sibbinda.

Research questions

The main research question to be answered by this study is as follows; what is the impact of Sibbinda rural settlement development on deforestation? based on past, current and forecasted Land Use/Cover Changes (LUCCs). Based on the main research question, research aim and objectives, this study will answer the following specific questions:

- What type of LUCCs are taking place at Sibbinda?
- Does past, present and future land use and land cover changes support deforestation at Sibbinda?
- What is the past, current and the expected future rate(s) of deforestation at Sibbinda?
- What is the amount of deforestation attributed to road networks at Sibbinda?
- What is the contribution of clearing land for settlement purposes to deforestation?
- Is there a relationship between dwelling unit constructions and deforestation?
- What is the past, current and the expected future rate(s) of reforestation at Sibbinda?

1.4. Significance of the Study

The study is expected to support forest conservation efforts as the impact of rural settlement development on deforestation will be quantified. Thus, conservation offices will use the results of the study to develop strategies to combat deforestation around the Sibbinda area. This will be achieved by using the information generated from the study to identify patterns of Land Use/Cover Changes (LUCCs) due to settlement development at Sibbinda. The study will further determine and forecast the rate at which forests are cleared to make way for rural settlement development. This study could be used as a benchmark for similar studies applying GIS and remote sensing techniques to support sustainable settlement developments in Namibia. The study could also provide a methodological framework for national LUCCs mapping and reporting efforts of the NSA (BEZUIDENHOUDT 2019).

1.5. State of the Art

Human Geography as a Discipline of Study

Geography plays a significant role in the development process as there are three spatial features which influence the economic development of a region, namely, the density (e.g., scale economies), the distance (e.g., spatial mobility) and division (e.g., the spatial integration of economies) (GILBERT, LINARD, NOOR, SNOW & TATEM 2012: 1). Geography is divided into two main branches: human geography and physical geography (BORNEMAN 2017; MISRA, SINHA & YADAV 2018: 4). The physical geography sub-disciplines are geomorphology, climatology, hydrology, biogeography which examines natural features and phenomena such as surface configuration climate, drainage, and natural resources, such as soil, minerals, water and forests (BORNEMAN 2017; MISRA et al. 2018: 4). Human geography deals with the spatial analysis of human population, its cultures, activities and landscapes (THE NEW JERSEY DEPARTMENT OF EDUCATION 2021: 278; BALASUBRAMANIAN 2015: 1). Human activities examined consists of but not limited to culture, technology, settlements, migrations and conflict.

There are additional branches in geography such as regional geography, cartography and integrated geography (BORNEMAN 2017). Integrated geography takes human and physical geographic issues and molds them together, making this area of geography useful for connecting humans and their impacts on the natural environment. GIS and remote sensing technologies applying drones, Light Detection and Ranging (LiDAR), earth observation satellites, and aerial photography are tools used to show where humans have physically altered an environmental landscape (NATIONAL ACADEMIES PRESS 2014; BORNEMAN 2017; ALTAWEEL 2020).

According to MISRA et al. (2018: 6), human geography has three closely linked tasks to perform:

- The spatial or locational analysis of manmade phenomena on the earth's surface; this relationship can be seen in two ways, that is, the impact of people on habitat (land), as well as of land on people.

- Ecological analysis, where the focus is on studying human-environment linkages within a geographical region.
- Regional synthesis wherein the spatial and ecological approaches are fused. The aim is to understand the internal morphology, ecological linkages and external relations.

Theoretical perspectives in human environment interaction are divided into two, environmental determinism where humans are clay to be molded by a dominant nature and environmental possibilism where it is augured that it is not the physical environment that influences man, but also human effort must be considered (LAHORE COLLEGE FOR WOMEN UNIVERSITY 2020). According to FEKADU (2014: 132), a determinist argues that 'man is entirely under the influence of nature' while a possibilist believes that man is never entirely free from the influence of the environment, but there is room for the efforts of man. Such efforts include technology and values of humans that influence man's action, which subsequently modify the physical environment. Possibilism sees the physical environment as a series of possibilities for humans to exploit it for their benefits.

Population Geography

Population geography is a branch of human geography that studies the ways in which spatial variations in the distribution, composition, characteristics and growth of populations are related to the environment (ELFAKI 2018; AJAERO, NNADI & ONUH 2017 cited in OGDEN & PHILIP 1998; AJAERO 2015; AJAERO & MADU 2016). Population geography as a scientific field of study, engages in spatial and temporal discourses of the patterns and processes of differences in population distribution in any defined geographical area (AJAERO, NNADI & ONUH 2017). According to AJAERO, NNADI and ONUH (2017), population characteristics refers to the attributes that individuals in the population possess biological or sociologically. Some of the biological characteristics include age and sex; these attributes are not changeable. Sociologically assigned attributes are changeable and include occupation, marital status, education and income.

Population Distribution and Density

Population distribution refers to the way the people are spaced over the earth's surface (THE NATIONAL COUNCIL OF EDUCATIONAL RESEARCH AND TRAINING [NCERT] 2020). The Earth's land surface is about 30 percent of the total earth's surface while the rest is water, and it must be noted that only about 11 percent of the land area is comfortably habitable by people (DAVIES 2014: 5; NCERT 2020: 8). Population distribution is highly influenced by geographic (e.g., availability of water, fertile soils and climate), economic (availability of employment opportunities and minerals) and social cultural factors such as religious, cultural or political systems (JK GEOGRAPHY 2021).

Arithmetic population density is a ratio between population and the size of land area that is derived from dividing the number of people in a unit area of land over the total land area (AJAERO, NNADI & ONUH 2017; MALPEZZI 2013). According to AJAERO, NNADI and ONUH (2017), population density is the most common measure of population pressure on the land surface. Physiological or nutritional density is a ratio between total population and total cultivated area or cropland (TOPPR 2021). Nutritional density can be used to measure the rate at which humans engage in crop farming in an area.

Population Growth

Population growth is the rate of natural increase combined with the effects of migration (BRITANNICA 2021). Therefore, a high or low rate of natural increase can be offset by a large net out or in-migration respectively. Natural increase is the difference between the number of births and deaths per thousand persons in a year, calculated based on Crude Birth Rate (CBR) and Crude Death Rate (CDR), respectively (UNITED NATIONS CHILDREN'S FUND [UNICEF] 2021). According to HONE and SIBLY (2002: 1152), the importance of the population growth rate lies partly in its central role in forecasting future population trends and central to our understanding of environmental stress.

Population Demographic Structure

Population's demographic structure or composition is the description of the characteristics of a group of people in terms of factors such as their age, sex, marital status, education and occupation (OPENLEARNCREATE 2021). The age-sex structure of a population depicts the number/proportion of males and females in each age group and have considerable impact on the population's current and future social and economic planning. The impact is reduced in circumstances where data errors such as age misreporting (age heaping/exaggeration) and coverage errors where net under enumeration occurred during national population and housing census data collection processes (PELLETIER & SPOORENBERG 2015).

Urbanisation and Economically Active Population

According to MCGRANAHAN and SATTERTHWAITE (2014: 4), urbanisation involves the shift in population from rural to urban settlements. In 2018, nearly 60 percent of the populations in Africa had urbanization levels below 50 percent (UNITED NATIONS 2018). Nevertheless, urbanisation is projected to be over 50% by 2050 in 44 African countries, of which 16 will be more than 75 percent urban. Economically active than none economically active people are more likely to migrate to urban areas (LYU, DONG, ROOBAVANNAN, KANDASAMY & PANDE 2019). This economically active population includes people from 15 to 64 years of age who are either employed or unemployed and who are seeking employment (STATISTICS SOUTH AFRICA 2014: 13). The proportional distribution of this active population under specific economic activities is known as occupational structure.

Population Occupational Structure

Occupation reflects the individual's position in the technical division of labour, occupational structure is often construed to represent the pattern of socioeconomic opportunity in modern societies (MAIA & SAKAMOTO 2015: 230). VARAT (2016: 2821) observed that occupational structure influences the socio-economic development of an area as any change in the occupational structure may be an indication of economic growth. Population occupational structure can be based on the below five categories of economic activities (PRASAD 2021: 4-5):

- Primary economic activities where people directly utilise earth's resources in the form of occupations such as agriculture, animal husbandry, forestry, fishing, mining, and quarrying to earn livelihood.
- The secondary activities add value to natural resources by transforming raw materials into valuable products and includes manufacturing industry, building and construction work.
- Tertiary activities include both production and exchange. The production involves the 'provision' of services that are 'consumed', and exchange, involves trade, transport and communication facilities.
- Quaternary economic activities involve collection, production and dissemination of information. It revolves around research and development and provides highly specialised services.
- Quinary economic activities are sophisticated services and focus on the creation, re-construction and interpretation of new and existing ideas. It includes highly skilled and heavily paid business executives, government officials, research scientists, financial and legal consultants.

Human Settlements

A settlement is a place where people live and interact through activities such as agriculture, trading and entertainment (CIKGU GEOGRAPHY 2013). STOUSE (2014: 1) defines settlement geography as the study of the distribution of functional units used by people to exploit or extract resources from the physical environment. According to BALASUBRAMANIAN (2017: 4), the primary aim of studying settlement geography is to acquaint with the spatial and structural characteristics of human settlements under varied environmental conditions. There are five elements relating to human settlements and these are Nature, Man, Society, Shells (Buildings) and Networks (BALASUBRAMANIAN 2015: 7).

Settlements can either be temporary or permanent; temporary settlements include refugee camps, while permanent settlements can be towns or cities (INTERNET GEOGRAPHY 2019; EXCELLUP 2021). According to EXCELLUP (2021), human settlements can also be categorised into rural or urban; rural settlement consist of the villages where the people are engaged in primary economic activities such as hunting and agriculture. Urban settlements include towns and cities, where most of the people are engaged in secondary and tertiary economic activity types such as manufacturing, trading and services. Classifying settlements into rural and urban based on the population size is the most important criterion used by many countries around the world (MISRA et al. 2018: 111). However, there are wide differences in the exact number that differentiates urban from rural, as countries with a low density of population tend to choose a lower number as the cut off figure compared to a densely populated country (MISRA et al. 2018: 111). For instance, areas with 10,000 people or more were classified as 'urban' in England and Wales (BIBBY & SHEPHERD 2001: 5). In Canada, settlements with less than 1,000 persons are classified as rural; in the United States the upper limit is 2,500 persons while in Japan, settlements having populations up to 30,000 are rural (MISRA et al. 2018: 107).

THE COUNTRYSIDE AGENCY (CA) (2004) classified settlements in England and Wales based on the following settlement forms; dispersed dwellings, hamlet, village, small town, urban fringe and urban (>10,000 population). Based on Figure 1.5.1 below, as one moves up the settlement hierarchy, the size of the settlement increases, as well as the population and the range of services available (INTERNET GEOGRAPHY 2019). Smaller settlements such as hamlets and isolated areas with small clusters of houses tend to provide only low order services such as a post office and newsagents (TEACHIT GEOGRAPHY 2019). Larger settlements such as large cities and conurbations have a population ranging from a hundred thousand to millions and have higher order services such as leisure centers, chain stores, railway stations, many big hospitals, secondary schools and universities (INTERNET GEOGRAPHY 2019; TEACHIT GEOGRAPHY 2019). The immediate implication here is that the larger the settlement, the greater the range of services and therefore the market area or sphere of influence.

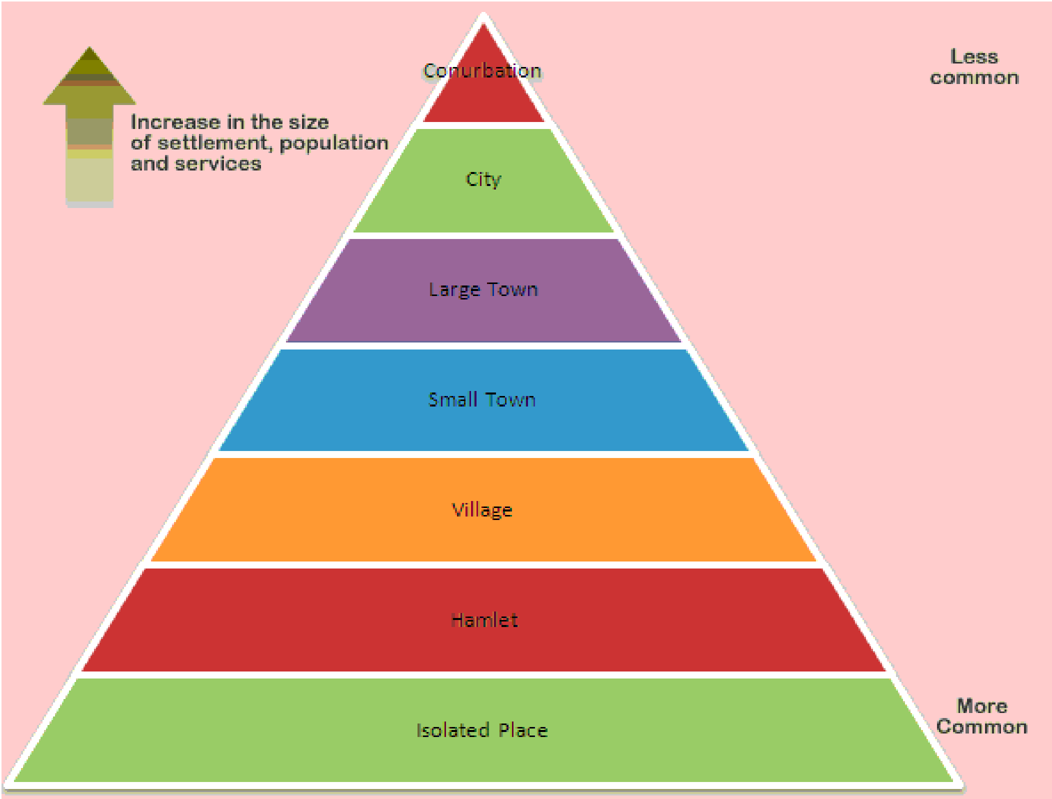


Figure 1.5.1: Settlement hierarchy catagorise: (INTERNET GEOGRAPHY 2019)

Rural Settlements

Rural settlements comprise of but are not limited to isolated farms, hamlets or villages and are concerned with the functional units used in primary economic activity. This means a rural settlement hosts a community involved predominantly in primary activities such as farming, hunting, gathering, fishing, lumbering, mining and tourism (JADHAV 2019: 2; STOUSE 2014: 1; CIKGU GEOGRAPHY 2013; ŠILJKOVIĆ & ČULJAK 2015: 42; RAJOVIĆ & BULATOVIĆ 2012: 177). Agricultural activities in rural settlements can be limited due to area topography. For instance, in the rural settlement of Rwanda, residential land is scarce because of the hilly terrain, and there is minimal growth of agricultural activities leading to food security concerns (NGOGA 2015). Settlements on hills have less land available for agricultural activities compared to flat areas.

Rural settlements are also characterised by low population size/density (CIKGU GEOGRAPHY 2013). In many rural settlements there is no planning of houses, roads, shapes, structure and there are minimal facilities of communication, transportation and other social facilities (JADHAV 2019: 1-2). Linear features such as roads can lead to the development of linear settlements along a transport route, normally a highway or district road in the rural areas, canals, along rivers and around flood plains of rivers in the hilly terrains (BALASUBRAMANIAN 2017: 26; MISRA et al. 2018: 108). Circular or Square settlements develop in flat level lands, around a pond, tank, crater, hilltop or a cattle corral while cross shaped or nuclear settlements develop as a small hamlet at the intersection of roads (MISRA et al. 2018: 108).

Settlements and Rural Development

According to NIEDZIELSKI (2015: 84), development is a process of quantitative and qualitative changes in the desired direction. Hence, not all changes taking place in rural areas can be read as signs of development as the change needs to benefit people residing in those rural areas. For example, when rural residents clear land for settlement purposes (build school and houses, they view it as development) as there are benefits attached to such activities. The same land clearing activities damage the environment (vegetation and animal's habitats). Even though there is a need to protect the environment from harm as result of rural development; development still needs to continue as rural exodus can precipitate the decline of farm numbers and a sharp drop in employment opportunities in the agriculture industry (DE ROEST, VAN DER PLOEG, RENTING, BRUNORI, KNICKEL, MANNION, MARSDEN, SEVILLA-GUZMÁN & VENTURA 2000: 2).

The origins of the rural development concept can be traced from the political and social challenges, and studies in comprehensive topics where power, scope, and effects of rural development practices form its main core (SARKAMARI & VARNOSFADERANI 2016: 364). According to THE TENDERING DISTRICT COUNCIL (2008: 22), Rural Settlement development is expected to: support the continued viability of agriculture and other economic activities (such as tourism); support the provision of housing for local needs; and to support the provision of housing for the sustainability of local services.

According to NIEDZIELSKI (2015: 86), rural settlements are concerned with the following:

- Landscape conservation and preservation, architecture (land development, buildings, structures, and design),
- Agricultural production activity (e.g., biodiversity, forest ratio and fruit farming),
- Culinary traditions (traditional products and eating habits),
- Non-agricultural rural manufacture (folk products and costumes, handicraft, craftwork), folk ceremonies and art.

In Namibia, rural development refers to actions which aim to improve the rural people's standards of living by providing basic social and economic services (MINISTRY OF REGIONAL AND LOCAL GOVERNMENT, HOUSING AND RURAL DEVELOPMENT [MRLGHRD] 2011: 1). Namibia's rural development policy aims at creating a political, legal, economic and social environment, which empowers people in rural areas to take charge of their own development (MRLGHRD 2011: 1). Several principles such as the Namibia Constitution, The Decentralization Policy; The Decentralization Enabling Act of 2000 and The National Rural Development Policy (KASHEETA & NAFELE 2018) guide the coordination of rural development in Namibia. The later legal frameworks give power to the people in Namibia to be environmental possibilist. For instance, the Coachella and Imperial Valleys were essentially deserts with very little precipitation and no prospect for agriculture (DAVIS 2019: 2). People decided to change the environment and diverted the Colorado River to help irrigate the land so that the once useless deserts became valuable agricultural fields (DAVIS 2019: 2). Equally, Namibians in rural areas can decide to clear land and start agricultural projects supported by irrigation mechanisms using water from the sea or rivers to produce at large scale cereals like maize and rice for export to other countries to generate income.

Types of Rural Settlement Development

The introduction of traffic, construction of utility infrastructure, construction of water reservoirs and industrial facilities can result in the transformation of rural settlements to urban ones or the change of agricultural to urban cultivated landscape (ŠILJKOVIĆ & ČULJAK 2015: 47). According to KREVS and REBERNIK (2013: 93), the characteristic of suburbanisation is that it spreads into formerly rural areas. There are three aspects of the conceptual understanding of suburbanisation, namely, physiognomic (the dispersal of settlement forms, the spread of urban forms of residence, changes in land use), functional (the de-concentration of urban functions) and social (the adoption of values, patterns of behaviour, and consumer habits of urban households in the suburbs) (KREVS & REBERNIK 2013: 93). Rural areas are not synonymous with agriculture any longer, because with the increase of urban-rural migrants and the emergence of new functions, rural settlements are increasingly becoming like city settlements (ŠILJKOVIĆ & ČULJAK 2015: 41) (cited in RONCKEN 2006: 8; ESTANY et al. 2008: 12).

The population growth in rural settlements is usually accompanied by an intensive spatial development and expansion of settlements due to a high increase in the extent of built-up areas in rural settlements (KREVS & REBERNIK 2013: 103). ROBINSON (2003: 419) revealed an increase in capital investment in South Africa's Qaukeni rural area in a form of good-quality houses in villages located along the main roads. This indicates that rural areas with good transport networks are likely to experience a high rate of rural development in terms of build-up structures like housing than rural areas with poor transport networks.

Chapter 2: Review of the Literature

2.1. Rural Settlement Development as a sub-branch of Settlement Geography

The term 'Settlement' is associated with the Settlement Geography that originated in the 1920s and focused on differences in settlement developments based on elements such as culture, economy and genetic aspects (HENNING 2018: 4). Settlement Geography is the study of human land, water and resource use, population density patterns, and settlement growth (WAGHERE 2022: 4). Studying the relationship between settlement development and the environment is part of Settlement Geography, a branch of Human Geography (FARIDI 2018). Settlement Geography has two sub-disciplines, Urban and Rural Settlement (WÓJCIK 2013: 125). Settlement geographers study villages, towns and the types of relationships generated between variables (WAGHERE 2022: 4). Rural settlement geographers can study rural farm buildings for patterns, functions, origins, and relationships to agricultural production (WARF 2010). The generated patterns on the physical environment due to human activities can be recorded as Land Use Land Cover changes (LULC), that is usually modelled using different change detection technics (HASSAN, SHABBIR, AHMAD, MALIK, AZIZ, BUTT & ERUM 2016). Spatial analysis that results into producing settlement LULC are needed to support land use planning efforts aimed for instance at environmental conservation.

Rural settlement development can be conditioned by several factors, such as physical geographical, social and political, and is manifested by the presence of various economic and non-economic activities (MADJEVIKJ, TOSHEVSKA & LJAKOSKA 2019: 299). This indicates that, the study of rural settlement development is well positioned in Human Geography, as the emphasis is placed on the rural population's social and economic activities and how such activities impact the local physical environment. Settlement Geography is tasked to evaluate the relationship between the development activities of settlements and the natural environment. Although, the influence of the natural environment on rural areas and settlements is bigger than on urban settlements (POTOSYAN 2017: 1). This is because rural settlements are concerned predominantly, though not exclusively, with primary activities, particularly food production (SILBERFEIN 2019: 3). This indicates that, activities in rural areas include but not limited to clearing large pieces of land for agricultural purposes, that has much negative consequences on the environment.

2.2. Deforestation as a Geographical Phenomenon

Human Geography deals with the study of people, communities, societies, economics, cultures and their interactions with the environment by studying their relations (UTTARAKHAND OPEN UNIVERSITY 2020: 2). Deforestation is one of products of the people's interactions with their local environment. For example, University of Cincinnati geography researchers applied high-resolution satellite imageries and identified areas impacted by human activities that contributed to deforestation (UNIVERSITY OF CINCINNATI 2020). Similarly, NOWOSAD and STEPINSKI (2019) developed a model of landscape dynamics, where deforestation was one of the products when forests transits to agriculture land. Deforestation causes and consequences has a geographical variation as the highly depend on the social and physical environmental characteristics of an area (GORTE and SHEIKH 2010). Hence geographers analyse natural and social processes at a define location at a point of time (SPRAY and MORAN 2006: 79). For instance, in the context deforestation, geographic analyses can be centred on research questions such as,

- Why are savannah forests located where they are?
- Why is deforestation is occurring at certain localities?

The causes and driving forces of deforestation are often region-specific which means that deforestation dynamics are shaped by geographical and socio-economic contexts (GAO, SKUTSCH, MASERA & PACHECO 2011). Deforestation is a human induced issue, as most of the variables such as spatial population demographic and socio-economic factors explaining and affecting deforestation are part of anthropogeography (INDARTO & MUTAQIN 2016: 117). Equally, VELASCO, KöTHKE, LIPPE and GŸNTER (2020: 7) argues that elements related to physio-geography, demographic and socio-economic aspects are explanatory variables for deforestation.

Population and economic geography are subbranches of Human Geography that are connected to the deforestation phenomenon. This is because, population dynamics have a direct effect on deforestation. For example, a rapid population growth in an area will result into high production (e.g., farmland expansion) and consumption patterns in forest resources (CARR, SUTER & BARBIERI 2005: 90). Populace around the world get their livelihood from forests particularly in developing countries. Forests are altered by human for economic gains, through activities such as timber harvesting that damages the ecosystems and the geomorphological landscapes (CLERICI, ARMENTERAS, KAREIVA, BOTERO, RAMÍREZ-DELGADO, FORERO-MEDINA, OCHOA, PEDRAZA, SCHNEIDER, LORA, GÓMEZ, LINARES, HIRASHIKI & BIGGS 2020).

Deforestation is interconnected with other sub-fields of physical geography such as climatology. Studies (PREVEDELLO, WINCK, WEBER, NICHOLS & SINERVO 2019: 1; ARMENTA, ANGULO, ROCHA, BARRAZA, ANDRADE & GONZALEZ 2016: 296) revealed that, deforestation is one of the major contributors to the increase of the surface and atmospheric temperature. This is due to inter-relationships between forest change and changes in albedo, evapotranspiration and temperature. Thus, it is not surprising that, deforestation is one of the factors that have the greatest impact on climate change, as it produces negative effects on the physical environmental (ARMENTA et al. 2016: 296).

2.3. Land Use and Land Cover (LULC) Changes

Land Use and Land Cover (LULC) changes have implications for land use suitability with subsequent impacts on natural vegetation cover, biodiversity, socio-economic stability and food security (KAMWI, KAETSCH, GRAZ, CHIRWA & MANDA 2017: 1). For example, in Namibia community forests have much potential to combat rural poverty and contributes to rural development (NIKODEMUS & HÁJEK 2015). This indicates that, forestland is a critical component of the Earth system, influencing land-atmosphere interactions, greenhouse gas fluxes, ecosystem health, and availability of food, fiber, and energy for human populations (SU, GUTMAN, GUTMAN, BYRNES, MASEK & COVINGTON 2016: 6). Yet, detrimental changes in land use and land cover are the leading contributors to terrestrial biodiversity loss (ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT [OECD] 2018: 2).

A survey by FAO and JRC (2012) conducted in 2005 estimated the total area of the world's forests at only 3.8 billion hectares, or 30 percent of the global land area. A net decline in global forest area of 1.7 percent (at an annual rate of change of 0.11 percent) between 1990 and 2005 was observed. This equates to an annual shift from forestland use to other land uses of 3 million hectares per year between 1990 and 2000 and of 6 million hectares per year between 2000 and 2005 (FAO & JRC, 2012).

In Africa, the total forest area in year 2010 was around 22.75% (6,744,190 km²) of the whole continent (LUTZENBERGER, BRILLINGER & POTT 2014: 28). This was after a decline of forest land cover of around 4.82% (341,450 km²) between year 2000 and 2010. Africa is one of the continents with the highest net forest loss. Though, northern parts of Africa in 1999 was barren or sparsely vegetated, central parts had evergreen needle leaf forest while the southern parts were dominated by grassland and savannah open shrubs (LOVELAND, ZHU, OHLEN, BROWN, REED & YANG 1999).

Figure 2.1.1 below shows that in 2014 northern parts of Africa was dominated by bare land, while broadleaf evergreen forest was found around central parts in countries such as Gabon and Congo (TATEISHI, HOAN, KOBAYASHI, ALSAAIDEH, TANA & PHONG 2014: 115).

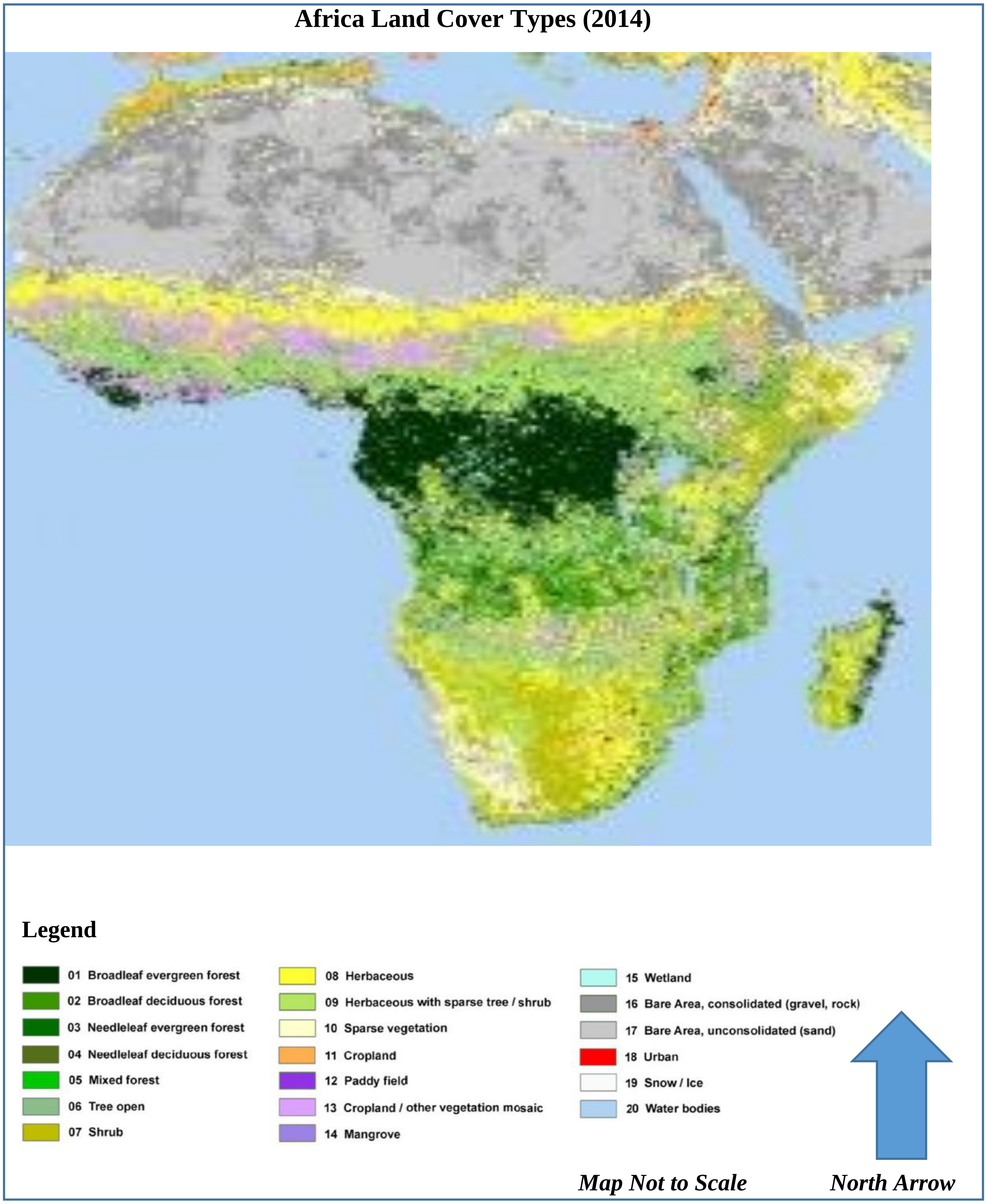
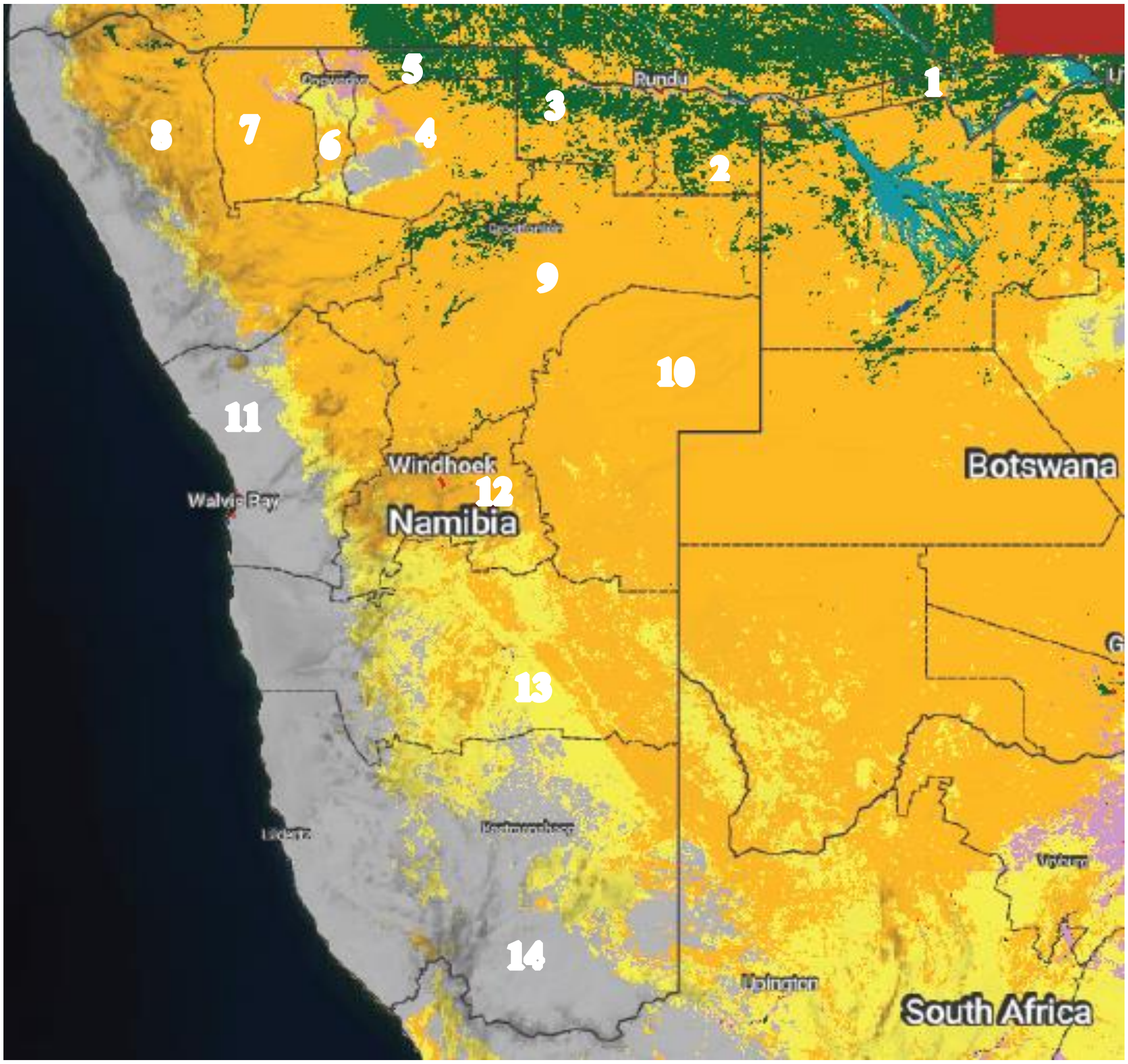


Figure 2.1.1: Africa land cover types, 2014: (TANESHA et al. 2014; Author's own 2021)

Namibia has a mixed and woody-savannah forest in the northeast, while open shrub land is found in the south of the country (LOVELAND et al. 1999). Figure 2.1.2 on the subsequent page highlight that, in 2015, Namibia had forests mainly in the northern (Ohangwena (5), Oshikoto (4)) and northeastern (Zambezi (1), Kavango East/West (2/3), Otjozondjupa (9)) regions. The Omaheke (10) in the east of the country was mainly characterised by shrub land (COPERNICUS 2021). Namibia's Forest Act No. 12 of 2001 made provision for the establishment of Community Forests (CFs). As of 2020 there are 32 registered CFs mostly in the woodland areas in the north-eastern parts of Namibia (NOTT, NOTT & NEWTON 2020: 51). Many assessments of LULC where change detection was applied revealed that settlement and agricultural areas are likely to increase resulting in substantial reduction of forest and barren land (HASSAN et al. 2016: 9).

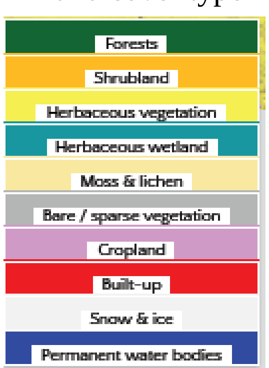
In the Zambezi region, negative vegetation cover changes were observed between 1982 and 2015 (GBAGIR, TEGEGNE & COLPAERT 2019: 13). Inversely, KAMWI et al. (2017) revealed that between year 2000 and 2010 conversion from crop/grass land to forestland was 11,634.21 ha, shrub land to cropland was 5213.26 ha and bare land to other land was 3.69 ha within the communal areas of Kongola and Sibbinda. Figure 2.1.3 below indicate the emerging forests around Sibbinda and Kongola areas as a result of the conversion of crop/grass land to forestland. These types of land cover change are one of the best measures currently available to monitor pressure on the environment locally and globally. This is accomplished by quantifying the loss and gain of natural and semi-natural vegetated land, conversions between land cover classes, including conversions to-and-from cropland and conversion to artificial surfaces (built-up area) (OECD 2018: 3).

Namibia Land Cover Types (2015)



Legend

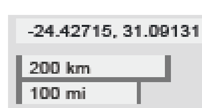
Land cover type



Regions in Namibia

Number	Region Name
1	Zambezi
2	Kavango East
3	Kavango West
4	Oshikoto
5	Ohangena
6	Oshana
7	Omusati
8	Kunene
9	Otjozondjupa
10	Omaheke
11	Erongo
12	Khomas
13	Hardap
14	ǁKaras

Scale Bar



North Arrow

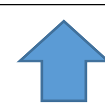


Figure 2.1.2: Namibia land cover types, 2015: (COPERNICUS 2021; Author's own 2021)

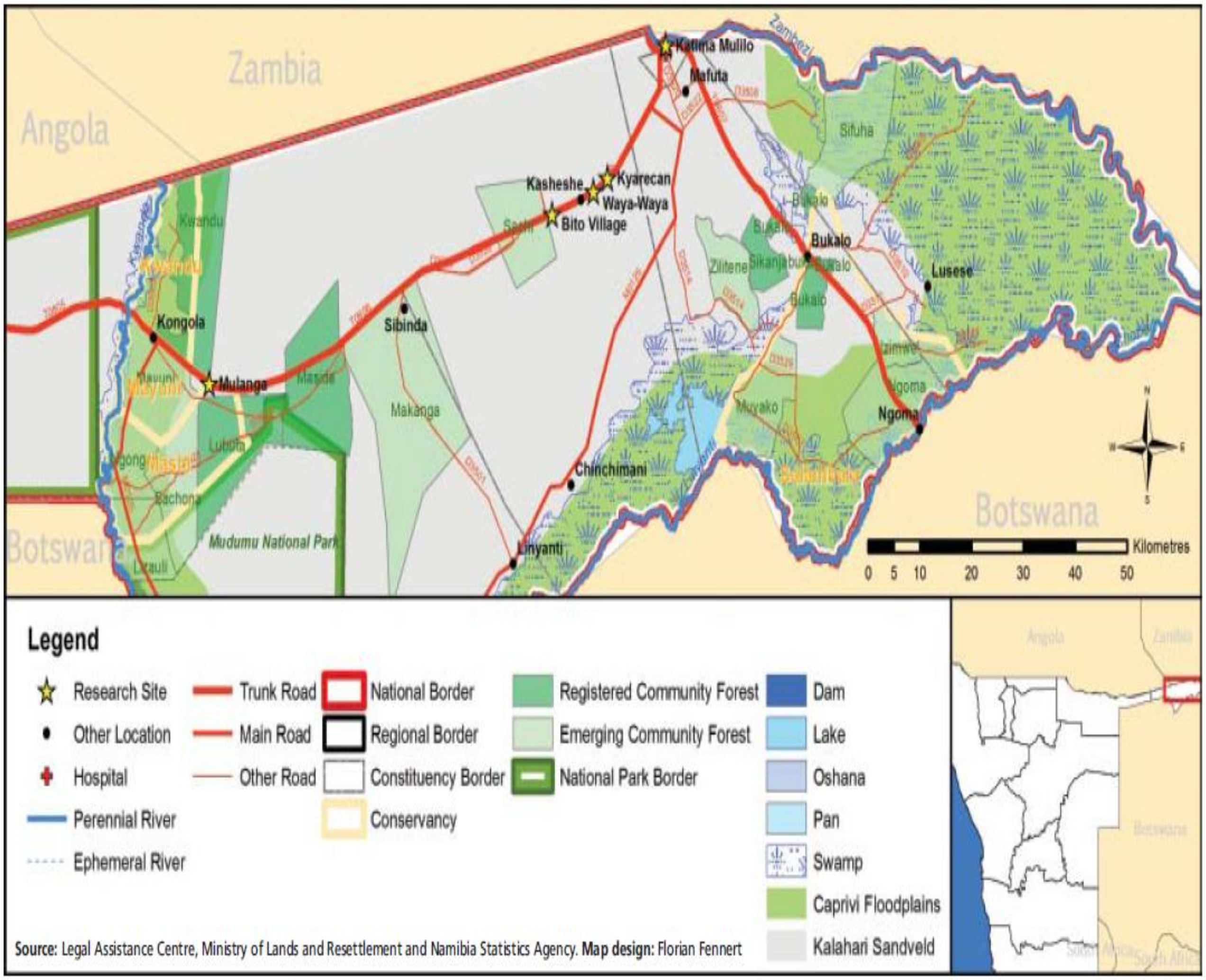


Figure 2.1.3: Zambezi Forest, national parks, others land cover types: (JONES & DIECKMANN, 2013:400)

The major driving forces of settlement land expansion are population growth and economic development (HASSAN et al. 2016: 9). Though, it has been argued in the past that, neither population nor poverty alone constitute the sole and major underlying causes of land-cover change worldwide. Peoples' responses to economic opportunities, as mediated by institutional factors, drive land-cover changes (LAMBIN, TURNER, GEIST, AGBOLA, ANGELSEN, BRUCE & COOMES 2001: 261). People guided by national markets create opportunities and constraints for new land uses. Global forces become the main determinants of land-use change, as they amplify or attenuate local factors (LAMBIN et al. 2001).

2.4. Deforestation

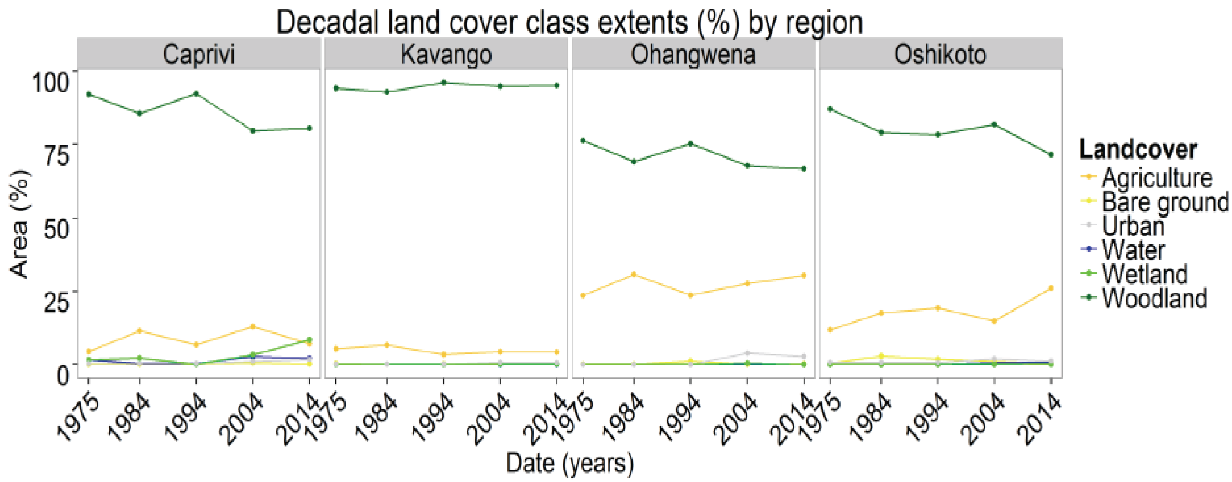
The conversion of forest and barren land to settlement land can cause varied and extensive environmental degradation (HASSAN et al. 2016: 9). HÜBLER (2017: 374) revealed that the forest cover and density of the Southeast Asian Mekong region (Laos and Cambodia) have declined during the last decades, and that forests have been cleared or replaced by scrubland. HÜBLER (2017: 374) notes that Cambodian forests will further decline in the future (cited in MICHINAKA et al. 2015). This indicates that, deforestation is a spatial process occurring in phases that one can map at local, regional, and country scales (DAWSON, KOUADIO & MENDOZA 2016: 399).

Clearing of forests and construction of large dams are perhaps among the best-known cases that damage the environment (SASSEN 2015). Other factor that has a strong negative impact on forest area change are high agricultural population density within poor agricultural land and road construction (MIYAMOTO 2020). ADNAN et al. (2018: 89) discovered that deforestation drivers in Tehsil Barawal, Dir Upper, Pakistan include agricultural practices, fuel forest collection, illegal cutting/harvesting, encroachment, and forest fire. Deforestation can occur in protected areas such as national parks when the communities residing in such areas abandon non-productive agricultural land and migrates to other areas with typical conditions (MUCOVA, FILHO, AZEITEIRO & PEREIRA 2018: 11). When such communities settle in new areas, they use fire to clean lands and cut down trees to construct their dwelling units, those activities result into deforestation. Other circumstances where deforestation can occur in protected areas are more liked to tourism. A study by NAKANYALA, HIPONDOKA and GRAZ (2015) concluded that, at the Etosha National Park in Namibia, an unrestricted development of roads is negatively correlated to vegetation cover.

Poor forestry policy implementation and management of forests can also lead to deforestation. For instance, according to DAWSON, KOUADIO and MENDOZA (2016: 398), the mechanism of defining, positioning and exploiting the logging perimeters and relegating portions of forest to waste and neglect was an important cause of the depletion of the Ivoirian Forest. In Kenya a national forest policy failed due to lack of political good will and poor governance structures that imposed lenient penalties to illegal forest destructors (MAINA 2019: 6-7). Hence, national forestry policies can turn managerial units (forestry regulations) into tools for deforestation instead of instruments for sustainable forestry (DAWSON, KOUADIO & MENDOZA 2016: 413).

Deforestation over the decades has been blamed on poverty mainly among agricultural populace (MAINA 2019; MIYAMOTO 2020). According to HENDERSON and LOREAU (2018: 5) as human population increases (e.g., in rural settlements), there is an increase in land change. Large areas of land are needed for agricultural expansion (e.g., crop cultivation) to meet the needs of a new large population. For instance, ANTROP, VAN DE VELDE and VAN EETVELDE (2010: 101) discovered that many rural settlements in the province of Antwerp in Belgium are surrounded by a fringe of arable land and, further away from settlements, there is animal grazing land. The human population acts as a multiplier of activities, such as consumption, environmental damage, and land conversion from forest to settlement areas (HENDERSON & LOREAU 2018: 5).

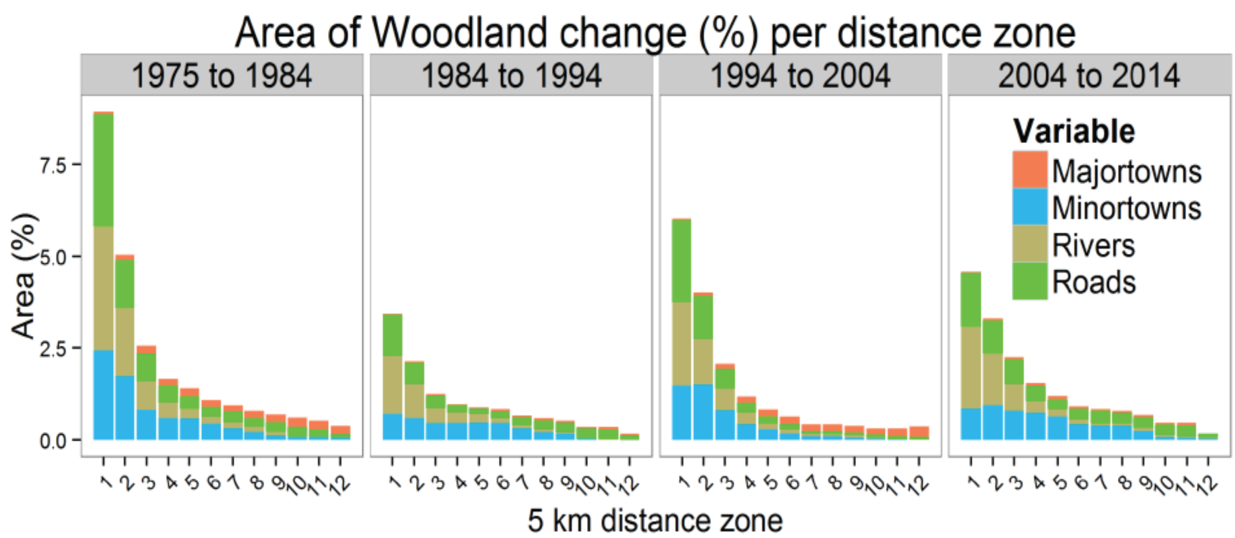
Figure 2.2.1 below reveals that, woodland in the Zambezi region (Caprivi) have declined from 92.06% in year 1975 to 80.56% in 2014. In Kavango an increase from 94.15% to 95.04 was observed. Decline in woodland in the Oshikoto and Ohangwena regions is linked to the expansion of agriculture land. In the Zambezi region, increase of wetland is the prominent factor that led to the reduction of woodland. The expansion of urban land has also significantly contributed to woodland decline in the Ohangwena region.



Landcover	Location	1975	1984	1994	2004	2014
Woodland	Caprivi	92.06	85.55	92.40	79.61	80.56
Woodland	Kavango	94.15	92.96	96.08	94.83	95.04
Woodland	Ohangwena	76.33	69.16	75.22	67.85	66.75
Woodland	Oshikoto	87.08	79.04	78.32	81.78	71.50

Figure 2.2.1: Namibia decadal land cover extents by region 2075-2014: (WINGATE, 2015:10)

Figure 2.2.2 below indicate that between 1975 and 1984, towns, roads and rivers were negatively correlated with woodlands in the Zambezi, Kavango, Ohangwena and Oshikoto regions of Namibia. This means that, the closer to towns, roads or rivers the more likely change/depletion in woodland (deforestation). As the distance from towns, roads or rivers increases, the less the amount of deforestation expected. Between 2004 and 2014, change in woodland was positively associated with major towns. This indicates that, major towns did not significantly contribute to deforestation. Key factors considered when choosing land for human settlement are aligned to the existence of basic conditions and resources such as rivers, natural wells, food, suitable land for agriculture and easy access to roads (MUCOVA et al. 2018: 11). Most of the factors linked to human settlements are negatively associated to the existence of forests. GBAGIR et al. (2019) observed that, in the Zambezi region between 1982 and 2015, there was a high rate of the vegetation cover change mostly around road infrastructures with high population densities. The main drivers of vegetation cover change in the region were subsistence farming, infrastructure expansion, including settlements, and (il)legal wood extraction for firewood.



	Variable	Date	r	Date.1	r.1	Date.2	r.2	Date.3	r.3
1	Minor towns	1975-1984	-0.77	1984-1994	-0.92	1994-2004	-0.75	2004-2014	-0.93
2	Rivers	1975-1984	-0.65	1984-1994	-0.70	1994-2004	-0.65	2004-2014	-0.67
3	Roads	1975-1984	-0.68	1984-1995	-0.75	1994-2004	-0.65	2004-2014	-0.83
4	Major towns	1975-1985	-0.26	1984-1994	0.57	1994-2005	-0.74	2004-2015	0.39

Figure 2.2.2: Namibia decadal land cover extents by region 2075-2014: (WINGATE 2015: 12)

2.5. Settlement Development and Deforestation

According to GAO, QIAO and TIAN (2014: 238), rural land development patterns can be influenced by agricultural activities, construction of new transport networks, natural amenities, economic and recreational characteristics of an area. Globally, 48% of deforestation in rural settlements is due to agriculture subsistence cultivating, while 32% is a result of people depending on fuel forest and 14% is due to logging (ADNAN, HUSSAIN & SAJJAD 2018: 89) (cited in THE UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC), 2007). ADNAN et al. (2018: 93) established that from 2000 to 2012, the Tehsil Barawal forest area diminished by 12% and agriculture area expanded by 7%. A study by CHEN, GUO, MA, TIAN and WANG (2017: 13), revealed that due to rural settlement development in Shandan County in a form of cleared land for agriculture expansion, there was conflict between rural settlement development and forest conservation.

GAO, QIAO and TIAN (2014: 238), posit that the major functions of rural settlements are living, farming and forestry production. Establishing houses, farming and forestry production involves the process of cutting down trees which at the end results in deforestation. The expansion and intensification of agricultural and pastoral uses in rural areas has supported high population growth and deforestation (HILL, PRÖPPER, SCHNEIBELA, STELLMESA & RÖDER 2015: 341). In Northern Namibia and Southern Angola, HILL et al. (2015: 352) established that, the conversion from savannah ecosystems to arable land was the most prominent land use transformation process between 1990 and 2010. A study by HILL et al. (2015: 352) revealed that in Namibia, the expansion of the urban agglomeration of Rundu into rural settlements land and the creation of large schemes of irrigation agriculture were additional factors contributing to the conversion of savannah ecosystems to arable land.

KREVS and REBERNIK (2013: 105-6) also note that housing areas in rural settlements are usually bounded by forest and agriculture land. In some cases, the rural settlers usually damage the environment when implementing their rural development projects. For instance, road construction broke the Ivoirian Forest into pieces, while the railway construction cleared about a 20 to 100 m wide path in the forest (DAWSON, KOUADIO & MENDOZA 2016: 399-402) (cited in HOUDAILLE 1905).

Since the 1970s, the Brazilian Federal Government has tried to colonise remote areas in regions which cover most of the Brazilian Amazon (ASSUNÇÃO & ROCHA 2016: 6). Rural settlements in remote areas received subsidised rates on credit and state technical assistance for agricultural projects (ASSUNÇÃO & ROCHA 2016: 6). As such, agricultural activities in new rural settlement areas contributed to deforestation. These rural settlements were responsible for 30% of deforestation in the Amazon Biome (ASSUNÇÃO & ROCHA 2016: 30). Population, road density, climate, rural credit, and agricultural commodity prices, among others were important drivers of forest clearing activities (ASSUNÇÃO & ROCHA 2016: 4).

Government policies which provide financial and technical assistance to farmers located in rural settlements could encourage deforestation, thus, offsetting the impact of conservation policies (ASSUNÇÃO & ROCHA 2016: 4). The total area of settlements in the Amazon Biome climbed from 220 thousand square kilometres in 2002 to 376 thousand square kilometres in 2014, an increase of 70% of settlement land use (ASSUNÇÃO & ROCHA 2016: 13). Despite the known risk of deforestation, the Brazilian Amazon has been deforested at an average rate of 1.89 million hectares per year since 1995, mainly along the main roads (METZGER 2001: 2) (cited in SKOLEAND & TUCKER 1993; LAURANCE 2000). The environmental damages are due to human activities such as timber plantation, mining activities, urbanisation and construction of roads (PAWAR & ROTHKAR 2015: 212; GÜNERALP, PERLSTEIN & SETO 2015: 539).

ADELI, MOAYERI, MOTLAQ and PARSAKHOO (2018: 316) discovered that forest clearance through land use changes and shifting cultivation practices is closely linked to the distance to roads and settlements. (ADELI et al. 2018: 316) (cited in GAO, LIU 2012; DU et al 2014) discovered that deforestation in China is associated with infrastructural parameters such as the location of rivers, roads and settlements. ADELI et al. (2018: 317) concluded that as road and housing density increases, forest landscapes become increasingly fragmented and smaller. Consequently, forest extent is positively correlated with distances to main roads and negatively with road quality and there are more disturbances to forests closer to roads (ADELI et al. 2018: 317). In their study, ADELI et al. (2018: 317), conclude that cultivation and settlement development are the strongest influential factors on forest extent reduction.

BURGDORFER and LÓPEZ-CARR (2013), contend that high population growth rates will constantly persist in remote rural settlements and will have notable implications for land cover change. They note that small scale farmers in rural settlements continue to be the main cause of deforestation in Latin America (BURGDORFER & LÓPEZ-CARR 2013). MEYERSON (2004) discovered that as agriculturally based population density increases in and near forested areas, deforestation is likely to occur. When local people arrive at the forest frontier, they are likely to clear land for subsistence farming (MEYERSON 2004). The contrary was observed by LE TOURNEAU and TRITSCH (2016) who discovered that the "deforested human deserts" pattern of Brazil's Amazon accounted for almost one third of the total deforestation, highlighting that the Amazon deforestation cannot be viewed as a result of a population pressure. Hence, regions with high population densities had little deforestation compared to regions with low population density (LE TOURNEAU & TRITSCH 2016).

The amount of forest cleared highly depends on the soil fertility, as the lower the soil fertility, the lower the agricultural production per hectare, and the more land area to be cleared (BURGDORFER & LÓPEZ-CARR 2013). Commercial farmers are likely to establish their crop cultivations in high fertile soil, thus reducing the number of areas cleared for cultivation. Small scale farmers are likely to lack the necessary equipment to identify high fertile soil thus ending up clearing large areas of land with low soil fertility (BURGDORFER & LÓPEZ-CARR 2013). Besides, small scale farmers can easily expand their farms by clearing more forest and practising none-intensive agriculture while export industrial agriculture is typically characterised by large rectangular clearings that are spaced closely together and are almost completely denuded of trees (BURGDORFER & LÓPEZ-CARR 2013).

ALKAN (2009: 369) examined the negative impact of rural settlements on natural resources in one of the protected areas (Kovada lake national park) in Turkey. The study revealed that, nomadic livestock caused over-grazing flora, and residents in settlements closer or in the protected area were using wood and none-wood forest product illegally (ALKAN 2009: 369). ALKAN (2009: 369) noted that, residents cleared sections of protected forests to build their houses, which is one of the most prevalent activities during settlement development. Likewise, in Namibia the lack of full governmental involvement in the management of community forest resources is one of the main contributors to deforestation around settlement areas (NIKODEMUS & HÁJEK 2015). This is because the local populace manages community forests, at the same time they are also the main beneficiaries of the forest resources.

CAVIGLIA-HARRIS and HARRIS (2011) investigated the impact of settlement design on tropical deforestation rates and the resulting land cover patterns. They discovered that, there are differences in the rates of deforestation that can be attributed to settlement design. Differences in deforestation per settlement design were only significant in the short run as all designs which were implemented met both environmental (conservation) and social (settlement development) objectives at a later stage (CAVIGLIA-HARRIS & HARRIS 2011: 466-7). This indicated that settlement design does not significantly influence land cover changes (CAVIGLIA-HARRIS & HARRIS 2011: 467). CAVIGLIA-HARRIS and HARRIS (2011: 467) also discovered that independent of the shape and size of settlement properties, land-clearing was extensive and was influenced by the household and property life cycles.

ATESOGLU, BUYUKSALIH and TUNAY (2002) established that, the Bartin forests in Turkey have been damaged by converting them to agriculture and settlement areas. Agricultural activities which are done without the necessary soil conservation measures cause the forest areas near to settlement areas to face recession and consequently cause damages to existing natural resources (ATESOGLU et al. 2002).

2.6. Forest Conservation

According to PAWAR and ROTHKAR (2015: 212), forest conservation involves the upkeep of the natural resources within a forest. Forests are vital for human life, as they store carbon and produce oxygen which is vital for existence of life on earth; but still there is a rapid depletion of forest cover (PAWAR & ROTHKAR 2015: 212). This is because keeping the balance between objectives of conservation and socio-economic development can be a challenge when combating both deforestation and rural poverty (NIKODEMUS & HÁJEK 2015; NAKANYALA et al. 2015). For instance, in China, a high rate of urbanisation resulted in urban land-cover changes negatively impacting animal habitats that are critical for biodiversity (GÜNERALP et al. 2015: 533).

GÜNERALP et al. (2015: 541) discovered that as urbanisation progresses large areas within the biodiversity hotspots and more land near nature reserves are likely to be affected by urban expansion. GÜNERALP et al. (2015: 538) forecasted that the amount of urban land within 50 km of the Protected Areas (PAs) will increase on average, nearly 150% by 2030 across China. According to METZGER (2001: 2), the deforestation of Brazils' Amazon tropical forests is one of the main sources of greenhouse gases (cited in LAURANCE et al. 1998, FEARNSIDE 2000). Deforestation is also the main cause of species extinction and loss of biodiversity (METZGER 2001: 2) (cited in LAURANCE et al. 1998; LAURANCE & BIERREGAARD 1997).

According to PAWAR and ROTHKAR (2015: 213), solutions to the loss of forest should include management of forest resources by local communities. Forest conservation organisations need to be involved for the restoration of forest goods and services for the benefit of the people and environment (PAWAR & ROTHKAR 2015: 213). According to GÜNERALP et al. (2015: 538) (cited in SHI et al. 2005), cooperation mechanisms among the local and regional land-use planning and conservation agencies would help protect trans-boundary resources under threat due to urbanisation. There is urgent need for strategies to direct urban growth away from forests and to establish land use planning mechanisms requiring the integration of local ecological knowledge into urban growth strategies (GÜNERALP et al. 2015: 539-540) (cited in NIEMELÄ 1999).

Forest conservation efforts can be negatively affected by state laws. For instance, in Brazil, the Legal Reserve (LR) of forestry definition and enforcement has provoked heated debates in the Brazilian Congress (METZGER 2001: 2). This is because of the agricultural groups who want to preserve their right to use their land and want LR to be reduced from 80% to 50 or 20% (METZGER 2001: 2). Another shortcoming to forest conservation efforts in Brazil was revealed by a report by the UNITED NATIONS DEVELOPMENT PROGRAMME (UNDP) (2014b: 4). The report states that although the Brazilian federal structure permits municipalities to assume responsibility for environmental licensing and regulation, it is still likely to offer concessions to large-scale enterprises than to impose environmental constraints (UNDP 2014: 4). Contrary, the Namibia Forestry Strategic Plan (NFSP) is designed to aid the development of community level natural resources management strategy (NIKODEMUS & HÁJEK 2015: 11). NFSP gives a mandate to local communities to manage their own forest resources and to formulate forest management bodies and conservation mechanisms.

Global efforts to reduce deforestation have been rapidly increasing by means such as, the implementation of climate change mitigation schemes, including reducing emissions from deforestation and the role of conservation, sustainable management of forests (MIYAMOTO 2020: 1). Yet, forest conservation efforts are negatively challenged by the high demand of forest products (timber/wood, carvings, and commercial wild fruits) which has contributed to the disappearance of forests particular in Africa (MAINA 2019: 9). Severe deforestation is currently occurring in tropical rainforests due to the high production of palm oil. The global market demand for palm oil in 2019 made 74.6 million tons, with an expected rise of 2.3% by 2027 (EARTH OBSERVING SYSTEM [EOS] 2021).

Developing countries in Africa have used state laws to be instruments which promote the sustainable use of forest resources. For illustration, in Zambia when the timber permit documentation was revised, it led to improvement in the quality of the analysis of timber resources which positively contributed to making sustainable timber resource management decisions (NOTT, NOTT & NEWTON 2020). In Namibia, poor timber permit documentation and implementation led to high levels of uncontrolled and unregulated commercial timber extraction (BROWN 2019).

ATESOGLU et al. (2002) suggested that in order to reduce the deforestation of Bartin forest in Turkey, legal measures should be enforced without any compensation to local communities. Hence, the need to increase deforestation legal sanctions and control mechanisms against forest clearing (ATESOGLU et al. 2002). ALKAN (2009: 370) discovered that, natural resources managers at Turkey Kovada Lake national park and local people have different goals and targets when it comes to conserving protected areas. This is because decision makers are concerned with the conservation of natural resources while the local people may be more concerned with economic benefits from the natural resources (ALKAN 2009: 370) (cited in KANGAS et al. 2006). Differing goals of forestry and local people has led to deforestation taking place in protected areas. For instance, MUCOVA et al. (2018) exposed that, between 1979 and 1999 the Quirimbas National Park in Northern Mozambique lost 31.75% of its vegetation, 9.71% was due to human settlements while 22.04% became non-vegetated areas. Conversely, a study conducted by KAMWI et al. (2017) in the Zambezi Region, Namibia (within protected areas (e.g., national parks, state forest) of Kongola and Sibbinda constituencies) revealed that between 2000 and 2010, shrub land (120,192.75 ha) was converted to forest land while bare land (2.34 ha) was transformed to other land types.

According to HENDERSON and LOREAU (2018: 14), natural and semi-natural land provide water, timber, grazing land and energy. There are numerous ecosystem services such as water and air purification, soil stability, and waste recycling that help regulate human well-being and sustain agriculture (HENDERSON & LOREAU 2018: 14). DAWSON, KOUADIO and MENDOZA (2016: 397) stipulate the need for sustainable harvests and utilisation of forest resources such as trees, and the enforcement of sustainability practices by government legislation and policies. Without natural and semi-natural land and the accompanying services, agricultural land cannot be maintained (HENDERSON & LOREAU 2018: 14). There is a need to practise sustainable agricultural because once natural land is degraded, the demand for resources and ecosystem services will be too great and may result in a human population decline (HENDERSON & LOREAU 2018: 5). There is a need for a stable development of rural settlements, as a balance between conservation and the needs of the rural community need to be realised (LV & ZHANG 2014: 121; ELLIS & ROY 2008: 2).

HÜBLER (2017: 376) aptly asserts that education is a critical factor in mitigating poverty related deforestation in Southeast Asian Mekong region. This indicates that there is a negative correlation between education and deforestation; when the education level ascends, deforestation declines. MIYAMOTO (2020: 1) established that poverty-reduction strategies can represent sound and effective methods for reducing tropical deforestation. For instance, when rural settlements engage in tourism activities to combat poverty, the result is a reduction in deforestation and forest conservation is prioritised. According to RAJOVIĆ and BULATOVIĆ (2012: 176), biogeography tourism in rural settlements where plants and animals are expressed as the direct and indirect tourism value are dominated by forest cover. People in such areas take measures to protect their forest, as their tourism activities are highly dependent on the forest land cover changes.

Chapter 3: Research Methodology

3.1. Description of the Study Area

Sibbinda settlement was randomly sampled from a list of all Zambezi sub regional growth points (Chinchimane, Kongola, Lusese, Ngoma, Sangwali, Bukalo and Sibbinda). The study area is located (17.7832° S, 23.8258° E coordinates) 60 km west of Katima Mulilo town in the Zambezi region north-eastern part of Namibia. It is the district capital of Sibbinda Constituency in the Zambezi Region (previously known as Caprivi Region). Figure 3.1.1 indicates the location of the study area.

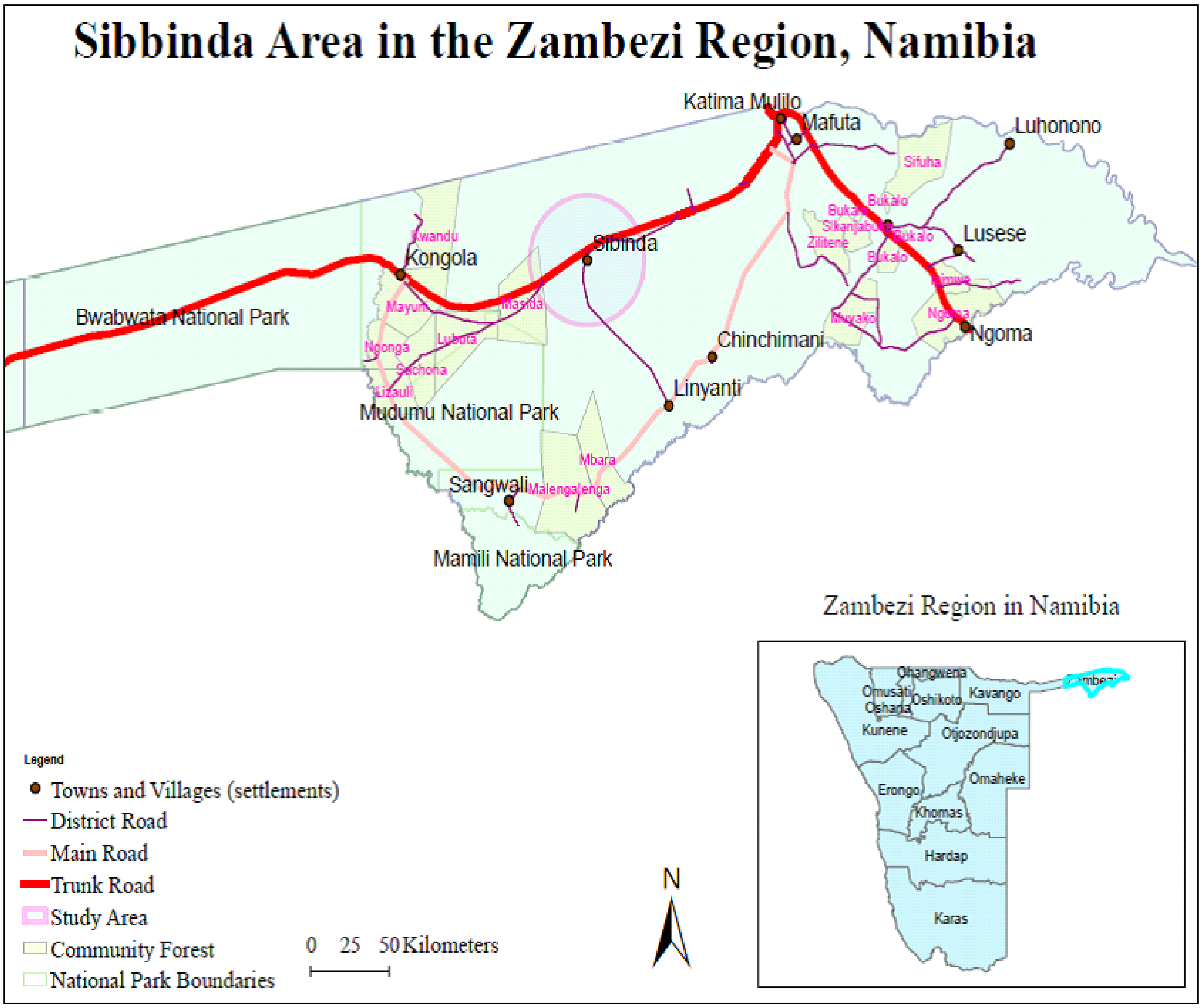


Figure 3.1.1: Study Area: (Authors own, data NSA 2020)

Physical Geography of Sibbinda

Sibbinda settlement is surrounded by Mopane and Kalahari woodlands (MENDELSOHN & ROBERTS 1997: 5). The amount of land in the Zambezi region covered by forest increased significantly between year 1991 and 2010, whilst crop/grass land decreased (KAMWI, CHIRWA, MANDA, GRAZ & KA¨TSCH 2014). Sibbinda receives an annual average rainfall of between 600 and 650 mm (MENDELSOHN & ROBERTS 1997: 6)

Population Characteristics

Sibbinda settlement had a total population of 463 in 2011 (NSA, 2017). The settlement has a balanced sex ratio of 100 males per 100 females; 14% of the people are aged below 5 years, 26% are aged between 5 and 14 years, 52% are aged between 15 to 59 years while 8% are aged 60 years and above (NSA 2014). The literacy rate is at 75%, and 25% of the people never attended school, 53% left school and 19% were still in school in year 2011 (NSA 2014). The population growth rate between 2001 and 2011 was recorded at 11% (NSA 2014). Most of the people who reside at Sibbinda settlement are from the Mafwe tribe and they communicated mainly in Sifwe language. The land is administered under the communal Mafwe traditional authority.

Economy

People's main source of income at Sibbinda is farming as 38% of the people earn their income through farming, 13% of the people's source of income is wages and salaries, 3% is cash remittance, 17% is businesses (none farming), 21% of the people's source of income is old age social government pension (NSA 2014). The employment rate was reported at 57% during the 2011 national population census; 93% of the people had access to safe drinking water, 88% had no toilet facility, 9% used electricity for lighting and 94% used wood/charcoal for cooking (NSA 2014). Sibbinda settlement is a key service area within Sibbinda constituency. According to the TENDRING DISTRICT COUNCIL (2008: 22) a key service centre is a large village with a good level of services, which includes:

- A primary and secondary school within the settlement.

• Easily accessible by frequent public transport to higher order settlements.

• Primary health care facilities.

• Local employment opportunities; and

• A range of retail and service provision capable of meeting day-to-day needs, for convenience shopping.

3.2. Research Design and Conceptual Framework

Research Design

This study applied a research methodology based on the positivism philosophical approach where change detection analyses was employed (AITKEN & VALENTINE 2006). The study also applies systematic prospective and spatial/regional approach by predicting future land cover changes and deforestation at the Sibbinda settlement. Predictive analyses were based on the past and present trends of land cover changes in relation to patterns and processes linked to man-environmental relationship. According to JADHAV (2019: 6-8), systematic prospective approach is concern with future but the past and present is considered as a relict feature for future probability need. Spatial/Regional approach is basically related to patterns and processes by considering man-environmental relationship (JADHAV 2019: 6-8).

Change detection analysis was used to calculate the rate of changes of land use/land cover from 1991 to 2031. Change detection analysis was conducted using aerial photographs or satellite imagery (image Landsat data) from the United State Geological Survey site. In terms of quantifying the amount of deforestation attributed to each rural development factors and for future prediction of LUCCs, a model integrating regression, Markov chain and cellular automata was used. CA-Markov is a combined Cellular Automata and Markov Chain land cover prediction procedure that adds an element of spatial contiguity as well as knowledge of the likely spatial distribution of transitions to the Markov chain analysis.

Three main processes followed were, creating CA-Markov model, validation of the model, and making predictions. The 2001 and 2011 imagery of the study area was used to forecast LUCCs of the study area in 2021 which was compared to the actual imagery for 2020 during the validation process. The model established was used to predict LUCCs of the study area in year 2031.

A hybrid spatial-temporal CA-Markov model was preferred since it has been widely employed in predicting changes in land use and land cover. The Markov chain process controlled temporal dynamics among the land use and cover classes based on transition probabilities, while the spatial dynamics were controlled by local rules determined by the cellular automata spatial filter (EID, HAMDY, OSMAN, SALHEEN & ZHAO 2016: 4).

Conceptual Framework

Figure 3.2.1 indicate that, the study explored rural settlement development in a form of human activities (land cleared for agricultural and human settlement purposes) and the impact of road networks on land cover changes at the Sibbinda settlement. Regression analysis was applied to quantify the contribution of road networks, land cleared for settlement purposes, and building construction to deforestation.

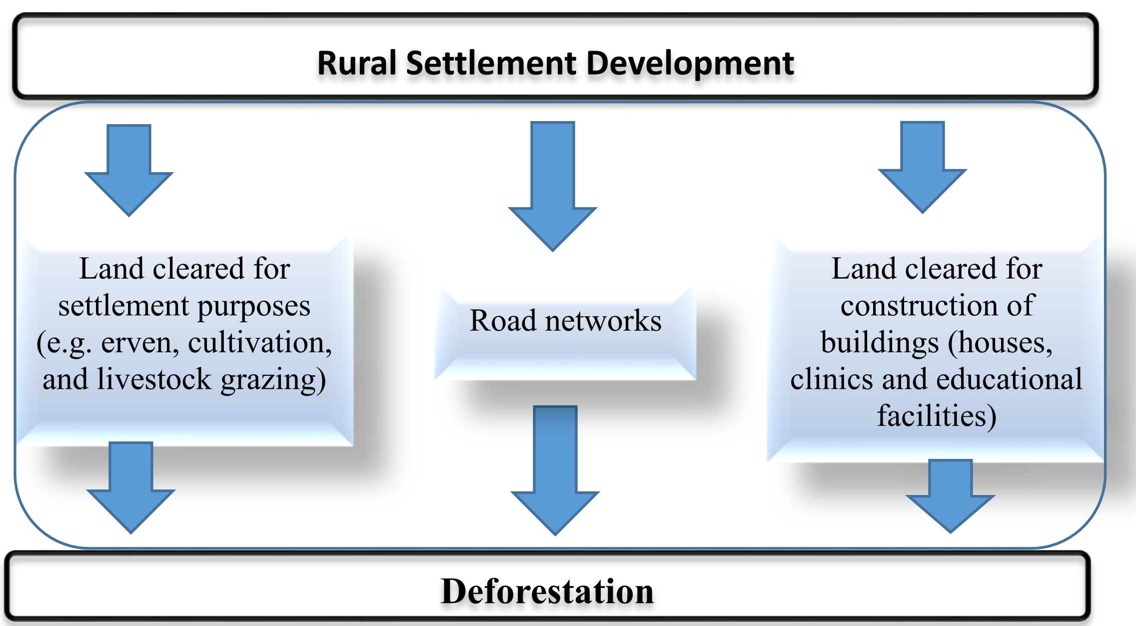


Figure 3.2.1: Conceptual Framework: (Author's own, 2019)

3.3. Background on Technics and Methods applied in the Study

The Markov analysis of land use change can be combined with GIS to create a tool for visualising and projecting the probabilities of land use change among categories of land use (EL-HALLAQ & HABBOUB 2015: 83). A study by HUSSIN et al. (2014) produced a framework for monitoring and evaluating land-use and land-cover changes in Kirkuk city, Iraq. PARSA and SALEHI (2016) applied the Spatio-temporal analysis and simulation pattern of land use/cover changes of Naghadeh in Iran. Urbanisation and urban growth were identified as a major issue throughout the many regions of the world (PARSA & SALEHI 2016: 43) (cited in SAMAT, HASNI & ELHADARY 2011; ZANGANEH & SHAHRAKI et al. 2011). Unplanned urbanisation and urban growth can result in numerous consequences and problems such as destruction of fertile agricultural lands, conversion of bare and range lands into human built environments (PARSA & SALEHI 2016: 43-4) (cited in QUAN et al. 2015; SHALABY & TATEISHI 2007; YU, ZANG, WU, LIU & NA 2011). PARSA and SALEHI (2016) discovered that agricultural land coverage increased by 25.84% during 2000 to 2014 while the share of urban area increased by 2.22% during 2000 to 2014, suggesting an ascending trend in the development of urban areas.

EL-HALLAQ and HABBOUB (2015) predicted the shape of the Dead Sea using the cellular automata-markov analysis and multi criteria evaluation. 1984 and 2000 imageries were used to predict the sharp of the Dead Sea in 2010 (EL-HALLAQ & HABBOUB 2015: 92). Prediction results of the 2010 imagery were compared to the actual 2010 imagery where the standard Kappa index was used to check whether the model is valid or not (usually the Kappa Index for a valid model is >70%). The model used to predict the 2010 Dead Sea sharp was used to predict the sharp of the Dead Sea in year 2020, 2030 and 2040 (EL-HALLAQ & HABBOUB 2015: 93). EID et al. (2016), applied a hybrid CA-Markov model in predicting urban growth based on the growth pattern of previous years of a northern Abouelreesh village located in the province of Aswan, in southern Egypt (EID et al. 2016: 4).

3.4. Materials and Methods

Multi-temporal Landsat imageries can be used to determine the temporal dynamics of land use and land cover change (KAMWI et al. 2017). Hence, Landsat imageries for year(s), 2001 (January 2001), 2011 (January 2011) and 2020 (December 2019) were downloaded from the website (https://glovis.usgs.gov/app?fullscreen=1#) of the United States Geological Survey (USGS) (2020). Imageries from year 2001 and 2011 were acquired using Landsat 5 Thematic Mapper (TM) sensors while 2020 imageries were attained using Landsat 8 Operational Land Imager (OLI) and Thermal Infrared (TIR) sensors. Landsat 5 imageries consisted of seven bands, with band 1-3 representing the visible spectral bands namely blue (with wavelength 0.45-0.52 micrometre (µm)), green (0.52-0.60 µm) and red (0.63-0.69 µm) respectively (USGS 2021). Band 4 (0.76-0.90 µm) and band 5 (1.55-1.75 µm) are the near-infrared bands while the mid-infrared band is represented by band 7 (2.08-2.35 µm). Band 6 (10.40-12.50 µm) is the only thermal band with 120 meters(m) spatial resolution while other bands all have a 30 m spatial resolution (USGS 2021).

The imageries were conveniently selected in order to fairly compare LULC (Land Use Land Cover) changes during the month(s) (December/January) of the start of the national (Namibia) yearly rainy season (INFO-NAMIBIA 2021). The other criteria considered was that the imageries needed to contain no-to few clouds for effective creation of precise LULC maps of the study area. The selected imageries were also aligned to the national (Namibia) population and housing censuses that are usually undertaken every after 10 years starting with 2001 as the baseline year. Information collected from the national population and housing census reports was used to link population pressure to some of the observed LULC changes derived from the current study results.

All image processing technics and approaches were conducted using IDRISI 17.0, the Selva Edition software, a complete integrated Geographic Information System (GIS) and Remote Sensing (RS) solution (CLARK LABS 2021).

Study area road network displayed in Figure 3.4.1 is derived through the digitisation process based on the false colour composite using 2020 processed imageries (sensor error, atmospheric and radiometric corrected imageries).

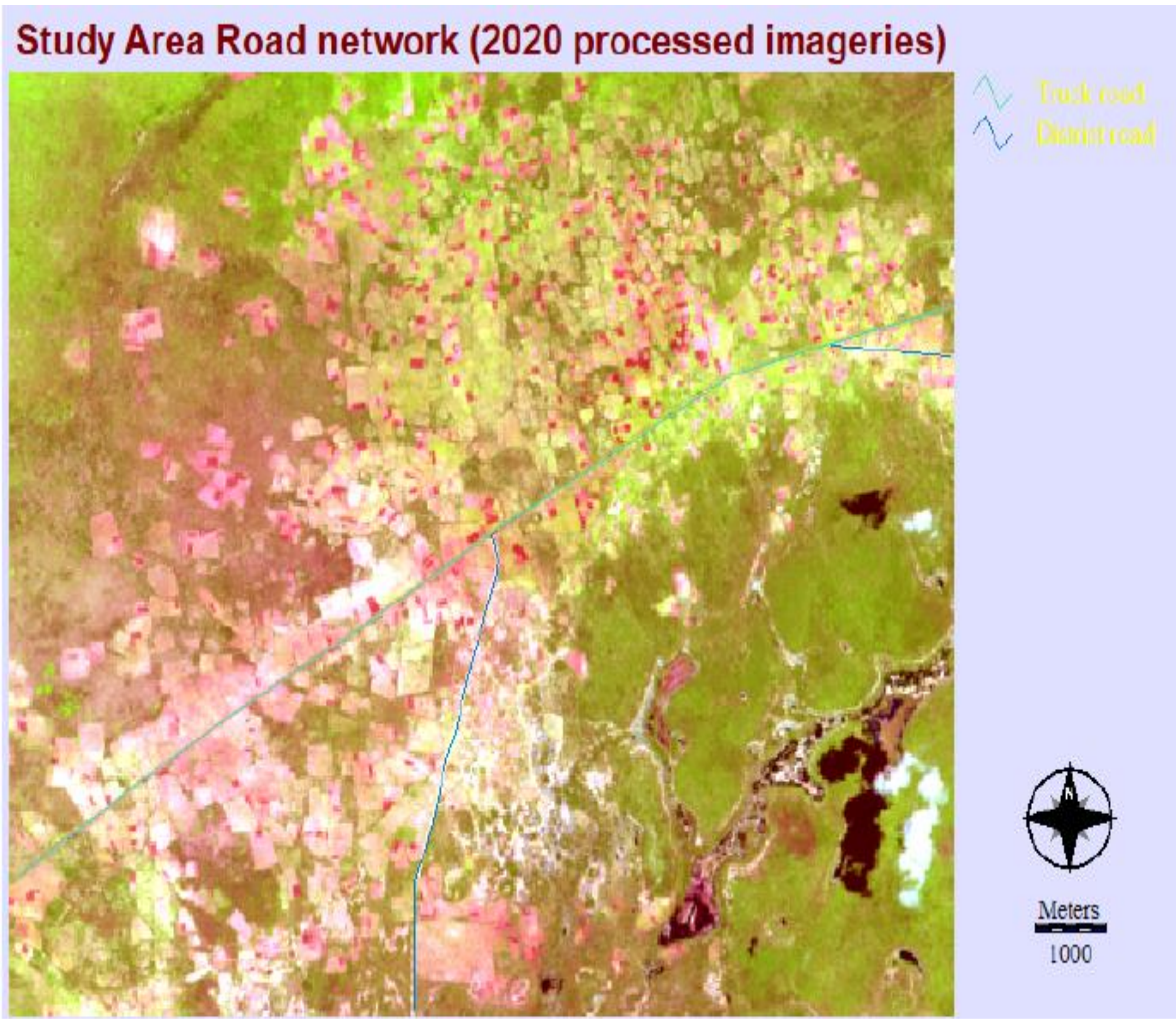


Figure 3.4.1: Study area road network with 2020 processed imageries: (Author's own, data USGS 2020)

3.5. Image Processing

Removing sensor errors and haze

The quality of Landsat imageries acquired during humid condition (e.g., rainy season) are in many cases degraded due to sensor distortion and haze (e.g., dust, mist, fumes and clouds) (XIAO, OUYANG, ZHANG & XIAN 2017: 56; LAN, ZHANG, SHEN, YUAN & LI 2013: 1-2). Haze consists of atmospheric aerosols and molecules that negatively affects the sensor spectral response pattern as the light received by the sensor from scene points is absorbed and scattered by haze (AHMAD, ABDUL GHANI, RAZALI, SAKIDIN & MD HASHIM 2014: 1756; LAN et al. 2013: 1). Sensor errors in terms of incorrect relative detector gains can cause stripes or noise (capturing useless information) which can lead to poor quality or loss of information on the acquired Landsat imageries (USGS 2021). According to (XIAO et al.,2017: 56; LAN et al. 2013: 1; AHMAD et al. 2014: 1756), Landsat imageries captured during haze (e.g., cloudy) conditions with sensors articulating errors need to undergo haze removal and sensor error correction procedures in order to improve the effectiveness of the classification accuracy when generating LULC maps. Hence, the Principal Component Analysis (PCA) technic was used to remove sensor errors and haze from the Landsat imageries applied in this study.

Seven bands (1-7) for both Landsat 5 and 8 was applied in the PCA T mode tool to generate seven components. T-Mode is the appropriate method if the goal of the analysis is to find spatial synoptic patterns and when they happen in time (BARREIRA 2011: 1). The PCA T mode technic assisted to determine the number of components that carries the most information of the study area per respective time period. This approach also assisted to assess the correlations among imagery bands, in order to be able to select the right bands for creating false colour imagery composites. LULC studies in many cases apply false colour composites (produced using any band(s) combination other than the vision bands (red, green and blue, representing true colour composites), this is done in order to aid image interpretation/classification to derive accurate LULC maps (HUMBOLDT STATE UNIVERSITY 2019; EOS 2021). This is because true colour composites are usually low in contrast and hazy due to the scattering of blue light by the atmosphere. False colour composites increase spectral separation among bands (due to less effect of the atmosphere) which makes differentiation of features in Landsat imageries less difficult than on true colour composites. In the current study, the bands used to create false colour composite falling within the visible and near infrared wavelength(s) from the PCA procedure were further atmospheric and radiometric calibrated in line with their metadata file using ATMOSC (Atmospheric correction) tool.

The "WINDOW" technic was used to clip the study area from Landsat scene (174072) of 2001, 2011 and 2020 using geographic coordinates (top left X156289.571429, Y-1961078.011094 and at bottom right at X169683.530612, Y-1972570.435816). The study area size is 15 408.09 ha (hectares) with Sibbinda CBD designated at the crossroad (centre of the imagery) of the truck and district roads, original unprocessed 2001 imageries were applied to produce Figure 3.5.1.

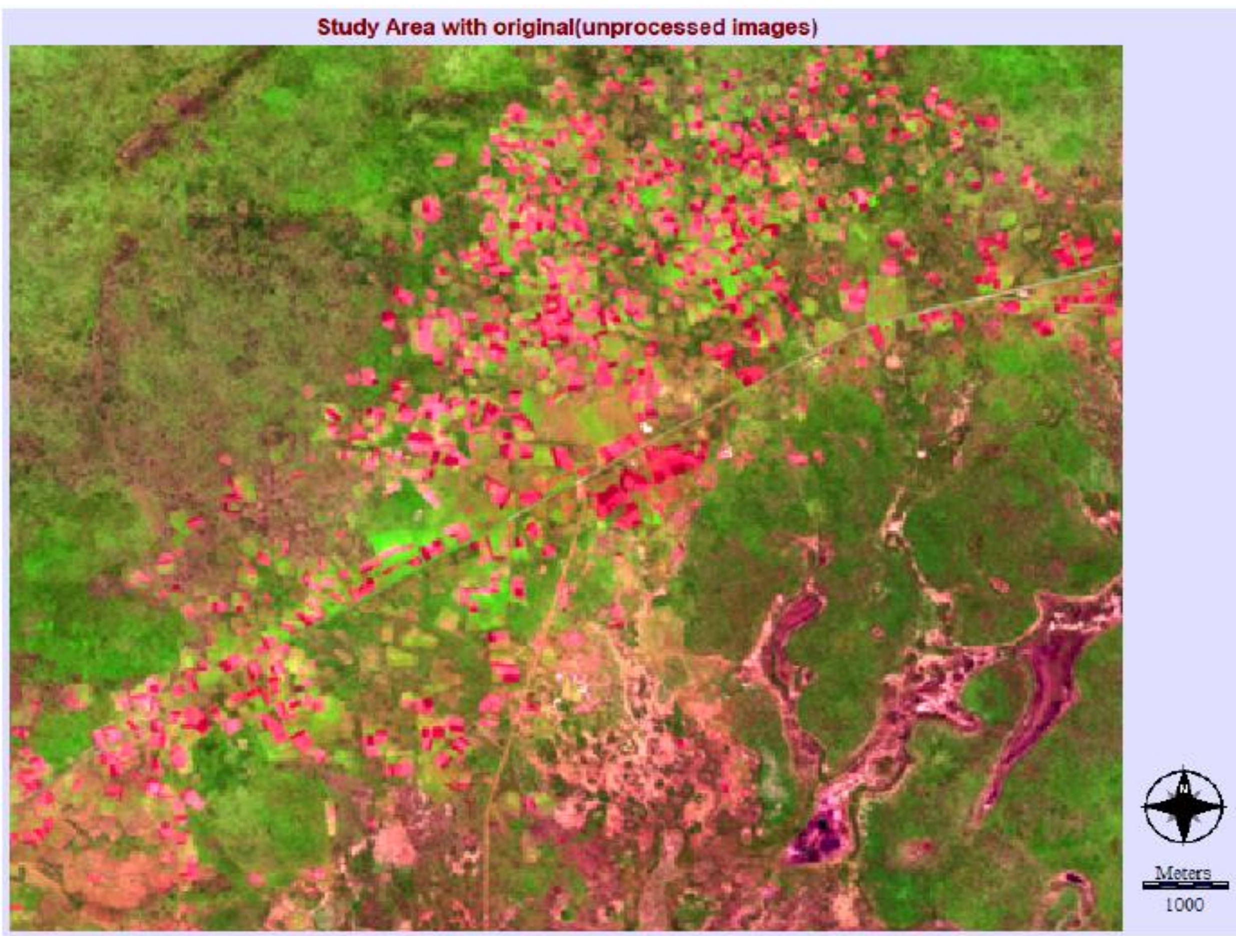


Figure 3.5.1: Study area with original unprocessed imageries: (Author's own, data USGS 2020)

Output from PCA: LT05_L1TP_174072_20010108

Based on the correlation matrix results of the 2001 imageries in Table 3.5.1, the false colour composite was derived. Band 3 (B3) was used to represent the blue band in the composite as it is highly correlated to band 1 at 96%. The near infrared band 4 was used to represent the green band, as it is correlated to band two (B2) at 88%. Band 5 was used to represent the red band, and it is correlated to band three (B3) at 83%. According to YU, DI, YANG, TANG, LIN, ZHANG, RAHMAN, ZHAO, GAIGALAS, YU and SUN (2019), the best three-band combination to generate a false colour composite for LULC studies are bands 4, 5, 6 for Landsat 8 and bands 3, 4, 5 for Landsat 5 TM representing blue, green and the red band respectively. The researchers reached such a conclusion after experimenting with all possible Landsat 8 three-band combination to generate false colour composites for LULC classification studies.

Table 3.5.1: Correlation matrix of the 2001 imageries: (Author's own, data USGS 2020)

T-MODE COR. MATRIX	B1	B2	B3	B4	B5	B6	B7
B1	1	0.98	0.96	0.87	0.80	0.59	0.80
B2	0.98	1	0.98	0.88	0.82	0.60	0.82
B3	0.96	0.98	1	0.86	0.83	0.57	0.85
B4	0.87	0.88	0.86	1	0.88	0.78	0.83
B5	0.80	0.82	0.83	0.88	1	0.86	0.97
B6	0.59	0.60	0.57	0.78	0.86	1	0.78
B7	0.80	0.82	0.85	0.83	0.97	0.78	1

Table 3.5.2 below displays that 98.2% (83.75+11.75+2.67) of information is contained in component 1-3. New 2001 imageries with little haze and no sensor errors were created with only three components using the PCA inverse T mode tool. The same procedure was applied to the 2011 and 2020 imageries (please see APPENDIX A: 2011 and 2020 Output from PCA). Figure 3.5.2 below displays the false colour composite with the new created 2001 imageries through the PCA inverse T mode procedure. The imagery in Figure 3.5.2 has a better contrast/visibility to derive precise study area's LULC types compared to the imagery in Figure 3.5.1.

Table 3.5.2: Components extracted from the 2001 imageries (Author's own, data USGS 2020)

T-MODE COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% VAR.	83.75	11.75	2.67	1.32	0.28	0.18	0.05

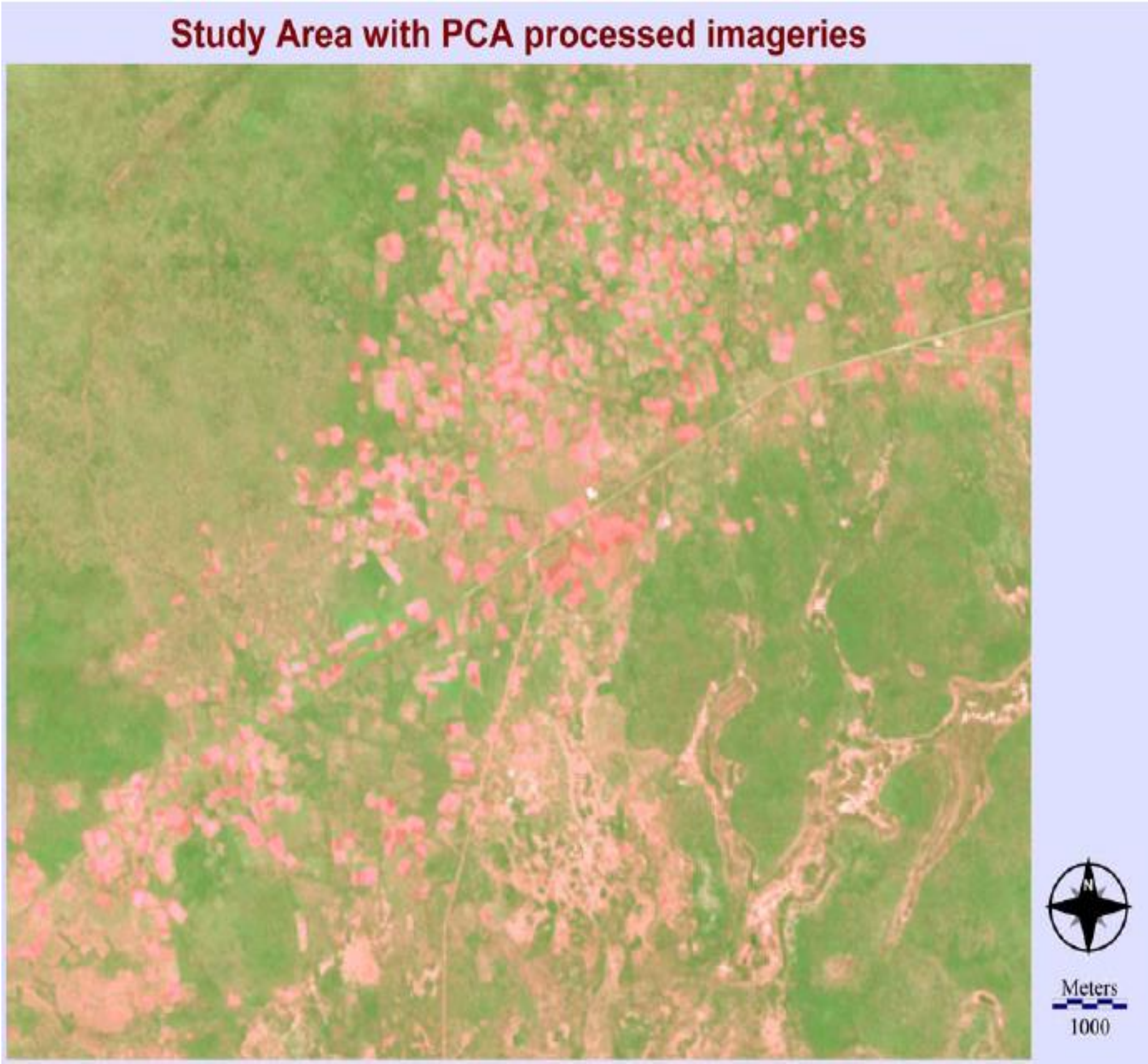


Figure 3.5.2: Study area with PCA processed imageries: (Author's own, data USGS 2020)

Atmospheric/Radiometric Correction

There is a need to perform image pre-processing in a form of atmospheric/radiometric correction on remotely sensed imageries before conducting LULC classification and change detection procedures (VITTEK, BRINK, DONNAY, SIMONETTI & DESCLÉE 2014: 665). Radiometric correction removes the negative atmospheric effects from Landsat imageries leading to having imageries with true surface reflectance values (THEMISTOCLEOUS & HADJIMITSIS 2008: 9). In this study, radiometric calibration was one of the most important imagery pre-processing procedure undertaken to enhance the quality of the Landsat imageries before conducting the LULC classification exercise. Atmospheric correction was done using the Cost model, an image-based absolute correction method which uses only the cosine of sun zenith angle (cos (TZ)) as an acceptable parameter for approximating the effects of absorption by atmospheric gases and Rayleigh scattering (MAHINY & TURNER 2007: 363).

In the ATMOSC (atmospheric correction) tool, the resulting 2001, 2011 and 2020 imageries (haze removed and sensor error corrected imageries) from the PCA inverse T mode procedure were applied. Atmospheric correction was only conducted for the vision and near infrared bands (band 3 and 4 for Landsat 5; band 4 and 5 for Landsat 8 imageries as such bands are acquired from the recorded shortwave radiation which is highly absorbed or scattered by atmospheric aerosols and molecules. Sensors which record electromagnetic radiation from the earth surface using visible or near-infrared radiation are more likely to record values that does not truly represent the true ground-leaving radiation per respective pixel location on a remotely sensed imagery due to the atmospheric effect (THEMISTOCLEOUS & HADJIMITSIS 2008: 10).

The average wavelengths of respectively bands were entered in the “ATMOSC” tool’s atmosphere parameter section as the metadata files of the imageries did not contain specific wavelengths when the imageries were acquired. In the “ATMOSC” tool’s imagery calibration parameter section, offset/gains option was applied, where gain(s) is represented by “RADIANCE_MULT_BAND_x” (values affiliated with bands 3-4 for Landsat 5 and 4-5 for Landsat 8). Offset/Bias was derived from the “RADIANCE_ADD_BAND_x” values, while the sun elevation was entered as specified in the respective imagery metadata files. Figure 3.5.3 presents a false colour composite of the 2001 atmospheric and radiometric corrected imageries with much better contrast (quality) for easy imagery interpretation to guide imagery classification exercise. Appendix B provides 2011 and 2020 unprocessed and processed imageries.

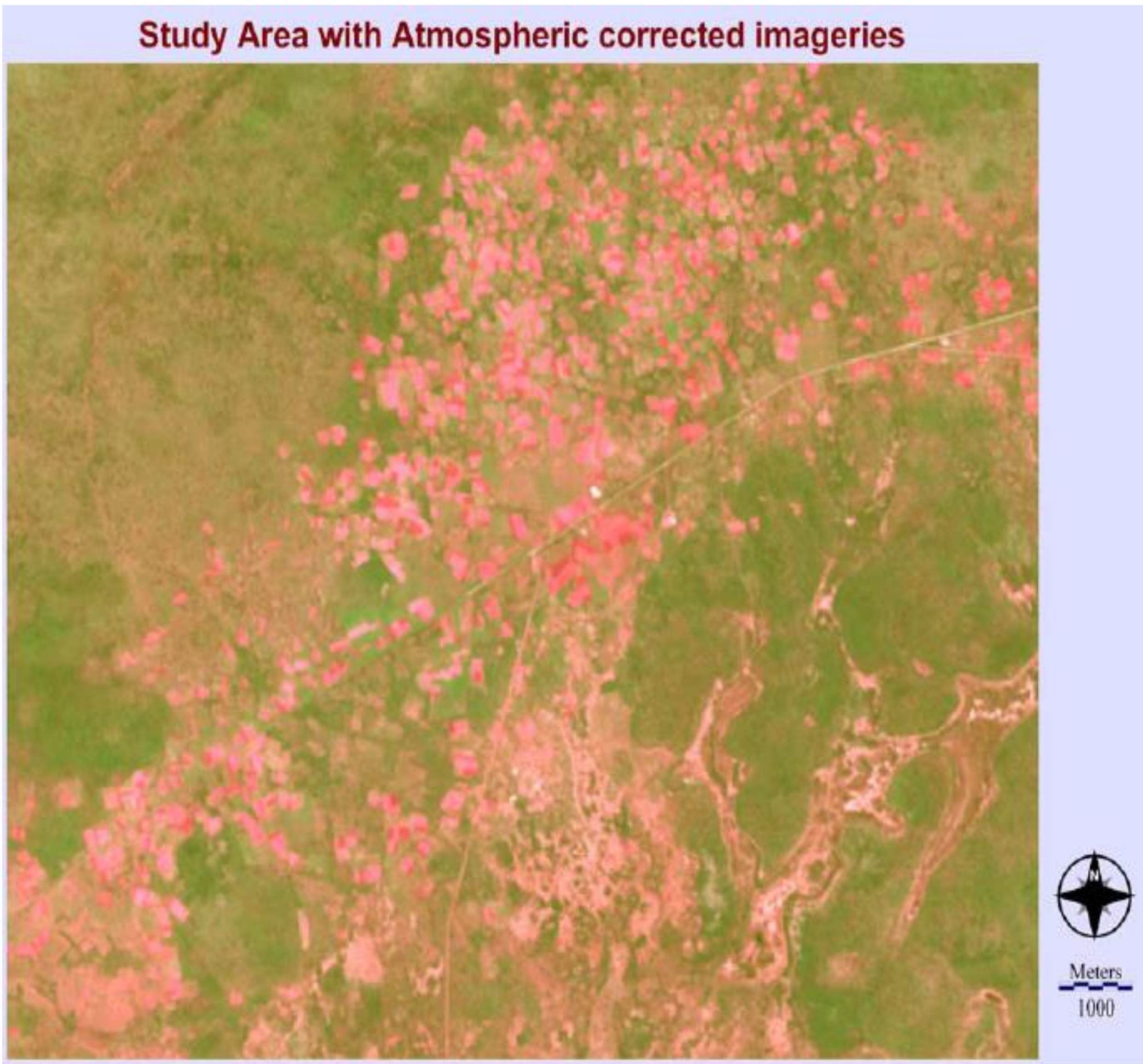


Figure 3.5.3: Study area with atmospheric corrected imageries: (Author's own, data USGS 2020)

3.6. Image Classification Procedure to Produce LULC Types

Landsat imageries can be classified using either the supervised or the unsupervised method, in some cases the combination of both the supervised and unsupervised methods are applied. The unsupervised method is conducted using a computer software without the user applying any initial input (knowledge of the study area) or training the software on the types of LULC which exists in the area (VOLDMAN, ALONSO, FERNÁNDEZ, ORTEGA, ALBANESI, BANCHIG, CARDÓ, MCWILLIAM & TEEUW 2005: 148; MOHAMMADY, MORADI, ZEINIVAND & TEMME 2015: 1518-19). The supervised classification method requires the user to select areas containing pixels of each LULC type and use those pixels to train a computer software to recognise the spectral responses of each LULC type (VOLDMAN et al. 2005: 148). VOLDMAN et al. (2005: 148) and MOHAMMADY et al. (2015: 1518-19) established that, supervised classification has a higher LULC classification accuracy than unsupervised classification method. In this study, a supervised classification method was used to classify the 2020 processed imagery into LULC types as displayed below in Figure 3.6.2. The first step involved creating a digital shape file to select/digitise classification-training sites for different LULC types in the study area, please see Figure 3.6.1. The first class (1) was assigned to vegetation, 2 was assigned to land cleared for settlement purposes (e.g., erven, animal kraal), 3 was assigned to dwelling units or buildings while 4 was assigned to bare soil. Since, the 2020 imagery consisted of few clouds and shadows, 5 was reversed for the identification of clouds and shadows.

The quality of the final classification is very important in providing precise information for developing a landscape-level understanding of deforestation that aid forest conservation decision-making processes (ENDERLE & WEIH 2005: 65). Therefore, the researcher verified and accurately assigned correct LULC types per each respective training site after conducting physical field visits to the study area during December 2019 (where the false colour composite based on December 12, 2019, Landsat 8 imageries were applied). The verified training sites that also featured in the 2001 and 2011 imageries were used as reference points when assigning correct LULC types per each respective training sites of the 2001 and 2011 imageries. This is because physical visits to verify LULC types per training site for 2001 and 2011 imageries was not possible as those imageries were acquired 20 and 10 years ago respectively. Figure 3.6.1 shows the 2020 training sites that were selected and used for generating a classification signature development file using the "MAKESIG" tool. All, three bands (4, 5 and 6 for Landsat 8 and 3, 4 and 5 for Landsat 5 imageries) were processed during the signature development processes.

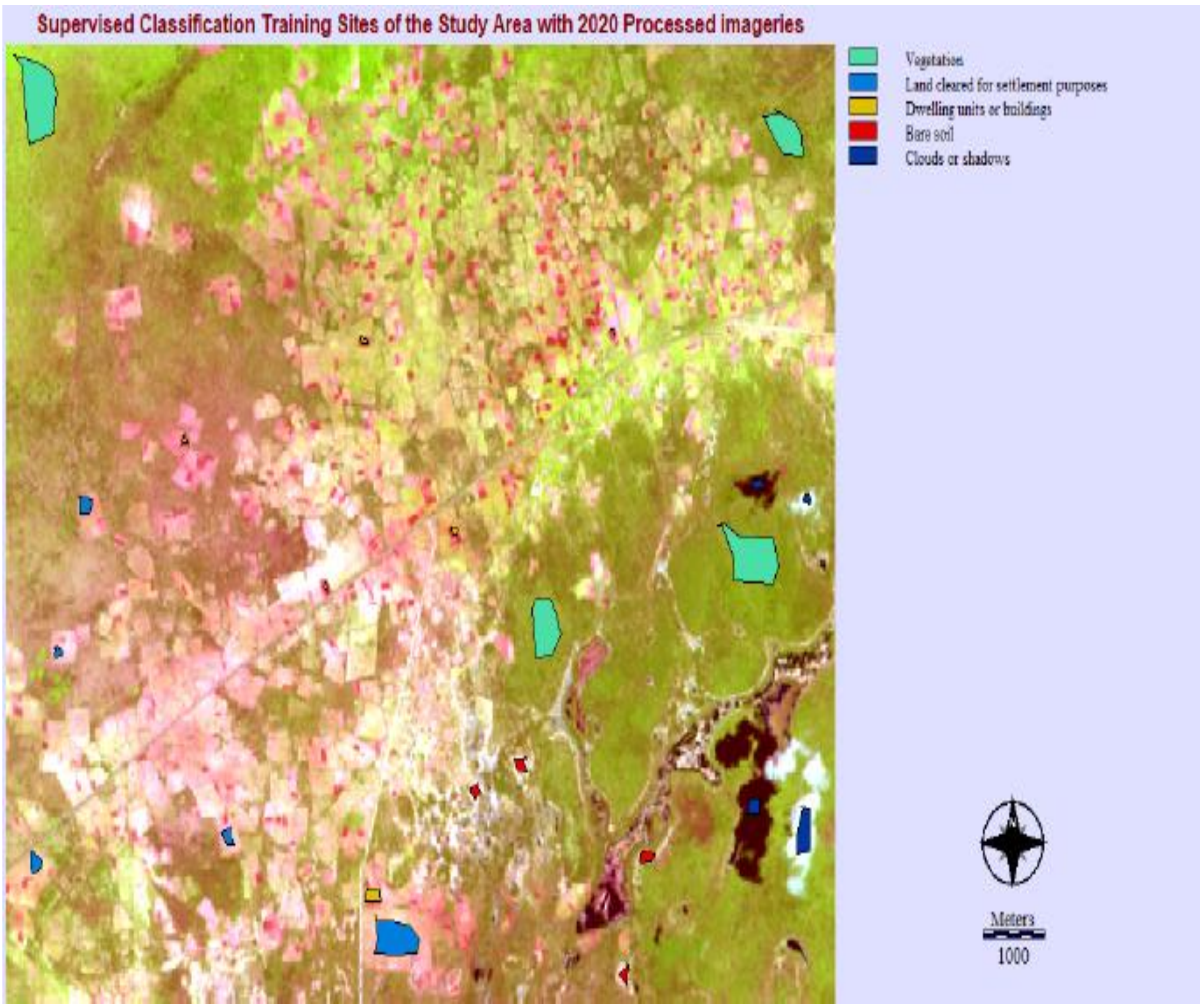


Figure 3.6.1: Supervised classification training sites of the study area: (Author's own, data USGS 2020)

The hard classifier "MAXLIKE" tool was used for the supervised classification procedure. The hard classifier option than soft classifier was preferred in order to assign all pixels to distinct LULC types as identified by the researcher (EASTMAN 2009: 30-31). "MAXLIKE" is a classification procedure that evaluates the probability that a given pixel will belong to a LULC type and classifies pixels to the LULC type based on the highest probability of membership. Since the training sites were verified in relation to the study's LULC types, maximum likelihood classification accurately led to generation of accurate LULC maps of the study area. Figures 3.6.2 to 3.6.4 provides the LULC types of the study areas for year(s), 2020, 2011 and 2001 respectively. 2020 and 2011 LULC classes has an additional category for clouds and shadows while the 2001 imageries had no "clouds or shadows" category.

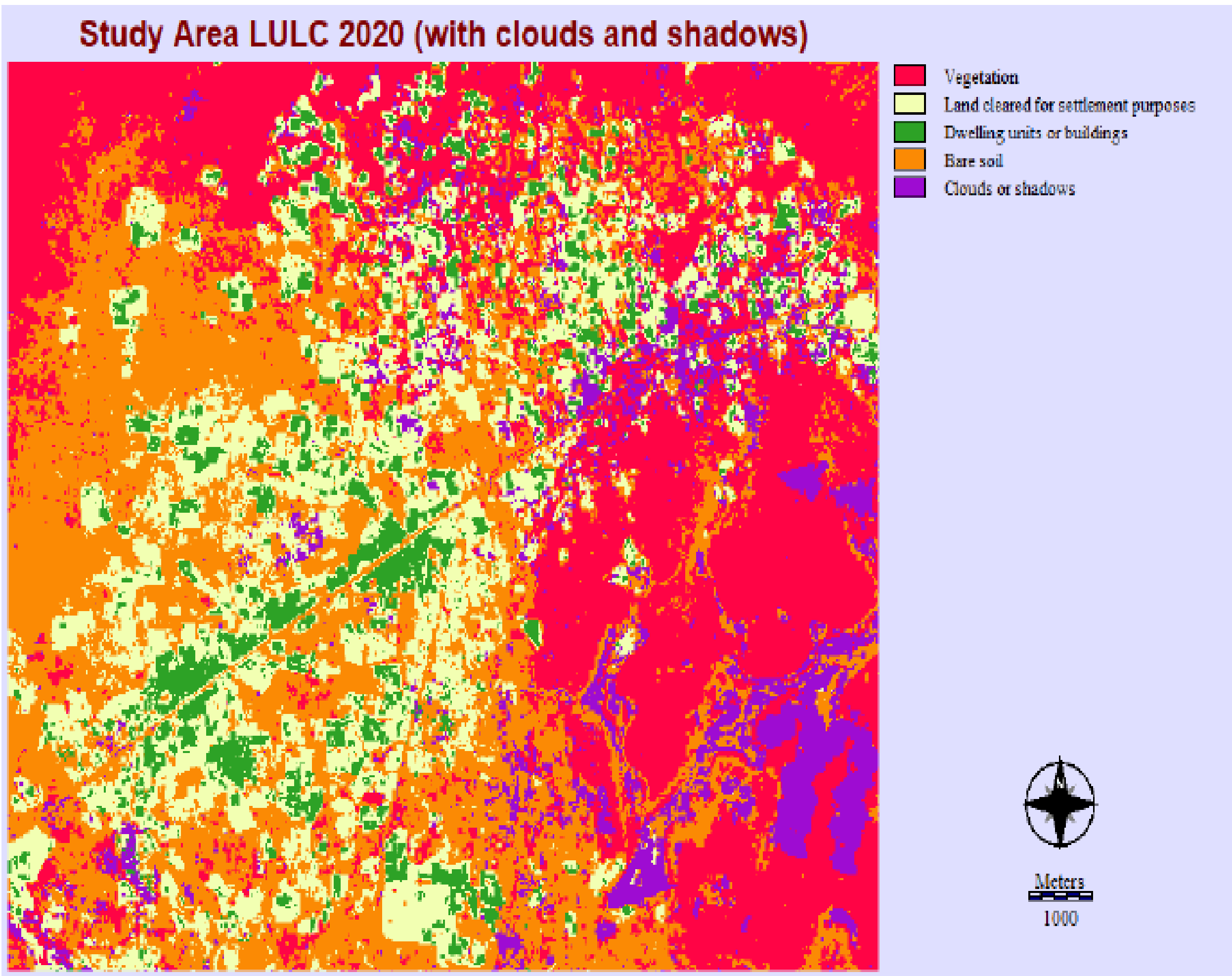


Figure 3.6.2: Study area LULC 2020 (with clouds and shadows): (Author's own, data USGS 2020)

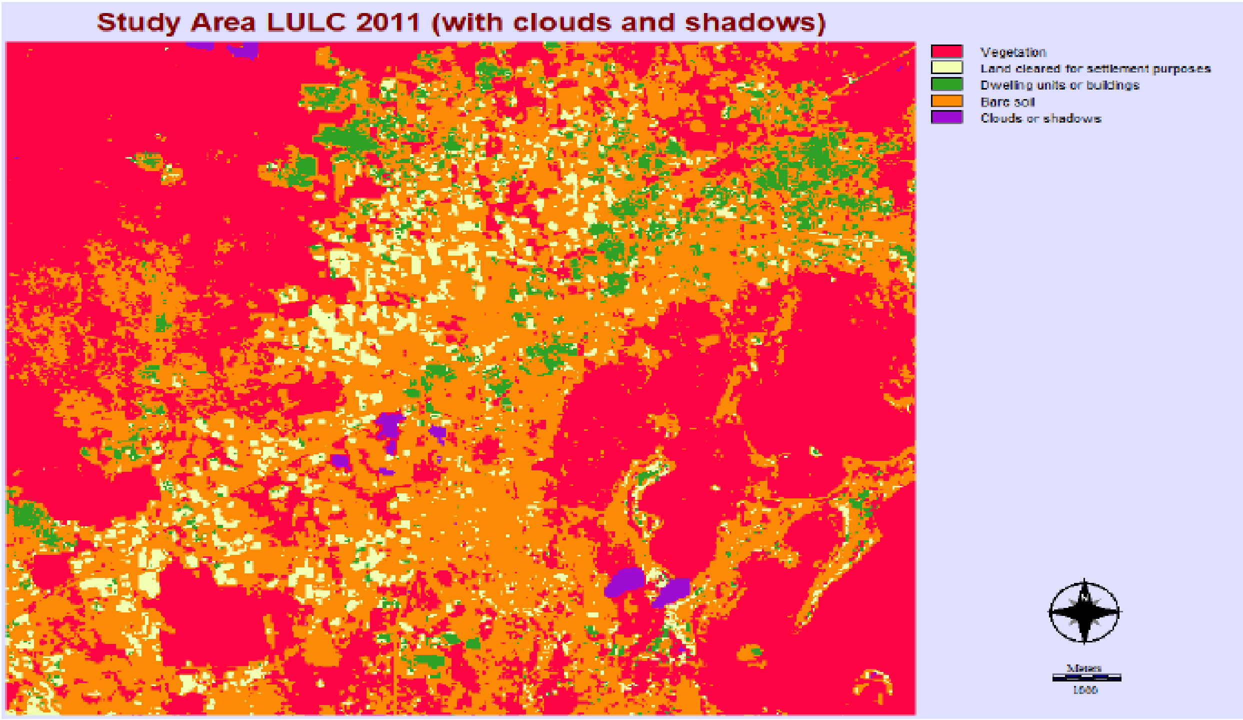


Figure 3.6.3: Study area LULC 2011 (with clouds and shadows): (Author's own, data USGS 2020)

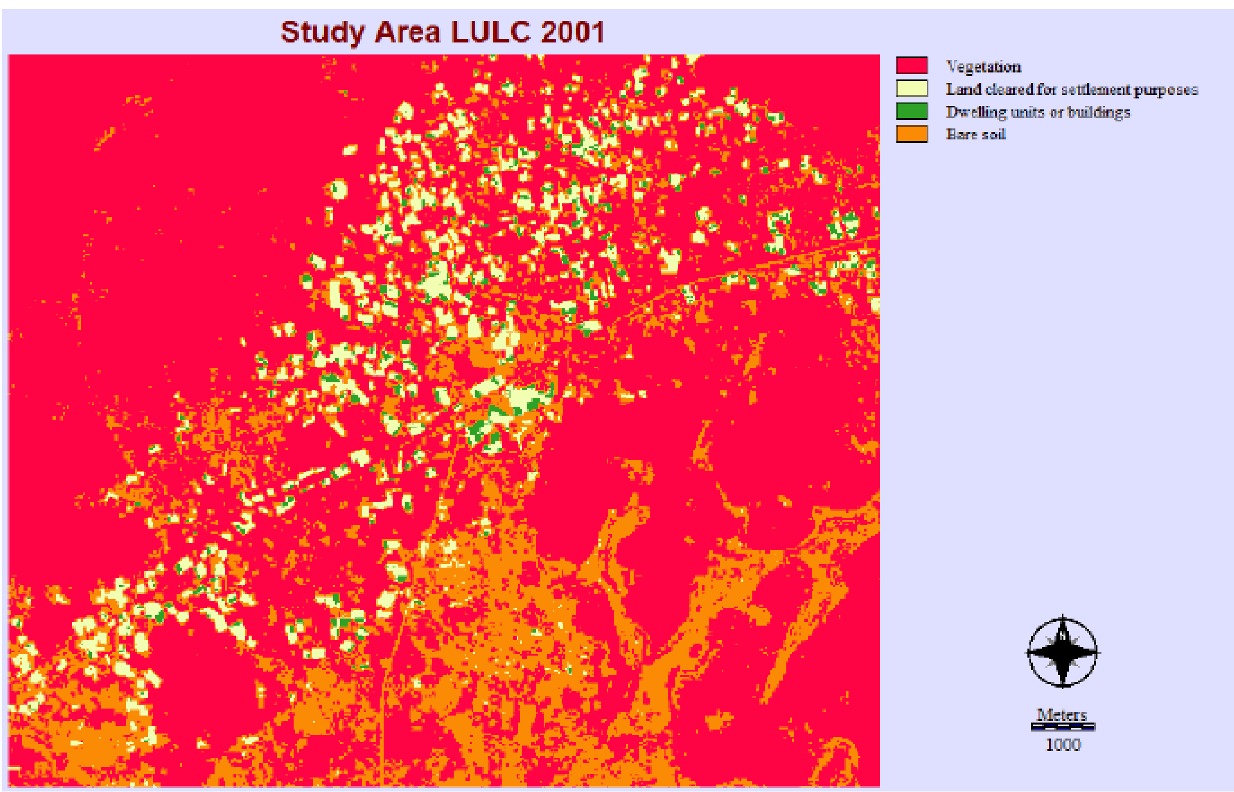


Figure 3.6.4: Study area LULC 2001: (Author's own, data USGS 2020)

3.7. Cloud Removal Process

Clouds and shadows pose a significant barrier for remote sensing image processing to attain accurate LULC maps (WANG, SHI, LETU, MA, LI & ZHENG 2019: 7207). Automated cloud detection and removal is an important step in imagery processing. This can be achieved by identifying pixels that covers clouds and shadows in the study area and replace them with LULC pixel values from a later cloud free imageries of the study area (STOURNARA, TSAKIRI-STRATI & PATIAS 2013: 33). In this study, the metadata file and false colour composite for the 2001 imageries (see Figure 3.5.1) revealed that there was no cloud cover in the study area during the acquisition of those imageries. No cloud identification and removal processes were undertaken on the 2001 imageries. The 2020 and 2011 imageries articulated few clouds and shadows; hence it was necessary to conduct cloud identification and removal processes using Landsat imageries covering the study area at a later date (May 2010 for Landsat 5 and May 2019 for Landsat 8 imageries were applied). Both metadata files for May 2019 and May 2010 indicated that there was no cloud cover within the study area. The same procedure applied to the 2001, 2011 and 2020 imageries to produce the LULC types was applied to the May 2019 and May 2010 imageries. Figures 3.7.1 and 3.7.2 on the subsequent page shows the LULC maps for year(s), May 2019 and May 2010 respectively.

Clouds and shadows in the 2011 and 2020 imageries were removed using the “RECLASS” tool, where “Clouds or shadows” (5) category was reclassified to “0” while the rest of the LULC types returned their original values.

Overlay technic with option “Where first cover Second except where Zero” was applied to imageries in Figures 3.6.2 and 3.6.3 as first imageries while Figures 3.7.1 and 3.7.2 were entered as second imageries. The overlay procedure replaced zero values (previously covered by clouds and shadows) in imageries displayed in Figure 3.6.2 and 3.6.3 with LULC values/categories from imageries in Figure 3.7.1 and 3.7.2 respectively. The process led to the creation of the final 2020 and 2011 LULC maps that were employed for further analyses, those imageries are displayed below in Figures 3.7.3 and 3.7.4 respectively.

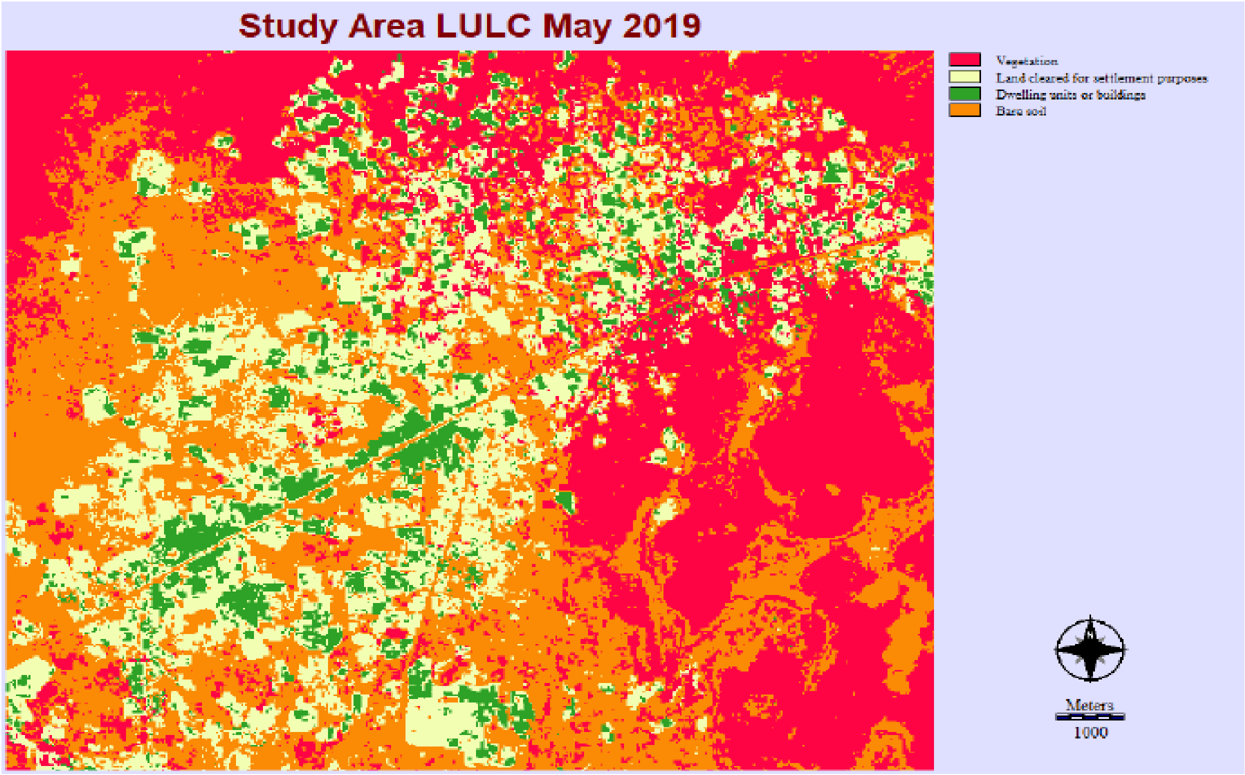


Figure 3.7.1: Study area LULC May 2019: (Author's own, data USGS 2020)

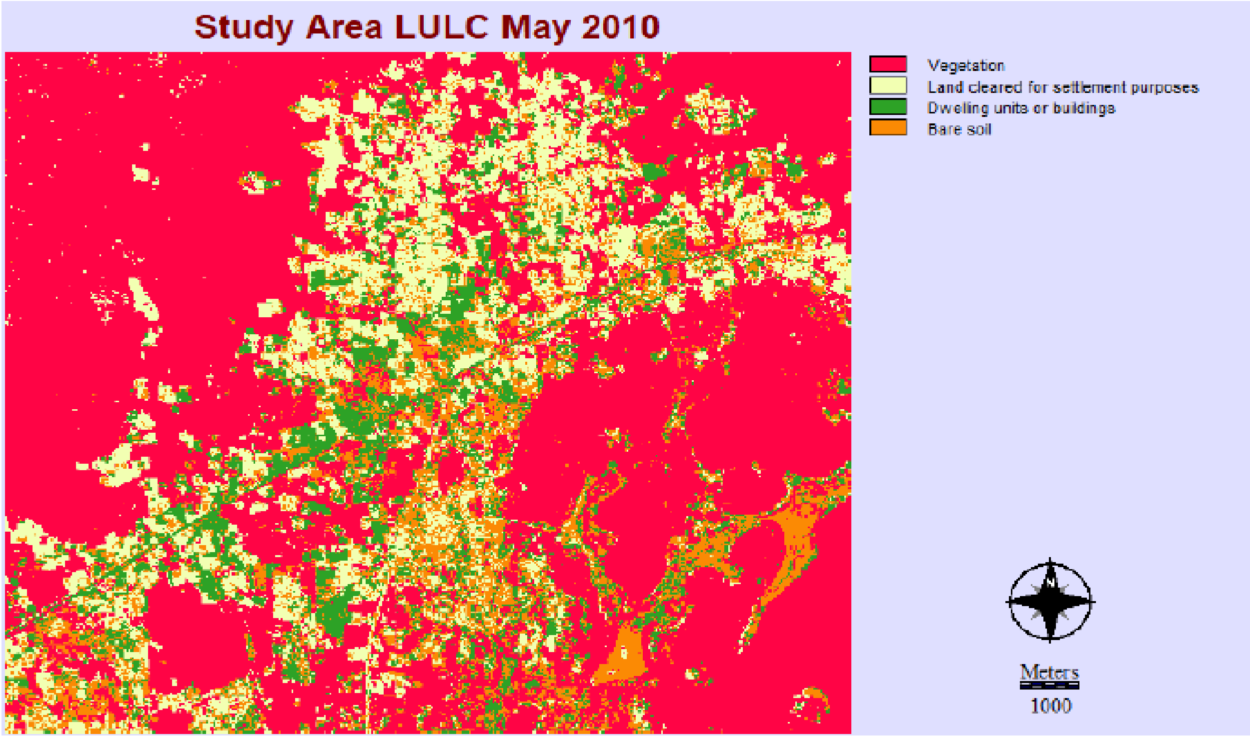


Figure 3.7.2: Study area LULC May 2010: (Author's own, data USGS 2020)

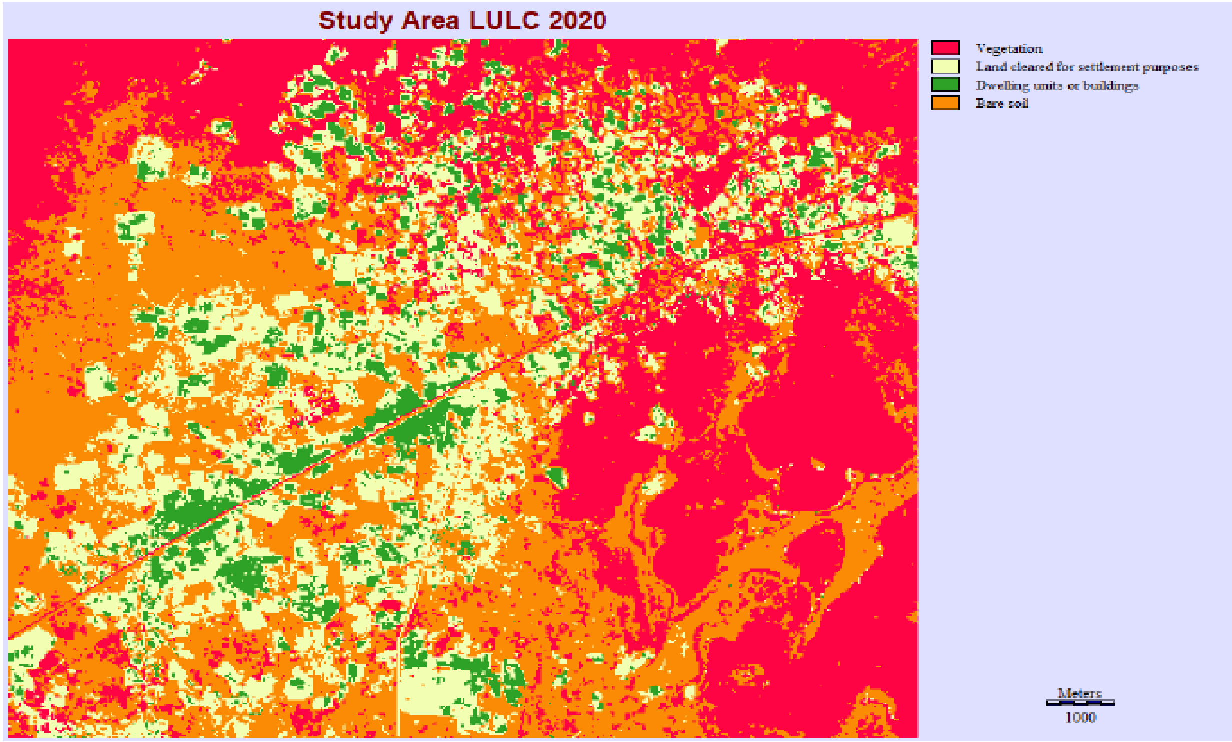


Figure 3.7.3: Study area LULC 2020: (Author's own, data USGS 2020)

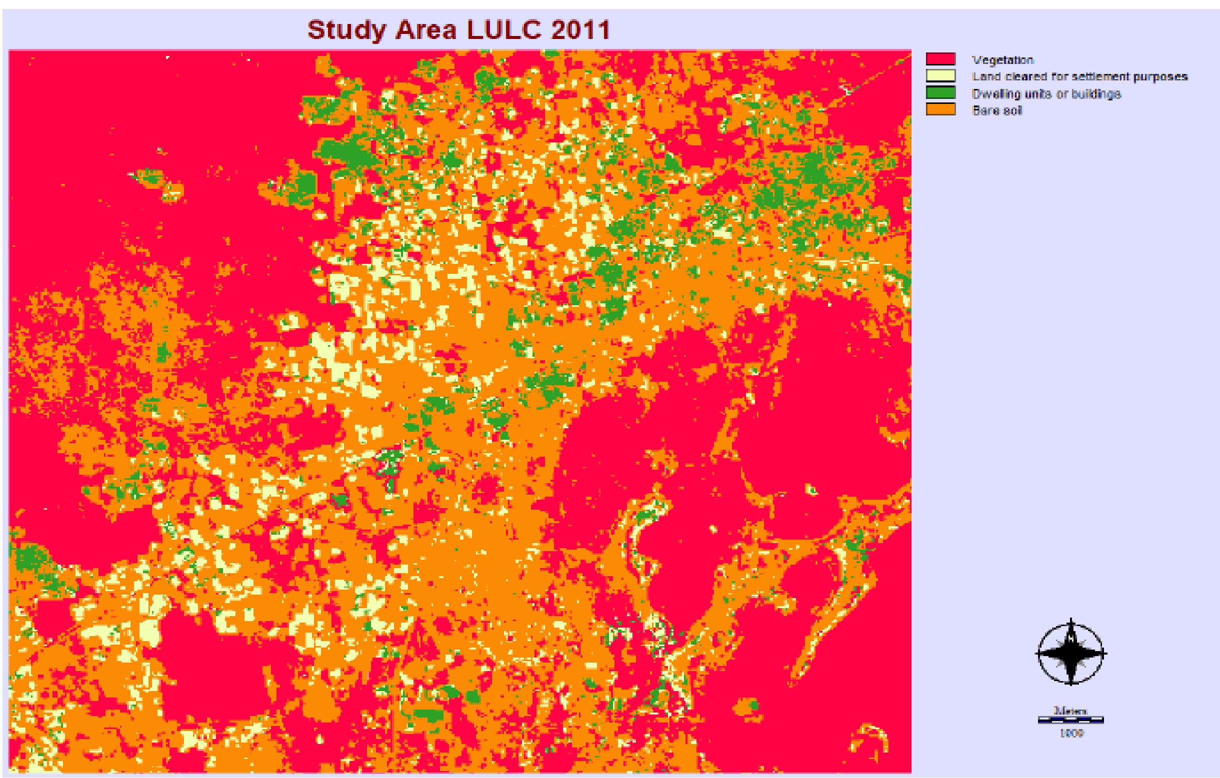


Figure 3.7.4: Study area LULC 2011: (Author's own, data USGS 2020)

3.8. LULC Prediction

Researchers such as PAUL, LI, WHEATE and LI (2018: 30) incorporated image classification and neural network aided Markov Chain (MC) modelling tools to produce LULC maps and to predict LULC changes. In this study, the Cellular Automata (CA)-Markov Chain model was applied to predict the study area's LULC types for year(s) 2021 and 2031.

LULC Prediction: 2011 to 2021

The study area's 2001 and 2011 LULC maps displayed in Figures 3.6.4 and 3.7.4 respectively were used to predict LULC in 2021. The first step involved creating a transition estimator using "Markov" tool, where the first (earlier) image was specified as the 2001 LULC map while the 2011 LULC map was entered as the second (later) image. The proportional error was set at 0.15 as it is typically known that most of the land use maps are 85% accurate (EASTMAN 2009: 48). Table 3.8.1 provides change probabilities between LULC classes//types based on 2001 and 2011 LULC maps as derived from the Markov Chain model. In Table 3.8.1, Class 1 (vegetation) has a 55% of probability to remain the same while the probability for vegetation to change to Class 3 (buildings) is only 0.3%. The probability for vegetation to change to Class 2 (Land cleared for settlement purposes) is 1%, and there is a 14% probability for vegetation to convert to Class 4 (bare soil).

Table 3.8.1: Change probabilities between LULC classes//types based on 2001 and 2011 LULC maps: (Author's own, data USGS 2020)

Given: Probability of changing to:				
	CI. 1	**CI. 2**	**CI. 3**	**CI. 4**
Class 1	0.547	0.045	0.049	0.370
Class 2	0.010	0.211	0.096	0.683
Class 3	0.003	0.235	0.152	0.610
Class 4	0.135	0.145	0.074	0.646

In the CA-Markov Chain parameters, LULC map of 2011 was entered as the basic land cover image. The Markov transition and the transition suitability image collection files which were created using Markov tool was entered in their respective fields. The number of cellular automata iterations was set at 10 as the LULC change prediction will be for the next 10 years from 2011. Table 3.8.2 below provides the LULC type sizes in ha from the actual 2020 LULC map and the two projected 2021 LULC maps (one projected using actual 2001 and 2011 LULC maps while the other was projected using actual 2011 and 2020 LULC maps).

Table 3.8.2 and 3.8.3 reveals that, the projected 2021 LULC (using actual 2001 and 2011 LULC maps) was weak in estimating the land cleared for settlement purposes as only 50% of that LULC type was accurately classified. The projected 2021 LULC using actual 2011 and 2020 LULC maps articulated a high estimation accuracy at 118%, which means it slightly overestimated the land cleared for settlement purposes. The projected 2021 LULC (using actual 2001 and 2011 LULC maps) was very weak in estimating bare soil as it overestimates that LULC type by 42%. This is because; bare soil is expected to decline drastically due to land cleared for settlement purposes, construction of houses, animal kraals and local administrative buildings in the area. The projected 2021 LULC using actual 2011 and 2020 LULC maps expressed a high estimation accuracy at 97% with reference to estimating dwelling units or buildings area size. Consequently, the 2021 LULC map using actual 2011 and 2020 LULC maps in Figure 3.8.1 was used for further analysis (e.g., for the estimation of LULC types in 2031).

Table 3.8.2: LULC type sizes in ha from two projected 2021 LULC maps and actual 2020 map: (Author's own, data USGS 2020)

LULC Types	**2021 LULC (Projected using 2001 and 2011 LULC maps)**	**2020 LULC**	**2021 LULC (Projected using 2011 and 2020 LULC maps)**
Vegetation	4817.52	5514.03	4688.28
Land cleared for settlement purposes	1627.47	3227.94	3801.96
Dwelling units or buildings	1030.05	1062.09	1454.58
Bare soil	7933.05	5604.03	5463.27
Total Area	**15408.09**	**15408.09**	**15408.09**

Table 3.8.3: Projection accuracy assessment based on LULC types from two projected 2021 LULC maps: (Author's own, data USGS 2020)

LULC Types	2021 LULC (Projected using 2001 and 2011 LULC maps)	2020 LULC	2021 LULC (Projected using 2011 and 2020 LULC maps)
Vegetation	87%	5514.03	85%
Land cleared for settlement purposes	50%	3227.94	118%
Dwelling units or buildings	97%	1062.09	137%
Bare soil	142%	5604.03	97%
Total Area	**100.0%**	**15408.09**	**100%**

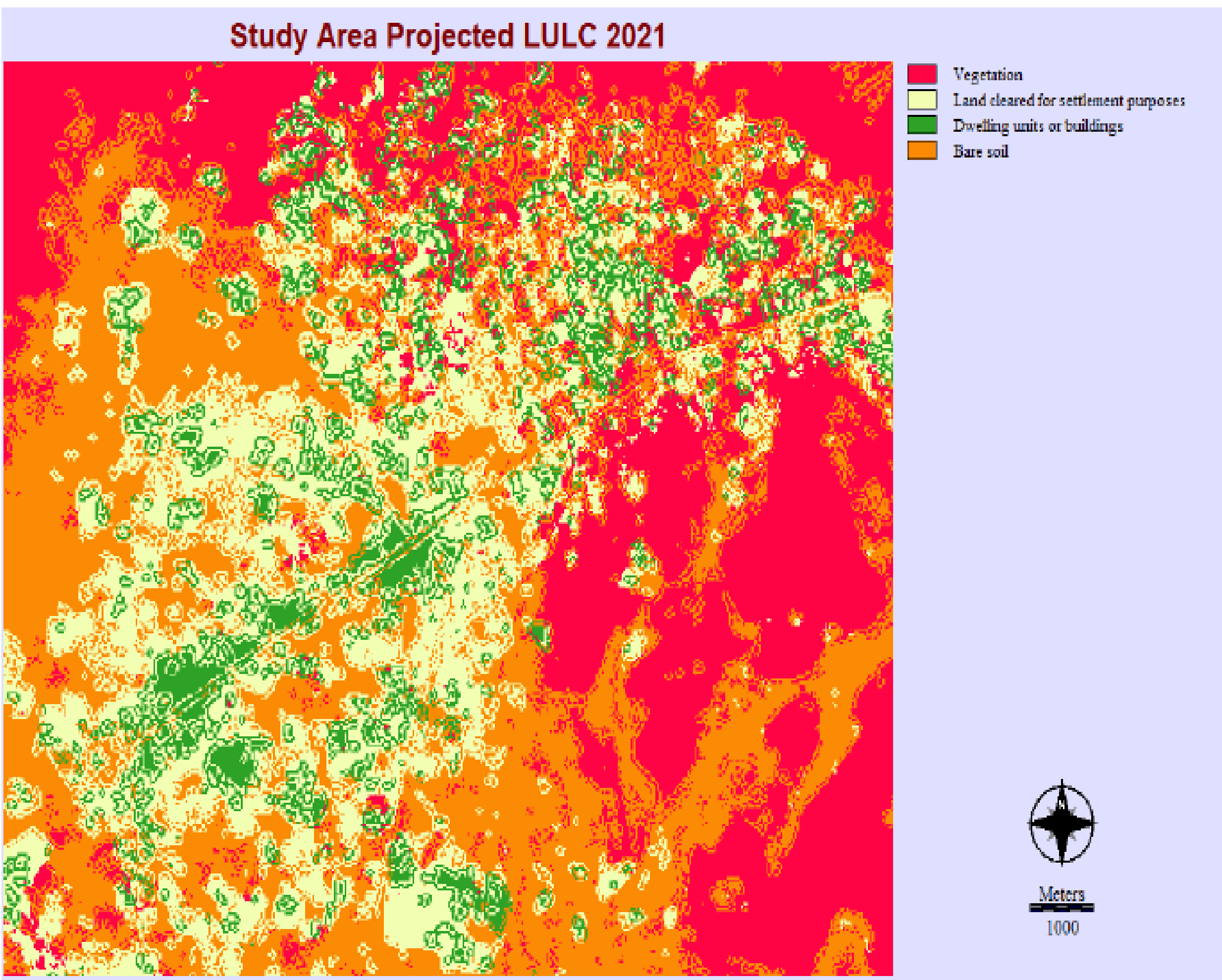


Figure 3.8.1: Study area projected LULC in 2021: (Author's own, data USGS 2020)

LULC Prediction: 2021 to 2031

The predicted LULC 2021 study area (using 2001 and 2020 LULC maps) and 2011 LULC map displayed in Figure 3.7.4 were used to predict LULC for year 2031. The first step involved creating a transition estimator using “Markov” tool, where the first (earlier) image was specified as the 2011 LULC map while the 2021 LULC map was entered as the second (later) image. Table 3.8.4 provides change probabilities between LULC classes based on 2011 and 2021 LULC maps as derived from the Markov Chain model. Class 1 (vegetation) has a 55% of probability to remain the same while a 0% probability for vegetation to change to Class 3 (dwelling units) or Class 2 (land cleared for settlement purposes) is observed. The probability for vegetation to change to Class 4 (bare soil) is only 1%. In the CA-Markov Chain parameters, the projected 2021 LULC map was entered as the basic land cover image. Figure 3.8.2 provides a map of the projected study area’s LULC for year 2031.

Table 3.8.4: Change probabilities between LULC classes//types based on 2011 and 2021 LULC maps: (Author’s own, data USGS 2020)

Given: Probability of changing to:				
	CI. 1	**CI. 2**	**CI. 3**	**CI. 4**
Class 1	0.554	0.054	0.061	0.331
Class 2	0.000	0.591	0.031	0.378
Class 3	0.000	0.191	0.565	0.244
Class 4	0.010	0.179	0.063	0.749

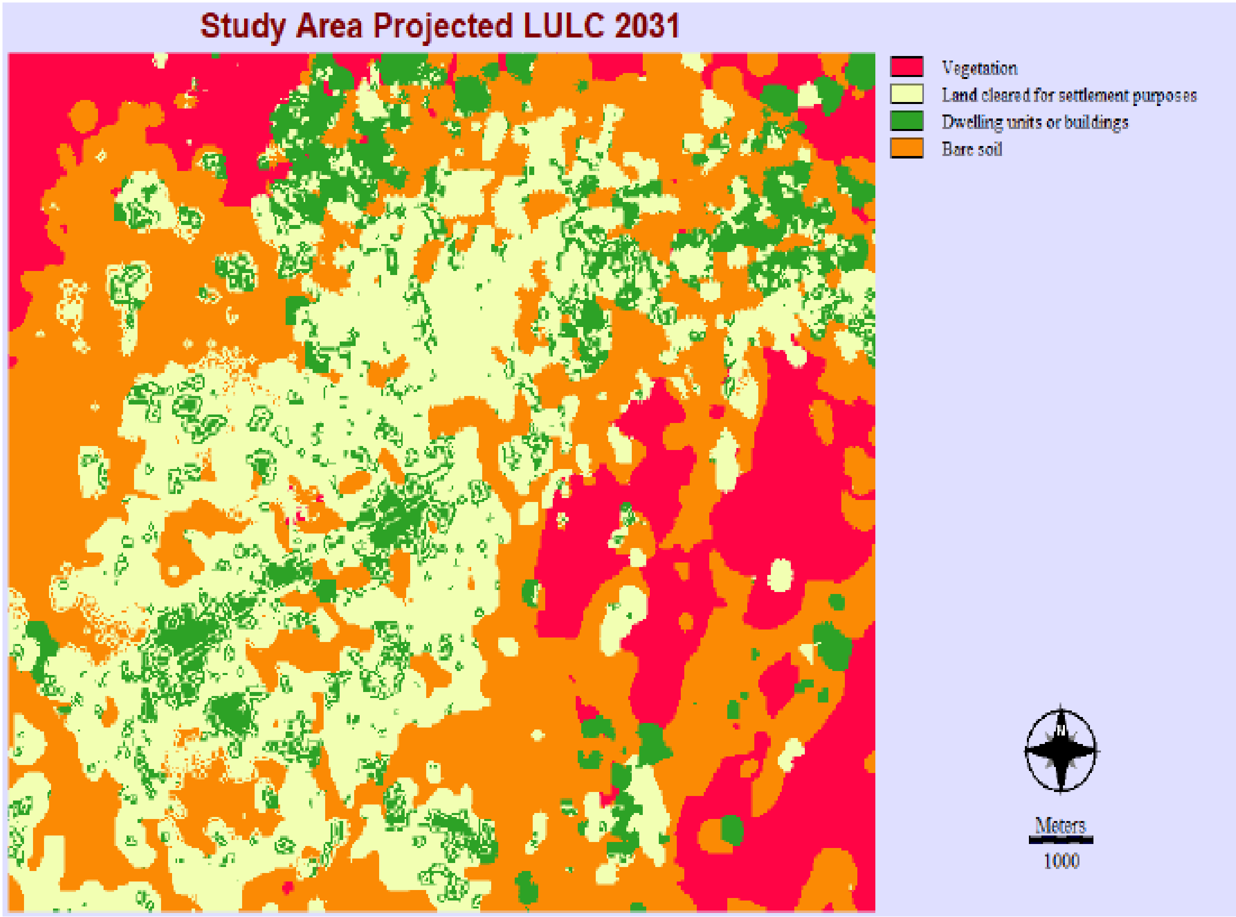


Figure 3.8.2: Study area Projected LULC 2031: (Author's own, data USGS 2020)

3.9. Data Analysis

Image cross tabulation ("CROSSTAB" tool) can assist to understand LULC changes in the characteristics of areas on the earth's surface over time because of human activities (ENDERLE & WEIH 2005: 65). The 2001 LULC map in Figure 3.6.4 was cross tabulated with the 2011 LULC map (Figure 3.7.4). The 2011 LULC map in Figure 3.7.4 was cross tabulated with the 2021 LULC map (Figure 3.8.1), and the 2021 LULC map was cross tabulated with the 2031 LULC map in Figure 3.8.2. The hard classification analysis type was selected in the CROSSTAB parameters; output type was set at both cross-classification and tabulation. The Kappa index of agreement per category was also selected to be part of the cross-tabulation results.

“Image Calculator” an interactive mathematical modelling tool was employed in the study, the tool provides a simple calculator-like interface for constructing algebraic and logical formulas with map layers as variables (EASTMAN 2009: 80). Deforested areas were modelled, by using the below logical expression formulas.

> For deforestation between 2001 and 2011 (LULC 2001 (in Figure 3.6.4) = 1 (vegetation) and LULC 2011 (in Figure 3.7.4) not = (1)). To estimate deforestation between 2011 and 2021 the following formula was applied (LULC 2011 (in Figure 3.7.4) = 1 and LULC 2021 (in Figure 3.8.1) not = (1)). “LULC 2021 (in Figure 3.8.1) = 1 and LULC 2031 (in Figure 3.8.2) not = (1)” was used to estimate deforestation in 2031. The same approach was used in some of the processes to create reforestation maps presented in the reforestation analysis result section.

Linear and multiple regression analysis was conducted using the “REGRESS” and “MULTIREG” tools, where the dependent variable(s) were deforestation between 2001 and 2011, 2011 and 2021, 2021 and 2031. Independent variables (distance from road, distance from vegetation, distance from land cleared for settlement purposes and distance from dwelling units or buildings) were created using the “Distance Operators” tool. Regression analyses assisted in predicting in which areas deforestation is more likely to occur, to determine relationships between two or more variables, and to understand how one variable change when another change (SAINANI 2013: 1063).

Reforestation analyses applied the “RECLASS” (image reclassification) tool which was used to reclassify vegetation in the 2001 LULC map to 0, while other 2001 LULC types were assigned a value of 1. This led to the creation of a Boolean image (all LULC types, excluding vegetation), which was overlaid (through multiplication) on the 2011 Boolean image for vegetation cover. The overlay technic led to the creation of a map (Figure 4.4.1.1) depicting new vegetation or reforested areas between 2001 and 2011. The same approach was used to generate maps displaying reforested areas between 2011 and 2031 (Figure 4.4.2.1 and 4.4.3.1).

Chapter 4: Results and Discussion

4.1. Dynamics of Land Use and Land Cover Changes

4.1.1. LULC Change 2001 and 2011

Table and Figure 4.1.1.1 below indicate that, 7044.57 ha of land in category 1 remained vegetation between 2001 and 2011. Category 2 reveal that, 8.01 ha of land converted from land cleared for settlement purposes to vegetation. Category 2 finding is in line with a study conducted by KAMWI et al. (2017) who established that within protected areas of the Sibbinda constituency, land cover conversion to forest land was more likely between year 2000 and 2010.

Category 3 specifies that, 0.54 ha was transformed from dwelling units or buildings to vegetation. LULC change in category 3 occurs when temporal rural building structures are demolished due to artificial or natural processes.

Category 4 indicates that 296.1 ha transformed from bare soil to vegetation, at the same time 397.17 ha (category 5) was transformed from vegetation to land cleared for settlement purposes. Category 6 disclose that, 204.39 ha remained the same (land cleared for settlement purposes); this category is derived mainly from permanent farming units and land cleared around permanent building structures.

Category 7 indicate that, 42.21 ha of land was transformed from dwelling units to land cleared for settlement purposes. Category 8 indicate that, 319.5 ha of land was transformed from bare soil to land cleared for settlement purposes. The land converted from bare soil to land cleared for settlement purposes is mainly a result of farming activities in the area, as most (44% and 38%) of the people's main source of income at Sibbinda in year 2001 and 2011 was farming respectively (NSA 2014).

Category 9 reveal that, 432 ha of land was transformed from vegetation to buildings while in category 10, only 75.15 ha was transformed from land cleared for settlement purposes to buildings. Category 11 indicate that, 33.21 ha of land remained unchanged with buildings land cover type, this category is mainly characterised with permanent building structures. Category 12 indicate that 162.99 ha of bare soil was converted to buildings while category 13 specifies that 3285.18 ha of vegetation was converted to bare soil.

Category 13 presents the highest LUCC experienced and is linked to human activities such as road construction/expansion and creation of new footpaths and the elements of erosion due floods in the area. A major contributor to vegetation land converting to bare soil is in line with the 2001 and 2011 census results for Sibbinda (study area) which revealed that, 97% and 94% of residents of the area used wood/charcoal for cooking in year 2001 and 2011 respectively (NSA 2014). This is because, when the people cut trees to produce firewood, in many cases it results into bare soil, as when trees are cut, there is less chance for grasses to remain on the land for a long time period due to factors such as the blowing of high-speed wind which breaks the grasses.

Category 14 reveal that, 536.58 ha of land was transformed from land cleared for settlement purposes to bare soil. Category 15 uncover that, 109.62 ha was converted from dwelling units or buildings to bare soil, while category 16 specifies that 2460.87 ha of land remained unchanged (bare soil).

Table 4.1.1.1: LULC Change 2001 to 2011: (Author's own, data USGS 2020)

Category	Ha	Legend	
1	7044.57	1	1
2	8.01	2	1
3	0.54	3	1
4	296.1	4	1
5	397.17	1	2
6	204.39	2	2
7	42.21	3	2
8	319.5	4	2
9	432	1	3
10	75.15	2	3
11	33.21	3	3
12	162.99	4	3
13	3285.18	1	4
14	536.58	2	4
15	109.62	3	4
16	2460.87	4	4

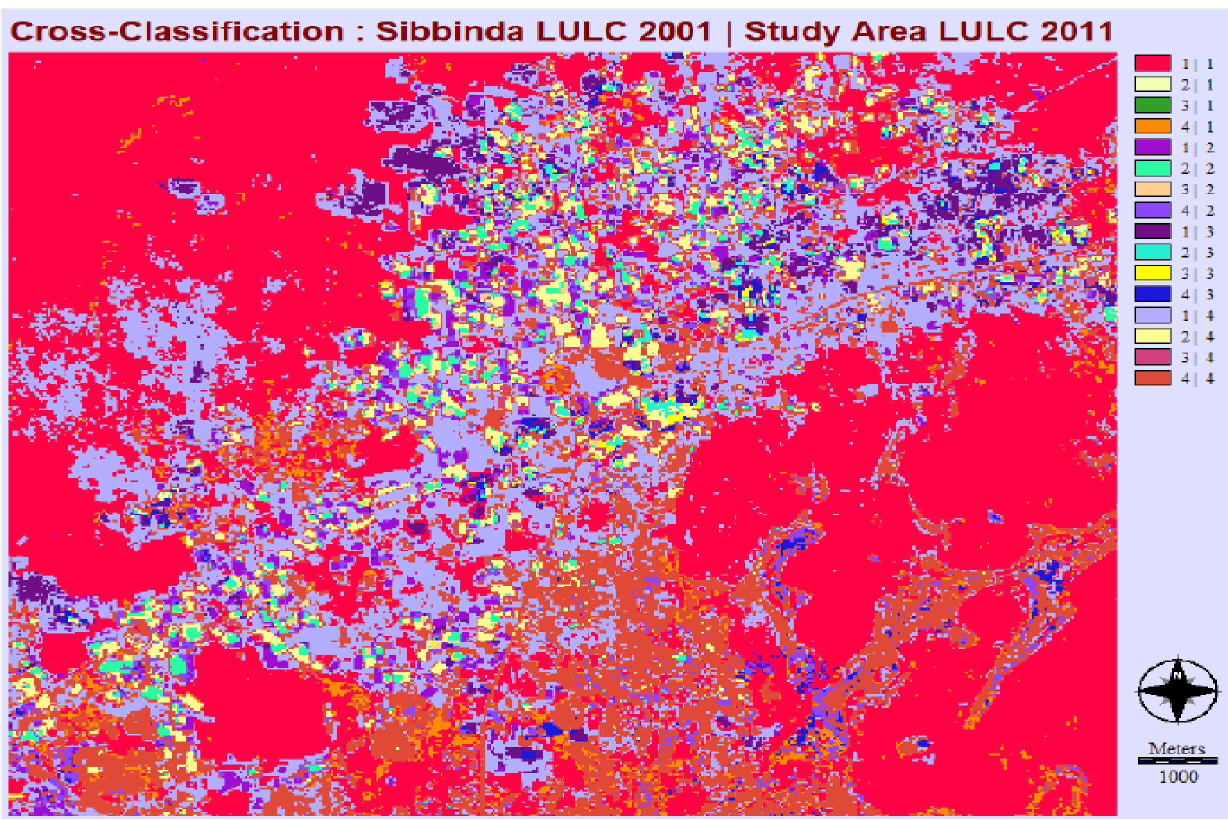


Figure 4.1.1.1: Cross tabulation: LULC 2001 and LULC 2011: (Author's own, data USGS 2020)

Table 4.1.1.2 indicate that between 2001 and 2011, the highest number of observations (78273) were from the vegetation-to-vegetation (1) where no LULC change was observed. This translates to a proportion of 46% of vegetation cover which remained unchanged between 2001 and 2011 as displayed in Table 4.1.1.3. Only 2% of the bare soil (4) in 2001 was converted to vegetation in 2011. The highest LUCC was observed from vegetation converting to bare soil at a rate/proportion of 21% (36502 observations in Table 4.1.1.2). The later current study results are in contrary to a study by TWISA and BUCHROITHNER (2019: 7) where it was discovered in Tanzania that settlement areas (dwelling units/buildings and land cleared for settlement purposes) are more like to remain unchanged). This contrary result could be due to a much larger study area that was applied in the study by TWISA and BUCHROITHNER (2019) compared to the current study. However, results from TWISA and BUCHROITHNER (2019) correspond with current study results that, vegetation (in TWISA & BUCHROITHNER 2019) is represented by forest) is more likely to remain unchanged at a proportion of 46% and 50% respectively.

Cramer's V (a measure of association that ranges from 0-1) is 0.3 and the overall Kappa Index of Agreement (KIA) is 0.3 in Tables 4.1.1.2 and 4.1.1.4 respectively. KIA indicates that the 2001 and 2011 images are significantly different as the imageries are only characterised with similar features or values at 30%. The Cramer's V stipulates that, the created cross-tabulation imagery of LULC 2001 and LULC 2011 is characterised of more heterogeneous LULC types at 70%.

Table 4.1.1.2: Cross-tabulation of LULC 2001 (columns) against LULC 2011 (rows): (Author's own, data USGS 2020)

	1	**2**	**3**	**4**	**Total**
1	78273	89	6	3290	81658
2	4413	2271	469	3550	10703
3	4800	835	369	1811	7815
4	36502	5962	1218	27343	71025
Total	**123988**	**9157**	**2062**	**35994**	**171201**

Chi Square = 48100.81641
df = 9
P-Level = 0.0000
Cramer's V = 0.3060

Table 4.1.1.3: Proportional Crosstabulation of LULC 2001 against LULC 2011: (Author's own, data USGS 2020)

	1	2	3	4	Total
1	0.46	0.00	0.00	0.02	**0.48**
2	0.03	0.01	0.00	0.02	**0.06**
3	0.03	0.00	0.00	0.01	**0.05**
4	0.21	0.03	0.01	0.16	**0.41**
Total	**0.72**	**0.05**	**0.01**	**0.21**	**1.00**

Table 4.1.1.4: Cross-tabulation LULC 2001 and 2011 Kappa Index of Agreement (KIA): (Author's own, data USGS 2020)

Category	KIA	
	Using LULC 2011 as the reference image	**Using LULC 2001 as the reference image**
1	0.8497	0.2951
2	0.1677	0.1979
3	0.0356	0.1397
4	0.2212	0.5892
Overall Kappa = 0.3475		

4.1.2. LULC Change 2011 and 2021 (estimated)

Figure 4.1.2.1 and Table 4.1.2.2 below reveal that, 3620.79 ha of land in category 1 is expected to remain vegetation between 2011 and 2021. Category 2 disclose that, 79.92 ha of land is likely to convert from land cleared for settlement purposes to vegetation while category 3 specifies that, 98.19 ha is expected to be transformed from dwelling units to vegetation. Category 2 and 3 is the lowest (least) expected LULC changes expected in the area as it normally occurs in rarely situation such as that highlighted below:

> The conversion of agricultural land to forest may be the result of natural forest expansion or tree planting. Natural forest expansion may occur when agricultural land is abandoned, for example when a rural population declines, land becomes sufficiently degraded that it becomes unproductive as agricultural land, or more productive agricultural land becomes available elsewhere (FAO 2016: 22).

Category 4 specifies that 889.38 ha is expected to transform from bare soil to vegetation, and 923.04 ha (category 5) is likely to transform from vegetation to land cleared for settlement purposes. Category 6 disclose that, 435.69 ha will remain the same (land cleared for settlement purposes). Category 7 indicate that, 280.35 ha of land is expected to be transformed from dwelling units to land cleared for settlement purposes. Category 8 indicate that, 2162.88 ha of land will transform from bare soil to land cleared for settlement purposes. Category 9 expose that, 249.21 ha of land is likely to transformed from vegetation to dwelling units while in category 10, only 234.54 ha is expected to be transformed from land cleared for settlement purposes to dwelling units or buildings.

Category 11 indicate that, 182.61 ha of land is likely to remain unchanged with dwelling units or buildings land cover type. Category 12 indicate that 788.22 ha of bare soil is expected to be converted to buildings. Category 13 specifies that 2556.18 ha of vegetation is likely to be converted to bare soil between 2011 and 2021. The conversions in category 12 and 13 is likely to be a result of the population pressure, as a 16% population increase is expected between 2011 and 2021 in Sibbinda area (NSA 2015: 18; FAO 2004). Most of the residents are still expected to heavily depend on the natural resources (forest/vegetation cover for their firewood, building houses and farming) to survive.

Category 14 disclose that, 213.12 ha of land is expected to be transformed from land cleared for settlement purposes to bare soil. Category 15 uncover that, 142.2 ha is likely to be converted from buildings to bare soil, while category 16 stipulates that 2551.77 ha of land is likely to remain unchanged (bare soil). This is more expected in the northeast direction of the study area, where bare soil is more likely to remain due to occurrences of water channels.

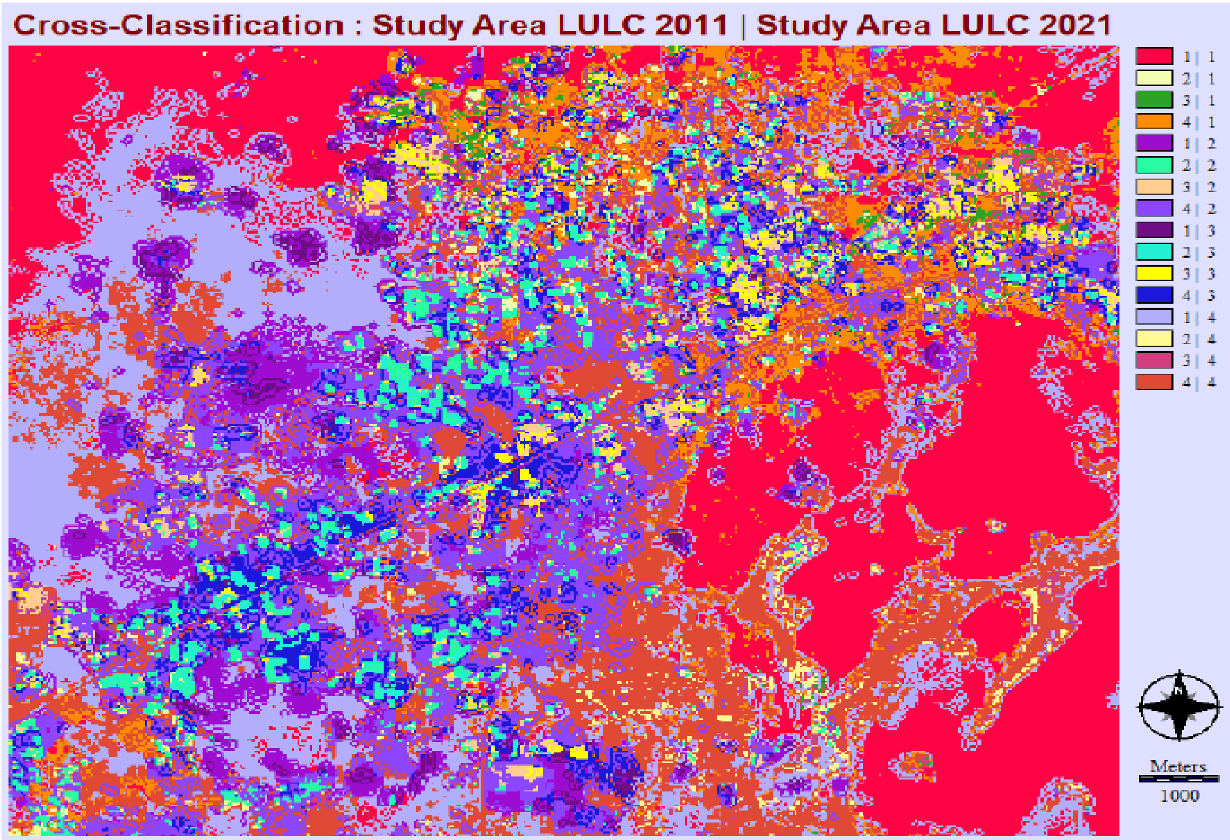


Figure 4.1.2.1: Cross tabulation: LULC 2011 and LULC 2021: (Author's own, data USGS 2020)

Table 4.1.2.1: LULC Change 2011 to 2021: (Author's own, data USGS 2020)

Category	Ha	Legend	
1	3620.79	1	1
2	79.92	2	1
3	98.19	3	1
4	889.38	4	1
5	923.04	1	2
6	435.69	2	2
7	280.35	3	2
8	2162.88	4	2
9	249.21	1	3
10	234.54	2	3
11	182.61	3	3
12	788.22	4	3
13	2556.18	1	4
14	213.12	2	4
15	142.2	3	4
16	2551.77	4	4

Table 4.1.2.2 indicates that between 2011 and 2021, the highest number of observations is 40231 which indicates that no vegetation LUCC is expected. This translates to a proportion of 24% of vegetation cover, which will remain unchanged between 2011 and 2021 as displayed in Table 4.1.2.3. Compared with the results of the 2001 and 2011 period, this is a significantly low area of unchanged vegetation cover, as during that period 46% of vegetation cover remained unchanged. Table 4.1.2.3 further indicate that, only about 6% of the bare soil (4) in 2011 will transform to vegetation in 2021, a form of reforestation process. The highest LUCC is expected from vegetation converting to bare soil at a rate of 17% (28402 observations in Table 4.1.2.2). This is expected because of the common vegetation cover type (woodland savannah and open grassland) which exists in the area (GBAGIR, TEGEGNE & COLPAERT 2019: 3). In a woodland savannah and open grassland forest, trees are dispersed which makes it easy for people to cut trees for human settlement purposes, the remaining grassland is then exposed to natural erosion processes such as moving floodwater and winds that destroy grasses leading to bare soil.

Cramer's V is 0.27 and the overall Kappa Index of Agreement (KIA) is 0.19 in Table 4.1.2.2 and 4.1.2.4 respectively. KIA indicates that the 2011 and 2021 images are significantly very different as the imageries are only characterised with similar values at 19%. The Cramer's V stipulates that, the created cross-tabulation imagery of LULC 2011 and LULC 2021 is characterised of more heterogeneous areas at 73%. Consequently, many areas' LULC types are expected to change between 2011 and 2021.

Table 4.1.2.2: Cross-tabulation of LULC 2011(columns) against LULC 2021 (rows): (Author's own, data USGS 2020)

	1	**2**	**3**	**4**	**Total**
1	40231	888	1091	9882	**52092**
2	10256	4841	3115	24032	**42244**
3	2769	2606	2029	8758	**16162**
4	28402	2368	1580	28353	**60703**
Total	**81658**	**10703**	**7815**	**71025**	**171201**

Chi Square = 38178.56641
df = 9
P-Level = 0.0000
Cramer's V = 0.2726

Table 4.1.2.3: Proportional Cross-tabulation of LULC 2011against LULC 2021: (Author's own, data USGS 2020)

	1	**2**	**3**	**4**	**Total**
1	0.235	0.0052	0.0064	0.0577	**0.3043**
2	0.0599	0.0283	0.0182	0.1404	**0.2468**
3	0.0162	0.0152	0.0119	0.0512	**0.0944**
4	0.1659	0.0138	0.0092	0.1656	**0.3546**
Total	**0.477**	**0.0625**	**0.0456**	**0.4149**	**1**

Table 4.1.2.4: Cross-tabulation LULC 2011 and 2021 Kappa Index of Agreement (KIA): (Author's own, data USGS 2020)

Category	**KIA**	
	Using LULC 2021 as the reference image	**Using LULC 2011 as the reference image**
1	0.5647	0.2708
2	0.0556	0.2729
3	0.0837	0.1824
4	0.0892	0.0691
Overall Kappa = 0.1872		

4.1.3. LULC Change 2021 and 2031 (estimated)

Figure 4.1.3.1 and Table 4.1.3.1 below indicate that, 2560.68 ha of land in category 1 will remain vegetation between 2021 and 2031. LULC in category 1 is mainly expected in areas (northwest, northeast and east directions) which are not easily accessible by roads. Category 2 reveal that, 54 ha of land will be converted from bare soil to vegetation while category 3 specifies that, 346.23 ha is expected to be transformed from vegetation to land cleared for settlement purposes. This result in category 3 is in line with YESUPH and DAGNEW (2019: 1) who established that, it is more likely for this LULC change to occur. This is because in many areas, vegetation cover usually disappears to make way for the expansion of settlements. Category 4 indicates that 3421.8 ha will remain unchanged (land cleared for settlement purposes) while category 5 discloses that, 226.62 ha of land will transform from buildings to land cleared for settlement purposes. Category 5 LUCC is usually observed when temporal dwelling units are removed especially in areas that are mainly used for crop cultivations and livestock farming.

Category 6 disclose that, 1020.51 ha is expected to convert from bare soil to land cleared for settlement purposes. Category 7 show that, 336.96 ha of land will transform from vegetation to building land cover type. Category 8 indicate that, 56.34 ha of land will transform from land cleared for settlement purposes to dwelling units or buildings. Category 9 disclose that, 1100.7 ha of land will remain unchanged (buildings) while in category ten, 354.78 ha is expected to be transformed from bare soil to buildings. Category 11 indicate that, 1444.41 ha of land will transform from vegetation to bare soil. The major factor likely to drive LUCC in category 11 is the expected 16% population increase in the area between 2021 and 2031 (NSA 2015: 18). Category 12 indicate that 323.82 ha of land cleared for settlement purposes will be converted to bare soil while category 13 specifies that 127.26 ha of buildings will be converted to bare soil. Category 14 reveal that, 4033.98 ha of land is likely to remain unchanged (bare soil).

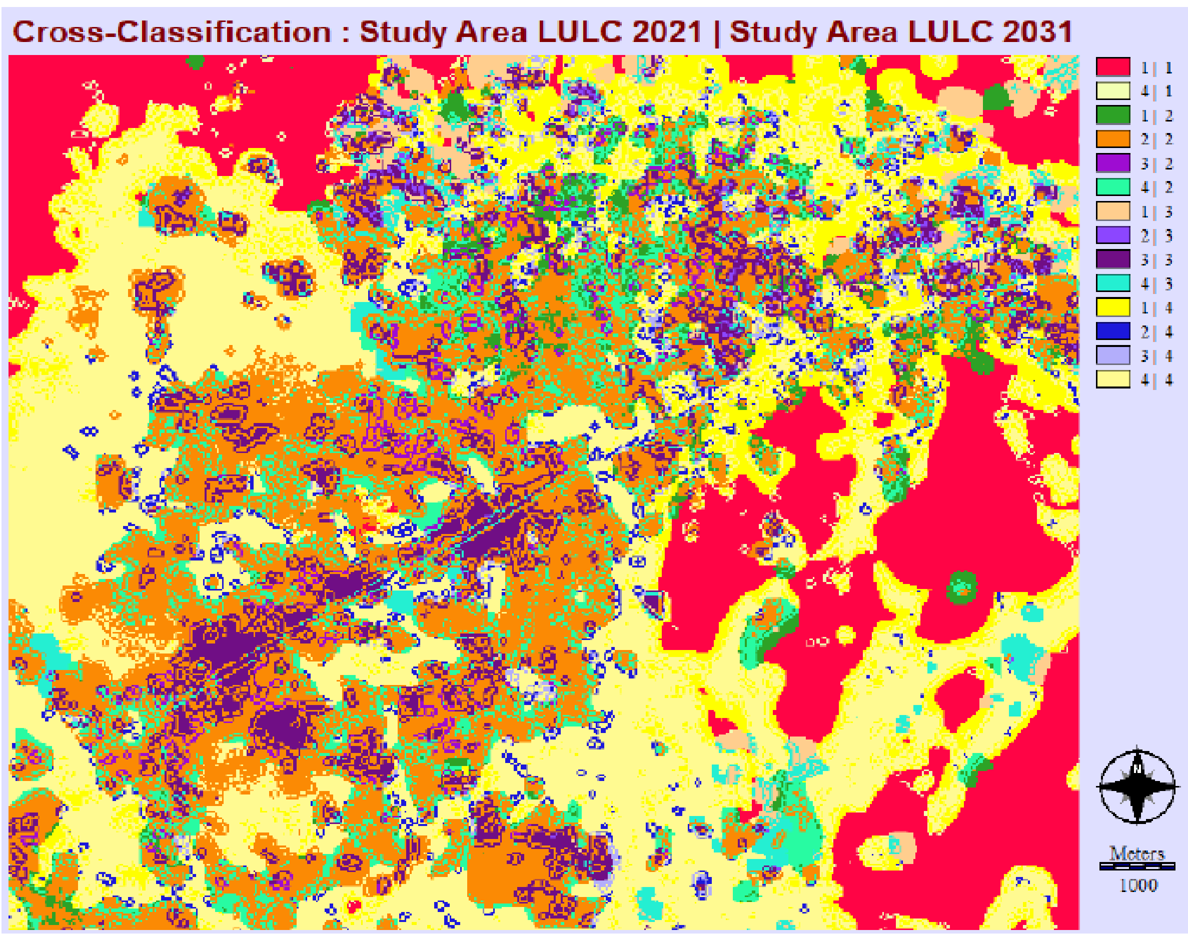


Figure 4.1.3.1: Cross tabulation: LULC 2021 and LULC 2031: (Author's own, data USGS 2020)

Table 4.1.3.1: LULC Change 2021 to 2031: (Author's own, data USGS 2020)

Category	Ha	Legend	
1	2560.68	1	1
2	54	4	1
3	346.23	1	2
4	3421.8	2	2
5	226.62	3	2
6	1020.51	4	2
7	336.96	1	3
8	56.34	2	3
9	1100.7	3	3
10	354.78	4	3
11	1444.41	1	4
12	323.82	2	4
13	127.26	3	4
14	4033.98	4	4

Table 4.1.3.2 indicate that between 2021 and 2031, the highest number of observations (28452) will be from the vegetation-to-vegetation (1) where no change is expected. This translates to a proportion of 17% of vegetation cover which is expected to remain unchanged between 2021 and 2031 as displayed in Table 4.1.3.3. Only 0.4% of the bare soil (4) in 2021 is expected to be transformed to vegetation in 2031. The highest LUCC is expected from vegetation converting to bare soil at a rate of 9% (16049 observations in Table 4.1.3.1). This LUCC is likely to be influenced by the changing socio-economic statuses of people, as a decline in the number of people who depend on farming activities is likely to occur between 2021 and 2031. This change in socioeconomic activities can lead to many people in the area resorting to clearing land for secondary and tertiary economic activities such as establishing small businesses for their means of survival (ZHANG, ZHAO, ZHANG & LI 2020; NSA 2014; FAO 2004).

Cramer's V is 0.65 and the overall Kappa Index of Agreement (KIA) is 0.61 in Table 4.1.3.2 and 4.1.3.4 respectively. KIA indicates that the 2021 and 2031 images are significantly similar as the imageries are characterised with similar features or values at 61%. The Cramer's V stipulates that, the created cross-tabulation imagery of LULC 2021 and LULC 2031 is characterised of more homogeneous areas at 65%. This indicates that, not so many areas' LULC types are expected to change between 2021 and 2031 as compared to the 2001 to 2021 period.

Table 4.1.3.2: Cross-tabulation of LULC 2021 (columns) against LULC 2031(rows): (Author's own, data USGS 2020)

	1	**2**	**3**	**4**	**Total**
1	28452	0	0	600	29052
2	3847	38020	2518	11339	55724
3	3744	626	12230	3942	20542
4	16049	3598	1414	44822	65883
Total	**52092**	**42244**	**16162**	**60703**	**171201**
Chi Square = 215676.12500 df = 9 P-Level = 0.0000 Cramer's V = 0.6480					

Table 4.1.3.3: Proportional Cross-tabulation of LULC 2021 against LULC 2031: (Author's own, data USGS 2020)

	1	**2**	**3**	**4**	**Total**
1	0.1662	0	0	0.0035	0.1697
2	0.0225	0.2221	0.0147	0.0662	0.3255
3	0.0219	0.0037	0.0714	0.023	0.12
4	0.0937	0.021	0.0083	0.2618	0.3848
Total	**0.3043**	**0.2468**	**0.0944**	**0.3546**	**1**

Table 4.1.3.4: Cross-tabulation LULC 2021 and 2031 Kappa Index of Agreement (KIA): (Author's own, data USGS 2020)

Category	**KIA**	
	Using LULC 2031 as the reference image	**Using LULC 2021 as the reference image**
1	0.9703	0.4534
2	0.5782	0.8518
3	0.5532	0.7235
4	0.5047	0.5747
Overall Kappa = 0.6134		

4.2. Deforestation Analysis

Establishing precise rate of forest has become a crucial component of global change monitoring, as programmes aimed at reducing deforestation depends on accurate forest change estimates (COUTURIER, NÚÑEZ & KOLB 2021). Different authors globally utilise different formulae to calculate the rate of the change of forest cover to quantify deforestation (PUYRAVAUD 2003: 593). In many deforestation studies (including the current study), deforestation estimates are based on the total area under study versus the degraded forest cover during a certain period (COUTURIER et al. 2021). The LULC type area sizes for land cleared for settlement purposes (2), dwelling units or buildings (3), bare soil (4) was summed up and divided by the total study area (Sibbinda settlement) size. The product of the later; was then multiplied by 100 to quantify (get a rate of) deforestation between 2001-2011, 2011-2021 and 2021-2031 respectively.

4.2.1. Deforestation between 2001 and 2011

Based on Table 4.2.1.1, deforestation in 2001 was recorded at 28% ((824.13 + 185.58 + 3239.46) / 15408.09 * 100). In year 2011, deforestation was very high at 52% ((963.27 + 703.35 + 6392.25) / 15408.09 * 100). The vegetation area lost between 2001 and 2011 is 3809.7 ha (11158.92 - 7349.22) representing 34% loss of vegetation mainly due to human activities. The rate of deforestation in the area is significantly higher than the national reported rate of 16.8% (1,472,000 ha) in loss of forest cover in Namibia between 1990 and 2010 (MONGABAY 2021).

Figure 4.2.1.1 highlight the deforested areas between 2001 and 2011. Most of the deforestation occurred at the central, north, northeast, south and south-west of the Sibbinda settlement. Figure 4.2.1.2 below display 397.17 ha (2.6%) of land that was deforested between 2001 and 2011 due to land cleared for settlement purposes. The deforestation occurred in a linear format in a northeast to south-west direction. Very few, in some case no deforestation was observed in the north-west and southeast directions of the Sibbinda settlement. Figure 4.2.1.3 below display 432 ha (2.8%) of land that was deforested between 2001 and 2011 due to the construction of dwelling units (houses). In Figure 4.2.1.3, the deforestation occurred more in the north and northeast direction. Figure

4.2.1.4 present 3285.18 ha (21.3%) of land that was deforested between 2001 and 2011 due to other human activities such as creating footpaths. The deforestation occurred at high intensity in a linear format (from northeast to south-west), south and the northern parts of the Sibbinda settlement.

Table 4.2.1.1: LULC Types in 2001 and 2011: (Author's own, data USGS 2020)

Category	**2001: Size in Ha**	**2011: Size in Ha**
Vegetation (1)	11158.92	7349.22
Land cleared for settlement purposes (2)	824.13	963.27
Dwelling units or buildings (3)	185.58	703.35
Bare soil (4)	3239.46	6392.25
Total	**15408.09**	**15408.09**

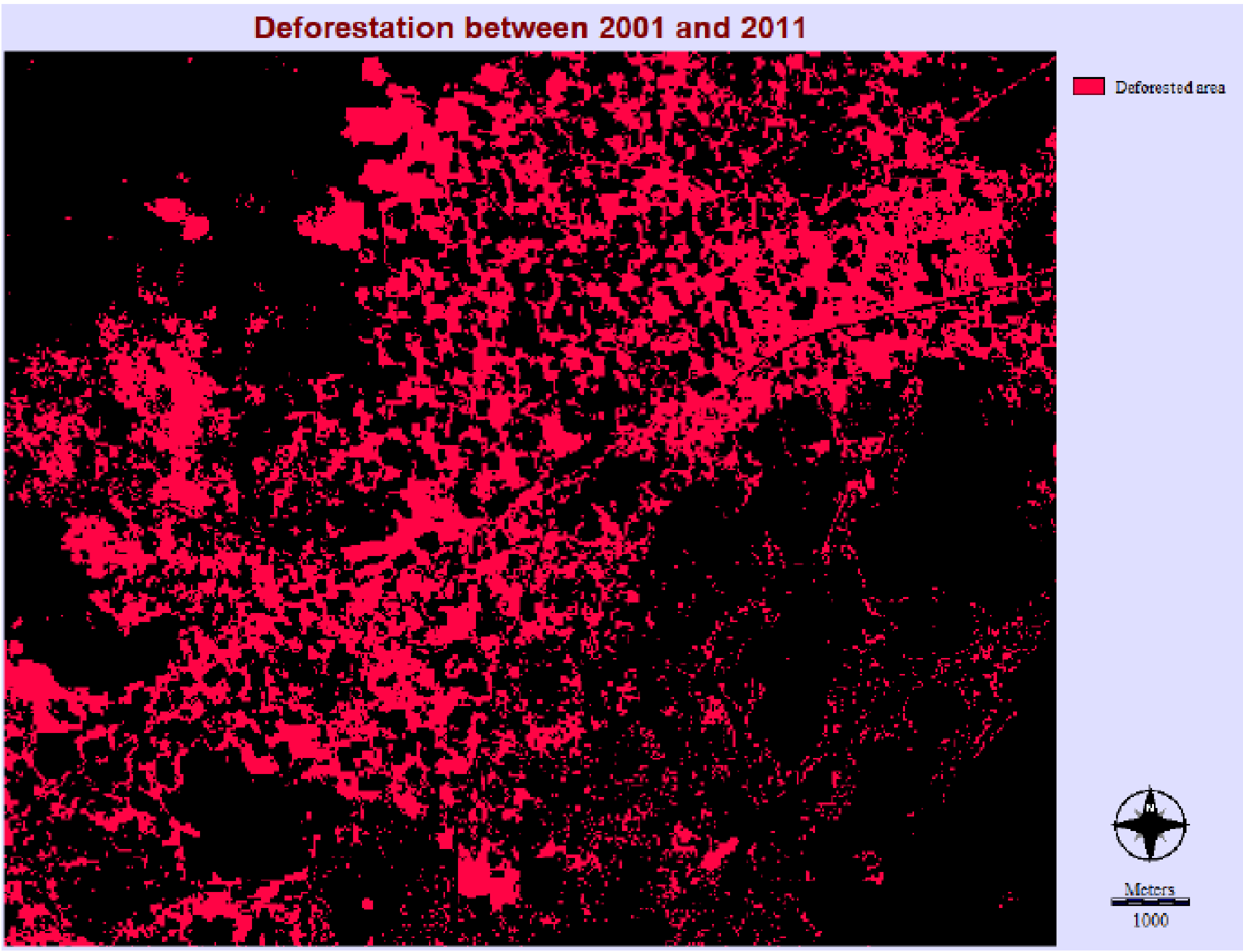


Figure 4.2.1.1: Deforestation between 2001 and 2011: (Author's own, data USGS 2020)

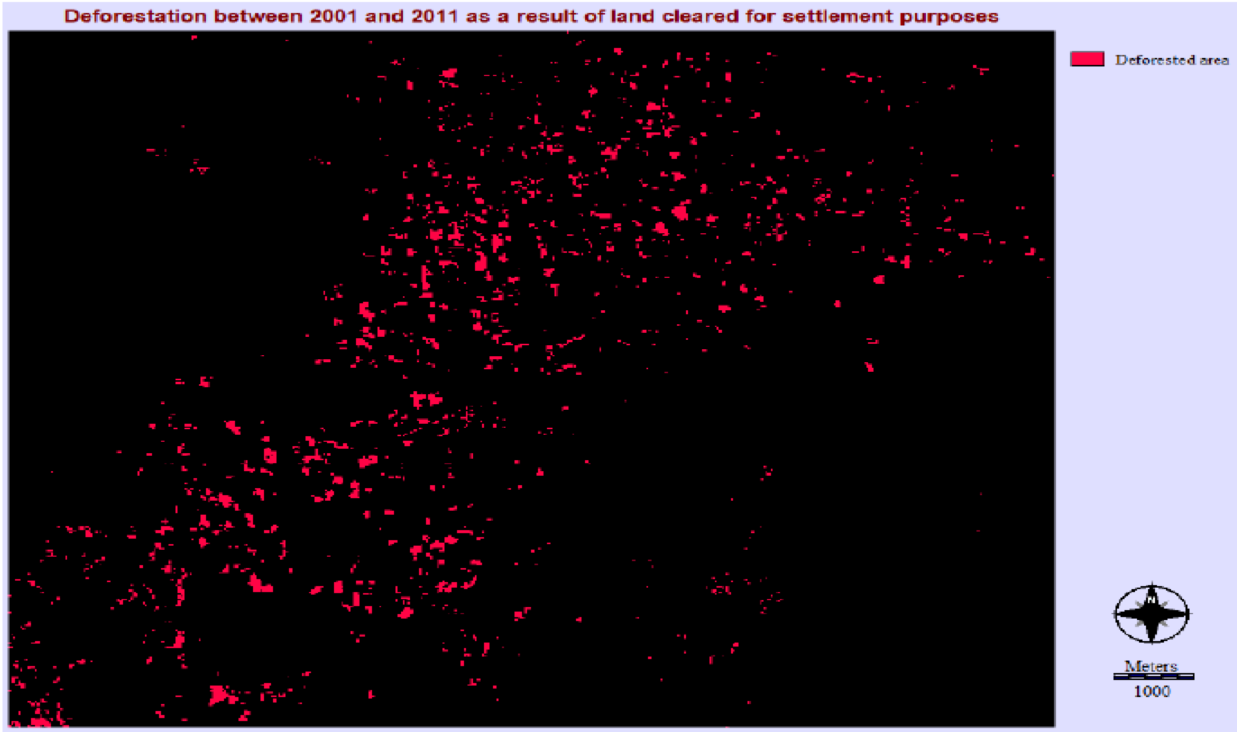


Figure 4.2.1.2: Deforestation between 2001 and 2011 due to land cleared for settlement purposes: (Author's own, data USGS 2020)

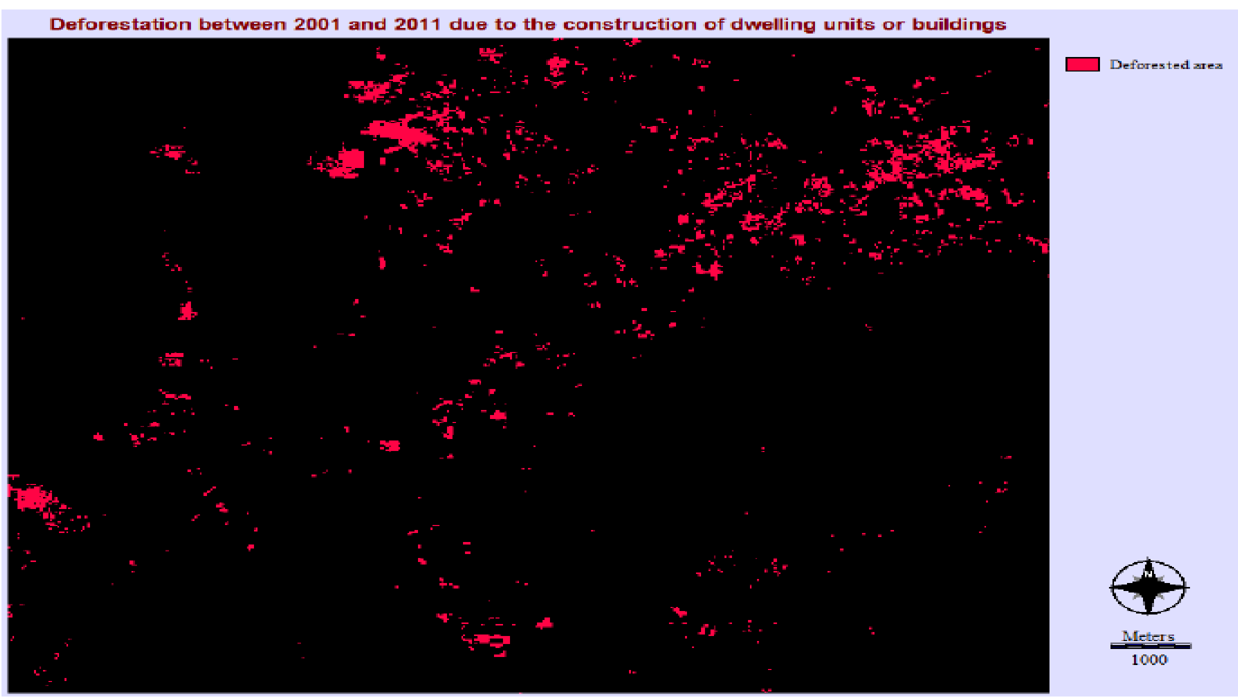


Figure 4.2.1.3: Deforestation between 2001 and 2011 due to the construction of dwelling units or buildings: (Author's own, data USGS 2020)

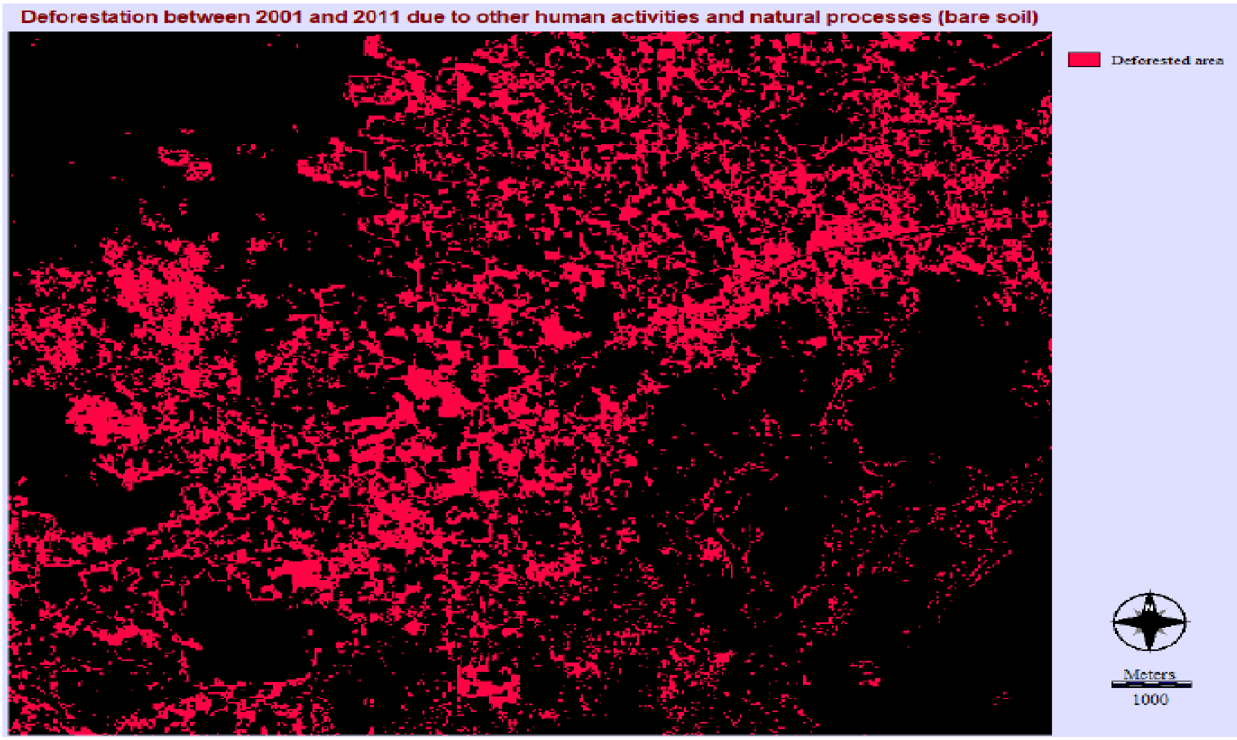


Figure 4.2.1.4: Deforestation between 2001 and 2011 due to other human activities and natural processes (bare soil): (Author's own, data USGS 2020)

4.2.2. Deforestation between 2011 and 2021

Table 4.2.2.1 below expose that deforestation is expected to remain very high at 69% in year 2021 ((1627.47 + 1030.05 + 7933.05) / 15408.09 * 100). The vegetation area to be lost between 2011 and 2021 is expected to be 2531.7 ha, representing 34% loss of vegetation cover in the area. The causes of deforestation are more like the one discovered by SIISKONON (1996) in the northern regions of Namibia, namely population pressure, settlement development patterns, land use practices, the structure of crop production and consumption patterns of wood. Alike, in Tanzania, small-scale crop farming of maize, banana and cassava occurred mainly on deforested areas (HAMUNYELA, BRANDT, SHIRIMA, DO, HEROLD & ROMAN-CUESTA 2020).

Figure 4.2.2.1, reveal the expected deforested areas between 2011 and 2021, where deforestation is likely to happen randomly across the Sibbinda settlement. There is less deforestation expected in the northwest and southeast of the Sibbinda settlement. Figure 4.2.2.2 below display 923.04 ha (6%) of land that is likely to be deforested between 2011 and 2021 due to land cleared for settlement purposes. Figure 4.2.2.2 indicate that, deforestation is likely to occur in the west, northwest and southwest directions. Very few, in some case no deforestation is expected in the east, northeast and southeast directions of the Sibbinda settlement. Figure 4.2.2.3 below display 249.21 ha (1.6%) of land that is likely to be deforested between 2011 and 2021 due to the construction of buildings.

Deforestation is expected to take place more in the north, northwest, south and south-west directions. Very few, in some case no deforestation is expected in the southeast direction of the Sibbinda settlement. Figure 4.2.2.4 display 2556.18 ha (16.6%) of land that is expected to be deforested between 2011 and 2021 due to other human activities and natural processes (vegetation cover turning to bare soil). The deforestation is likely to occur at high intensity in the northwest and west direction, while less deforestation is expected around CDB and northeast of the Sibbinda settlement. The high rate of deforestation in the northwest and west direction is more likely to be triggered by the need to improve service provision in rural settlement by the government through the construction of roads (MLR 2015).

Table 4.2.2.1: LULC Types in 2011 and 2021: (Author's own, data USGS 2020)

Category	**2011: Size in Ha**	**2021: Size in Ha**
Vegetation (1)	7349.22	4817.52
Land cleared for settlement purposes (2)	963.27	1627.47
Dwelling units or buildings (3)	703.35	1030.05
Bare soil (4)	6392.25	7933.05
Total	**15408.09**	**15408.09**

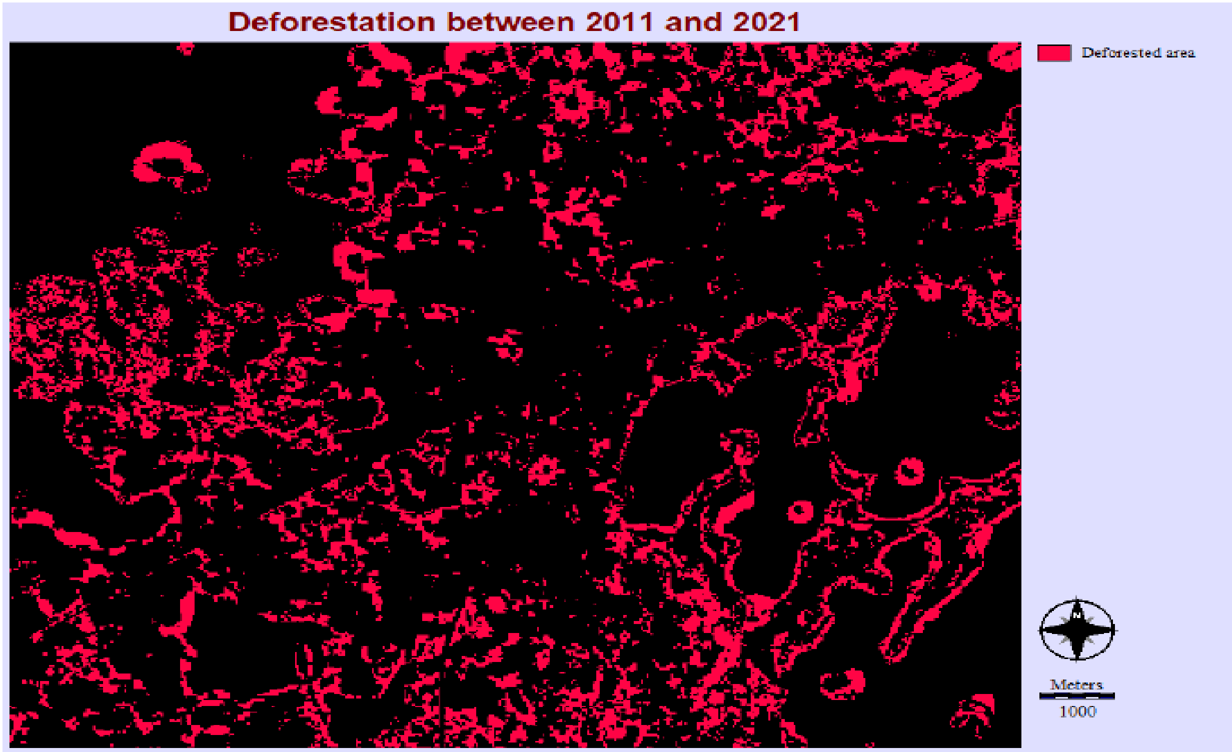


Figure 4.2.2.1: Deforestation between 2011 and 2021: (Author's own, data USGS 2020)

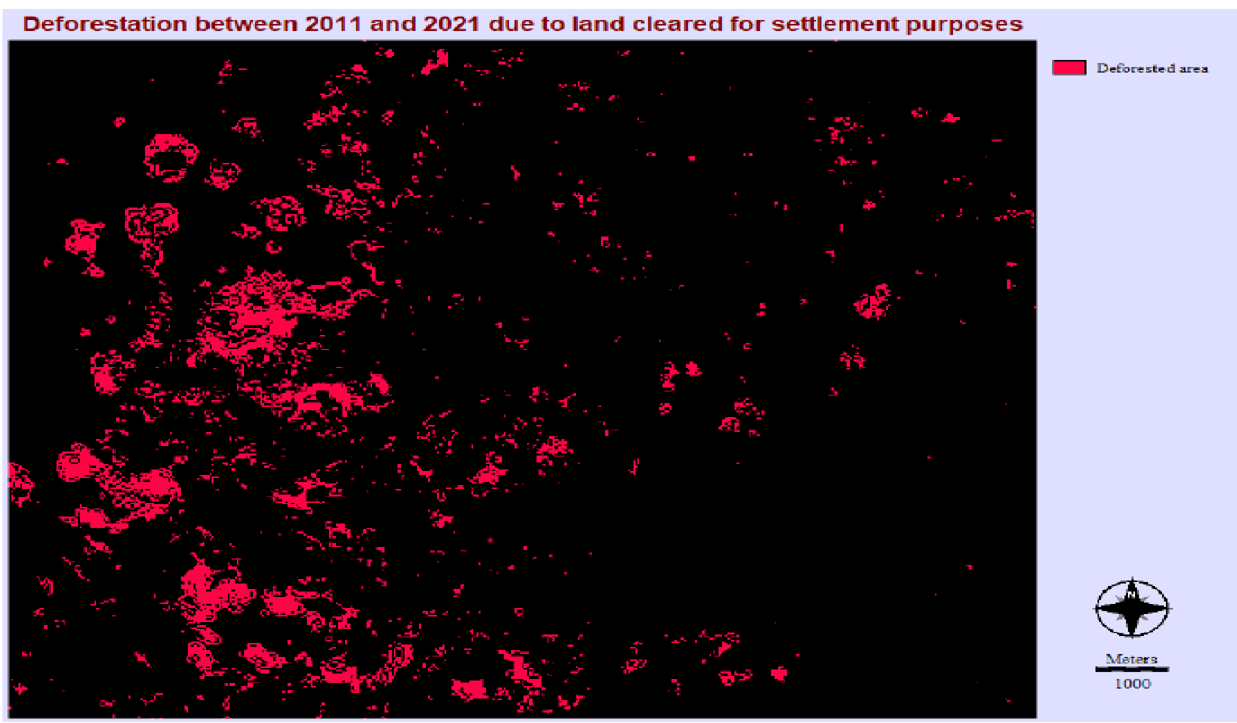


Figure 4.2.2.2: Deforestation between 2011 and 2021 due to land cleared for settlement purposes: (Author's own, data USGS 2020)

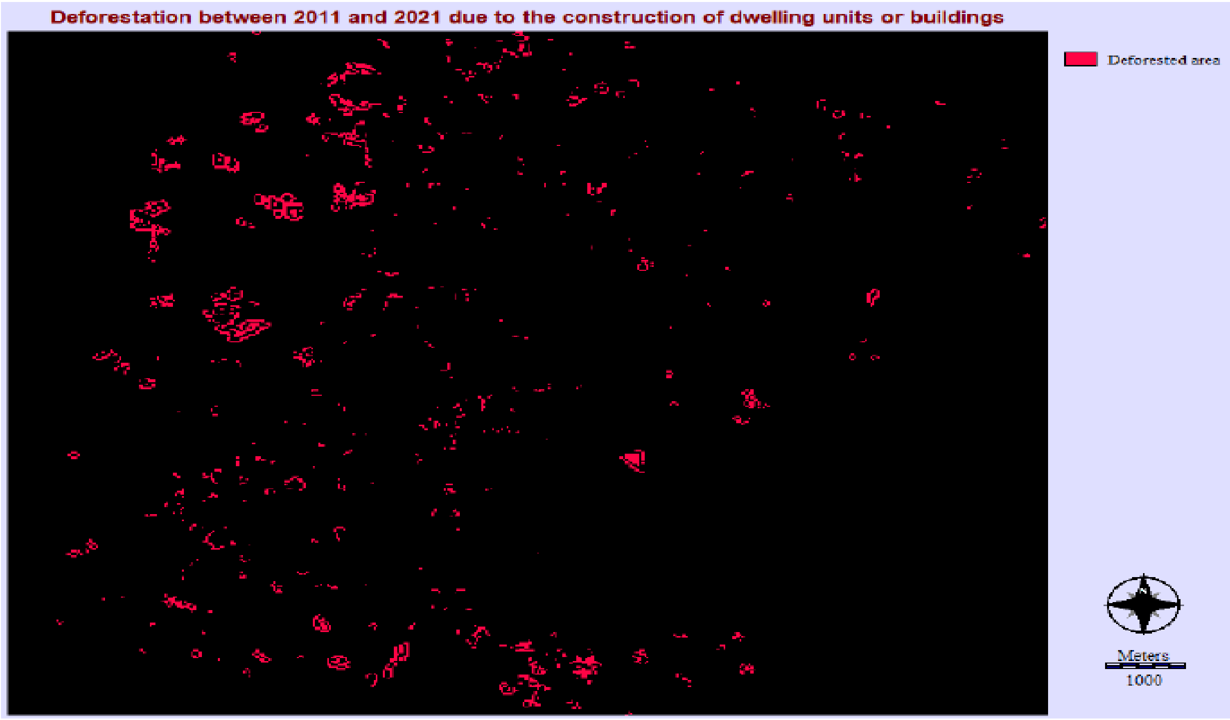


Figure 4.2.2.3: Deforestation between 2011 and 2021 due to the construction of dwelling units or buildings: (Author's own, data USGS 2020)

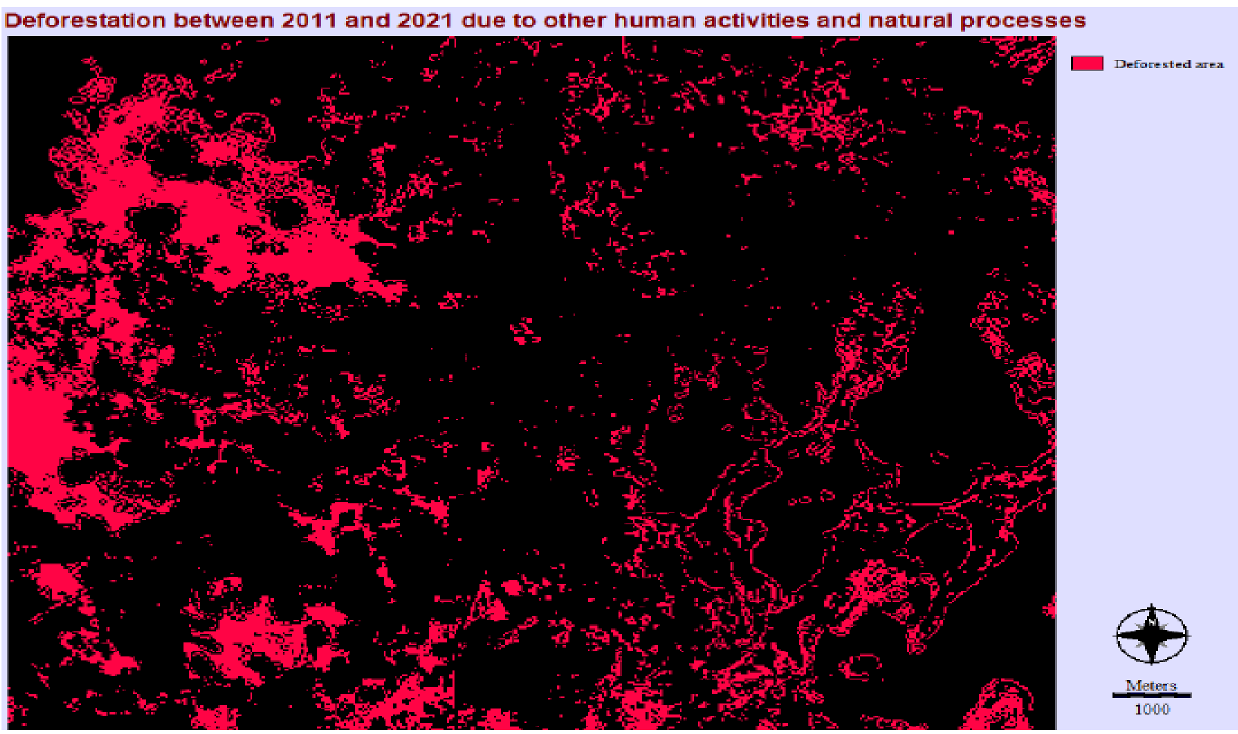


Figure 4.2.2.4: Deforestation between 2011 and 2021 due to other human activities and natural processes (bare soil): (Author's own, data USGS 2020)

4.2.3. Deforestation between 2021 and 2031

Table 4.2.3.1 disclose that deforestation is expected to reach 83% in year 2031 ((5015.16 + 1848.78 + 5929.47) / 15408.09 * 100). The expected vegetation loss between 2021 and 2031 is 2202.84 ha, which translates to a very high rate of 46% vegetation cover loss between 2021 and 2031. Deforestation is likely to continue in the study area and beyond until at saturation stage (close to no vegetation cover). BROWN (2019) argues that some of the reasons for the continuation of deforestation is due to Namibia's Ministry of Forestry and the Ministry of Agriculture, Water and Wildlife not doing enough to conserve woodland forest in Namibia. Another factor expected to contribute to deforestation, is the lack of government incentives (e.g., free fertilizers for farmers to avoid abandoning unproductive land) that supports small-scale farmers to adopt intensive farming practices (BLOEMERTZ, NAANDA, WINGATE, ANGOMBE & KUHN 2018). Forest fire started by people/natural processes also is likely to significantly contribute to deforestation in the area. For instance, FAO (2004) established that, in year 2001, 5 million ha were burned in Namibia with 66 percent of this area situated in the Zambezi, Kavango, Otjozondjupa and Omaheke regions.

Figure 4.2.3.1 disclose the expected areas to be deforested between 2021 and 2031. Deforestation is likely to transpire mainly in the northwest of the Sibbinda settlement, with no deforestation expected around Sibbinda CBD (centre). Figure 4.2.3.2 below present 346.23 ha (2.2%) of land that is likely to be deforested between 2021 and 2031 due to land cleared for settlement purposes. The deforestation is likely to occur in the north and northeast directions, with very few, in some cases no deforestation is expected in the north-west and southeast directions of the Sibbinda settlement.

Figure 4.2.3.3 below present 336.96 ha (2.2%) of land that is expected to be deforested between 2021 and 2031 due to the construction of buildings. The deforestation is likely to ensue more in the north, northeast and southeast directions, with very few, in some cases no deforestation is expected in the east, west, southwest and northwest directions of the Sibbinda settlement.

Figure 4.2.3.4 display 1444.41 ha (9.1%) of land that is expected to be deforested between 2021 and 2031 due to other human activities and natural processes. The deforestation is likely to occur at high intensity in the north, northeast and east directions, while no to less deforestation is expected around CDB and west of the Sibbinda settlement.

Table 4.2.3.1: LULC Types in 2031: (Author's own, data USGS 2020)

Category	**2021: Size in Ha**	**2031: Size in Ha**
Vegetation (1)	4817.52	2614.68
Land cleared for settlement purposes (2)	1627.47	5015.16
Dwelling units or buildings (3)	1030.05	1848.78
Bare soil (4)	7933.05	5929.47
Total	**15408.09**	**15408.09**

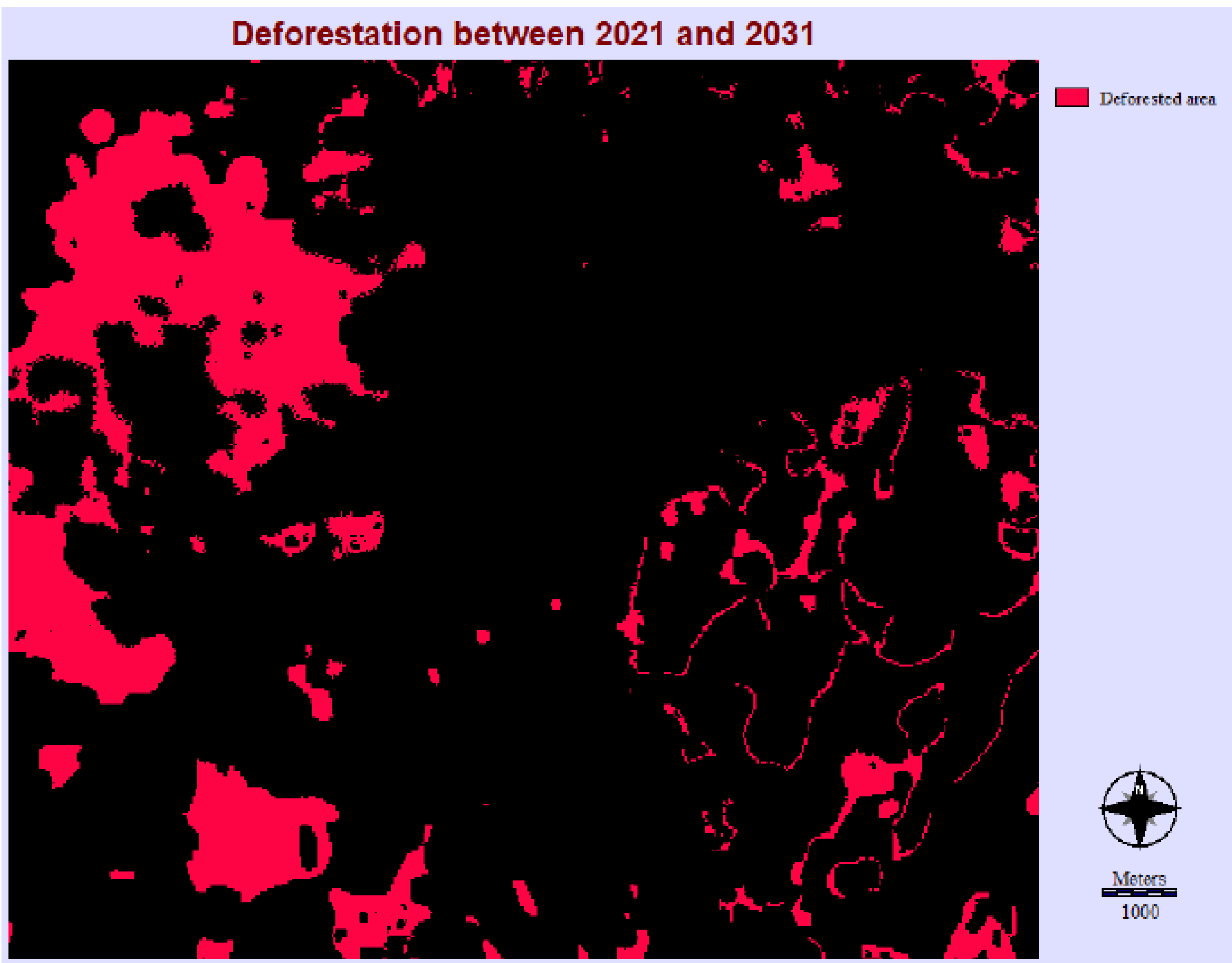


Figure 4.2.3.1: Deforestation between 2021 and 2031: (Author's own, data USGS 2020)

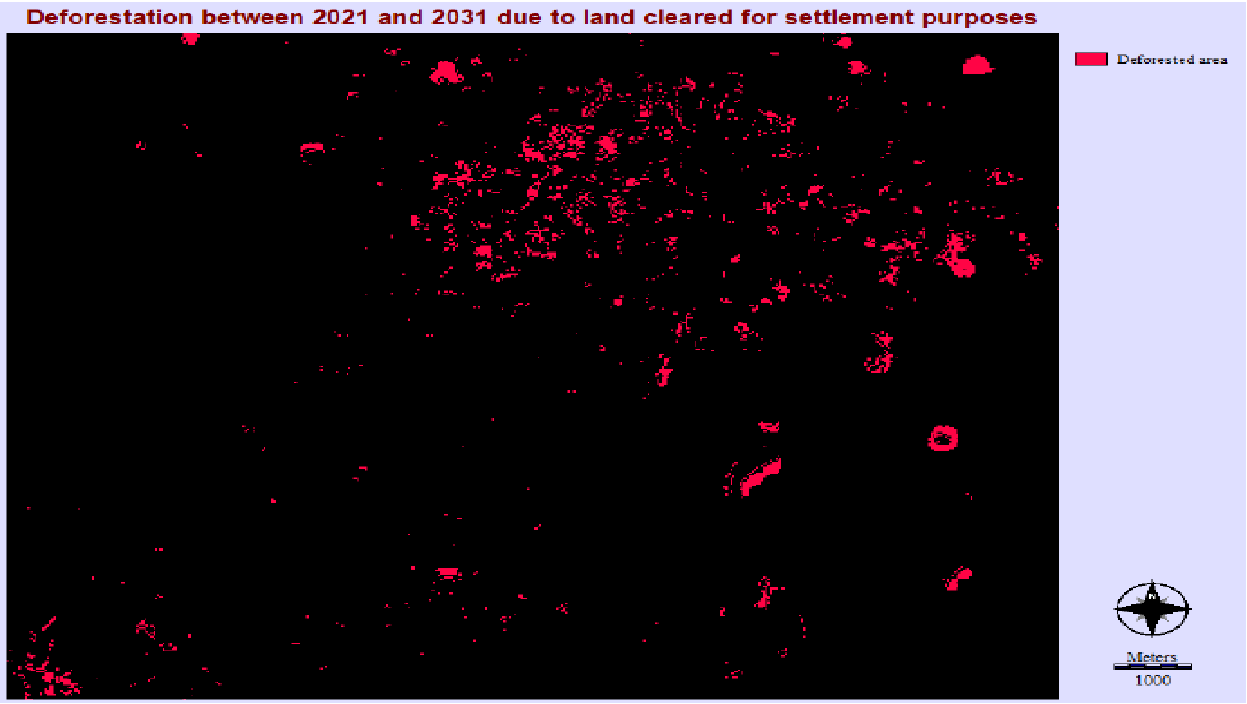


Figure 4.2.3.2: Deforestation between 2021 and 2031 due to land cleared for settlement purposes: (Author's own, data USGS 2020)

Figure 4.2.3.3: Deforestation between 2021 and 2031 due to the construction of dwelling units or buildings: (Author's own, data USGS 2020)

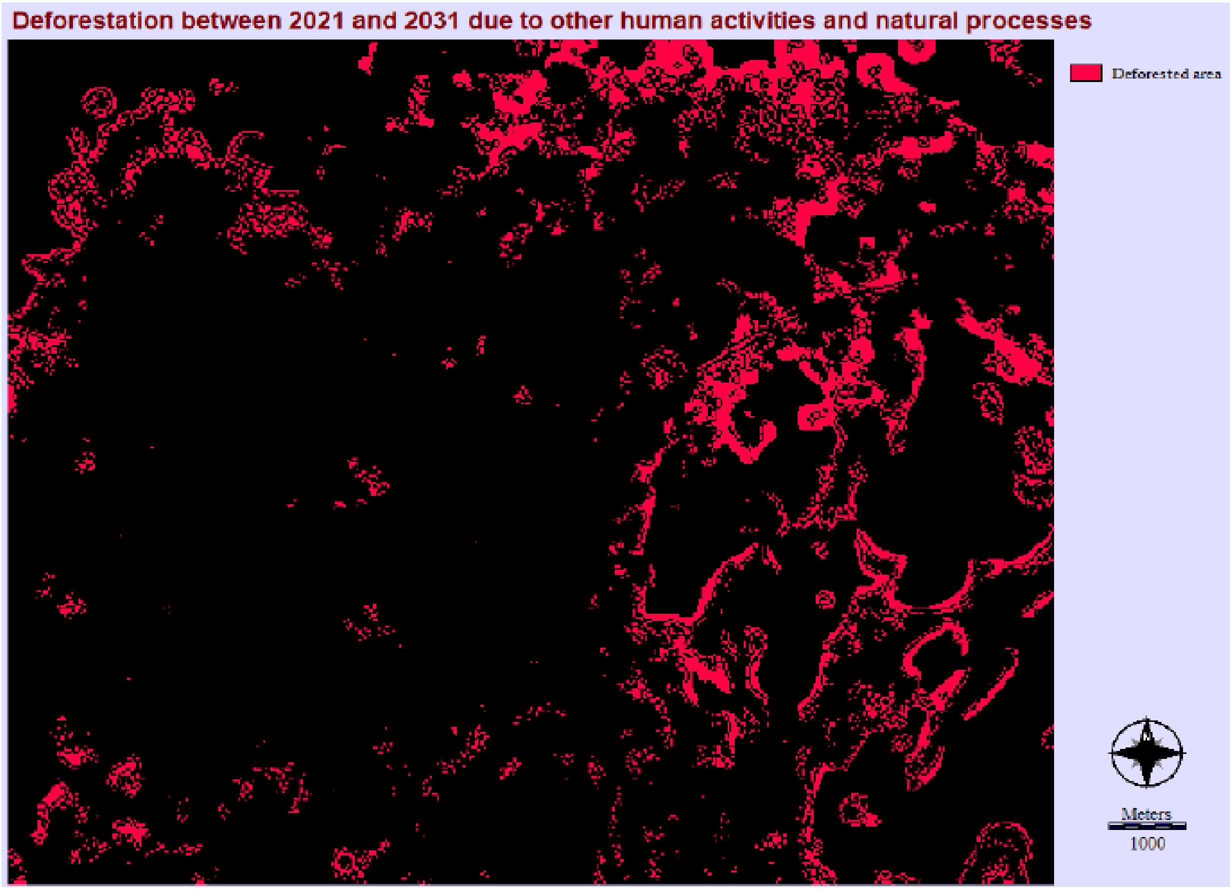


Figure 4.2.3.4: Deforestation between 2021 and 2031 due to other human activities and natural processes (bare soil): (Author's own, data USGS 2020)

4.3. Regression Results: Factors Associated with Deforestation

Deforestation drivers in Namibia can be categories into natural causes and the one related to human activities. Natural causes are very difficult to identify due to Namibia's arid climate exacerbated by low and erratic varying rainfall that in many cases leads to prolonged drought periods and decline in vegetation cover in the most vulnerable environment (FAO 2004). In the current study, only factors related to human activities, particularly the distance from roads, vegetation, land cleared for settlement purposes, and distance from buildings were considered for the regression analyses in modelling the causes of deforestation in the area.

4.3.1. Factors associated with Deforestation: 2001 to 2011

Distance from road and deforestation

Figure 4.3.1.1 stipulate that the correlation coefficient (r) is -0.24 that indicate a weak negative relationship between distance from road (independent variable) and deforestation (dependent variable). Deforestation is likely to decrease as the distance from the road increases. Areas far from roads in the Sibbinda settlement during 2001 to 2011 period were less deforested. In some cases, deforestation can be positively associated with distance from roads as the lack of road access to forests can lead to a delayed response time to wildfires (UNITED NATIONS DEVELOPMENT PROGRAMME [UNDP] 2014a: 25).

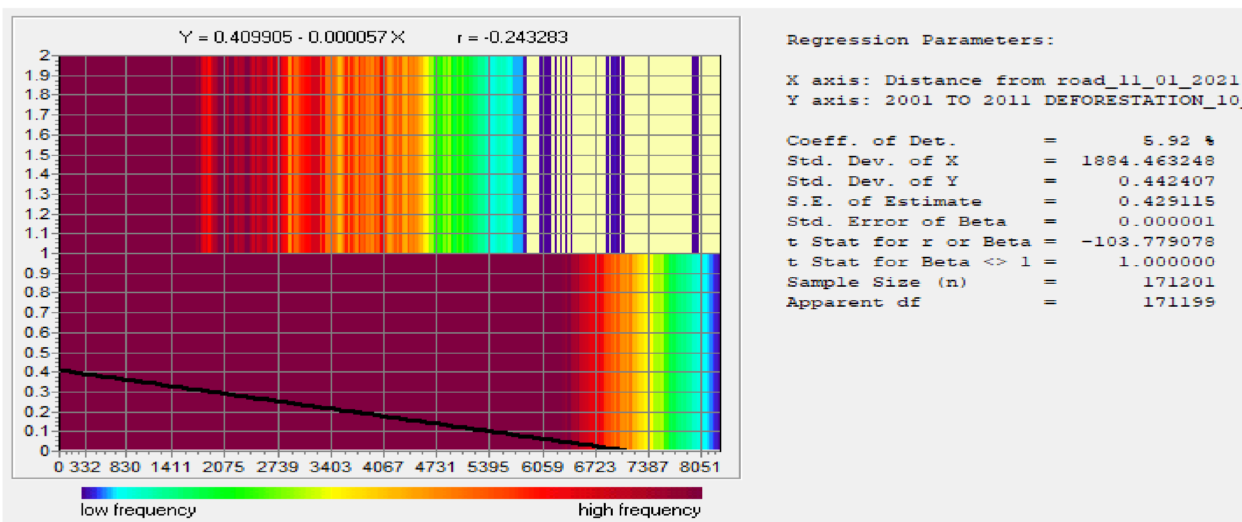


Figure 4.3.1.1: Distance from road and deforestation between 2001 and 2011: (Author's own, data USGS 2020)

Distance from vegetation edges and deforestation

Figure 4.3.1.2 below stipulate that the correlation coefficient (r) is -0.31, which means there is a weak negative relationship between distance from vegetation edges and deforestation. Deforestation is likely to decrease as the distance from vegetation edges increases. Correspondingly, BROADBENT, ASNER, KELLER, KNAPP, OLIVEIRA and SILVA (2008: 1746) established that forestry edges are associated with a high rate of deforestation.

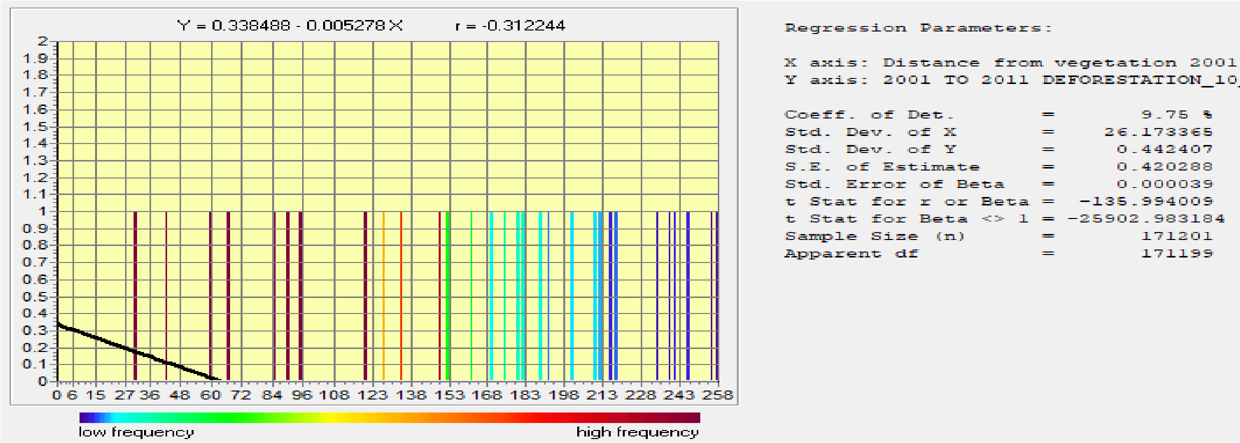


Figure 4.3.1.2: Distance from vegetation and deforestation between 2001 and 2011: (Author's own, data USGS 2020)

<u>Distance from edge of land cleared for settlement purposes and deforestation</u>

Figure 4.3.1.3 specify that the correlation coefficient (r) is -0.23, which indicate a weak negative relationship between distance from edges of land cleared for settlement purposes and the deforestation. Deforestation is likely to decrease as the distance from land cleared for settlement purposes increases. Areas far from land cleared for settlement purposes in the Sibbinda settlement during 2001 to 2011 period were less likely to be deforested. In order to reduce this form of deforestation, there might be a need to implement a settlement design that accounts for both environmental (conservation) and social (settlement development such as the clearing of land for cultivation purposes) objectives (CAVIGLIA-HARRIS & HARRIS 2011: 467).

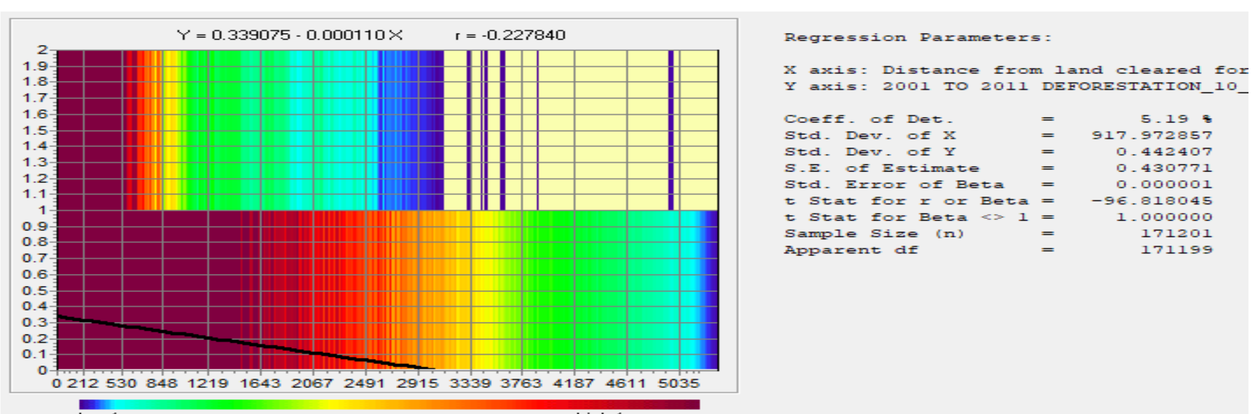


Figure 4.3.1.3: Distance from land cleared for settlement purposes and deforestation between 2001 and 2011: (Author's own, data USGS 2020)

Distance to edges of dwelling units or buildings and deforestation

Figure 4.3.1.4 stipulate that the correlation coefficient (r) is -0.30, which indicate a weak negative relationship between distance from edges of buildings and deforestation. Deforestation is likely to decline as the distance from buildings increases. Areas far from buildings in the Sibbinda settlement during 2001 to 2011 period were less likely to be deforested. This is because close-by trees and grasses have been exploited for the construction of houses as most of the building structures at 94.1% were classified as traditional dwellings in the Sibbinda area during Namibia's 2011 population and housing census (NSA 2014: 42).

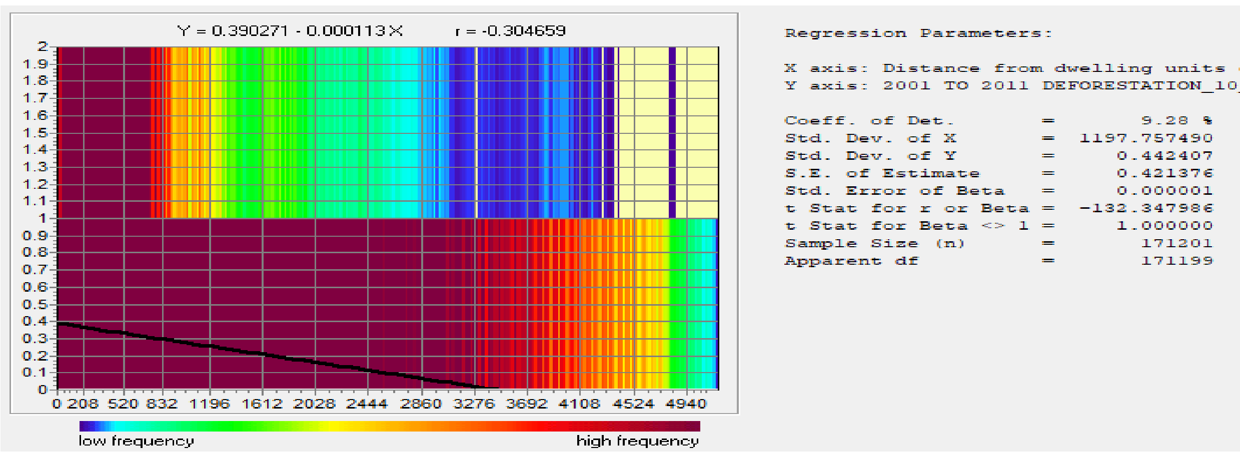


Figure 4.3.1.4: Distance from dwelling units or buildings and deforestation between 2001 and 2011: (Author's own, data USGS 2020)

4.3.2. Factors associated with Deforestation: 2011 to 2021

Distance from road and deforestation

Figure 4.3.2.1 below specify that the correlation coefficient (r) is -0.01, which indicates a very weak negative relationship between distance from road and deforestation. Deforestation is likely to decline as the distance from the road increases. Areas far from roads in the Sibbinda settlement during 2011 to 2021 period are less likely to be deforested. Roads are usually negatively associated with forests, as construction of roads in forest areas can break such forests into pieces (DAWSON, KOUADIO & MENDOZA 2016).

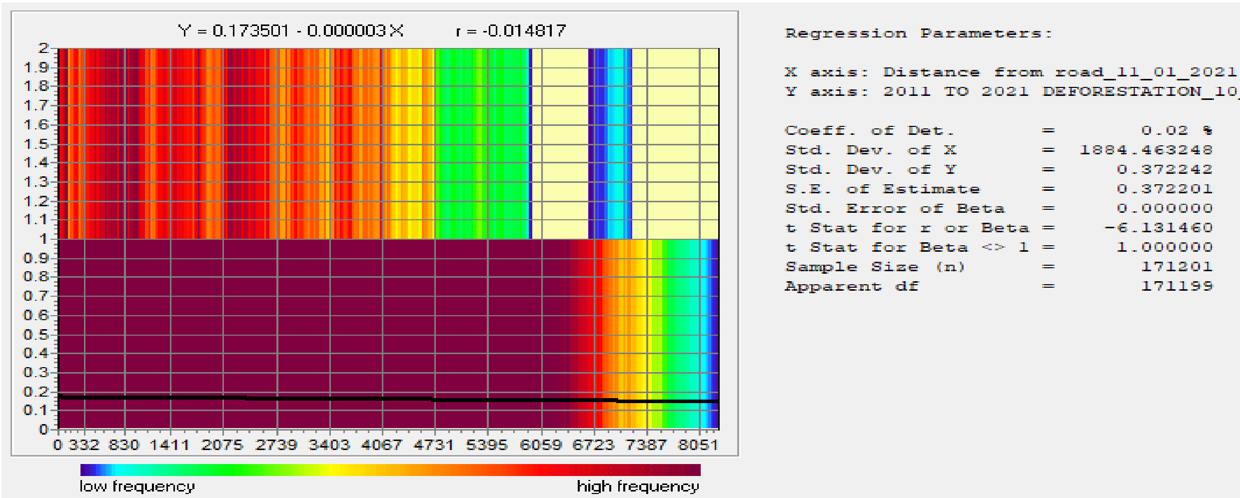


Figure 4.3.2.1: Distance from road and deforestation between 2011 and 2021: (Author's own, data USGS 2020)

Distance from vegetation edges and deforestation

Figure 4.3.2.2 reveal that the correlation coefficient (r) is -0.30, which means there is a weak negative relationship between distance from vegetation edges and deforestation. Consequently, deforestation is likely to decrease as the distance from vegetation edges increases. Areas highly dominated by vegetation LULC in the Sibbinda settlement during 2011 to 2021 period are less likely to be deforested.

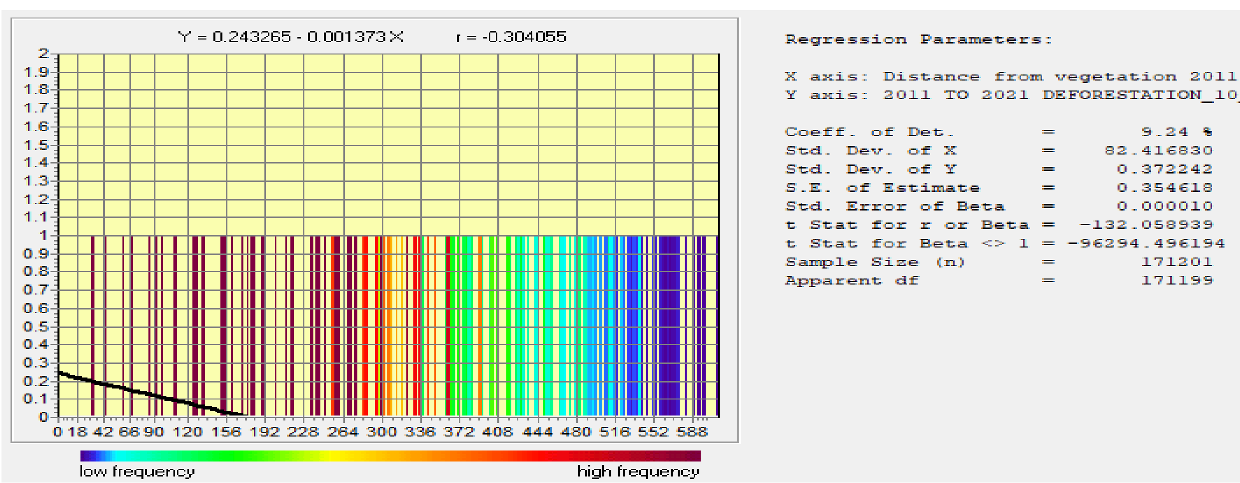


Figure 4.3.2.2: Distance from vegetation and deforestation between 2011 and 2021: (Author's own, data USGS 2020)

Distance from edge of land cleared for settlement purposes and deforestation

Figure 4.3.2.3 stipulate that the correlation coefficient (r) is -0.03, which indicate a very weak negative relationship between distance from edges of land cleared for settlement purposes and the estimated 2011 to 2021 deforestation (dependent variable). Deforestation is likely to decrease as the distance from land cleared for settlement purposes increases. Areas far from land cleared for settlement purposes in the Sibbinda settlement during 2011 to 2021 period are less likely to be deforested. Though, such areas can be deforested more when unexpected government rural development projects (e.g., rural water supply) aimed at improving people's standards of living at Sibbinda are implemented by the Namibian government (MRLGHRD 2011).

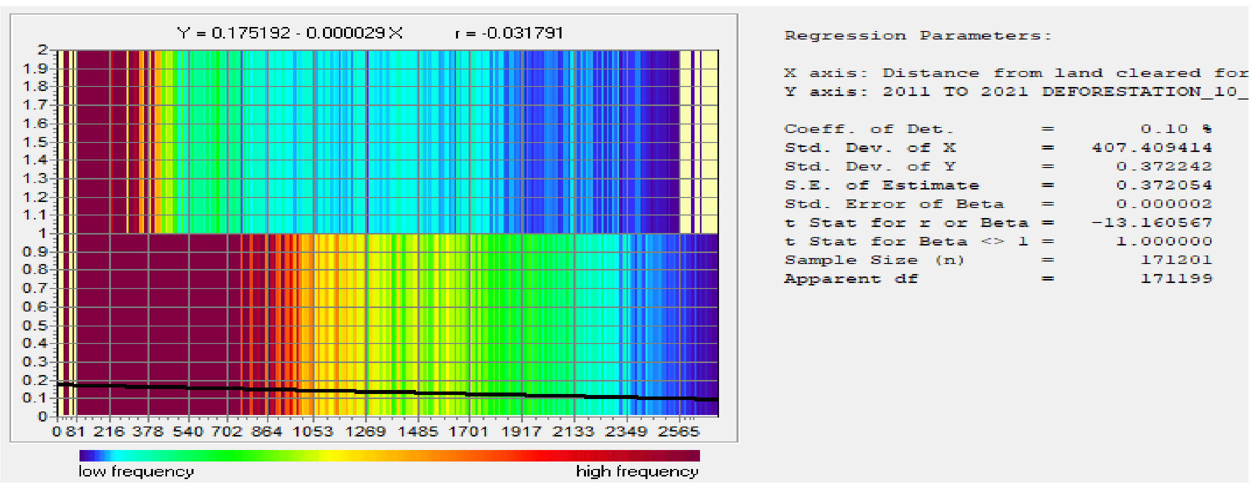


Figure 4.3.2.3: Distance from land cleared for settlement purposes and deforestation between 2011 and 2021: (Author's own, data USGS 2020)

Distance from dwelling units or buildings and deforestation

Figure 4.3.2.4 reveal the correlation coefficient (r) at -0.10, which indicate a very weak negative relationship between distance from edges of buildings and the estimated 2011 to 2021 deforestation. Deforestation is likely to decline as the distance from buildings increases. Areas far from houses at the Sibbinda settlement during 2011 to 2021 period are less likely to be deforested. This is because, in rural settlements housing areas are usually surrounded by agriculture land (KREVS & REBERNIK 2013).

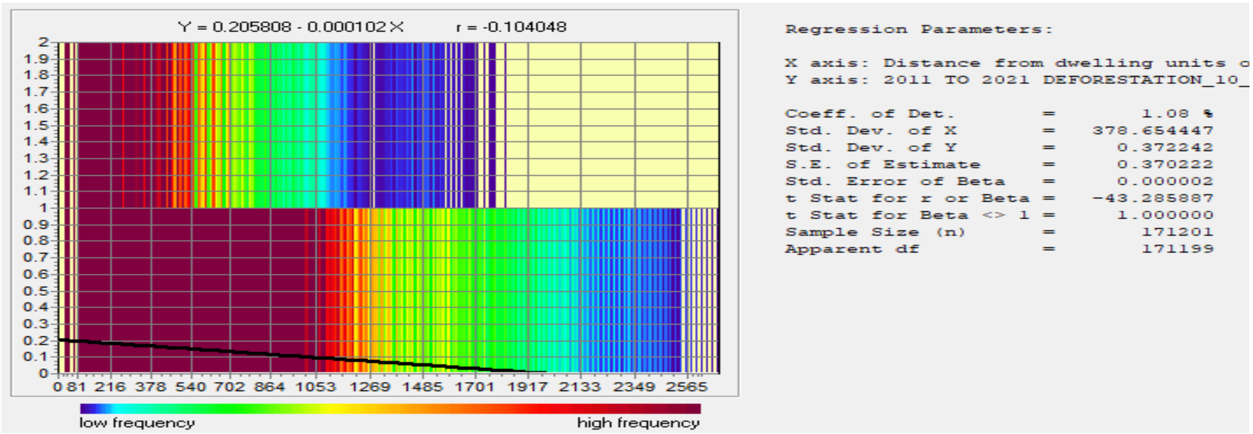


Figure 4.3.2.4: Distance from dwelling units or buildings and deforestation between 2011 and 2021: (Author's own, data USGS 2020)

4.3.3. Factors associated with Deforestation: 2021 to 2031

<u>Distance from road and deforestation</u>

Figure 4.3.3.1 reveal a correlation coefficient (r) of 0.1, which indicates a very weak positive relationship between distance from road and deforestation. Deforestation is expected to slightly increase as the distance from the road increases. Areas far from roads during 2021 to 2031 period are expected to be deforested more. When residents adopt possibilism, they are more likely to aggressively explore even distant areas with limited roads for their benefits (FEKADU 2014).

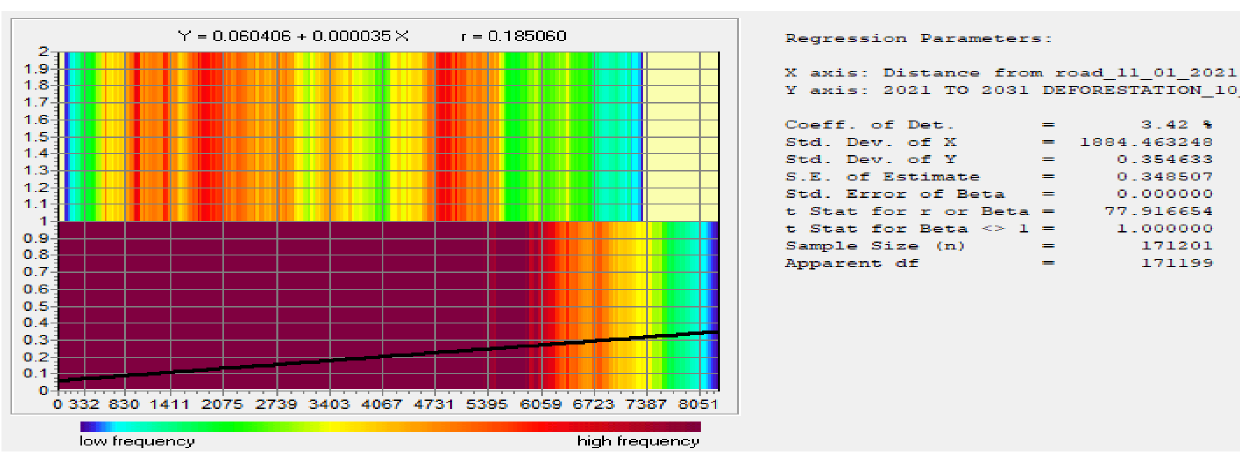


Figure 4.3.3.1: Distance from road and deforestation between 2021 and 2031: (Author's own, data USGS 2020)

Distance from vegetation edges and deforestation

Figure 4.3.3.2 reveal a correlation coefficient (r) of 0.1, which means there is a very weak positive relationship between distance from vegetation edges and deforestation. Consequently, deforestation is likely to increase as the distance from vegetation edges increases. As distance increase to densely vegetated areas at the Sibbinda settlement during 2021 to 2031 period, deforestation is likely to occur more.

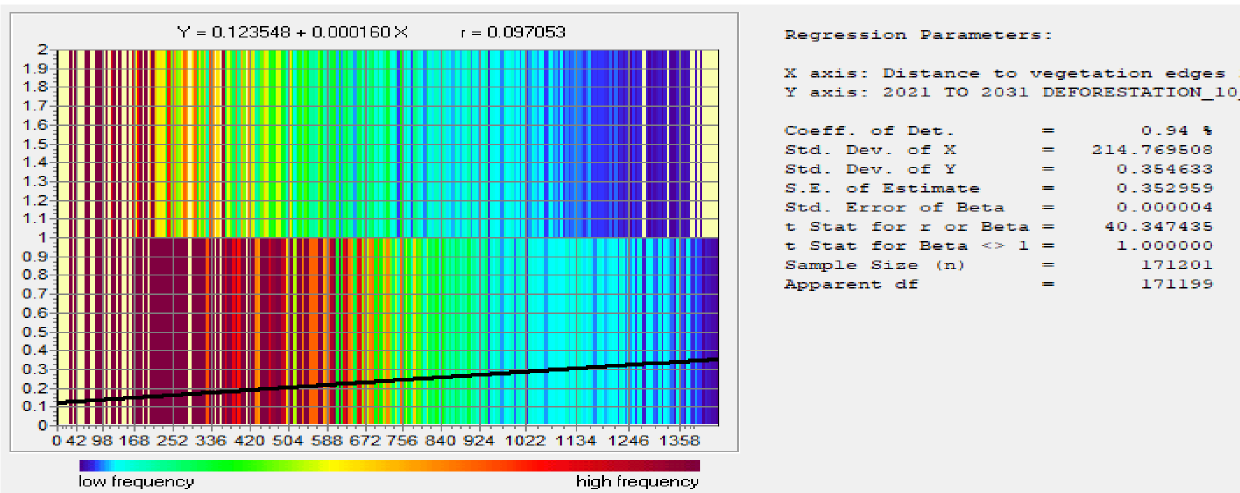


Figure 4.3.3.2: Distance from vegetation and deforestation between 2021 and 2031: (Author's own, data USGS 2020)

Distance from edge of land cleared for settlement purposes and deforestation

Figure 4.3.3.3 stipulate that the correlation coefficient (r) is 0.03, which indicate a very weak positive relationship between distance from edges of land cleared for settlement purposes and the estimated 2021 to 2031 deforestation. Deforestation is likely to increase as the distance from land cleared for settlement purposes increases. Areas far from land cleared for settlement purposes in the Sibbinda settlement during 2021 to 2031 period are more likely to be deforested. This may be due to Sibbinda being one of the rural settlements without a formal structure responsible for the planning of houses and roads (JADHAV 2019), thus residents can opt to construct houses in areas which are far from the land initially reserved for settlement purposes.

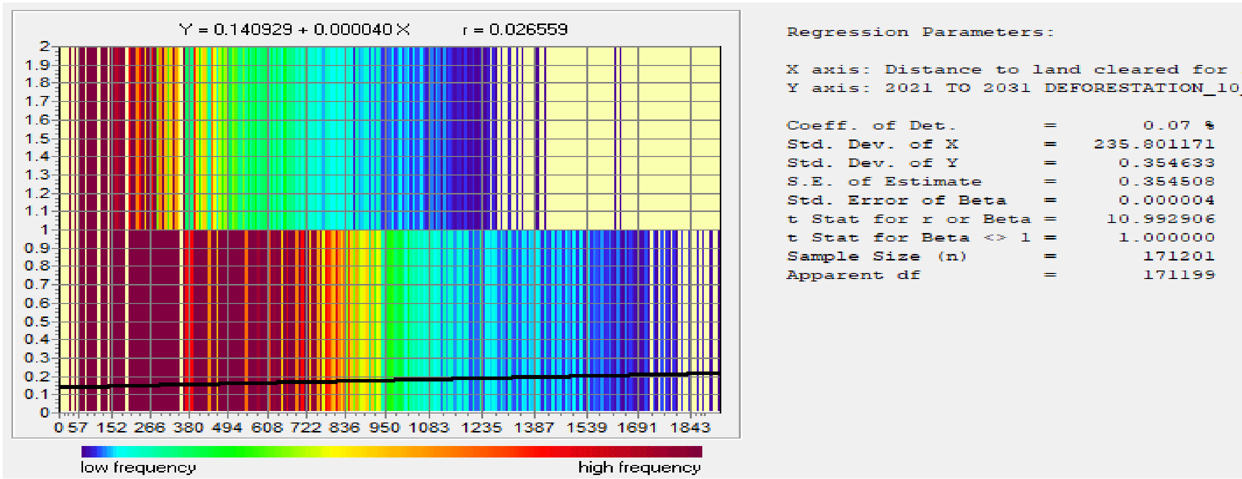


Figure 4.3.3.3: Distance from land cleared for settlement purposes and deforestation between 2021 and 2031: (Author's own, data USGS 2020)

<u>Distance from dwelling units or buildings and deforestation</u>

Figure 4.3.3.4 reveal the correlation coefficient (r) at 0.01, which indicate a very weak positive relationship between distance from edges of buildings and the estimated 2021 to 2031 deforestation. Deforestation is likely to increase as the distance from houses increases. Areas far from houses in the Sibbinda settlement during 2021 to 2031 period are more likely to be deforested.

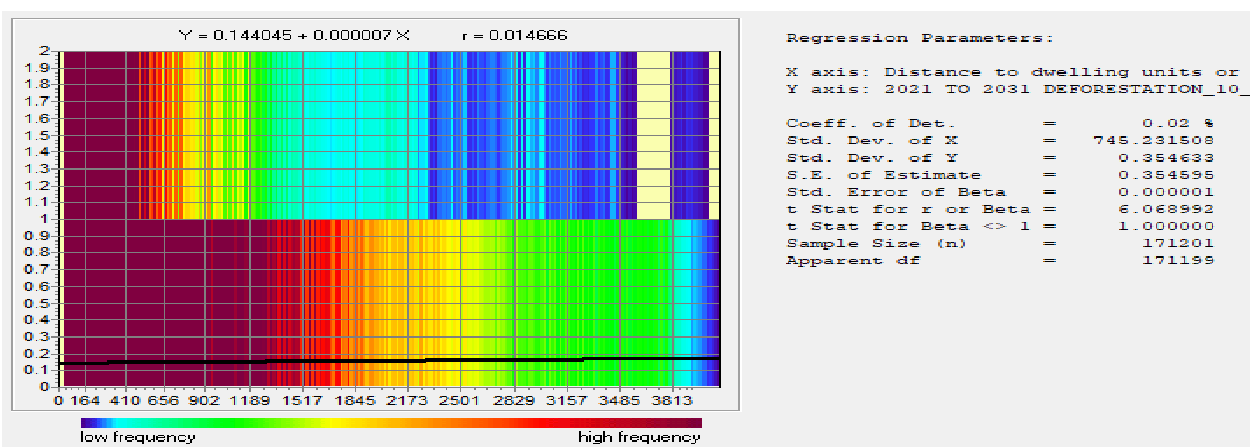


Figure 4.3.3.4: Distance from dwelling units or buildings and deforestation between 2021 and 2031: (Author's own, data USGS 2020)

4.3.4. Deforestation versus Distance from road, vegetation, land cleared for settlement purposes, and dwelling units or buildings: 2001 to 2011

The regression equation in Table 4.3.4.1 below was used in the regression model to derive the coefficient for each of the independent variable and the intercept value (value of the dependent variable when all independent variables take the value of 0). The regression equation considers the deforested areas between 2001 and 2011 in relation to the distance from roads, vegetation, land cleared for settlement purposes and buildings. The adjusted R square in Table 4.3.4.1 indicate that, 24% of the variation in the dependent variable (deforestation between 2001 and 2011) is explained by the independent variables (Distance from road 2001, Distance from vegetation 2001, Distance from land cleared for settlement purposes 2001 and the Distance from dwelling units or buildings 2001). The $F(4, 171196) = 13552$ values, indicate that the overall regression model is significant at 99% confidence level as 13552 is greater than 4.46.

Table 4.3.4.1: Regression Equation and Statistics: Deforestation versus distance from road, vegetation, land cleared for settlement purposes, and dwelling units or buildings: 2001 to 2011: (Author's own, data USGS 2020)

Regression Equation:

2001 TO 2011 DEFORESTATION = 0.5315 - 0.0000 * Distance from road 2001 - 0.0067 * Distance from vegetation 2001- 0.0000*Distance from land cleared for settlement purposes 2001 - 0.0001 * Distance from dwelling units or buildings 2001

Regression Statistics:

Apparent R = 0.490407 Apparent R square = 0.240499
Adjusted R = 0.490393 Adjusted R square = 0.240485

F (4, 171196) = 13552.452148

Table 3.24: ANOVA Regression Table

Source	Degree of freedom	Sum of squares	Mean square
Regression	4	8058.62	2014.65
Residual	171196	25449.32	0.15
Total	**171200**	**33507.94**	

Table 4.3.4.2 stipulates that all the independent variables are negatively correlated to the dependent variable. In other words, a one unit increase in the distance from road will result into a decline of 0.000016 unit in deforestation. A single unit increase in the distance from vegetation will result into a decline of 0.006682 unit in deforestation. A unit increase in the distance from land cleared for settlement purposes will lead to a 0.000013 unit decline in deforestation while a unit increase in the distance from buildings will lead to a 0.000114 unit decline in deforestation. Figure 4.3.4.1 present the predicted deforestation based on deforestation between 2001 and 2011 and factors (distance from road, vegetation, buildings and land cleared settlement purposes).

Table 4.3.4.2: Individual Regression Coefficients: 2001 to 2011: (Author's own, data USGS 2020)

	Coefficient	**t_test (171196)**
Intercept	**0.531539**	**302.109528**
Distance from road 2001	-0.000016	-19.231373
Distance from vegetation 2001	-0.006682	-181.604538
Distance from land cleared for settlement purposes 2001	-0.000013	7.190895
Distance from dwelling units or buildings 2001	-0.000114	-80.802742

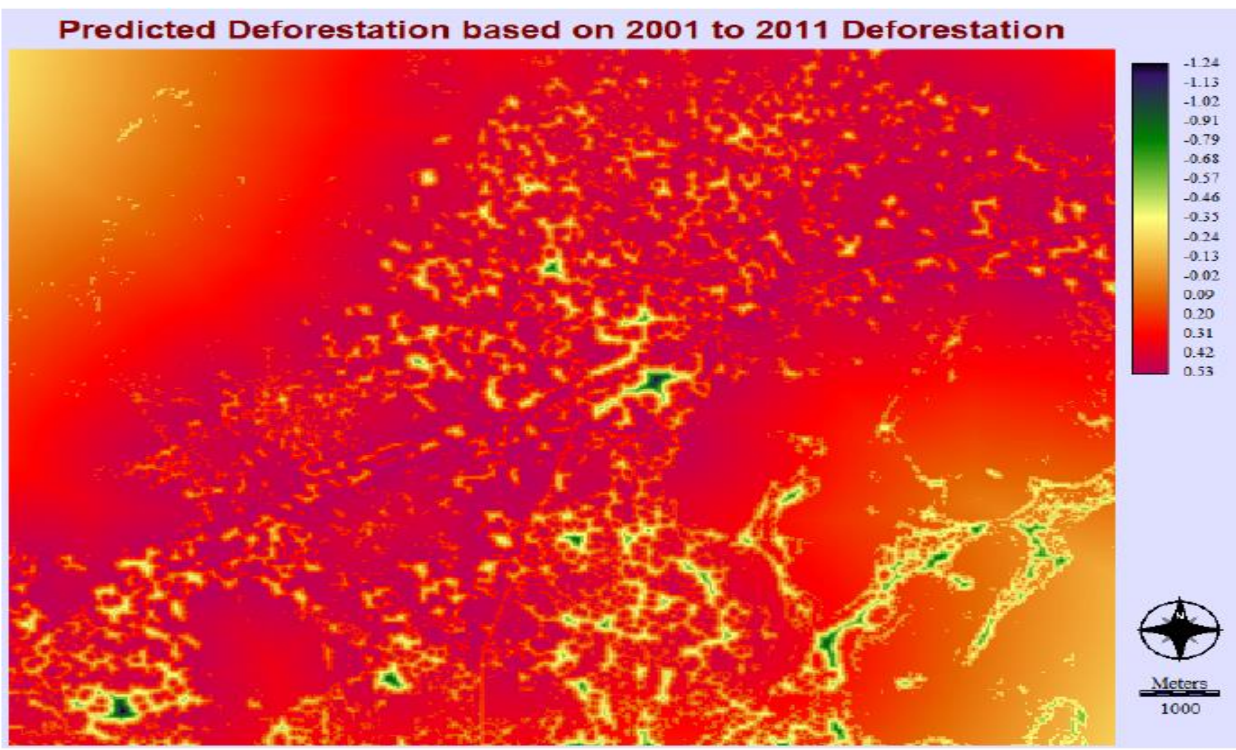


Figure 4.3.4.1: Predicted deforestation based on deforestation between 2001 and 2011 and distance from road, vegetation, dwellings and land cleared factors: (Author's own, data USGS 2020)

4.3.5. Deforestation versus Distance from road, vegetation, land cleared for settlement purposes, and dwelling units: 2011 to 2021

The regression equation in Table 4.3.5.1 below was used in the regression model to derive the coefficient for each of the independent variable and the intercept value. The adjusted R square in Table 4.3.5.1 indicate that, 15% of the variation in the dependent variable (deforestation between 2011 and 2021) is explained by the independent variables (Distance from road 2011, Distance from vegetation 2011, Distance from land cleared for settlement purposes 2011 and the Distance from dwelling units 2011). The F (4, 171196) = 7550 values, indicate that the overall regression model is significant at 99% confidence level as 7550 is greater than 4.46.

Table 4.3.5.1: Regression Equation and Statistics: Deforestation versus distance from road, vegetation, land cleared for settlement purposes, and dwelling units: 2011 to 2021: (Author's own, data USGS 2020)

Regression Equation: 2011 TO 2021 DEFORESTATION = 0.3897 - 0.0000 * Distance from road 2011 - 0.0019 * Distance from vegetation 2011 + 0.0000 * Distance from land cleared for settlement purposes 2011 - 0.0002 * Distance from dwelling units or buildings 2011			
Regression Statistics: Apparent R = 0.387241 Apparent R square = 0.149956 Adjusted R = 0.387222 Adjusted R square = 0.149941 **F (4, 171196) = 7550.149414**			
ANOVA Regression Table			
Source	**Degree of freedom**	**Sum of squares**	**Mean square**
Regression	4	3557.28	889.32
Residual	171196	20164.93	0.12
Total	**171200**	**23722.21**	

Table 4.3.5.2 reveal that three independent variables (Distance from road 2011, Distance from vegetation 2011 and the Distance from dwelling units 2011) are negatively correlated to the dependent variable (deforestation between 2011 and 2021). A one-unit increase in the distance from road will result into a decline of 0.000014 unit in deforestation. A one-unit increase in the distance from vegetation will result into a decline of 0.001864 unit in deforestation. A unit increase in the distance from land cleared for settlement purposes will lead to a 0.000007 unit increase in

deforestation while a unit increase in the distance from houses will lead to a 0.000224 unit decline in deforestation. Figure 4.3.5.1 present the predicted deforestation based on deforestation between 2011 and 2021 and factors (distance from road, vegetation, dwellings and land cleared settlement purposes).

Table 4.3.5.2: Individual Regression Coefficients: 2011 to 2021: (Author's own, data USGS 2020)

	Coefficient	**t_test (171196)**
Intercept	**0.389665**	**209.761108**
Distance from road 2011	-0.000014	-25.626064
Distance from vegetation 2011	-0.001864	-165.706146
Distance from land cleared for settlement purposes 2011	0.000007	2.605538
Distance from dwelling units or buildings 2011	-0.000224	-75.676888

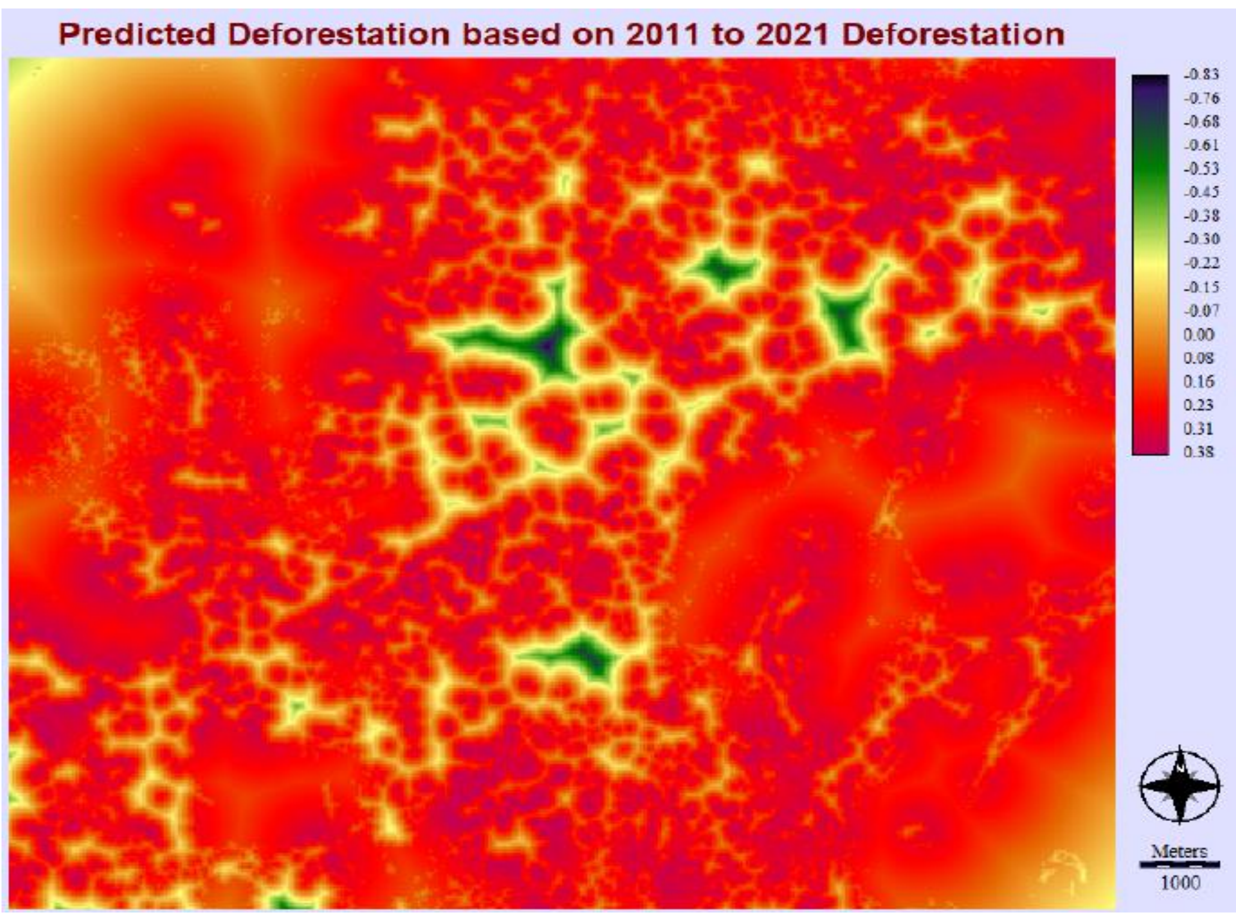


Figure 4.3.5.1: Predicted deforestation based on deforestation between 2011 and 2021 and distance from road, vegetation, dwellings and land cleared factors: (Author's own, data USGS 2020)

4.3.6. Deforestation versus Distance from road, vegetation, land cleared for settlement purposes, and dwelling units: 2021 to 2031

The regression equation in Table 4.3.6.1 was used in the regression model to derive the coefficient for each of the independent variable and the intercept value. The adjusted R square indicate that, 7% of the variation in the dependent variable (deforestation between 2021 and 2031) is explained by the independent variables (Distance from road 2021, Distance from vegetation 2021, Distance from land cleared for settlement purposes 2021 and the Distance from dwelling units 2021). The F (4, 171196) = 3017 values, indicate that the overall regression model is significant at 99% confidence level as 3017 is greater than 4.46.

Table 4.3.6.1: Regression Equation and Statistics: Deforestation versus distance from road, vegetation, land cleared for settlement purposes, and dwelling units or buildings: 2021 to 2031: (Author's own, data USGS 2020)

Regression Equation:

2021 TO 2031 DEFORESTATION = 0.0058 + 0.0001 * Distance from road 2021 + 0.0002 * Distance to vegetation edges 2021 - 0.0000 * Distance to land cleared for settlement purposes edges 2021 - 0.0001 * Distance to dwelling units or buildings edges 2021

Regression Statistics:

Apparent R = 0.256593 Apparent R square = 0.065840
Adjusted R = 0.256562 Adjusted R square = 0.065824

F (4, 171196) = 3016.500732

ANOVA Regression Table

Source	Degree of freedom	Sum of squares	Mean square
Regression	4	1417.60	354.40
Residual	171196	20113.28	0.12
Total	**171200**	**21530.88**	

Table 4.3.6.2 below reveal that two independent variables (Distance from road 2021 and Distance from vegetation 2021) are positively correlated to the dependent variable (deforestation between 2021 and 2031). A one-unit increase in the distance from road will result into an increase of 0.000056 unit in deforestation. Correspondingly, a one-unit increase in the distance from vegetation will result into an increase of 0.000225 unit in deforestation. A unit increase in the distance from land cleared for settlement purposes will lead to a 0.000015 unit decline in

deforestation while a unit increase in the distance from houses will lead to a 0.000057 unit decline in deforestation. Figure 4.3.6.1 reveal the predicted deforestation based on the estimated deforestation between 2021 and 2031 and factors (distance from road, vegetation, dwellings and land cleared for settlement purposes).

Table 4.3.6.2: Individual Regression Coefficients: (Author's own, data USGS 2020)

	Coefficient	**t_test (171196)**
Intercept	**0.005753**	**3.492167**
Distance from road 2021	0.000056	98.562210
Distance from vegetation 2021	0.000225	55.190899
Distance from land cleared for settlement purposes 2021	-0.000015	-3.252308
Distance from dwelling units or buildings 2021	-0.000057	-36.114098

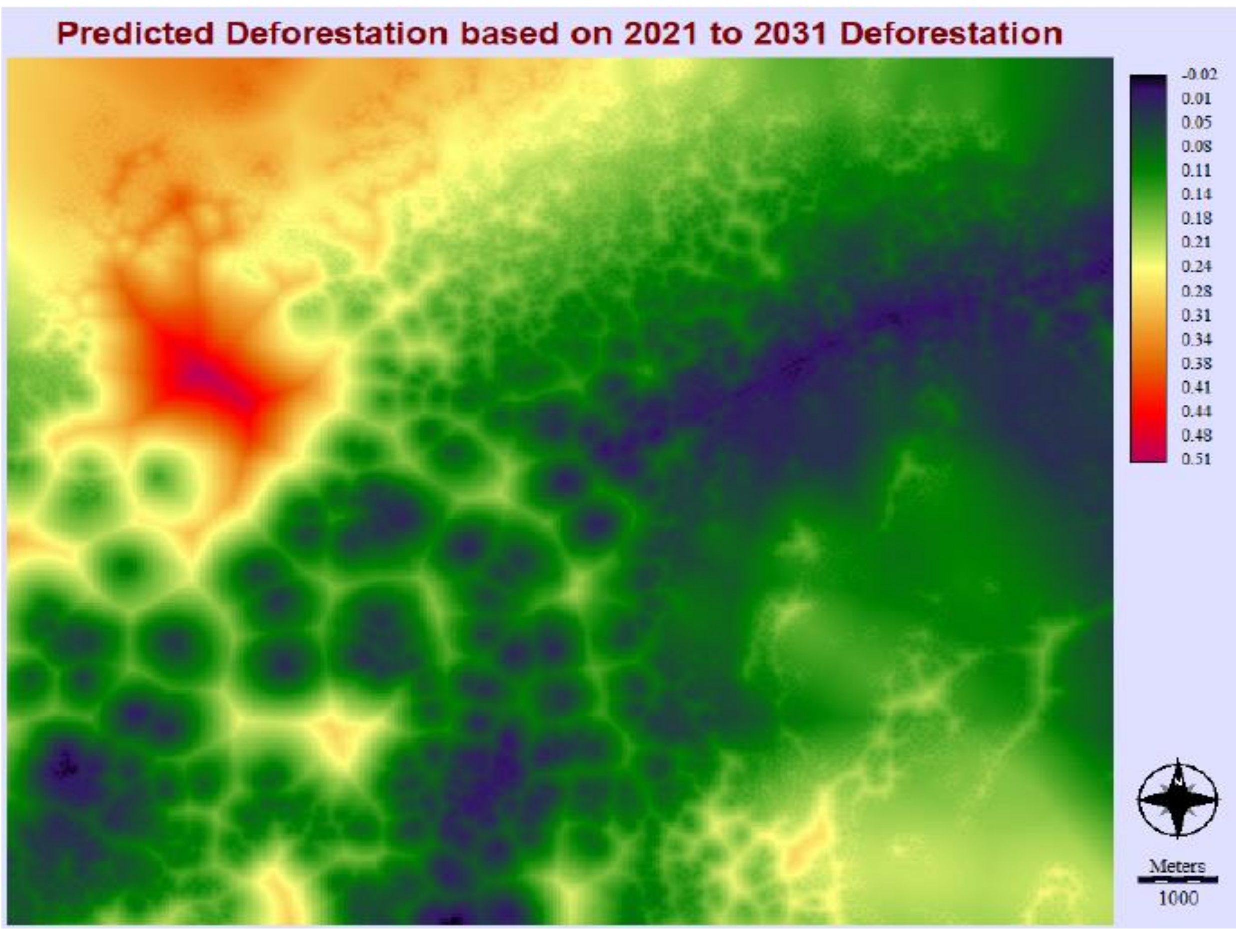


Figure 4.3.6.1: Predicted deforestation based on deforestation between 2021 and 2031 and distance from road, vegetation, dwellings and land cleared factors: (Author's own, data USGS 2020)

4.4. Reforestation Analysis

4.4.1. Reforestation Analysis between 2001 and 2011

Figure 4.4.1.1 below illustrate the new vegetation cover of 741.60 ha (the false colour composite base map is based on 2001 Landsat imageries) generated between 2001 and 2011 from other LULC types (land cleared for settlement purposes, dwelling units and bare soil). This indicate that, reforestation was at a rate of 6.6% between 2001 and 2011. Reforestation rate is based on new vegetation in 2011 (741.60 ha) and vegetation cover size in year 2001 (11158.92). Increase in vegetation cover can be a result of a decline in crop cultivation and decrease in overgrazing (ALMOHAMAD & DITTMANN 2016: 109). This might have been the case at the Sibbinda settlement, as there was a decline from 44% (2001) to 38% (2011) in the percentage of people who derive their main source of income from farming activities (NSA 2014).

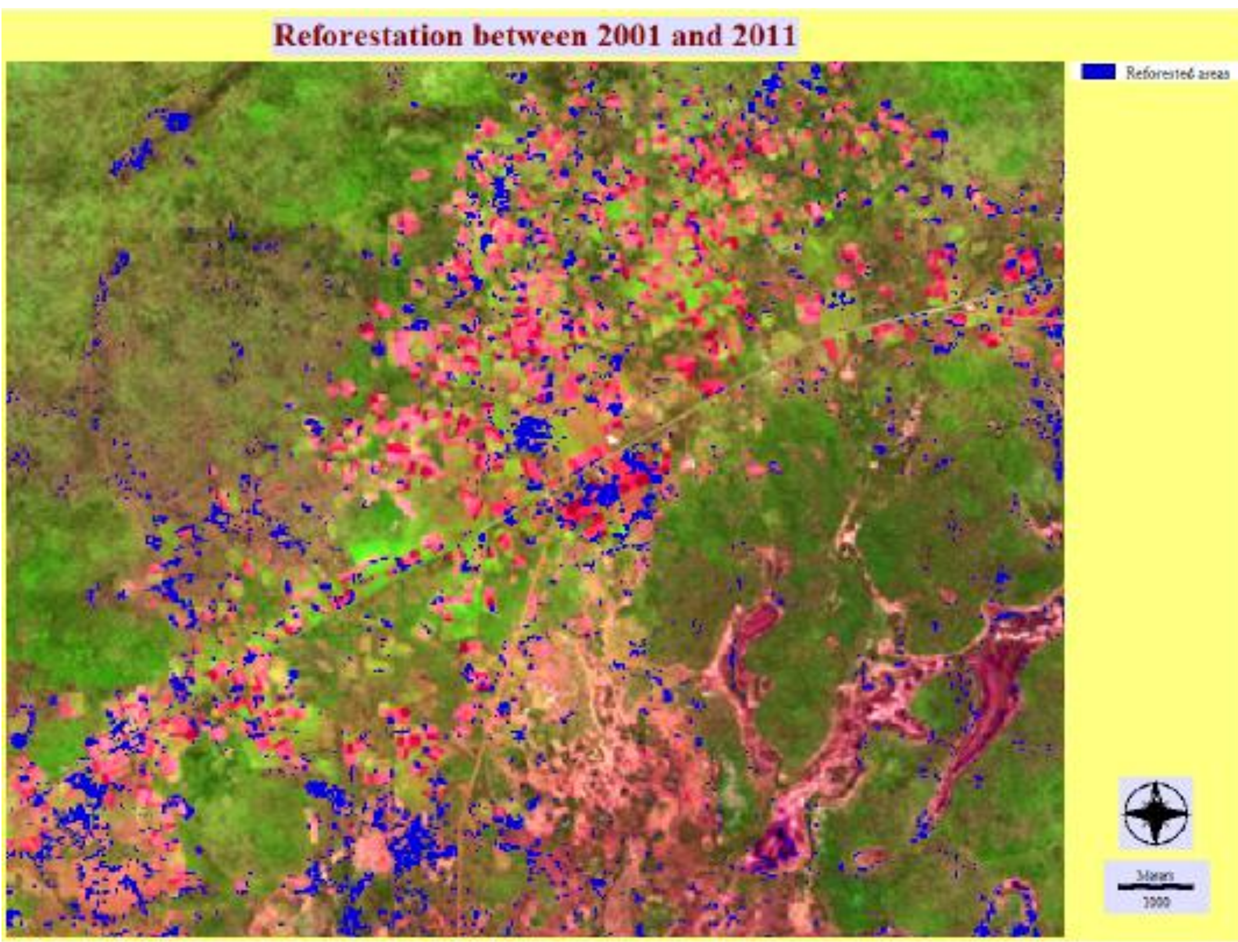


Figure 4.4.1.1: Reforestation between 2001 and 2011: (Author's own, data USGS 2020)

4.4.2. Reforestation Analysis between 2011 and 2021

Figure 4.4.2.1 reveals the new expected vegetation cover of 314.82 ha to be generated between 2011 and 2021. Reforestation rate is estimated at 4.3% between 2011 and 2021. The false colour composite base map in Figure 4.4.2.1 is established using 2010 May Landsat imageries. Reforestation rate is based on new estimated vegetation cover size in year 2021 (314.82 ha) and the vegetation cover size in year 2011 (7349.22). Reforestation is unlikely at the CBD (centre of the image), as settlement densification (a concentration process of the population, building units, employment, and transportation in a defined area) is expected at Sibbinda (GHADAMI, DITTMANN & SAFARRAD 2020: 3).

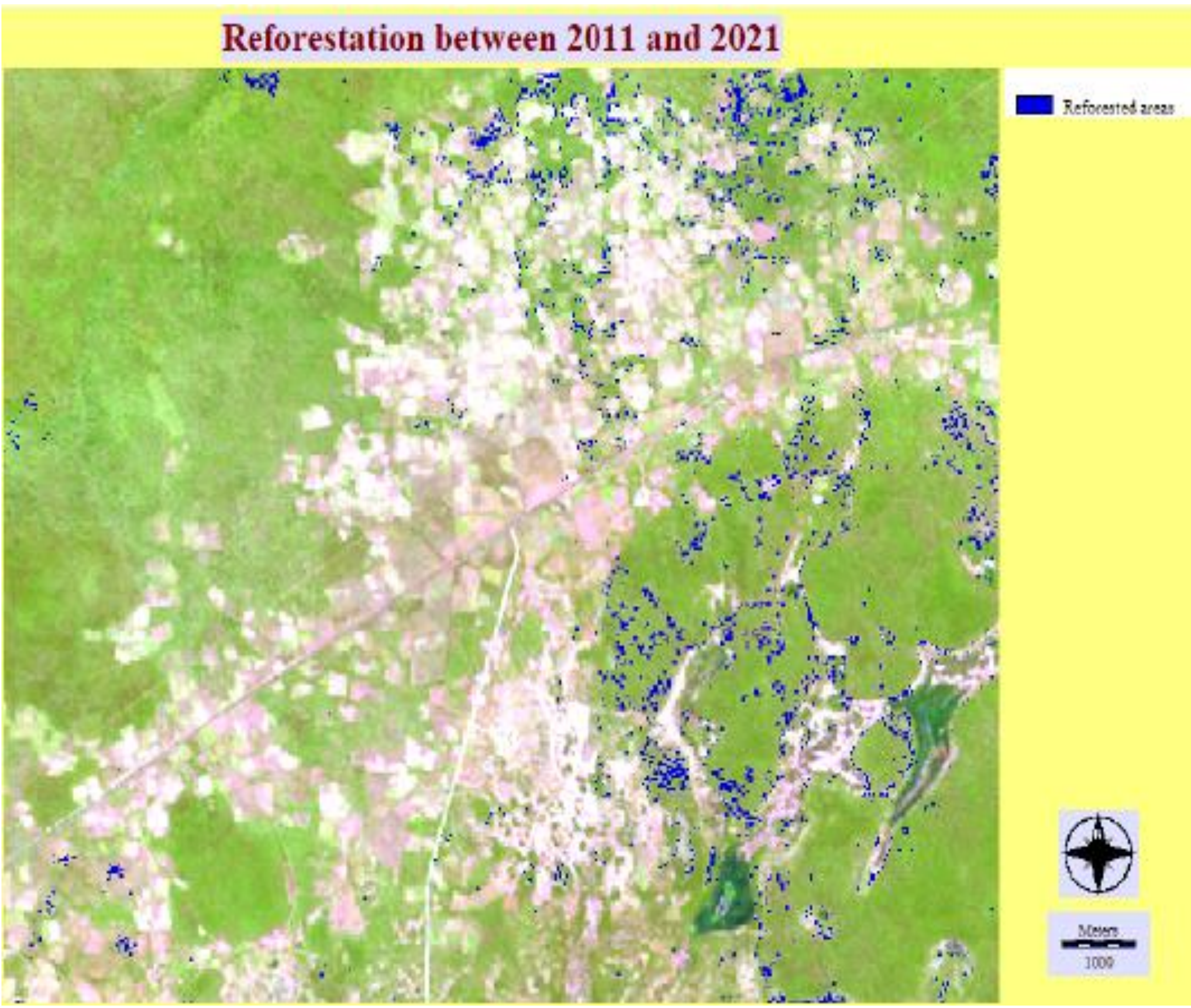


Figure 4.4.2.1: Reforestation between 2011 and 2021: (Author’s own, data USGS 2020)

4.4.3. Reforestation Analysis between 2021 and 2031

Figure 4.4.3.1 displays the new expected vegetation cover of 105.03 ha to be generated between 2021 and 2031. The false colour composite base map in Figure 4.4.3.1 is created using 2019 May Landsat imageries. Reforestation is estimated at a rate of 2.2 % between 2021 and 2031. The new produced vegetation can contribute to Sibbinda settlement becoming environmentally resilient and sustainable by the year 2030 (UNESC 2017). Current national legal rural development frameworks are likely to upset the achievement of environmental sustainability. For instance, Namibia's rural development policy is likely to create an environment that will empower people at Sibbinda to take charge of their own development (MRLGHRD 2011). When local people are the main decision makers on development issues, deforestation is more likely to occur as they are likely to favour settlement development at the expense of forest conservation.

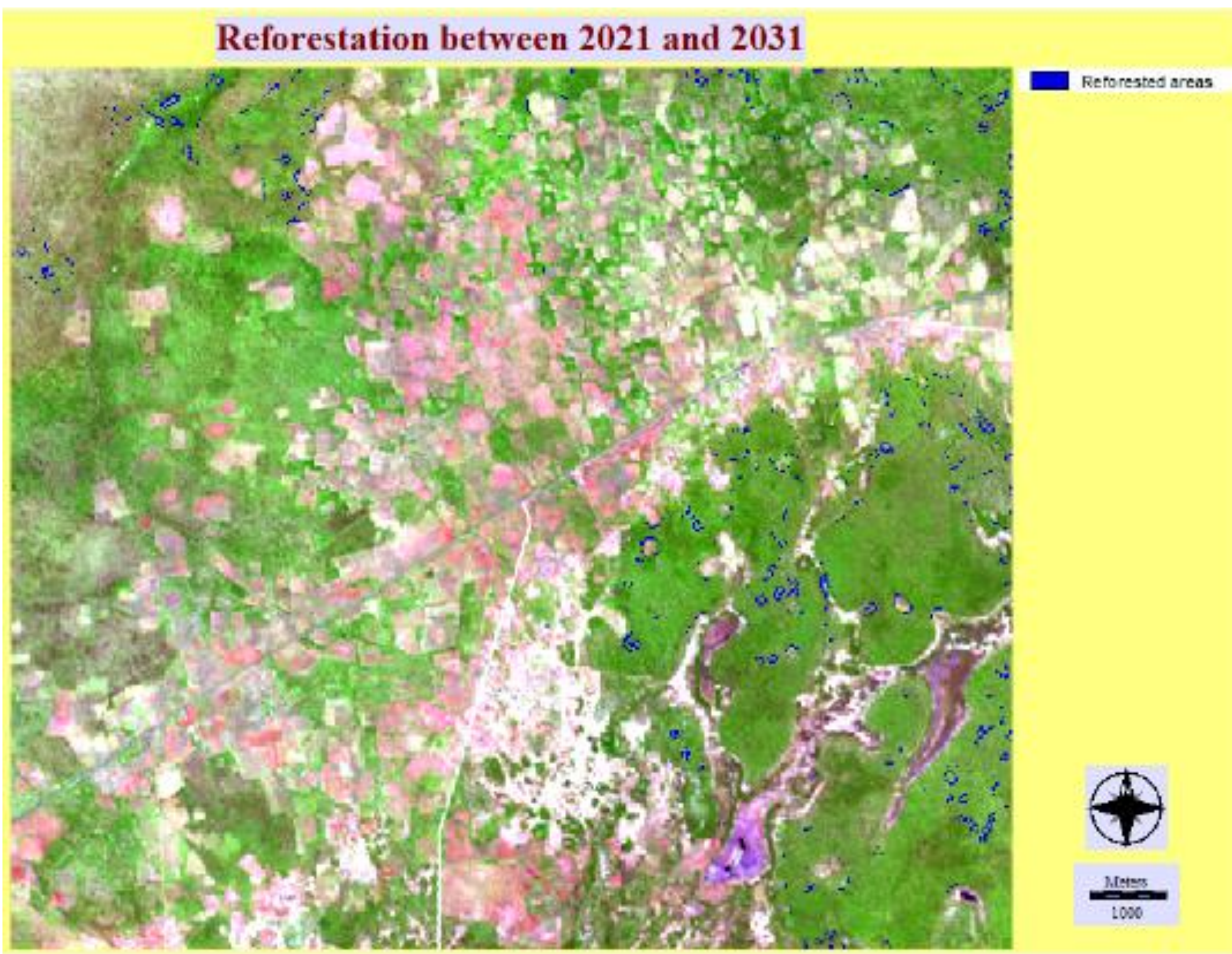


Figure 4.4.3.1: Reforestation between 2021 and 2031: (Author's own, data USGS 2020)

Chapter 5: Conclusion and Recommendation

This study has demonstrated that Spatio-temporal analyses using GIS and remote sensing techniques are tools which can be used to model rural settlement development as a catalyst of deforestation. The study quantified the past, current and future impact of Sibbinda rural settlement development on deforestation. The study results have led to a general conclusion that, rural settlement development is positively associated with deforestation at the Sibbinda settlement. Conclusions and recommendations are arranged per respective study objective.

5.1. Dynamics of Land Use and Land Cover Changes

The highest LUCC between 2001 and 2031 is expected to be vegetation converting to bare soil at a rate of 21% (3285.18 ha between 2001 and 2011), 17% (2556.18 ha between 2011 and 2021) and 9% (1444.41 ha between 2021 and 2031). Sibbinda settlement is still expected to be mainly characterised by vegetation land cover type in year 2011 and 2021 as per results in Table/Figure 4.1.1.1, Figure 4.1.2.1 and Table 4.1.2.2 respectively. In year 2031, Sibbinda settlement is anticipated to be primarily characterised by bare soil (4033.98 ha), please see Table 4.1.3.1. *Past, present and future land use and land cover changes as a result of Sibbinda rural settlement development are still geared towards deforestation.* To minimise the extent of deforestation, future Sibbinda settlement development projects need to correspond to aims of SDG11 (UNESC 2017: 13). SDG11 is likely to influence future land use and land cover changes to be positively associated with forest conservation.

5.2. Deforestation Analysis: Past, Present and Future

Deforestation at the Sibbinda settlement is expected to increase from 28% in 2001 to 83% in year 2031. The vegetation area lost between 2001 and 2011 was 3809.7 ha mainly due to land cleared for settlement purposes (e.g., construction of buildings). The vegetation area to be lost between 2011 and 2021 is 2531.7 ha while 2202.84 ha is expected to be lost between 2021 and 2031. *Deforestation (caused by land clearing and building constructions) is a product of Sibbinda rural settlement development*. Since many residents of the Sibbinda settlement survives mainly on farming activities. Such activities favour deforestation which is likely to lead to desertification that undermines the land's productivity and contributes to poverty (BADRELDIN, FRANKL & GOOSSENS 2013). There is a need to draw future settlement land-use plans depicting the future growths of the settlement and forestry conservancy areas based on the emerging forests as identified by JONES and DIECKMANN (2013).

5.3. Factors Associated with Deforestation

At the Sibbinda settlement, distance from road was negatively associated with deforestation between 2001 and 2021. Deforestation decreased as the distance from the road increased. Between 2021 and 2031 a positive relationship between distance from road and deforestation is expected. Deforestation will increase as the distance from the road increases. *In a rural settlement setup with no major road network development; deforestation is positively associated with road networks for a limited time period (2 decades in the current study), and thereafter as deforestation moves towards saturation stage, it becomes negatively associated with road networks.* Even though road networks will become negatively associated with deforestation. It is not recommended to construct roads in forest areas as new roads can accelerate deforestation through the development of houses along such transport route (BALASUBRAMANIAN 2017; MISRA et al. 2018; ROBINSON 2003).

There is a negative relationship between distance from vegetation edges and deforestation. Deforestation is likely to decrease as the distance to vegetation edges increases between year 2001 and 2021. Between 2021 and 2031, a positive relationship between distance from vegetation edges and deforestation is expected. Deforestation will increase as the distance from the vegetation edges increases. *Vegetated areas which are easily accessible to humans are more likely to be deforested for a limited time period (2 decades in the current study), and thereafter as deforestation moves towards saturation stage, deforestation is more likely to occur at distant vegetated areas, which are not easily accessible to humans.*

A negative relationship between distance from edges of land cleared for settlement purposes and deforestation between year 2001 and 2021 is estimated. Between 2021 and 2031, a positive correlation between distance from edges of land cleared for settlement purposes and the deforestation is expected. Hence, between 2021 and 2031 deforestation is likely to increase as the distance from land cleared for settlement purposes increases. *As deforestation moves towards saturation stage within a rural settlement establishment, deforestation is more likely to occur at areas far away from land cleared for settlement purposes.*

There is a negative relationship between distance from edges of dwelling units and deforestation between year 2001 and 2021. Deforestation declines as the distance from houses increases. Areas far from buildings during 2001 to 2021 period are less likely to be deforested. The opposite is expected between 2021 and 2031, as a positive correlation between deforestation and distance from buildings is estimated. *During the initial stage of rural settlement development; vegetation close to human dwelling units are more likely to be devastated. At a later stage, deforestation moves to areas far away from buildings as the local/close-by areas are fully degraded.*

5.4. Quantifying the Contribution of Settlement Development to Deforestation.

Twenty-four percent of deforestation which occurred between 2001 and 2011 at the Sibbinda settlement is due the short distance between forests (vegetation) and roads, land cleared for settlement purposes and buildings. A one-unit increase in the distance from roads, vegetation, land cleared for settlement purposes and buildings respectively resulted into a decline of 0.000016, 0.006682, 0.000013 and 0.000114 unit of deforestation. *Between 2001 and 2011, distance of an area from a road network is the most valued factor in terms of aiding deforestation at that specific area.*

Fifteen percent of deforestation which is likely to occur between 2011 and 2021 at the Sibbinda settlement will be due to the short distance between forests (vegetation) and roads, land cleared for settlement purposes and buildings. A one-unit increase in the distance from roads, vegetation, and buildings will respectively result into a decline of 0.000014, 0.001864 and 0.000224 unit of deforestation. A unit increase in the distance from land cleared for settlement purposes will led to a 0.000007 unit increase in deforestation. *Between 2011 and 2021, distance of an area from buildings is the most valued factor of deforestation at that specific area.*

Seven percent of deforestation expected to occur between 2021 and 2031 at the Sibbinda settlement will be due to the distances between forests (vegetation) and roads, land cleared for settlement purposes and buildings. A one-unit increase in the distance from roads and vegetation, will respectively resulted into an increase of 0.000056 and 0.000225 unit of deforestation. A unit increase in the distance from land cleared for settlement purposes or buildings will respectively led to 0.000015 and 0.000057 units decline in deforestation. *Between 2021 and 2031, areas far away from roads/without road networks are more likely to be deforested. Though, the distance of an area from buildings will be the most valued factor of deforestation at that specific area.*

5.5. Deforestation Hotspots Forecast

Deforestation between 2021 and 2031 is expected to be more prevalent in northwest direction of the study area (please see Figure 4.3.6.1). *Deforestation is more likely to occur in areas far from roads, yet more densely vegetated*. Since, rural settlements also need to be concerned with landscape conservation and preservation (NIEDZIELSKI 2015), there is a need to designate northwest of Sibbinda as a protected area under full government control, as if managed by the local community the area is more likely to be heavily deforested (NIKODEMUS & HÁJEK 2015). The local community need to be involved through participatory mapping of the protected areas around Sibbinda settlement. Participatory mapping can aid rural land use planning and natural resource management (MUNDIA 2013).

5.6. Reforestation Analysis: Past, Present and Future

Natural reforestation was highest between 2001 and 2011, as 6.6% (741.60 ha) and 4.3% (314.82 ha) of new vegetation was reported in year 2011 and 2021 respectively. Reforestation is expected to be lowest between year 2021 and 2031, as only 2.2% (105.03 ha) reforestation is predicted. *Compared to deforestation, reforestation is very low in the area, as it is mainly a result of the unusual conversion (through natural processes) of land cleared for settlement purposes, temporal* *dwelling units and bare soil to vegetation.* In line with FAO (2016), it is recommended to promote rotational crop farming system(s) among residents of the Sibbinda settlement so that unproductive agricultural land can be given enough time to covert to forests. Also, since almost all households in the Sibbinda area use wood for cooking (NSA 2014). There is a need to explore the possibility of implementing renewable energy/biofuel projects, for instance methane gas could be produced from household wastes and used for cooking purposes. The use of biofuel could enhance ecological quality and contribute to the reduction of deforestation at the Sibbinda settlement (MWEWA 2019).

5.7. Limitation of the Study and Recommendations for further studies

The study was limited to the Sibbinda settlement area with geographic coordinates, top left; X156289.571429, Y-1961078.011094 and at bottom right; X169683.530612, Y-1972570.435816. Landsat scene (174072) of 2001, 2010, 2011, 2019, and 2020 were mainly the satellite imageries applied in the study. A national study which evaluates the role of rural settlement development as a catalyst of deforestation in all Zambezi sub-regional growth points is recommended.

It was not possible to conduct physical visits to verify historical land cover types in 2001, 2010 and 2011 Landsat imageries.

The Landsat imagery spatial resolution of 30 meters made it impossible to further categorise the forest land cover type into tree, shrub and grassland forests. Buildings in the study area could not be effectively classified into modern or traditional dwelling unit types due to the low spatial resolution of Landsat imageries applied. Satellite imageries with higher spatial resolution to be acquired (even at cost) and applied in future LULC studies in order to analyse LUCCs exhaustively.

Deforest factors were limited to roads, land cleared for settlement purposes, dwelling/housing construction. Further rural settlement development studies are encouraged to incorporate other deforestation factors particularly linked to climatology (atmosphere and weather patterns over time).

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Appendices

APPENDIX A: 2011 and 2020 Output from PCA

2011 Imageries

Output from PCA: LT05_L1TP_174072_20110104_20161011: *(*Author's own, data USGS 2020*)*

T-MODE COR. MATRIX	B1	B2	B3	B4	B5	B6	B7
B1	1	0.97	0.93	0.88	0.88	0.75	0.87
B2	0.97	1	0.98	0.87	0.87	0.69	0.88
B3	0.93	0.98	1	0.82	0.86	0.64	0.90
B4	0.88	0.87	0.82	1	0.89	0.83	0.81
B5	0.88	0.87	0.86	0.89	1	0.85	0.96
B6	0.75	0.69	0.64	0.83	0.85	1	0.75
B7	0.87	0.88	0.90	0.81	0.96	0.75	1

T-MODE COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% VAR.	87.00	7.97	2.69	1.70	0.39	0.20	0.05

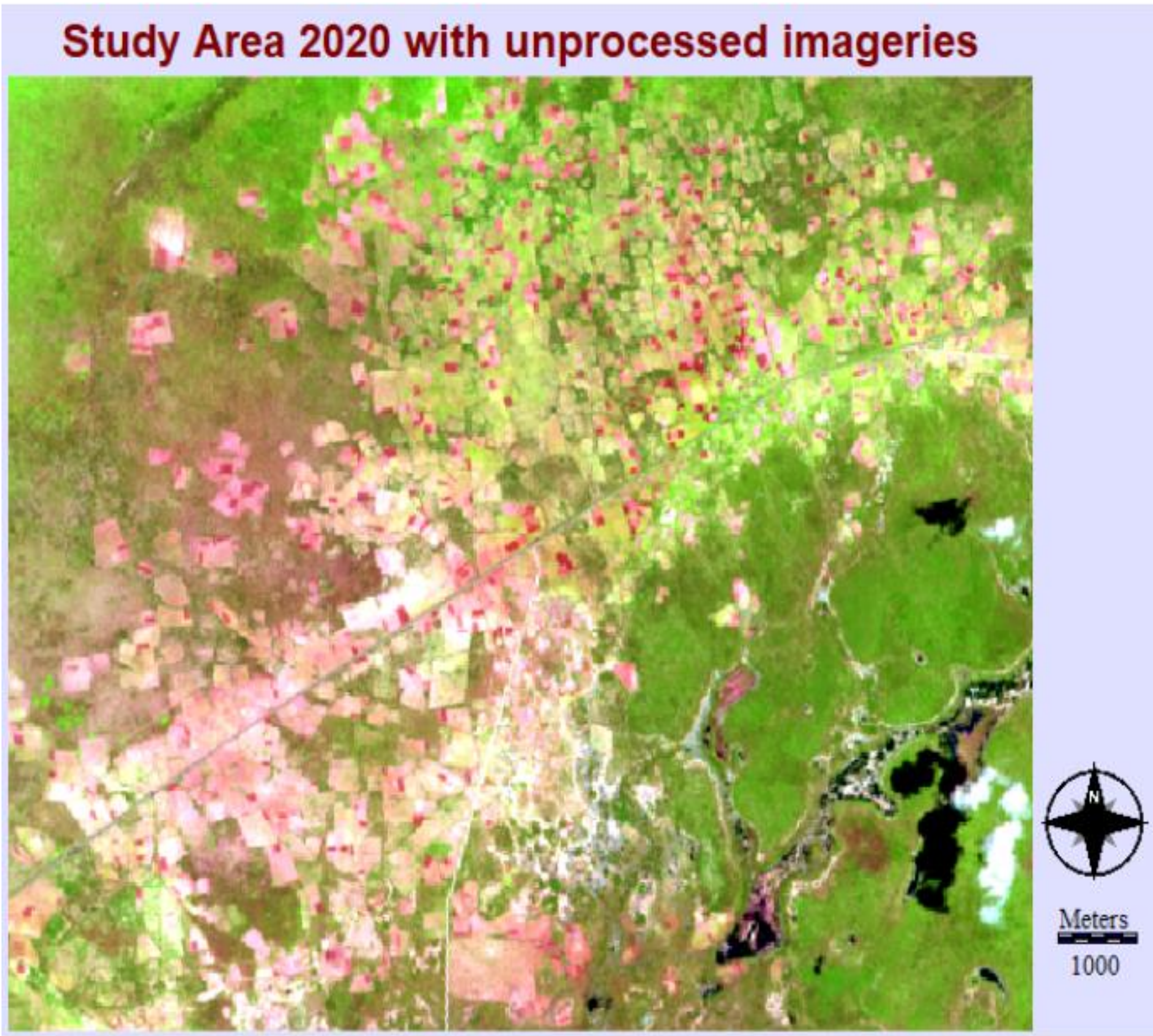
2020 Imageries

Output from PCA: LC08_L1TP_174072_20191212_20191217: *(*Author's own, data USGS 2020*)*

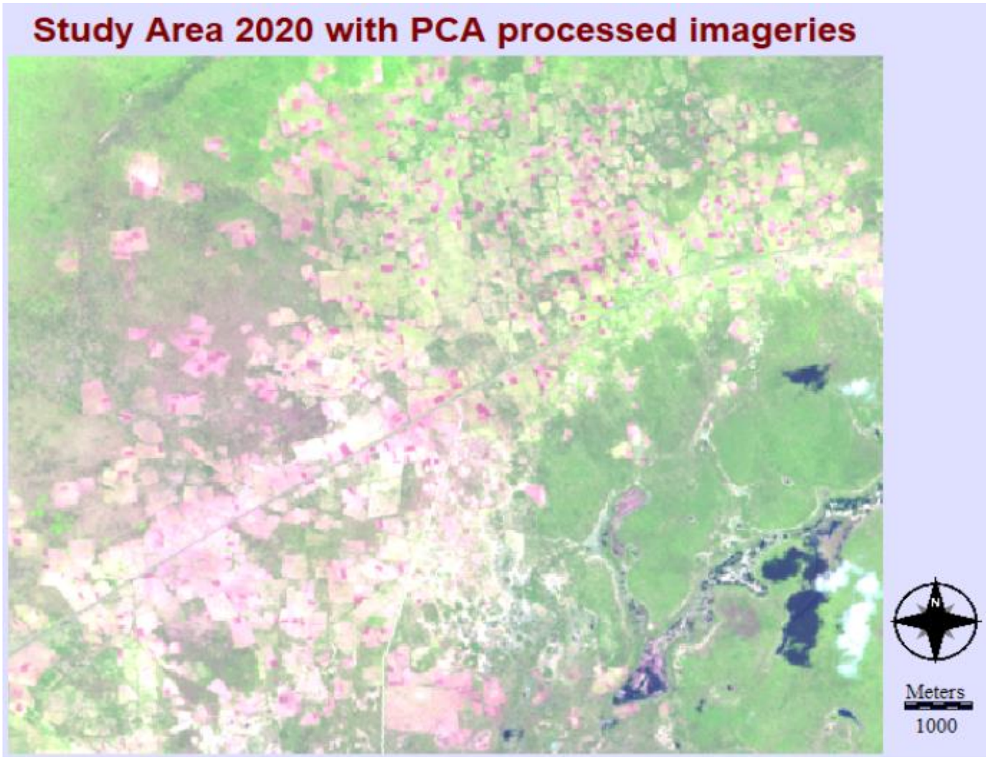
T-MODE COR. MATRIX	B1	B2	B3	B4	B5	B6	B7
B1	1	0.999	0.996	0.988	0.965	0.964	0.951
B2	0.999	1	0.998	0.992	0.961	0.964	0.954
B3	0.996	0.998	1	0.996	0.967	0.971	0.961
B4	0.988	0.992	0.996	1	0.950	0.973	0.972
B5	0.965	0.961	0.967	0.950	1	0.962	0.929
B6	0.964	0.964	0.971	0.973	0.963	1	0.992
B7	0.951	0.954	0.961	0.972	0.929	0.992	1

T-MODE COMPONENT	C 1	C 2	C 3	C 4	C 5	C 6	C 7
% VAR.	97.20	1.66	1.01	0.08	0.03	0.004	0.002

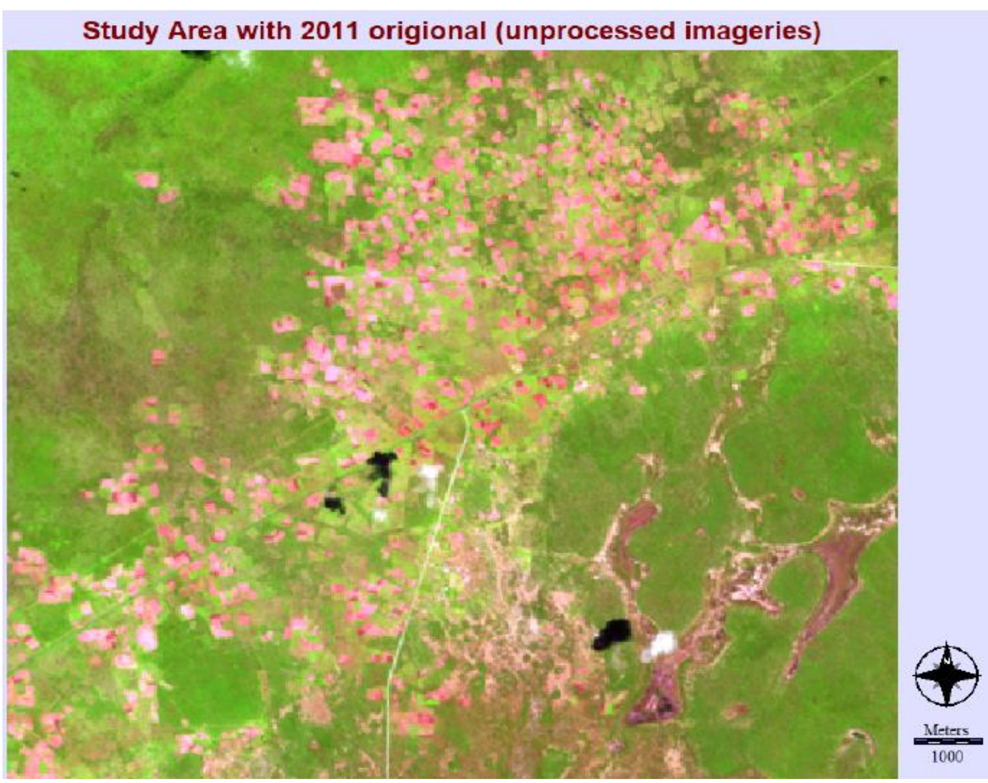
APPENDIX B: 2011 and 2020 unprocessed and processed imageries



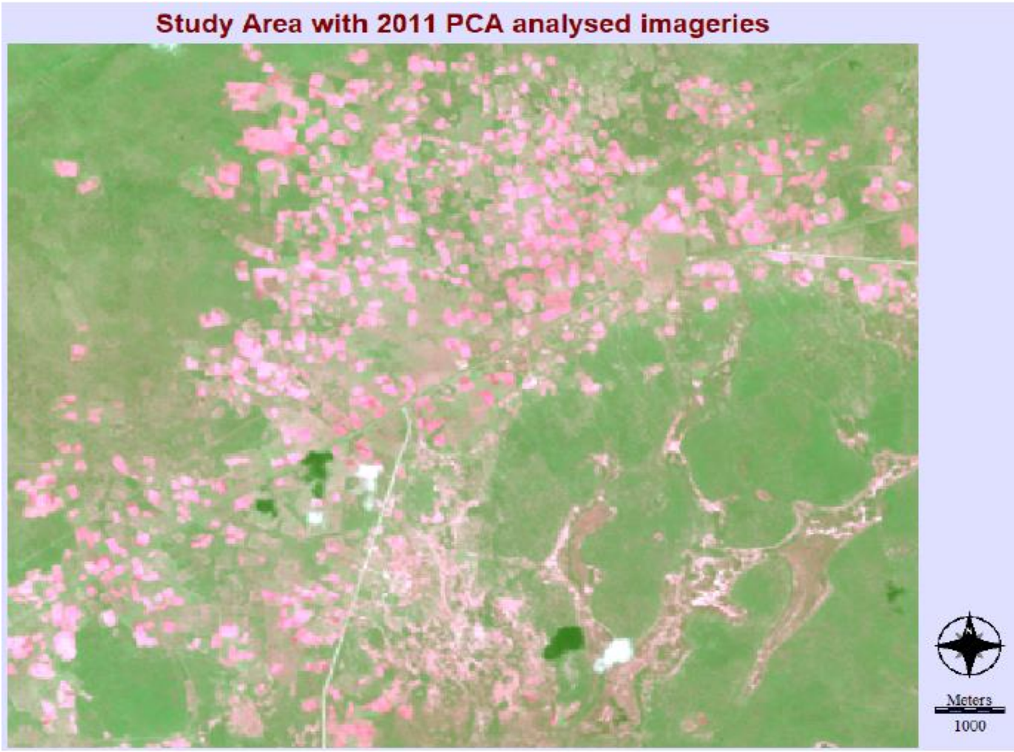
(Author's own, data USGS 2020)



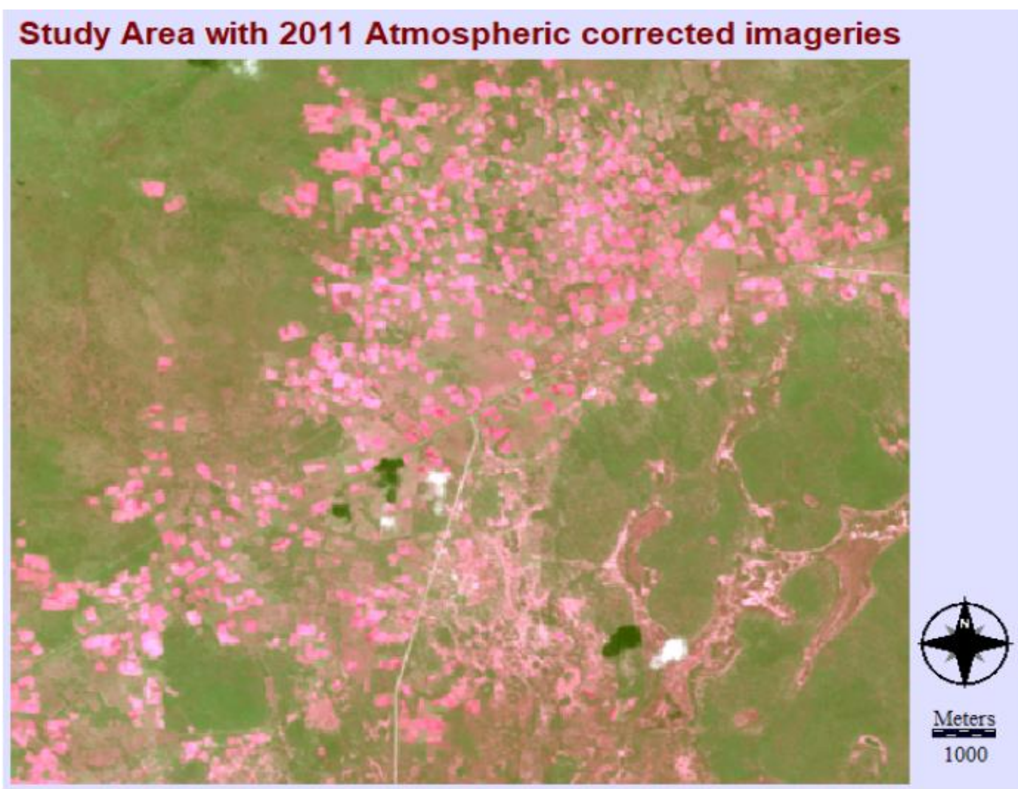
(Author's own, data USGS 2020)



(Author's own, data USGS 2020)



(Author's own, data USGS 2020)



(Author's own, data USGS 2020)