An Assessment of the effects of climate variability on Forest cover in Liberia

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Declaration

This dissertation is my original work and has never been presented for a degree in any other University.

Signed________________________ Date_______________

David M. Mulbah Jr

This dissertation has been submitted for examination with our approval as University Supervisors.

Name: __________________________ Signed:_________________ Date_______

Name: __________________________ Signed: _________________Date_______

Dedication

This dissertation is dedicated to my Daddy (Attorney. David M, Mulbah Sr).

Acknowledgement

First, I say thanks to the Almighty God for giving me the energy that I needed to complete my course work, and then the dissertation. I also wish to express my gratitude to my supervisors: Dr. G. Ouma, and Prof. F. Mutua for their guidance through all of the stages of this dissertation.

I knowledge Dr. Lex Voorhoeve of the "Digital Tree Atlas'' of Liberia project for his contribution and support during the project development phase, Mr. Richard Samolah the programme officer and technical adviser at the Flora and Fauna International office in Monrovia for mentorship and support.

Thanks to my colleagues and the entire climate change class of 2012-2014 for their comments, concerns and input that help to make my dissertation better.

Table of Contents

List of Figures

List of Tables

List of Acronyms

AVHRR……………………Advanced Very High Resolution Radiometer

CI……………………………Conservation International

EPA…………………………Environmental Protection Agency

ECMWF……………………European Center for Medium Range Weather Forecasting Re-analysis

FAO…………………………Food and Agriculture Organization

FDA…………………………Forestry Development Authority

HRPT………………………..High Rate Picture Transmission

IPCC…………………………Intergovernmental Panel on Climate Change.

IRI……………………………International Research Institute for Climate and Society.

IUCN…………………………International Union for the Conservation of Nature

NASA…………………………National Aeronautics and Space Administration

NDVI………………………….Normalized Difference Vegetation Index

NOAA…………………………National Oceanic and Atmospheric Administration

REDD…………………………...Reducing Emission from Deforestation and Degradation

R-PIN………………………….Readiness Preparation Ideas Notes

Abstract

This dissertation presents an assessment of the effects of climate variability on forest cover in Liberia. The objectives of the study were: to determine the spatial variability of rainfall, temperature, and NDVI, to determine the temporal variability of rainfall, temperature, and NDVI and to determine the relationship between rainfall, temperature, and NDVI. The methodology included: composite analysis of NDVI data, coefficient of variation analysis of rainfall and temperature, time series analysis of NDVI, rainfall and temperature and cross correlations of NDVI, rainfall and temperature. The data used in the study were: NDVI, and re-analyzed rainfall and temperature data.

The results of the study showed that Liberia has a large forest area especially in the south-eastern region. NDVI, rainfall, and temperature spatially and temporally varies across the area of study. The spatial variation of the mean annual rainfall from 1983-2012 is 741.5-872.0 mm in the north-west, and 1275.7-1393.0 mm in the south-east, while the spatial variation of the main annual temperature is 21.9-22.3 degree Celsius in the north-west and 23.4-25.1 degree Celsius in the south-east. Temperature variation in the north-west is high and low in the south-east. The effect of this variation is attributed to the high forest cover in the south-east and low forest cover in the north-west. Rainfall, temperature and NDVI were found to be significantly correlated in the south-east.

In conclusion, it is clear that, climate variability (rainfall and temperature) have effects on forest in Liberia. Some of the effects can be determine by the use of NDVI and re-analyzed data, especially where local data is limited. This dissertation recommends the following: Validation of the NDVI and re-analyzed data with ground truth data and a comprehensive study to fully understand the effects of climate variability and change on the forest of Liberia.

CHAPTER ONE

1 INTRODUCTION

1.1 Background of Study

Liberia is located within the tropical rain forest belt of West Africa and covers about 43% of the remaining Upper Guinea Forest (CAAS-Lib, 2007). The "Upper Guinea" is described by bio-geographers as the forest belt that runs from the western tip of Senegal and Guinea Bissau, eastwards to the Dahomey gap. The eastern boundary is in the mountains of western Togo. The Dahomey gap is dry and largely not forested (see figure 1.1 under Study Area). The total land area in the country is about 9.8 million hectares (ha). Table 1.1 shows the distribution of land use in Liberia.

Table 1.1: Land use in Liberia

Land type	Area (million ha)	Percent of total land
Forest	4.9	50
Arable (upland and lowland)	4.6	47
Uplands	*4.0*	*41*
Lowlands	*0.6*	*6*
Others	0.3	3
Total Area	9.8	100

Source: CAAS-Lib, 2007.

Table 1.1 shows that Liberia has a large amount of forest area. This could be attributed to the low population (3.5 million) in the country. Moreover, during the fourteen years civil war, the conversion of forest area for livelihood activities such as shifting cultivation, plantations among others were reduced (NAPA, 2008).

Climate variability and change has affected forest in Liberia. According to Liberia National Adaptation Programme of Action slower tree growth and the short life span of some tree species in the southeast and the northwest were attributed to the longer period of rainfall in the regions. Furthermore, higher temperatures pose threats to the forest. For example, it facilitate the prevalence of pests and other vectors such as the *Dandrolmus punctatus*. It also hinders the growth of some plant species for example the *Tetra berlinatubmanan* a tree species endemic to Liberia (NAPA, 2008).

At present, the status of the forest in Liberia significantly depends on the existence of the government national forest management policies and regulations. Some of the policies promote timber or wood harvesting, forest protection and wildlife conservation.

1.2 Problem Statement

Reduction in forest cover results in the decrease in forest ecosystem services such as carbon dioxide sequestration. This is because forest captures and stores carbon dioxide. Forest reduction can also cause habitat destruction, land degradation, biodiversity loss among others. Climate variability and change is expected to aggravate the situation. Generally, some impacts of climate variability and change on forest are wildfire, facilitation of the spread of pests, low or high forest growth among others.

The country is recuperating from a 14 years civil conflict that destroyed all of its facilities; as a result, the data gap at the local level is wide. Local information on the effects of climate variability is limited. This could contribute to poor forest management planning and policy formulation. Therefore, the need for the implementation of this project was necessary to collect and collate information on the effects of climate variability on forest in Liberia.

1.3 Research Questions

The following research questions have been addressed.

1. How does rainfall, temperature, and vegetation differ spatially in Liberia?
2. How does rainfall, Temperature and vegetation differ temporally in Liberia?
3. How does rainfall, Temperature, and vegetation does related in the study area?

1.4 Objectives of the study

The main objective of this study was to assess the effects of climate variability on forest cover in Liberia. The specific objectives included;

1) To determine the spatial variability of rainfall, temperature and the Normalized Difference Vegetation Index (NDVI) in Liberia

2) To determine the temporal variability of rainfall, Temperature and the Normalized Difference Vegetation Index (NDVI) in Liberia.

3) To determine the relationship between rainfall, Temperature and the Normalized Difference Vegetation Index (NDVI) in Liberia.

1.5 Hypothesis of the Study

In this study, the hypothesis was that changes in climate variables (rainfall and Temperature) do affect forest cover (NDVI) in Liberia.

1.6 Justification

Forests play a vital role in carbon dioxide sequestration. Carbon dioxide is one of the greenhouse gases that cause global warming because of its heat trapping capacity. Global warming is responsible climate change according to scientific evidence. Additionally, forest plays a key role in economic development of Liberia through the sale of timber tree spices, charcoal and fuel production among others. In 2003, forestry contributed 22% of the country's GDP (NAPA, 2008).

Liberia is recovering from a 14 years of civil conflict that destroyed all of its facilities as the result the data gap at the local level is wide. Local information on the effects of climate variability is limited. This could contribute to poor forest management planning and policy formulation. Therefore, the need for the implementation of this project was necessary to collect and collate information on the effects climate variability on forest in Liberia.

There are several climatic parameters that can be used in assessing the effects of climate variability on forest in Liberia. For examples, rainfall, temperature, humidity, wind, vapor-transpiration among others. However, due to local limited data the project limited itself to re-analysis data precipitation and temperature. The project chose the Normalized Difference Vegetation Index (NDVI) as a proxy for vegetation for this study because it is widely used and generally accepted. Additionally, it is one of the most cost-effective ways of determining vegetation cover especially for developing and least developed countries.

1.7 Study Area

Liberia is located on the west coast of Africa as shown in Figure 1.1. It is bounded by longitudes 7° 30’ and 11° 30’ west and latitude 4° 8’ and 8° 30’ north and covers an area of 43,000 square miles (111,370 square kilometers). The country is bounded on the west by the Republic of Sierra Leone, on the east of Ivory Coast, on the north by the Republic of Guinea and on the south by the Atlantic Ocean. The movement of the Inter Tropical Front (ITF) that describes the tropical climate determines the climate of Liberia (Voorhoeve, 1979). The country has two seasons. The seasons are either dry or rainy. The rainy seasons begin from mid-April to mid-September while the dry seasons commence in mid-September to mid-April. Some years experience changes in seasonal patterns (Voorhoeve, 1979).

Changes have occurred in the seasonal pattern in Liberia. For an example, the rainy season of 2008 ended in mid-November with the beginning of the dry season while in 2009, the dry season ended in May with the beginning of rainy season (Sambolah, 2009). Over the last 20-30 years, the average annual rainfall has decreased from about 4,000 mm at the coast to about 800 mm. The average daily temperature ranged between 24°C -30°C (Voorhoeve, 1979).

On the overall, the climate in Liberia is a tropical climate. Liberia was chosen as the area of interest for this study because of limited existing information and given that it is has about 43% of the remaining forest in the Upper Guinea forest zone (CAAS-Liberia, 2007). Figure 1.1 shows the map of the study area.

Figure 1.1: Forest cover map Source: (CAAS-Liberia, 2007)

CHAPTER TWO

2 LITERATURE REVIEW

This chapter presents the literatures that were assessed in the study

2.1 Literature Review

Research on the assessment of the impact of climate variability and change on forest in Liberia is limited. Most of the literature are focused on forest resource assessment, forest land management, biodiversity conservation, classification of forest type, agriculture, none timber forest product trade and timber product trade sector. However, some studies have been done on vegetation and climatic parameters using NDVI in the region.

Yelwa and Eniolorunda (2012) simulated the movement of desertification in Sokoto and its environs using 1 km resolution Normalized Difference Vegetation Index (NDVI) data from the SPOT instrument. Results show that the inter-annual vegetation vigour exhibited a diminishing trend over the time series. The direction of desertification is North-West to South-East. As desertification threatens human survival intensive tree planting around these areas in form of afforestation and establishment of more shelter belts and cattle ranches to curtail indiscriminate grazing, sensitisation of people towards being friendly with the environment and provision of alternative use of energy such as kerosene and gas for domestic uses at affordable prices as well as improvement in distribution and availability as immediate measures were recommended.

Yaw et al. (2011) evaluated the effect of three climate parameters on forest cover in Ghana using NDVI for Digya National Park derived from Landsat image data. Climate data (temperature, humidity, dew point, rainfall) were assembled from statistics provided by Ghana's Meteorological Agency. The study introduced a weighted averaging method by computing weather information from neighboring stations. Also, this research developed a model for dew point, enabling the direct calculation of dew points from temperature and humidity data. The major finding is that while temperature significantly affects forest cover and Park vegetation, dew-points and rainfall do not. The paper suggests that future research may be more fruitful in analyzing the effects of climate on vegetation.

Aweda and Adeyewa (2011) studied the inter-annual variations of vegetation anomaly over Nigeria using NDVI derived from the Advanced Very High Resolution Radiometer (AVHRR) data sets. The study covers the period between the year 1982 and 2000. The analysis was done for the various vegetation belts of the country with some years of extreme anomalies noted. These anomalies have been linked to extreme El Nino Southern Oscillation (ENSO) events that took place within this period.

Sherman (2009) reviewed of the Forest Management Concession documents. Shearman's assessment of forest cover/available timber is based on repeating the methodology of Bayol while using 2009 imagery with a higher spatial resolution. Shearman reported that the total forest of Liberia was about 4.65 million hectares in the 80s compared to 4.52 million in 2001.

Bayol and Chevalier (2004) described a small scale mapping effort of Liberia's forests undertaken in 2003-2004. The description of the mapping methods provides appropriate detail and good assumptions. The analysis undertaken is important and was valid to get an overview of the situation regarding forest cover and land use after the civil war. The main finding was that Liberia has 36% forest cover which is equal to 3.4 million hectares. The total surface area of Liberia is 9.591 million hectares.

Stibig and Baltaxe (1993) used a practicable and cost effective method for obtaining a country's forest area by remote sensing, the computer processing of NOAA AVHRR HRPT data covering Liberia. The only cloud-free scene then recorded turned out to be severely and unevenly affected by atmospheric haze. To mitigate the effects of this, the country was divided into six areas (strata) of more uniform haze conditions. Pixel DN values were obtained for forest and adjoining formations on transects within each stratum, for the first four AVHRR channels and three transforms: NDVI (2-1/2 + 1), IND3 (3-2/3 + 2), IND4(4-2/4 + 2). After analyzing the transects and comparing them with the available reference data (a mixture of large scale colour composite Landsat TM and MSS images for 1989 and 1986 respectively), channels 2, 3, 4 and IND3 were retained for processing. This was done by applying three methods to each stratum - thresholding, maximum likelihood classification using clustering signatures (hybrid), using training area signatures - and directed at separating the 5 main classes distinguishable on the Landsat images: Closed forest, Disturbed forest, Shifting cultivation and re-growth, Cultivation and Other.

Lyons (1984) presented the results of an exercise to model forest industry development in Liberia. It presents background information about Liberia and the forestry sector, then discusses the trends and projections in forest cover and production and trade of forest products. It suggests that forest resources will not be able to meet future demand for wood and recommends that forest plantations should be planted to meet this demand.

Doe (1984) assessed the current status of the forestry sector in Liberia, covering the planted and natural forest resource and supply and demand for wood and wood products. It concludes by presenting a number of policy issues and recommendations.

CHAPTER THREE

3 Data and Methodology

The chapter discusses the data and methods that were employed in the implementation of the research.

3.1 Data

Climate and forest cover data were used in the study. The climate variables included rainfall and temperature while NDVI was used as proxy for forest.

3.1.1 Climate data

The research used re-analyzed rainfall and temperature data due to limited available local data. The temperature data from ERA-40 and ERA-Interim were retrieved from European Center for Medium Range Weather Forecasting Reanalysis Data (ECMWF). ERA-40 is a global three-dimensional reanalysis dataset produced by the ECMWF and available for the period September 1957 to August 2002 while ERA-Interim reanalysis product from ECWMF covers the period from 1989 to the present day (Simmons et al., 2007). The data is archived at the model spectral resolution of T159 (approximately 1.125^ox1.125^o) and 60 vertical levels. Rainfall was retrieved from the African Rainfall Climatology version 2 (ARC2), a high resolution gridded precipitation estimates with a spatial resolution of 0.1˚ by 0.1˚ (Novella et al., 2013). The rainfall and temperature data retrieved from the ARC2 and ECMWF respectively covered the period between 1983 and 2012. Mean monthly temperature and rainfall data were retrieved for the study.

3.1.2 Forest cover data

The Normalized Difference vegetation Index (NDVI) was used as a proxy for vegetation. NDVI was used because it gives a clear idea about the vigour of forest/vegetation in a particular area. The NDVI as an indicator of vegetative is derived from remotely sensed data in the red and near-infrared spectral regions. This is because chlorophyll absorbs a maximum amount of radiation at a wavelength in the region, 640nm, where photosynthetic efficiency is maximized and reflectance is minimized. Thus Channel 1 (Visible) spectral response in therefore inversely related to chlorophyll density. The Channel 2 (near-infrared) spectral responses, wavelength

730nm-1.1m, are directly related to scattering in individual leaves and between leaves in a canopy. Amalgamating data from two adjacent spectral regions compensate for the difference in irradiance and provides an estimate of the intercepted fraction of the photo-synthetically active radiation or photosynthetic capacity. NDVI is given by the equation 1.

$$NDVI = \frac{NIR\ (Channel\ 2) - Visible\ (Channel\ 1)}{NIR\ (Channel\ 2) +\ Visible\ (Channel\ 1)} \qquad (1)$$

These channels are:
The near-infrared (NIR) wavelength (Channel 2)
Visible (VIS) wavelength (Channel 1)

The NDVI ranges between 0 and 1, undefined when NIR and VIS are zero. The values of the NDVI for vegetated land generally range from about 0.1 to 0.7. The value greater than 0.5 indicating dense vegetation. That is high vegetation: > 0.4, Medium vegetation 0.2 to o.4, light vegetation: 0.1 to 0.2 and bare soil:< 0.1 (Holme et al 1987).

NDVI data was retrieved from the Moderate Resolution Imaging Spectro-radiometer of the National Aeronautics and Space Administration (NASA) through the easily accessible International Research Institute for Climate and Society (IRI). The data are averaged on a two weekly basis and archived as such (Huete et al., 2002). The data spans the periods January 2001 to December 2012.

3.2 Methods

3.2.1 Data Quality Control

The reanalyzed and NDVI data were already quality controlled by the developers and hence no quality control procedures were performed during the study.

3.2.2 Composite Analysis

Change in forest cover was determined through composite analysis of four-year NDVI images for the period between 2001 and 2012. At first, the two weeks archived NDVI were downloaded for the period 2001-2004. The two weeks NDVI was aggregated into monthly NDVI. The monthly NDVI was then aggregated and annual NDVI images were obtained for 2001, 2002, 2003 and 2004. Finally, the annually NDVI images were aggregated to form a four year composite NDVI image. This exercise was repeated for 2005-2008 and 2009-2012. The data was retrieved and processed through the International Research Institute for Climate and Society (IRI).

3.2.3 Coefficient of Variation

The coefficient of variation (CV) was used in the study to map the temporal variability of rainfall and temperature. The coefficient of variation is the statistical measure of the dispersion of the data points in a data series around the mean. The coefficient of variation was computed as shown in the equation 2

$$Coefficient\ of\ Variation\ (C_v) = \frac{Standard\ Deviation\ (STDEV)}{Mean} \qquad (2)$$

3.2.4 Time Series Analysis

Graphical analysis was used to determine trends in NDVI from year 2001 to 2012 and rainfall and temperature from 1983 to 2012. Changes in vegetation cover as indicated by the NDVI values were determined by comparing different 4 year NDVI composite images and by comparing the trend of NDVI in the various counties. The significance of the trend was assessed via the non-parametric Mann-Kendall test. The details of the Mann-Kendall test can be found in

(Frei, 2013).

3.2.5 Correlation Analysis

Correlation measures the degree of association between two variables. The higher the correlation, the more one variable explains the variability in the other variable (Wilks, 1995). Positive correlation implies that when one quantity increases, the other one increases and vice-versa. If it's negative, it implies that when one quantity increases, the other decreases and vice-versa. The significance of the strength of the correlation is tested using the student t-test. Product moment correlation coefficient was computed between the climate variables temperature and rainfall) and NDVI as proxy for forest cover using Equation 3.

$$r_{xy} = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\bar{x})^2\frac{1}{n}\sum_{i=1}^{n}(y_i-\bar{y})^2}} \qquad (3)$$

In Equation 3, r_{xy} is the correlation coefficient, n is the sample size, xi and yi are the variables being correlated and $(\bar{x}), (\bar{y})$ are the mean values of variables of satellite and gauge based data respectively. The student t-test with n-2 degrees of freedom was used to assess the significance of the correlation at the 95% confidence level. The t-test is given by the equation 4.

$$t_{n-2} = r\sqrt{\frac{n-2}{1-r^2}} \qquad (4)$$

Where r is the Pearson correlation coefficient while n is the sample size

CHAPTER FOUR

4 RESULTS AND DISCUSSIONS

4.1 Introduction

The in the chapter, the results obtained from specific objectives are indicated and discussed.

4.2 Spatial variability of Normalized Difference Vegetation, Rainfall and Temperature in Liberia

Spatial variability of NDVI, rainfall and Temperature are discussed in this subsection

4.2.1 Spatial Variability of Normalized Difference Vegetation in Liberia

Spatial variability of NDVI was based on four years set of composite analysis of images for the periods 2001-2004, 2005 to 2008 and 2009 to 2012 and are presented in figure 4.1 to 4.3

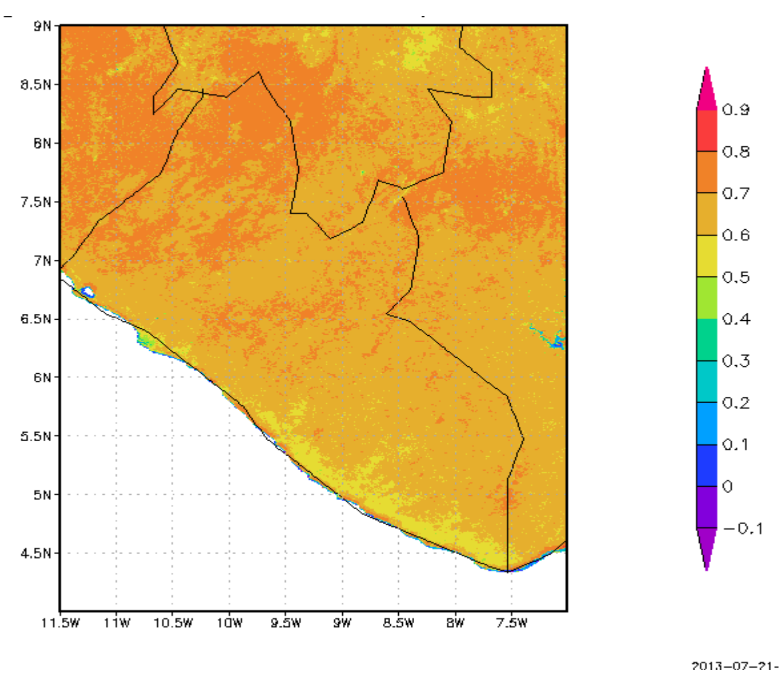

Figure 4.1: Spatial variability of NDVI for 2001-2004

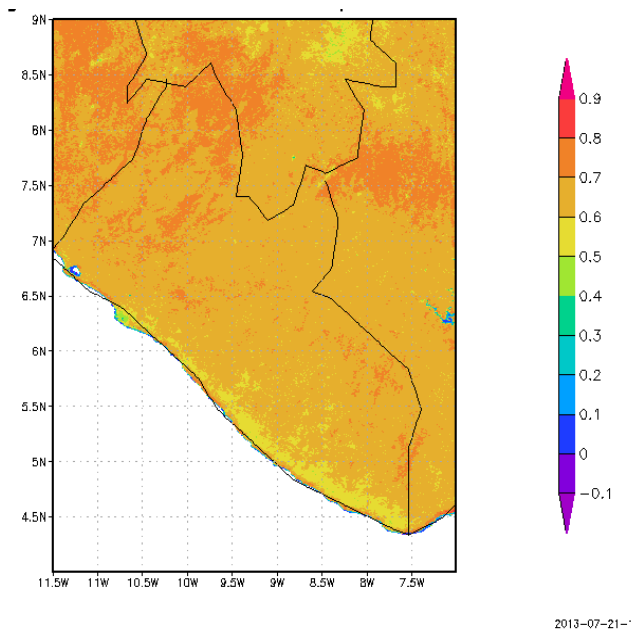

Figure 4.2: Spatial variability of NDVI for 2005-2008

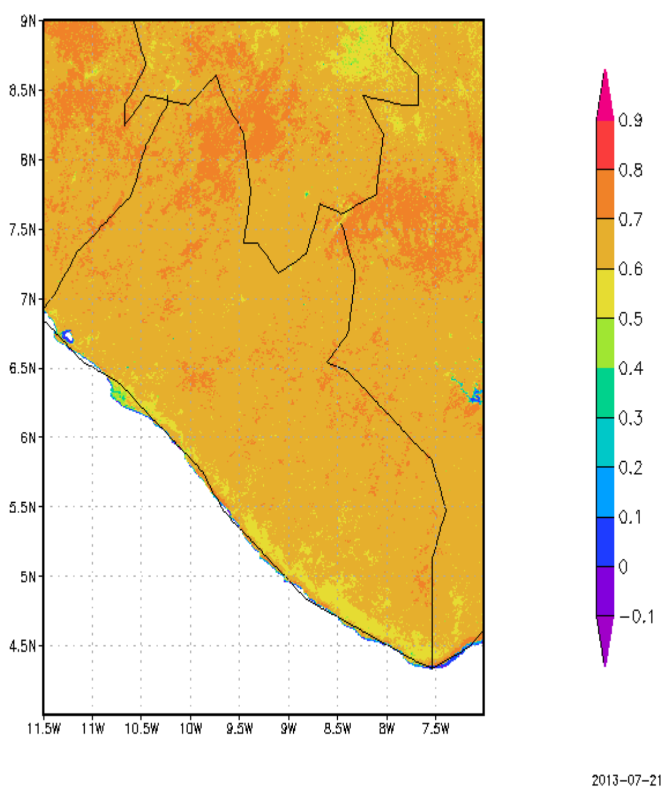

Figure 4.3: Spatial variability of NDVI for 2009-2012

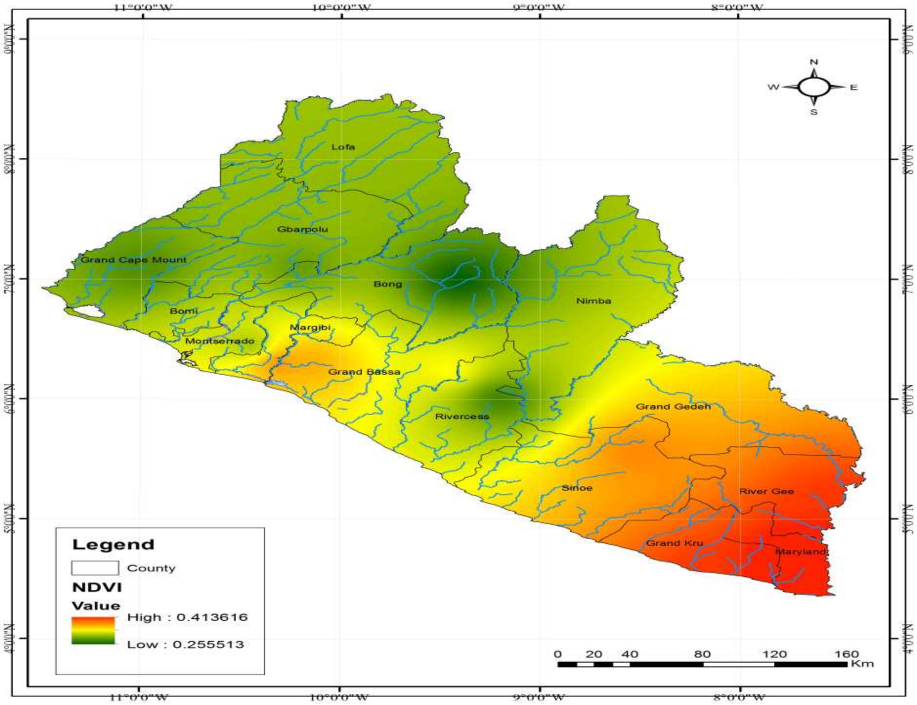

Figure 4.4: Spatial variability for NDVI coefficient of variation in Liberia

The NDVI image from the period 2001-2004 as shown in figure 4.1 had values between 0.6 to 0.7 in the entire country except for the north-western region where the value was between 0.7 to 0.9. This means that deforestation was low in the region during the period mentioned. Higher temperature and higher rainfall influence forest growth. The legend of the spatial variability of NDVI maps (figure 4.1 to 4.3) shows that there is no significant difference between the composite image of 2001-2004 and that of the composite image of 2005-2008 (figure 4.2). However, the 2009 -2012 (figure 4.3) illustrated slight change especially in the Northern region when compared to the composite image of 2001-2004 (figure 4.1).

The study notes that the decreasing NDVI values in Liberia indicate that forest cover is decreasing. However, study by Bayol et al. (2004) notes that the country still has a relatively large amount of intact forest area and thus the observed changes are expected to be gradual.

Spatial variability for NDVI coefficient of variation in Liberia is presented in figure 4.4. The map shows a high coefficient variation in the southeastern region and low in the northwestern regions. It means that forest cover variation is high in the southeastern region and low in the northwestern regions. The difference in the variation is because the southeast region is closer to the coast and northwestern region is farther away from the coast.

4.2.2 Spatial variability of Rainfall in Liberia

Spatial variability of rainfall in Liberia was based on 15 stations/Counties and the results presented in the figure 4.5

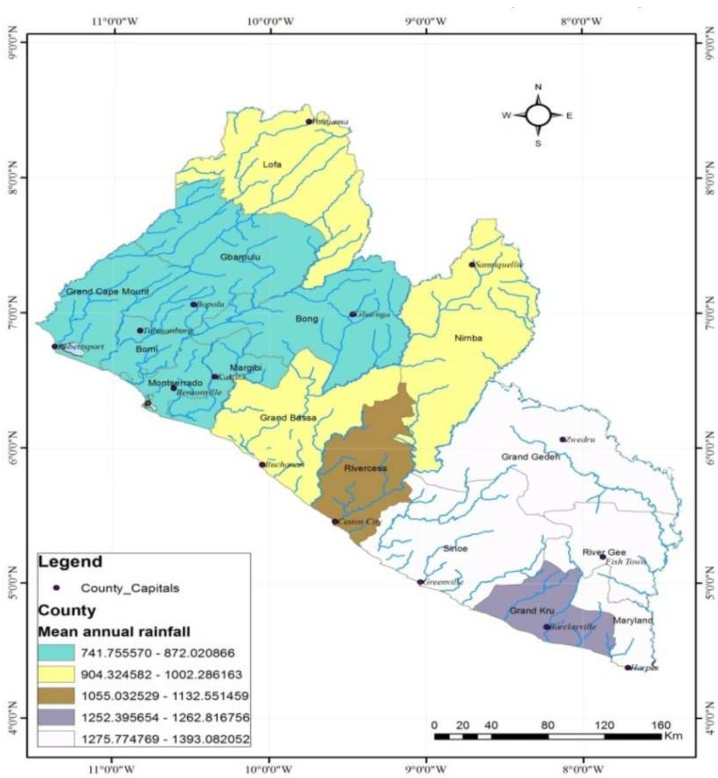

Figure 4.5: Spatial variability for Rainfall in Liberia from 1983 to 2012.

The figure 4.5 showed that all counties had mean spatial rainfall above 741mm. River Gee station recorded the highest annual rainfall of 1393.1 mm of rainfall compared to Bomi station which recorded the lowest amount of annual rainfall of about 741mm. These showed that rainfall over Liberia spatially varied.

4.2.3 Spatial variability of Temperature in Liberia

Spatial variability of Temperature in Liberia was based on 15 stations/Counties and the results presented in the figure 4.6.

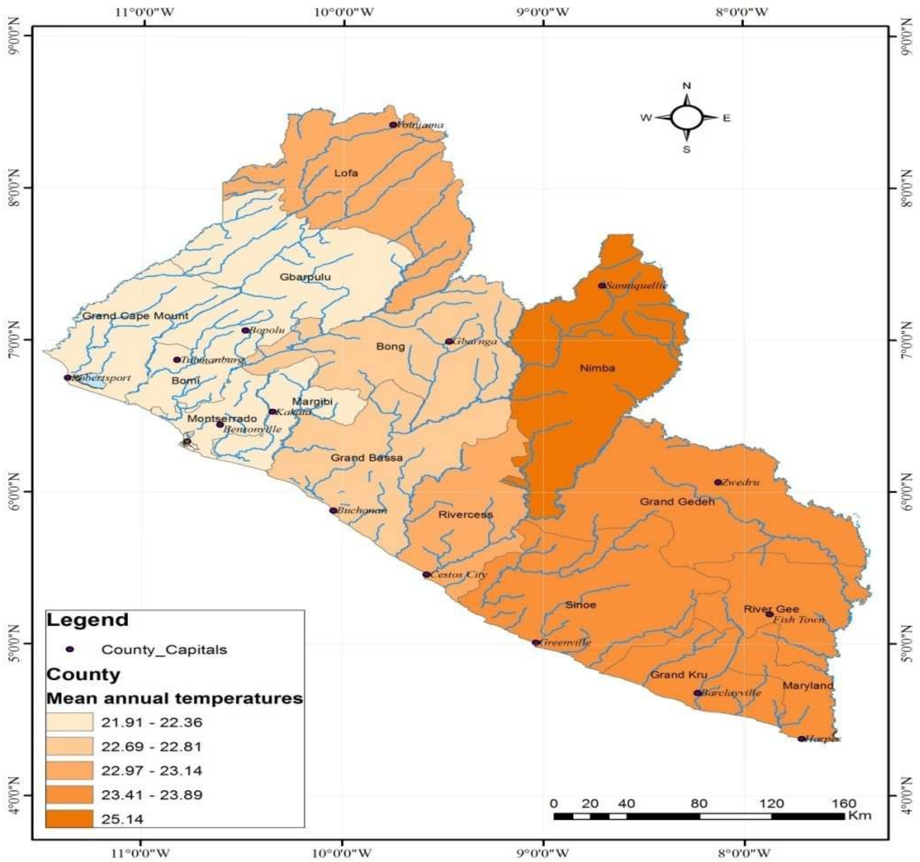

Figure 4.6: Spatial variability of Temperature in Liberia from 1983 to 2012

In the figure 4.6, mean spatial temperature showed an average of 22.0^{o}C with Nimba station recording the highest mean annual temperature of 25.1^{o}C while Cape Mount Station recorded the lowest temperature of 22.0^{o}C.

4.3 Temporal variation of Normalized Difference Vegetation Index, Rainfall and Temperature

4.3.1 Temporal variation of Normalized difference Vegetation Index in Liberia

The temporal variability of Normalized difference Vegetation Index was determined and the results presented in the figures 4.7 and 4.10

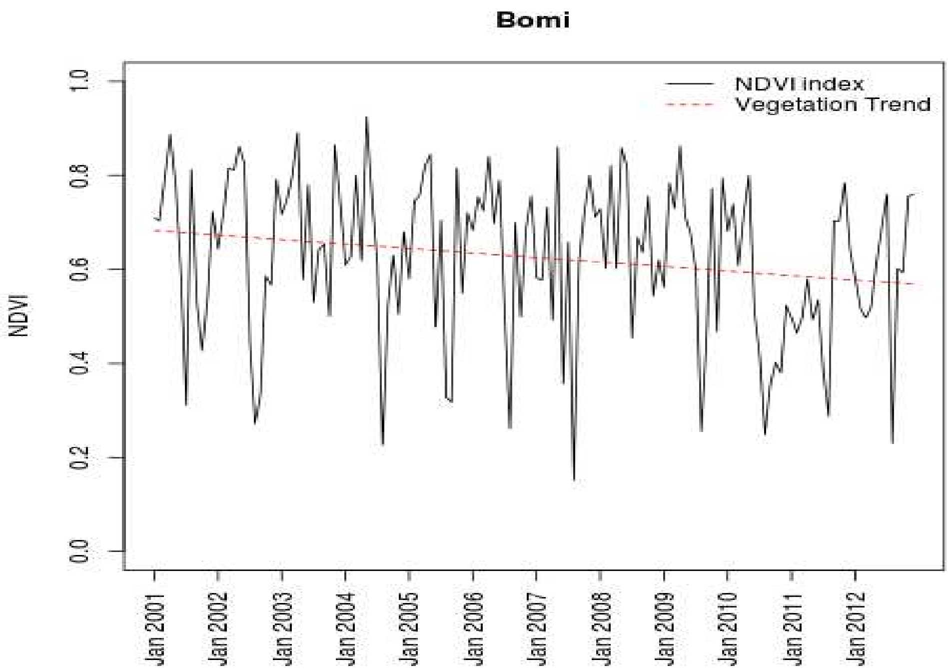

Figure 4.7: The temporal variability of NDVI over Bomi in Liberia

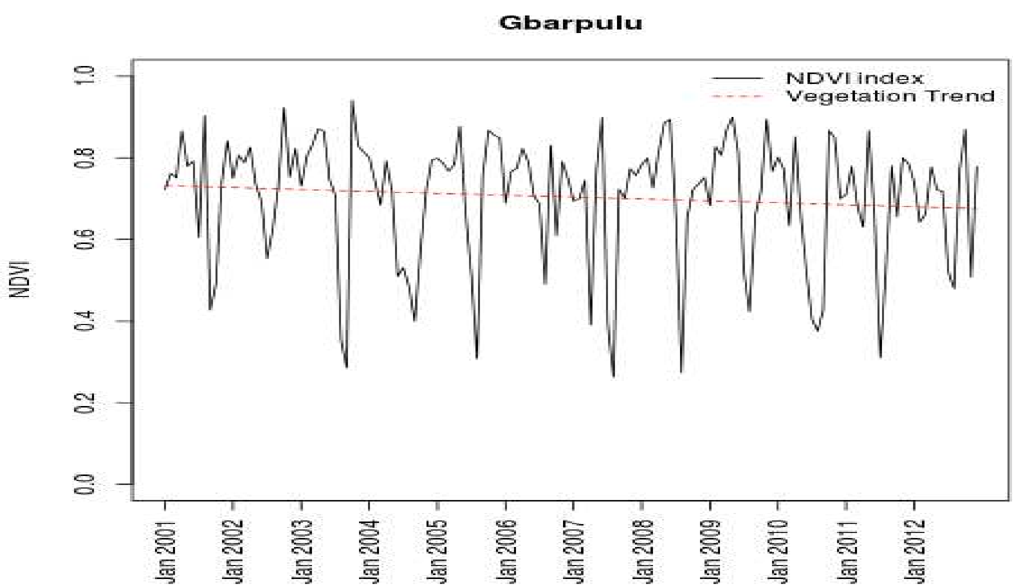

Figure 4.8: The temporal variability of NDVI over Gbapolu in Liberia

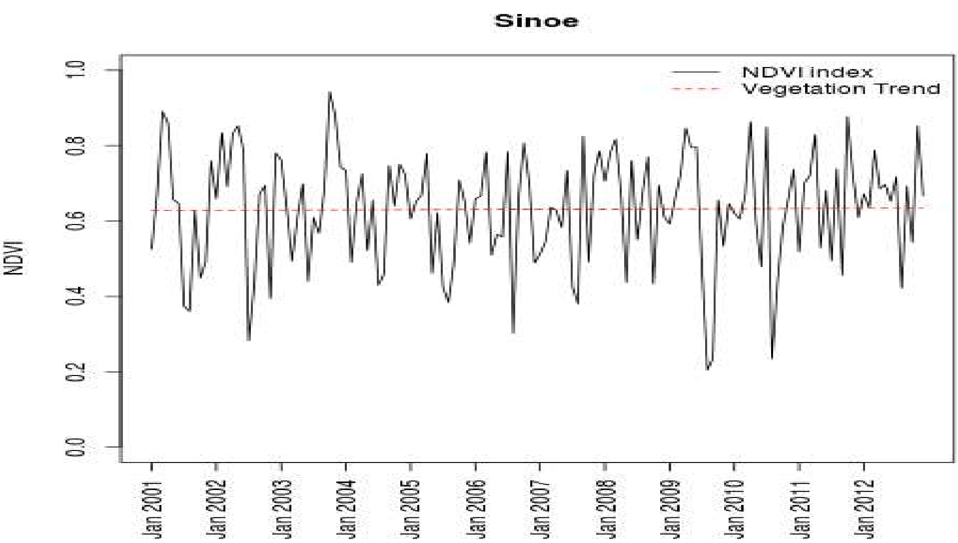

Figure 4.9: The temporal variability of NDVI over Sinoe in Liberia

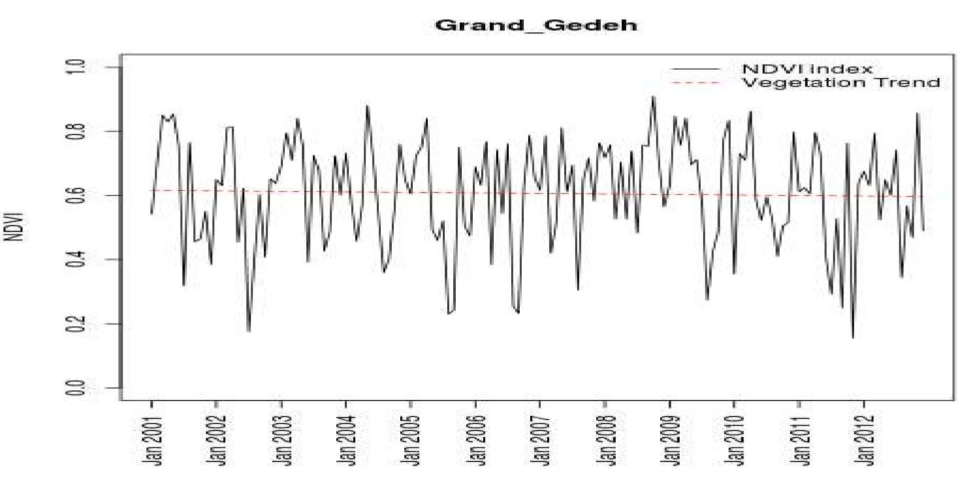

Figure 4.10: The temporal variability of NDVI Grand Geddeh in Liberia

The figure 4.7-4.10 showed the NDVI trends over the study period in Liberia were decreasing except Sinoe County Grand Geddeh and River Gee counties.

4.3.2 Temporal variability of Rainfall in Liberia

The temporal variability for rainfall coefficient of variation was determined and the selected results presented in the figures 4.11 to 4.14.

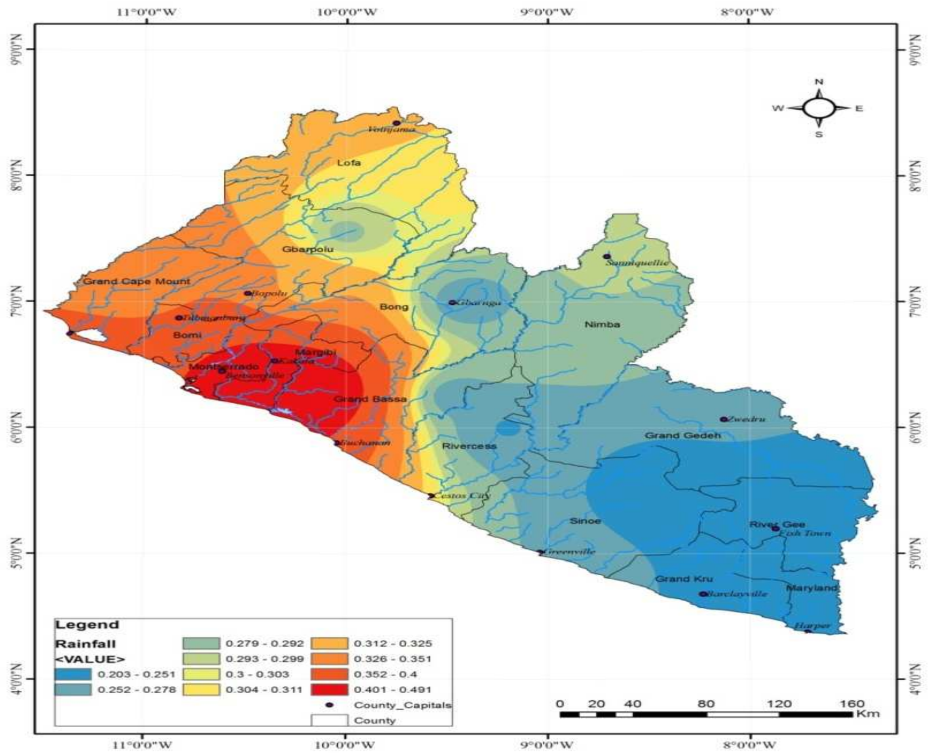

Figure 4.11: temporal variability of rainfall coefficient of variation in the Liberia from 1983-2012

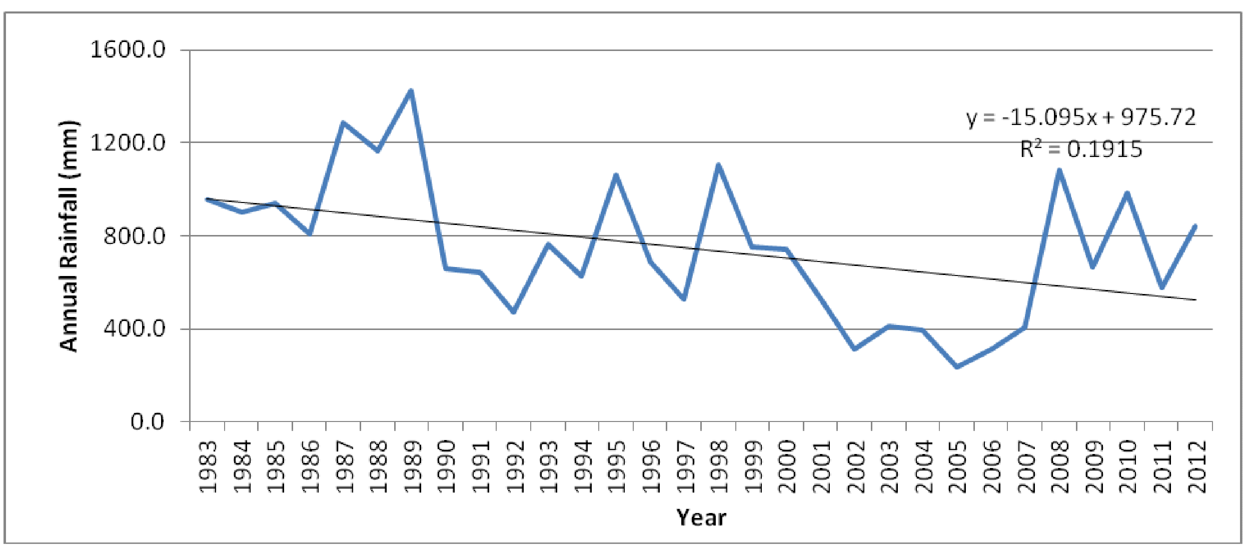

Figure 4.12: The temporal variability of rainfall over Bomi County in Liberia

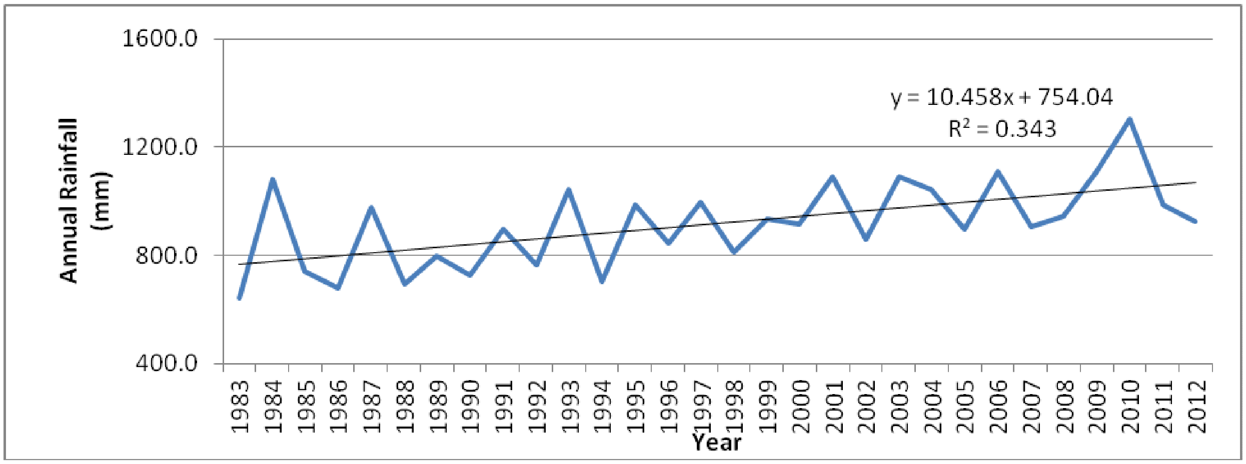

Figure 4.13: The temporal variability of rainfall over Nimba County in Liberia

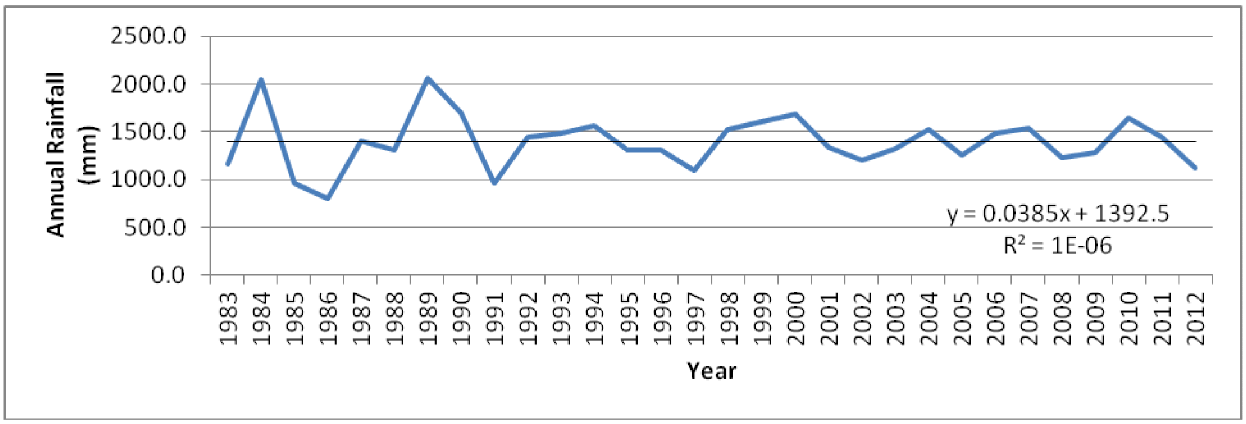

Figure 4.14: The temporal variability of rainfall over River Gee County in Liberia

Figure 4.11 showed the temperature variability for rainfall coefficient of variation in the entire country on a map. It showed that rainfall varies largely in north-west and varies less in the Southeast. It means that rainfall is more stable in the southeast and can be attributed to the high forest cover observed in the region. Figure 4.12 to 4.14 showed that the temporal variability of temperature in Liberia in a graphical format. It showed that the temporal variability of rainfall in Bomi County was decreasing. Other stations with a decreasing trend included Bong, Cape Mount, Gbapolu, Grand Bassa, Grand Gedeh, Lofa, Margibi, Maryland, Montse and Rivercess. In these stations, the coefficient of determination ranged between 0.2% in Grand Kru to 26.0% in Montserrado. Figure 4.13 showed an increasing trend in Nimba with coefficient of variation at 34.3%. The other countries with the increasing trend of rainfall in Liberia included Grand Kru and River Gee counties. In general, most countries were noted to have a decreasing trend in rainfall.

4.3.3 Temporal variability of Temperature in Liberia

The temporal variability of temperature was determined and the selected results presented in the figures 4.15 to 4.18

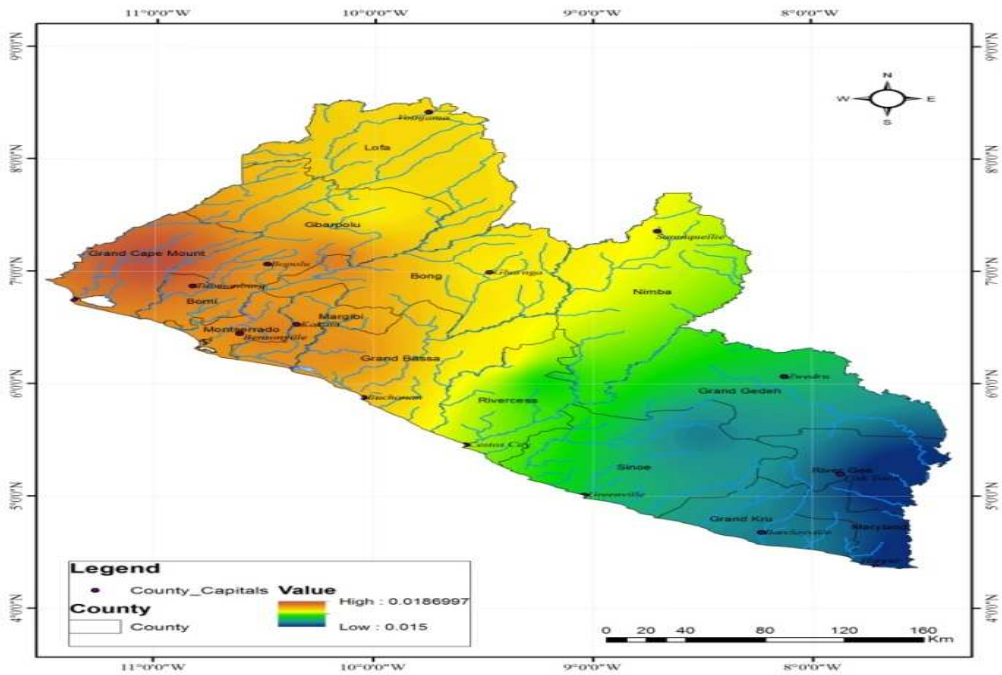

Figure 4.15: Temporal variability of temperature in Liberia from 1983-2012

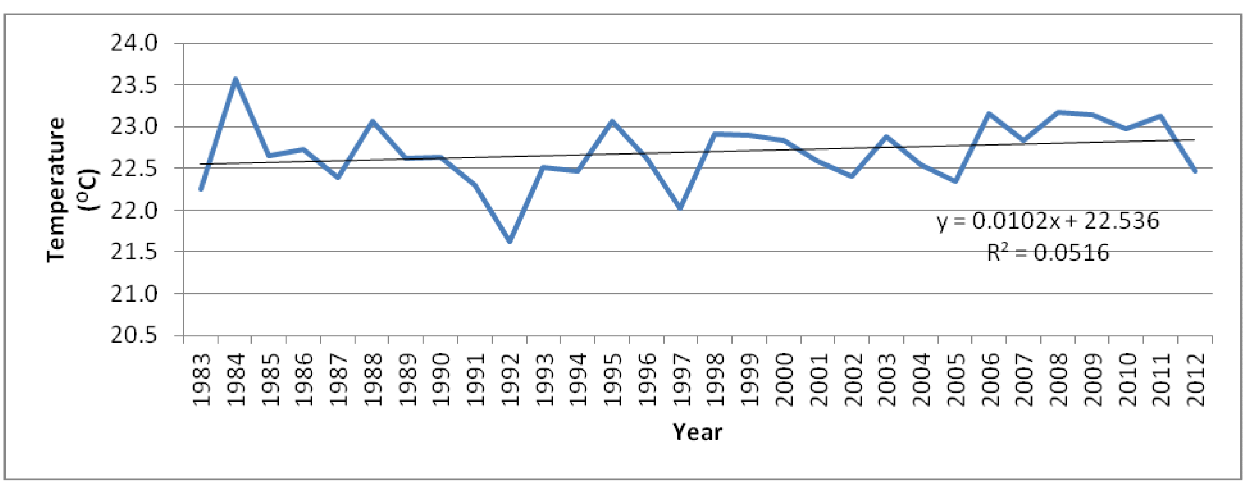

Figure 4.16: The temporal variability of temperature over Grand Bassa County in Liberia

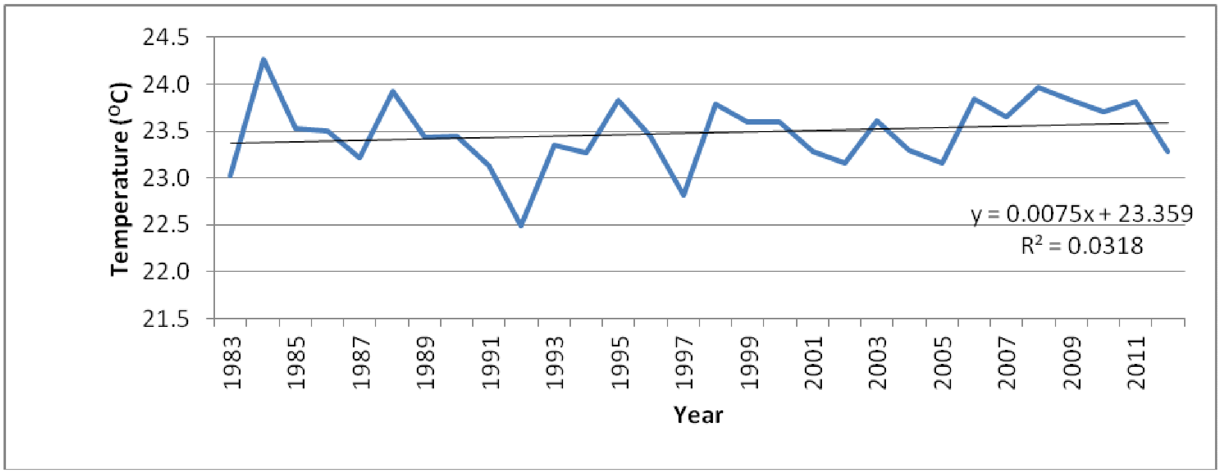

Figure 4.17: The temporal variability of temperature over Grand Gedeh County in Liberia

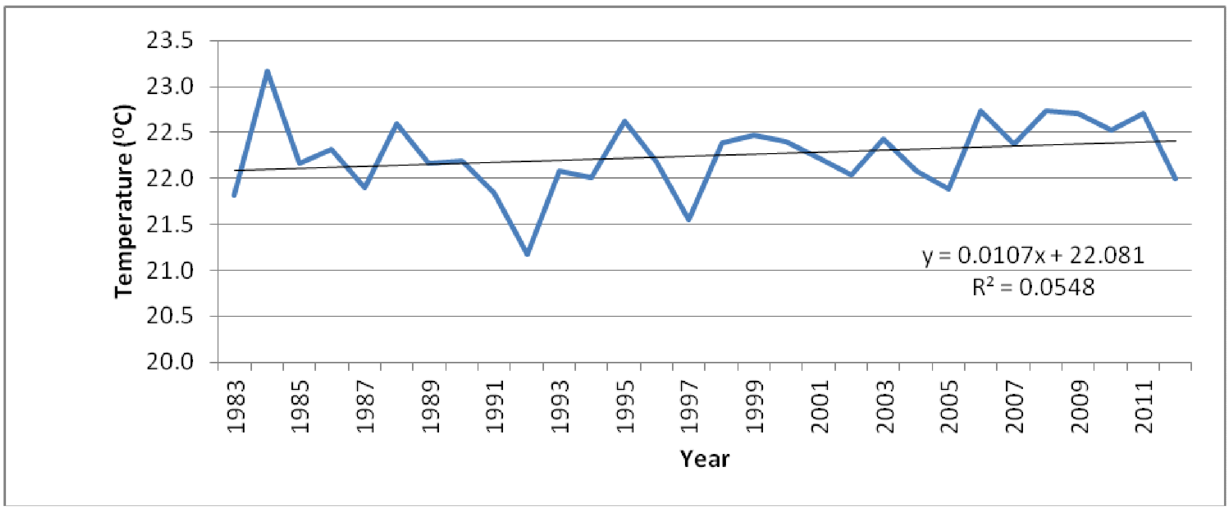

Figure 4.18: The temporal variability of temperature over Margibi County in Liberia

Figure 4.15 presents temporal variability for the temperature coefficient of variation. The map revealed that the temperature varies greatly in the northwest and down to the south and in parts of the central region while it varies less in the southeast. This means that the temperature is more stable in the southeast.

Figure 4.16 to 4.18 presents the temperature variation of temperature in a graph. The results of temporal variability of temperature in all Counties over Liberia showed an increasing trend with the coefficient of determination values ranging between 0.02 and 0.08 which showed that only 2% to 8% of data points could fit along the linear line.

4.4 The Relationship between Rainfall, Temperature and Normalized Difference Index in Liberia

4.4.1 Correlation Analysis of Rainfall and Normalized Difference Index in Liberia

Correlation analysis was carried out between mean monthly rainfall and NDVI as results presented in table 4.1. The student t test was then used to test the significance of correlation coefficient and the results tabulated in table 4.2. On table 4.2, the shaded fields indicate the areas where NDVI significantly correlated with rainfall.

Table 4.1: NDVI and Rainfall mean monthly correlation for the period 2001-2012

Month	Bomi	Bong	Cape_Mt	Gbarpulu	Grand _Bassa	Grand _Gedeh	Grand_ kru	Lofa	Margibi	Maryland	Montserrado	Nimba	Rivercess	River_Gee	Sinoe
Jan	0.18	0.39	-0.26	0.11	-0.12	-0.02	0.21	0.27	-0.35	-0.28	-0.26	-0.58	0.14	0.27	0.38
Feb	-0.41	0.02	-0.44	0.08	-0.20	-0.27	-0.23	0.15	-0.20	-0.03	0.01	-0.03	0.29	-0.20	0.14
Mar	-0.23	-0.19	0.01	0.01	0.22	-0.13	0.38	0.13	0.19	0.48	-0.51	0.10	-0.44	0.45	0.24
Apr	-0.06	0.44	0.18	0.16	0.31	0.07	-0.81	0.07	-0.33	0.27	0.01	0.62	0.15	0.42	-0.22
May	0.06	0.23	0.13	-0.19	0.25	-0.32	0.11	0.38	-0.09	-0.34	0.08	-0.12	0.01	-0.25	-0.05
Jun	0.15	0.53	-0.13	0.50	0.16	0.06	0.04	-0.15	0.04	-0.05	0.14	0.53	0.40	0.57	-0.11
Jul	0.29	0.53	-0.16	0.15	0.57	-0.08	0.10	0.38	-0.08	0.15	0.13	0.70	-0.10	0.65	-0.24
Aug	0.41	0.68	0.56	-0.06	0.12	0.04	0.15	0.40	0.42	0.11	0.70	0.41	-0.42	0.24	-0.24
Sep	0.17	0.08	-0.44	-0.07	0.54	-0.25	0.49	-0.38	0.18	0.42	-0.40	0.06	0.28	-0.11	0.22
Oct	0.04	0.21	-0.10	0.28	0.23	0.24	0.04	0.03	0.23	0.31	0.09	0.15	0.11	-0.13	-0.03
Nov	0.04	0.05	0.09	-0.29	0.20	0.23	0.47	0.10	-0.68	-0.09	-0.24	0.01	-0.39	-0.44	0.42
Dec	-0.62	-0.34	-0.40	-0.57	-0.02	-0.01	0.17	-0.28	-0.12	-0.50	-0.26	-0.63	-0.36	0.42	0.11

Table 4.2: T-test for NDVI-Rainfall mean monthly correlation significance for the period 2001-2012. The cut-off value here is 2.2.

Month	Bomi	Bong	Cape_Mt	Gbarpulu	Grand_ Bassa	Grand_ Gedeh	Grand_ kru	Lofa	Margibi	Maryland	Montserrado	Nimba	Rivercess	River_Gee	Sinoe
Jan	0.60	1.35	-0.83	0.35	-0.39	-0.07	0.68	0.89	-1.18	-0.93	-0.84	-2.24	0.44	0.90	1.30
Feb	-1.42	0.05	-1.57	0.27	-0.66	-0.88	-0.75	0.49	-0.66	-0.11	0.03	-0.09	0.96	-0.64	0.46
Mar	-0.74	-0.61	0.04	0.03	0.71	-0.41	1.32	0.40	0.62	1.75	-1.89	0.30	-1.54	1.58	0.77
Apr	-0.18	1.53	0.59	0.52	1.05	0.23	-4.37	0.23	-1.09	0.89	0.03	2.51	0.49	1.46	-0.72
May	0.20	0.76	0.40	-0.62	0.83	-1.08	0.35	1.31	-0.29	-1.13	0.24	-0.39	0.04	-0.81	-0.15
Jun	0.49	1.95	-0.40	1.84	0.51	0.18	0.14	-0.49	0.13	-0.16	0.45	1.96	1.38	2.18	-0.36
Jul	0.94	1.99	-0.51	0.47	2.17	-0.24	0.32	1.31	-0.26	0.48	0.43	3.07	-0.32	2.73	-0.77
Aug	1.44	2.90	2.14	-0.19	0.39	0.11	0.49	1.38	1.44	0.35	3.10	1.40	-1.48	0.76	-0.76
Sep	0.54	0.26	-1.56	-0.22	2.03	-0.81	1.75	-1.29	0.56	1.47	-1.36	0.20	0.91	-0.35	0.70
Oct	0.13	0.68	-0.32	0.92	0.75	0.76	0.11	0.10	0.76	1.03	0.27	0.47	0.34	-0.41	-0.09
Nov	0.13	0.14	0.29	-0.96	0.64	0.75	1.70	0.33	-2.91	-0.27	-0.77	0.03	-1.35	-1.56	1.47
Dec	-2.47	-1.15	-1.36	-2.22	-0.05	-0.03	0.54	-0.94	-0.38	-1.82	-0.86	-2.57	-1.23	1.47	0.35

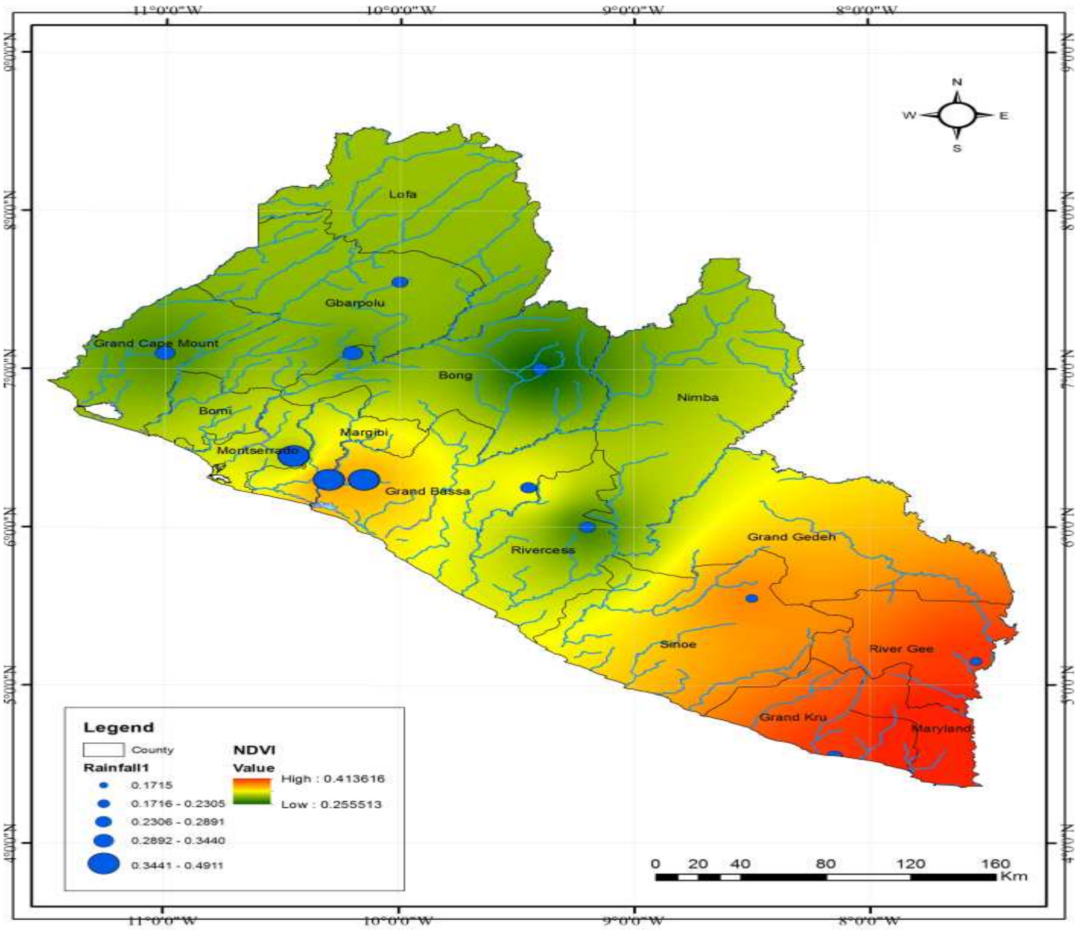

Figure 4.19: Overlay map for coefficient of variability of NDVI and rainfall in Liberia

The table 4.1 shows that there is a relationship between NDVI and rainfall. The correlation coefficient values ranged between -0.616 in Bomi in the month of December to 0.676 in Bong in the month of August. These values were tested for their significance (table 4.2) and found to be significantly correlated with NDVI in some of the counties, especially during the rainy season. The rainfall period is from April to September of each year while the dry season is from October to March. However, there can be dry spells during the rainy season as well as wet spells during the dry season. Seven (7) out of the fifteen (15) counties correlation was significant. The countries that were significantly correlated with rainfall after the student t-test was done included. Bomi in December, Bong in August, Lofa in September, Margibi in November, Montserrado in August, Nimba in April, July and December, and River Gee in July. It means that forest/vegetation in these countries was impacted by rainfall in these countries at the time.

Figure 4.19: Overlay map for coefficient of variability of NDVI and rainfall in Liberia. The map shows that in regions where rainfall coefficient of variation is high NDVI (forest cover) coefficient of variation is low. While in the areas where rainfall coefficient of variation is low NDVI (forest cover) coefficient of variation is also low.

4.4.2 Correlation analysis of Normalized Difference Index and Temperature in Liberia

The correlation between the main monthly temperature and NDVI are presented in the table 4.3 while table 4.4 shows the student t test. The dark green field indicates the significant correlation values.

Table 4.3: NDVI-Temperature mean- monthly correlation for the period 2001-2012

Month	Bomi	Bong	Cape_ Mt	Gbarpulu	Grand_ Bassa	Grand_ Gedeh	Grand_ kru	Lofa	Margibi	Maryland	Montserrado	Nimba	Rivercess	River_Gee	Sinoe
Jan	0.23	-0.22	0.43	0.47	0.03	-0.19	-0.68	-0.02	0.32	0.20	0.12	-0.13	0.01	-0.32	0.03
Feb	0.49	0.62	0.07	0.33	0.61	0.16	0.31	0.07	-0.13	0.59	-0.21	-0.52	0.14	0.48	-0.17
Mar	0.40	-0.21	-0.20	0.05	0.13	-0.16	-0.36	-0.15	-0.54	-0.30	-0.49	-0.32	-0.02	-0.22	-0.48
Apr	0.30	0.19	-0.25	-0.01	0.39	0.09	0.06	-0.15	-0.22	0.61	-0.06	0.17	0.40	0.31	0.00
May	0.35	0.19	0.07	-0.39	0.37	-0.01	-0.42	0.15	0.06	0.26	0.16	-0.15	0.38	-0.55	0.03
Jun	-0.67	-0.35	0.02	-0.11	-0.48	-0.35	-0.83	0.04	0.19	0.51	0.19	-0.09	0.01	-0.14	0.04
Jul	-0.12	-0.39	-0.10	-0.11	0.27	0.41	0.08	0.13	0.11	0.47	-0.12	-0.33	0.37	0.28	0.63
Aug	-0.17	0.08	0.30	0.22	-0.15	0.11	-0.26	0.27	-0.32	0.42	0.21	0.37	0.08	0.27	0.06
Sep	-0.16	-0.17	-0.07	0.28	-0.52	-0.33	0.63	0.15	0.11	0.05	-0.46	0.20	-0.23	0.08	-0.44
Oct	-0.05	-0.62	-0.43	-0.14	-0.06	0.47	0.32	-0.20	-0.15	0.29	0.04	0.00	0.49	-0.35	0.22
Nov	-0.05	0.14	0.11	0.03	-0.05	0.00	-0.15	0.01	0.05	0.48	0.25	0.17	0.46	0.31	0.44
Dec	0.51	0.32	-0.09	-0.12	0.50	0.28	0.06	-0.03	0.40	-0.18	0.34	0.32	0.26	-0.40	-0.73

Table 4.4: NDVI-Temperature mean-monthly correlation significance for the period 2001-2012. The cut-off value here is 2.2.

Month	Bomi	Bong	Cape_ Mt	Gbarpulu	Grand_ Bassa	Grand_ Gedeh	Grand_ kru	Lofa	Margibi	Maryland	Montserrado	Nimba	Rivercess	River_ Gee	Sinoe
Jan	0.751	-0.723	1.506	1.679	0.082	-0.622	-2.877	-0.07	1.057	0.652	0.366	-0.428	0.041	-1.053	0.098
Feb	1.787	2.525	0.231	1.109	2.441	0.526	1.042	0.235	-0.424	2.293	-0.693	-1.94	0.454	1.716	-0.559
Mar	1.372	-0.676	-0.639	0.171	0.411	-0.516	-0.768	-0.486	-2.029	-0.991	-1.797	-1.061	-0.076	-0.727	-1.73
Apr	0.976	0.612	-0.823	-0.025	1.339	0.283	0.184	-0.473	-0.696	2.422	-0.184	0.549	1.384	1.02	-0.013
May	1.189	0.605	0.235	-1.331	1.271	-0.019	-1.593	0.476	0.177	0.851	0.519	-0.476	1.279	-2.056	0.079
Jun	-2.862	-1.182	0.07	-0.344	-1.726	-1.178	-2.606	0.139	0.602	1.87	0.595	-0.295	0.022	-0.454	0.12
Jul	-0.379	-1.347	-0.308	-0.334	0.88	1.438	0.244	0.424	0.337	1.666	-0.392	-1.102	1.252	0.922	2.565
Aug	-0.532	0.247	0.987	0.696	-0.493	0.334	-0.717	0.901	-1.057	1.476	0.683	1.255	0.238	0.887	0.193
Sep	-0.516	-0.542	-0.206	0.929	-1.92	-1.121	2.137	0.49	0.353	0.152	-1.652	0.632	-0.751	0.238	-1.545
Oct	-0.168	-2.505	-1.498	-0.457	-0.187	1.666	0.987	-0.652	-0.493	0.947	0.123	-0.009	1.782	-1.197	0.71
Nov	-0.168	0.454	0.36	0.101	-0.149	0	-0.398	0.016	0.165	1.712	0.81	0.552	1.62	1.031	1.541
Dec	1.680	1.083	-0.276	-0.389	1.831	0.937	0.123	-0.104	1.392	-0.585	1.159	1.053	0.848	-1.38	-3.398

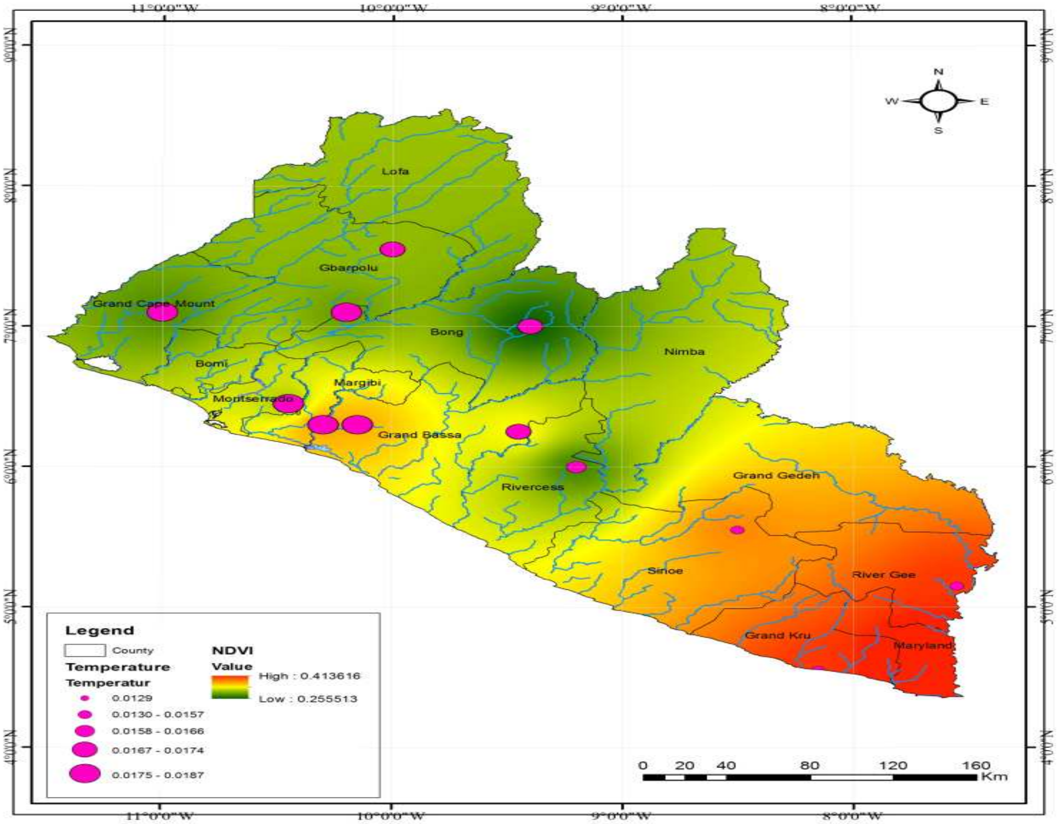

Figure 4.16: Overlay map for coefficient of variability of NDVI and Temperature in Liberia

The table 4.3 showed that there is a relationship between NDVI and Temperature. The test of significance (Table 4.4) showed that temperature significantly correlated with NDVI especially during the dry season in six (6) counties. The countries that were significantly correlated with temperature after the student t-test was done included: Bomi in June, Bong in February, and October, Grand Bassa February, Grand Kru in June, Maryland in April and Sinoe in December. This means that vegetation in these counties was influenced by temperature during the periods.

Figure 4.16 shows an overlay map for coefficient of variability of NDVI and temperature in Liberia. The map shows that in regions where temperature coefficient of variation is high NDVI coefficient of variation is also high. While in the areas where temperature coefficient of variation is low NDVI coefficient of variation is also low.

CHAPTER FIVE

5 SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 SUMMARY

From the composite NDVI images, the project found that forest cover is gradually decreasing in the Liberia as was noted by Bayol et al (2004). The decrease was observed particularly in the northeastern and parts of the central regions. Bomi, Grand cape Mount, Margibi and Bong were observed to be affected by the decreased in the regions. The observation was based on the NDVI values in the region (figure 4.1 to 4.3). The northeast and parts of the central region also showed a reducing rainfall and temperature with high rainfall and temperature variability. Although rainfall and temperature are not the only climatic parameters that influence forest growth, they are significant factors. Therefore, since rainfall and temperature were found to be low and with high variability, the effect of this could be the low forest cover observed in the regions. However, this could not be factor for low forest cover. Other factors are such as unsustainable land use change practices such as the shifting cultivation, conversion of a large forest area for permanent plantation, harvesting of forest tree for charcoal production, illegal logging and mining, among others, could lead to low forest cover (Shearman, 2009).

Based on this study forest cover in the southeast region was found to be high. The counties that showed the more stable trends were River Gee, Sinoe and Grand Geddeh. Temperature and rainfall was also shown to be high in this region while rainfall and temperature variability was observed to be low. The effects of higher temperature and rainfall along with low rainfall and temperature variability could be attributed to forest cover stability in the regions. However, they are the only factor responsible for forest stability or growth. Sustainable land use practices such as forest conservation, reforestation, climate smart agriculture, agro-forestry among others are also significant factors responsible for forest stability and growth.

The countries whose NDVI significantly correlated with rainfall after the correlation significance was done (t-test) included, Bomi in December, Bong in August, Lofa in September, Margibi in November, Montserrado in August, Nimba in April, July and December, and River Gee in July. It means that forest/vegetation in these countries was impacted by rainfall in these countries at the time.

The counties that were significantly correlated with temperature after the t-test was done included: Bomi in June, Bong in February, and October, Grand Bassa February, Grand Kru in June, Maryland in April and Sinoe in December. The means that vegetation in these counties were influenced by temperature during the periods.

5.2 Conclusion

The study concludes that climate variability, that is, rainfall and temperature have effects on forest cover in Liberia. The effect of climate variability on forest , that is, rainfall and temperature are contributing factors to the stability of forest cover in the southeast region of Liberia and the decreasing forest cover in the northwestern and parts of the central regions. However, for forest like the tropical rain forest in Liberia low temperature and rainfall may not be a major factor in the decreased forest cover observed in the region. As was mentioned, decreasing forest cover could be significantly attributed to unsustainable forest land use practices while forest stability or increased in forest cover could be greatly attributed to sustainable forest land use practices.

5.3 Recommendation

The following commendations should be considered:

1. Validation of the NDVI and re-analyzed data with ground truth data.

2. A comprehensive study should be done to establish the actual effects of climate variability and change on forest in Liberia.

References

Aweda E. D. and Adeyewa Z. D, 2011: Inter annual variation of vegetation anomaly over Nigeria using satellite-derived index. Pelagia Research Library, Advances in Applied Science Research, 2 (3): 468-475

Bayol N. and Chevalier J.F, 2004: Current state of the forest cover in Liberia -forest information critical to decision making, Forest Resources Management

CAAS ,2007: Comprehensive Assessment of the Agricultural Sector in Liberia. Monrovia, LiberiaCBL ,2009: Central Bank of Liberia, Annual report of 2008

Doe, J W, 1984: The Liberia forest sector assessment: pertinent policy issues and recommendations for consideration, FAO Field Document, FAO, Rome

FAO, 2010: Global Forest Resource Assessment.Retrieved www.fao.org/forestry/fra/fra2010/en January 5. 2013.

FDA, 2006: National Forestry Policy and Implementation strategy. Forestry Development Authority, Monrovia- Republic of Liberia.

FDA, 200: Liberia National Adaptation Programme of Action, Monrovia- Republic of Liberia

FDA, 2007: National Forest management Strategy, Forestry Development Authority, Monrovia Republic of Liberia

Frei,2013: Analysis of Climate and Weather Data, Federal office of Meteorology and climatology Metroswiss, Zurich.

Huete , 2002: Overview of the radiometric and biophysical performance of the MODIS vegetation indices, REMOTE SENSING OF ENVIRONMENT 83 (1-2): 195-213

Holme, A.McR., Burnside, D.G. and Mitchell, A.A. (1987): The development of a system for monitoring trend in range condition in the arid shrublands of Western Australia. Australian Rangeland Journal 9:14-20.

Holben, B.N, 1986: Characteristics of maximum value composite images from temporal AVHRR dada. Int. J. Remote Sens7, 1417–1434.

IPCC , 2003: Good practice guidance for land use, land-use change and forestry. Retrieved from www.ipcc-nggip.iges

IPCC, 2007: Climate Change. The physical science basis. Contribution of working Group I to the Fourth Assessment Report of the Intergovernmental panel on Climate Change. Cambridge University press.

Lyons, 1984. FIAG assistance programme to the African Timber Organization (ATO): the Republic of Liberia, FAO Field Document, FAO, Rome.

NAPA, 2008: Liberia National Adaptation Programme of Action, the Environmental Protection Agency of Liberia

Shearman, 2009: An Assessment of Liberian Forest Area, Dynamics, FDA Concessions Plans, and their Relevance to Revenue Projections: A report commissioned by Green

Sambolah, 2009: Mainstreaming and Capacity Building for Sustainable Land Management in Liberia; A study on Sustainable Forest Harvest and Best practices. Environmental Protection Agency of Liberia

Sio, 1986: Liberia: the legal and institutional framework for citizen participation in forest industries, chapter from FAO Forestry Paper 68, FAO, Rome.

Simmons, A., S. Uppala, D. Dee, S. Kobayashi, 2007: ERA-Interim: New ECMWF reanalysis products from 1989 onwards. ECMWF Newsletter, 110.

Stibig, H J, and Baltaxe, R, 1993: Use of NOAA remote sensing data for assessment of the forest area of Liberia, RSC Working Paper 66, FAO, Rome

Voorehoeve, A. G 1979: Liberia High Forest tree (Agricultural Research Report), Backhuys Publisher

Wilks.1995: Statistical methods in the atmospheric sciences, second edition. International Geophysics Series, Vol 59, Academic Press, 464pp.

Yaw A. Twumasi1, Tommy L. Coleman, Andrew Manu, Edmund C. Merem, Albert Osei, 2011: Relationships between Climate Parameters and Forest Vegetation At and Near Digya National Park, Ghana: British Journal of Environment & Climate Change 1(4): 201-215, 2011

Yelwa S. A and Eniolorunda N. B, 2012: Simulating the Movement of Desertification in Sokoto and its Environs, Nigeria Using 1 km SPOT-NDVI Data. Environmental Research Jounal, 6:175-181