Seminar series nr 205

Climate variability and satellite – observed vegetation responses in Tanzania

Wilbert Timiza

2011
Department of Earth and Ecosystem Sciences
Physical Geography and Ecosystems Analysis
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

Timiza, W. (2011) Climate variability and satellite – observed vegetation responses in Tanzania. *Master thesis Physical Geography and Ecosystem Analysis, Lund University*, Seminar series 205, 30 ECTS.

LUND UNIVERSITY
Department of Earth and Ecosystem Sciences

Climate variability and satellite – observed vegetation responses in Tanzania

A Dissertation Submitted in Partial Fulfilment of the requirement for the
Degree of M.Sc. Physical Geography and Ecosystem Analysis
At Lund University, Sweden

WILBERT TIMIZA, 2011

Supervisor:
Lars Eklundh

Abstract

Climate and vegetation growth of an area are interrelated processes; both take place on small to global scales. However, climate change and variability impacts on vegetation in most places in the world including Tanzania is of great concern since vegetation supports many socio-economic sectors, and plays a crucial role in atmospheric greenhouse gas moderation. This study aims at investigating the changes in satellite observed vegetation greenness through the use of Normalized Difference Vegetation Index (NDVI) and its relationship with the climatic factors, mainly rainfall and sea surface temperatures (SST) in Tanzania. Advanced Very High Resolution Radiometer (AVHRR)-NDVI data from 1982 to 2008 (27 years) were used in this study. These data have been proved to be useful in studying vegetation-climate relationships in various places including East Africa and Tanzania. Correlation and simple linear regression analyses were employed to reveal the nature and magnitude of the relationship as well as trends in both rainfall and NDVI data. This study found on average decreasing trends for both NDVI and rainfall for most part of the country during the study period. Despite these trends being statistically significant, they are weak ones. The coefficients of explanation obtained from the relationship between NDVI, rainfall and SST were improved (between 50% and 80%) with the use of noise filtering technique and time lagging of the datasets. This improvement is in comparison with the weak and less than 50% before filtering and lagging of the data. These results suggest that variability in rainfall or SST, especially the Niño 3.4 SST can explain only half of the variability in vegetation amidst other environmental and human factors. Rainfall variability was found to explain more of the vegetation variability in the unimodal than in the bimodal areas while Niño 3.4 SST explains more of the vegetation variability in the bimodal than in the unimodal areas. This study has improved the current understanding of the vegetation and rainfall trends together with their relationships. The study also forms a basis for future studies in climate-vegetation relationship studies.

Key words: NOAA-AVHRR-NDVI, rainfall, Sea surface temperature, Tanzania, trend, correlation, climate variability.

Acknowledgements

To God be all the glory. I acknowledge His protection, provision and strength throughout the study period.

I am very grateful to my supervisor Lars Eklundh for his invaluable supervision and guidance. His simplicity and patience inspired me, thank you.

I would also like to thank Tanzania Meteorological Agency (TMA) for allowing me a study leave and providing the climate data.

My appreciation goes to Erasmus Mundus Lot. 10; a European Union scholarship coordinated by Petter Pilesjö. This programme would have been impossible without the financial support from the scholarship.

I sincerely thank lecturers at the department of Earth and ecosystem services for equipping me with the knowledge I needed in this thesis, without forgetting my fellow students for their valuable discussions and encouragement.

Last but not least, I would like to thank my family for their love and patience they have always shown me. My wife Aisa, my children Abigail and Jonathan, their smiles have given me a reason to work harder.

Table of contents

1 Introduction

Climate and vegetation growth of an area are interrelated processes; both take place on a small to global scale. Climate change is projected to have significant impacts on conditions affecting vegetation growth. Periods of prolonged drought and heavy precipitation like during El Niño Southern Oscillation (ENSO*) in the tropics affect the amount and development of vegetation, hence the carbon sink (IPCC, 2007). IPCC projects slight increase in rainfall events over East Africa during the main rainfall season. However in the past few years (1961-2000) there has been an observed decreasing averaged total rainfall trends in some parts of Tanzania, but with increased daily rainfall intensity (New *et al*. 2006). Further this study by New *et al*. (2006) found that, increasing temperature trend for most parts of Southern (including Tanzania) and Western Africa are in consistence with the global warming trend. This creates uncertainties whether the situation will abruptly change in a near future especially for rainfall which is the main limiting factor for vegetation growth in East Africa.

With the ongoing climate change including temperature, precipitation and growing levels of carbon dioxide (CO_2); it is evident that vegetation of some parts of the globe will be altered. In this sense, it is interesting to study the magnitude, nature of the change and the role of vegetation in biogeochemical feedbacks to climate, vegetation-atmosphere interactions and how they can be used in greenhouse gasses (GHG) modeling in East Africa. Changes in vegetation caused by climate change and variability such as ENSO or any other natural hazards in Tanzania, affect many vegetation dependent sectors including food production (agricultural areas), forestry activities and wildlife. (Ogutu *et al*. 2007 and Plisnier *et al.* 2000).

The use of satellite and remote sensing products such as Normalized Difference Vegetation Indices (NDVI) is one of approaches, which help in the study of the impact of climate variability such as ENSO on vegetation in regional and local scale.

** See appendix **A** for abbreviations used in this study.*

Climate variability and vegetation relationships have been studied in eastern Africa (e.g. Eklundh, 1998; Plisnier *et al.* 2000 and Ogutu *et al.* 2007; Pelkey *et al*. 2000; Nagai *et al*. 2007) among many other studies. NDVI can show regions of improved vegetation during rainfall season and drought affected areas. Further analysis between past environmental variables and NDVI such as ones done in this study, can reveal the previous vegetation conditions (trends) and their relationships which in turn may reveal the expected vegetation conditions on large and small areas. Studies by Anyamba and Tucker, (2005); Eklundh and Olsson (2003) found that Sahel was greening and recovering from the long time experienced drought. A recent study by Shisanya *et al*. (2011) on the impact of rainfall variability on NDVI in semi-arid lands of Kenya during 1981 to 2003 period, concluded that October to December (OND) had more effect toward increased vegetation greenness than the March to April (MAM) season.

Tanzania boast large areas covered by natural and conserved vegetation types, such as forests, woodlands, grasslands, wetlands and cultivated lands. According to CEEST (1999), forests and woodlands constitute 50% of the total land, grasslands and shrubs is about 40% and 6 to 8% is cultivated land. However, in the recent years there have been changes in the vegetation patterns in different parts of the country partly due to the changing climate or human activities. Pelkey *et al.* (2000) found that vegetation types been affected differently in the period from 1982 to 1994, where forests and woodlands were found to increase in greenness while bush lands, grasslands and swamps greenness decreased.

Famine Early warning system network (FEWS-net) based in Gaberone, Botswana, collaborates with national early warning organizations in Tanzania such as Tanzania Meteorological Agency and Ministry of Agriculture in providing NDVI data for the area. These are thereby interpreted and distributed to the public and other sectors so that they understand and make appropriate decisions based on the current vegetation status in their respective areas. Therefore studying the past relationship between climate and NDVI pattern in the country is crucial. This will help to reveal changes in vegetation greenness and climatic-vegetation relationship, giving a clue of how various sectors supported by vegetation cover in Tanzania such as agriculture, livestock, energy, wildlife and tourism will be affected in future. This in turn, will help in saving lives, natural resources and improved socio-economic status of the country.

Knowledge gap

Although a considerable amount of work has been done on climate variability and vegetation relationships in the broader Eastern and southern African regions, not many studies have been done in investigating the same relationships specifically over Tanzania or to its climatological zones. Also there is a need of assessing the extent to which climate and vegetation has changed over time in the country as whole and in smaller areas. The knowledge will be useful for planning purposes both in Government and private sectors such as in agriculture, conservation of forest and their biodiversity under the changing climate. This study aims to contribute towards bridging this gap by considering the climate and NDVI variability from 1982 to 2008, together with their relationships over specific regions and climatological zones of Tanzania.

1.2 Aim

The aim of this thesis is to assess changes in vegetation greenness through the use of NDVI data for a 27 years period (1982-2008) in relation to climate trends in Tanzania.

1.3 Specific objectives.

This thesis seeks to answer the following research questions.

1. Whether there have been changes (e.g. trends) of vegetation greenness and rainfall in Tanzania for the 27 years period (1982-2008).
2. Can any vegetation greenness change observed be attributed to trends or variations in rainfall?
3. How strong is the relationship (degree and nature of the relationship) between rainfall and NDVI?
4. What is the effect of global weather phenomena such as ENSO to the vegetation greenness in Tanzania?

1.4. Study area

Tanzania is located in East Africa between latitudes 1°S and 12°S and longitudes 29°E to 41°E (Figure 1.1). Lake Victoria in the North, Lake Nyasa and River Ruvuma in the South, Lake Tanganyika in the West and Indian Ocean in the East form a water boundary to the country. It border Kenya and Uganda in the North, Malawi and Mozambique to the South, Democratic Republic of Congo, Rwanda and Burundi to the West and Zambia to the Southwest. The total area of Tanzania is about 945,200 square kilometres (URT, 2011)

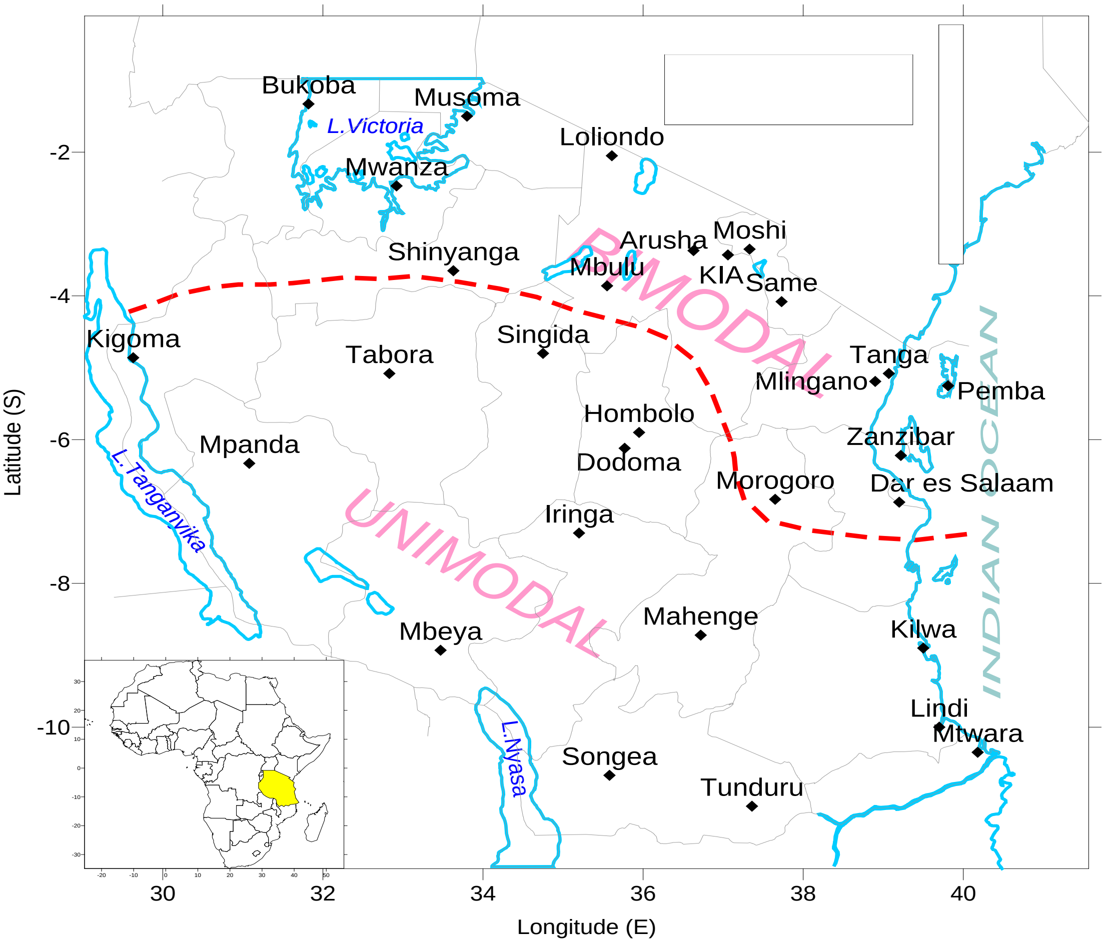


Figure 1.1. *Tanzania map showing rainfall pattern and stations used in the study. The insert shows the location of Tanzania on a map of Africa.*

1.4.1 Topography

Elevations in Tanzania range from 358m below sea level at the floor of Lake Tanganyika (the lowest place in Africa) and 5950m above sea level at the summit of Mount Kilimanjaro (the highest point in Africa) located in the North Eastern Highlands. Most part of the country’s elevation is part of the Central African plateau (1000-1500 above sea level) except for the coastal plains which is less than 500m (Figure 1.2).

Apart from these landforms, Tanzania is traversed by the great East African rift valley with its two branches; the Eastern and the Western branches. The eastern branch runs all the way from South-western parts, through Central and North-eastern highlands of Tanzania to Kenya. The western branch starts from Lake Nyasa running northwards through Lake Tanganyika to Lake Kivu in Uganda. The North-eastern highlands are located along the eastern branch of the great East African rift valley and South-western highlands are partly located between the eastern and the western branches. Both North-eastern and South-western highlands rises above 1500m above sea level.

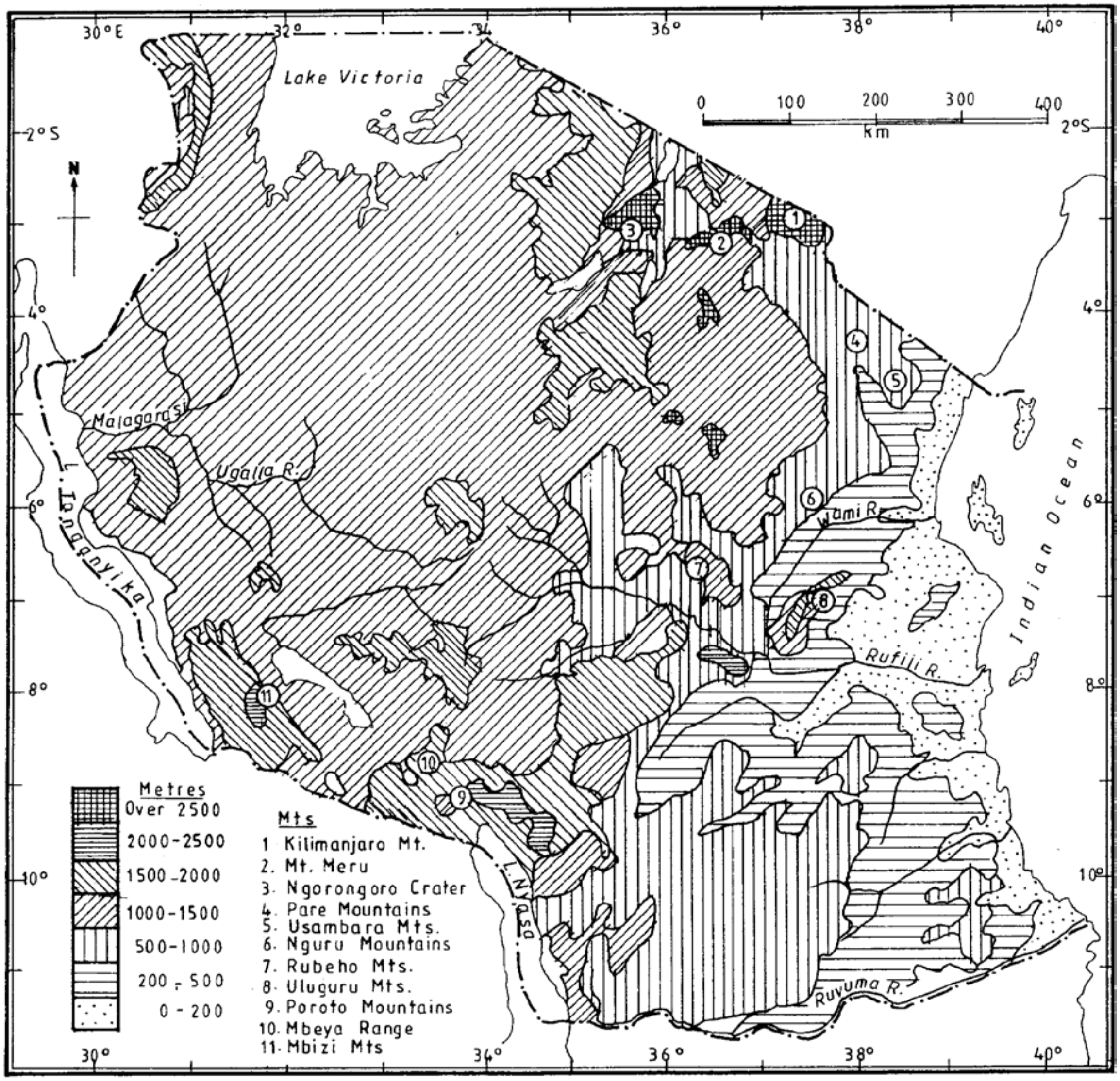
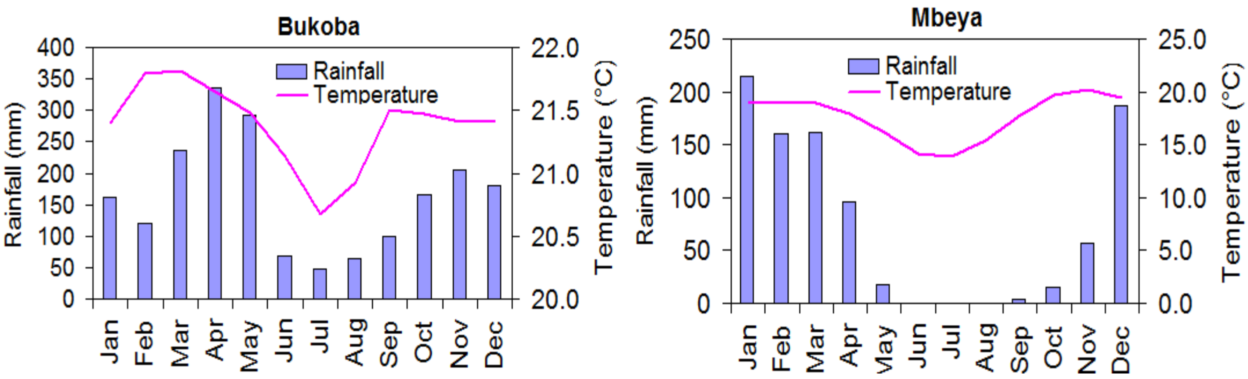


Figure 1.2. *Topographical features of Tanzania. Source, Basalirwa et al. (1999)*

1.4.2 Climate

Tanzania has a tropical equatorial type of climate. However its climate has a great diversity due to the country's diversity in topography. The country is characterised by two rainfall regimes: namely unimodal and bimodal rainfall regimes (Figure 1.1). The seasonal rains over the unimodal regime occur between October and May (*Msimu*) over the Southern, South-western, Central and Western areas of the country. The bimodal rainfall regime has two rain seasons, the long rain season (*Masika*) experienced between March and May (MAM) and the short rain season (*Vuli*) occurring between October and December (OND) over the Northern coast, North-eastern Highlands, Lake Victoria basin and the Islands of Zanzibar (Unguja and Pemba) (Figure 1.3).

The short rains (OND) are highly variable in space and time as compared to relatively less variable long rains (MAM) over the bimodal and the October to May (*Musimu*) rains over the bimodal (Camberlin *et al*. 2009; Zorita and Tillya, 2002). Annual rainfall varies from 200 mm to 1000 mm over most parts of the country. Higher rainfall amounts are recorded over the highlands to the Northeastern and Southwestern parts. Central Tanzania is a semi - arid region with some parts receiving annual rainfall amount of less than 400 mm. The annual mean temperature range from 25°C to 32°C. In the highlands, average temperatures for the hot (February) and cold (July) months are about 20^0C and 10^0C respectively. The rest of the country has temperatures hardly falling below 20^0C, with highest temperatures along the coastal belt and the western parts of the country. The high temperature season is between October and March while the coldest season occurs between May and August. Figure 1.3 shows the average monthly distribution of rainfall and temperature for typical bimodal (Bukoba) and unimodal (Mbeya) stations (TMA, 2011& URT, 2011). Table 1.1. shows distribution of annual mean rainfall and the corresponding mean NDVI for the zones computed in the period 1982-2008. Account of the climate/weather controlling systems in Tanzania and East Africa is given in section 2.3.



a

b

Figure 1.3. *Monthly mean rainfall and monthly mean temperature (1982-2008) for (a) Bukoba (a bimodal station) and (b) Mbeya (a unimodal station). Data Source: TMA (2011).*

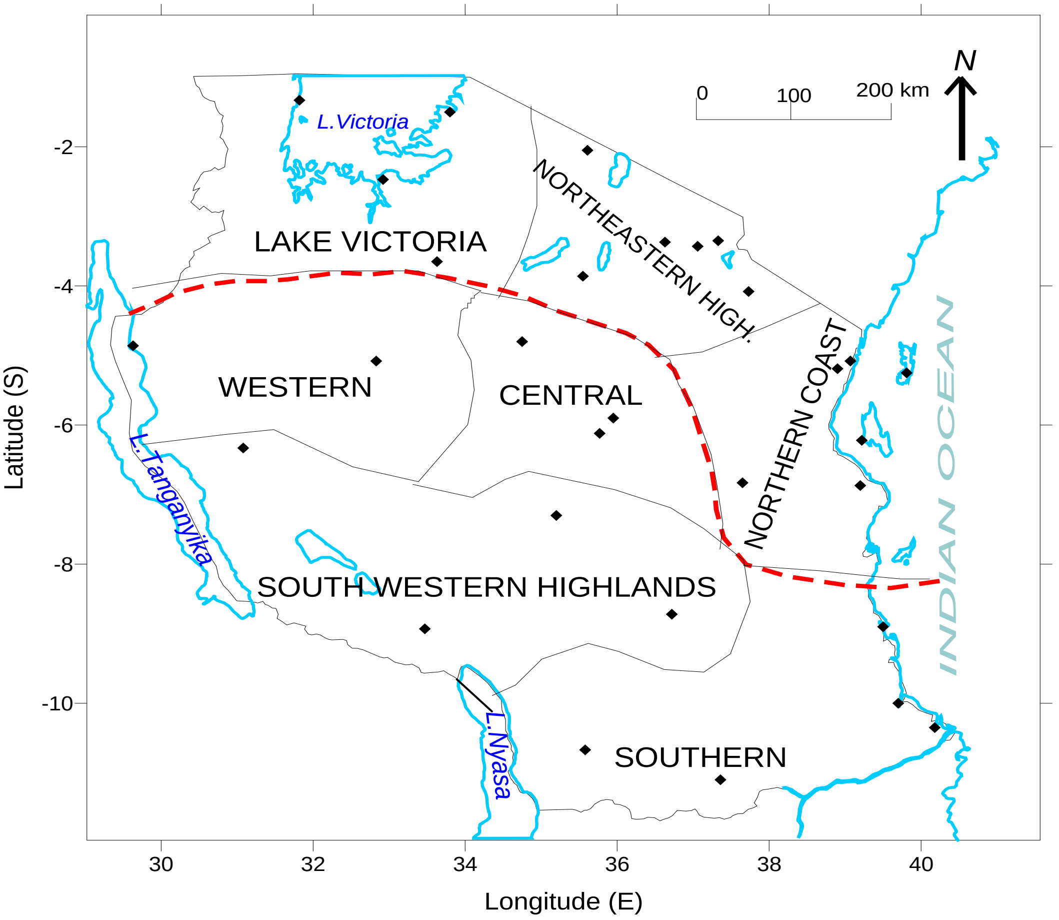


Figure 1.4. *Rainfall zones in Tanzania. Source, TMA (2011)*

Table 1.1. Annual mean rainfall and NDVI for the zones (1982-2008)

Zone	Rainfall (mm)	NDVI
NEH	860	0.442
NC	1542	0.470
Lake_V	1583	0.412
Western	1178	0.464
SWH	1293	0.530
Southern	991	0.536
Central	561	0.381

1.4.3 Vegetation

Vegetation in Tanzania also varies depending on the climatic conditions of the area, especially amount of rainfall received and the topography. Forested areas are mainly found over the highlands and isolated patches on the coastal belts.

Woodland is the largest vegetation cover type, covering most of the Southern and Western parts of the country, while bush land and shrub thicket are dominant over Central and Eastern parts. Savannah (mixed Woodland and bush grassland) is common over the Northern low lands and some parts of Central, West and Coastal areas. Grassland and dwarf shrub grassland are common over Southern parts of Lake Victoria and some parts of Central areas (FAO, 2002 and Pelkey, 2000).

1.4.4 Soils

The coastal areas are covered with sandy to heavy texture soils having moderate to high water storage capacity (*Arenosols*). Low lands of Northeastern and Southern plateau is covered by drought-prone soils (*Cambisols*). Large part of Central and Western plateau areas are characterized by sandy loam soils which have low nutrients and low water holding capacity (*Acrisols*). Northeastern and Southwestern highlands are covered with volcanic type of soils which are well drained and having moderate to high water holding capacity (*Andosols*). Detailed information on different soil types in Tanzania can be found in Kauzeni *et al*. (1993); citing De Pauw (1983) and FAO (2011): Africover project.

2 Theoretical background

2.1 The Advanced Very High Resolution Radiometer (AVHRR)

The Advanced very High Resolution Radiometer sensor on-board the National Oceanic and Atmospheric Administration's (NOAA) sun-synchronous polar satellite series is the cross-track scanning radiometer. The NOAA satellite series (7, 9, 9-(descending), 11, 14, 16, 17 and 18) have been in operation in different times since July 1981 to present. In all the satellite series, the spectral location (wavelength) of the AVHRR red (R) and near infrared (NIR) bands (band 1 and 2) are located at 0.58-0.68(μm) and 0.725-1.00(μm) respectively. The 2 bands among the other 5 are useful in the monitoring of vegetation (e.g. through the use of NDVI), day time cloud, snow and water bodies (Lillesand *et al*., 2007; Tucker *et al*. 2005). The NDVI is further explained in the next section 2.2.

The spatial resolution of the AVHRR sensor data are acquired up to 1km at nadir and then sampled down to reduced resolutions of 4 and 8 km which are useful in monitoring of large-scale coverage. The daily global coverage of the AVHRR sensor is another advantage useful in the analysis of various Earths' surface properties which require a short time scale response such as in the monitoring of wildfires, snow cover and flood (Lillesand *et al*. 2007).

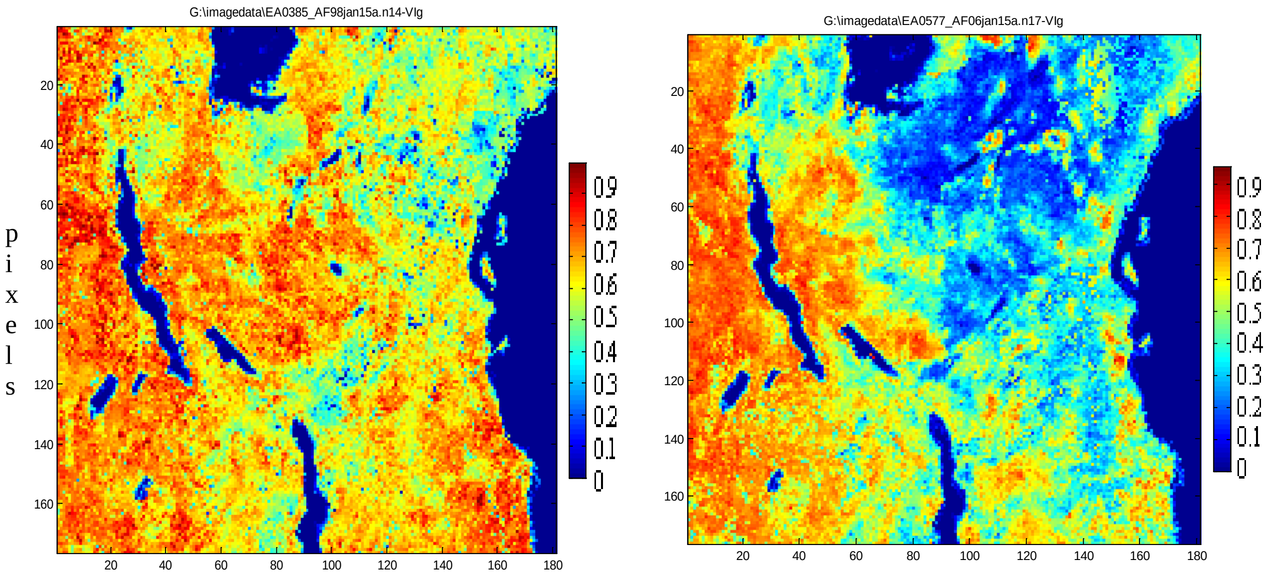
2.2 Normalized Difference vegetation Index (NDVI)

Vegetation properties of an area can be determined by various vegetation indices derived from earth observing satellites, among them being the Normalized Difference vegetation Index (NDVI).

The Normalized Difference vegetation Index is defined as:

$$NDVI = \frac{NIR - R}{NIR + R} \qquad (1)$$

Where NIR is the spectral reflectance in the near-infrared band and R is the spectral reflectance in the red band. The NIR and R correspond to channel 2 and 1 of the NOAA/AVHRR sensor respectively. The NDVI is useful in studying the status of the vegetation on the ground, where Chlorophylls in healthy green plants absorb much of the radiation in the visible wavelengths (at about 0.45 to 0.67 µm) and reflect in the infrared. The NDVI is used as a measure of how vegetation makes use of the photosynthetic active radiation (PAR), ranges from -1 to +1. High NDVI corresponds to high vegetation cover (termed as greenness in this study) while low NDVI correspond to low vegetation cover or non-vegetated areas such as snow cover, water and bare grounds. Figure 2.1 show the contrast between the NDVI images following wet and dry seasons respectively. During the first 15 days of January 1998 following a wet season of OND 1997 (a strong El Niño year); almost the whole country had a higher NDVI. On the other hand during similar period of 2006 following a dry season of OND 2005 (La Niña year), most of the country experienced lower NDVI except for the western and some parts of southern regions. The higher NDVI in these regions during dry seasons can be attributed to the Congo rain forest, highlands and large water bodies such as Lake Tanganyika, Lake Nyasa and Indian Ocean. These features continually supply enough moisture in favor of the surrounding vegetation. More explanation on the factors controlling rainfall and vegetation in Tanzania is given in the following sections 2.3 and 2.4.



a

b

Figure 2.1. *AVHRR-NDVI images showing periods of (a) high vegetation cover in the first 15 days of January 1998 after a wet season of OND 1997 and (b) low vegetation cover in in the first 15 days of January 2006 after a dry season of OND2005 in Tanzania.*

Normalized Difference Vegetation Index (NDVI), one of the vegetation index derived from AVHRR sensors is the most used to monitor vegetation properties (Cracknell, 2001). The National Aeronautics and Space Administration's (NASA) Global Inventory Modeling and Mapping Studies (GIMMS) has further processed and archived the NDVI data acquired from NOAA/AVHRR sensors. The data have been available since August 1981 to present and makes a longest vegetation index record valuable for global and regional vegetation change studies (Tucker *et al*. 2005). The NDVI has been sampled to 8km spatial resolution and has been corrected for sensor degradation and sensor inter-calibration differences, effects of persistence cloud, satellite drift and volcanic aerosols (Tucker *et al*. 2005). These corrections give an improved result of the NDVI over an area. Tucker *et al*. (2005) gives further detail of the GIMMS data set processing methods.

Numerous studies have used NOAA/AVHRR NDVI to study vegetation conditions and changes in relation to environmental parameters in global as well as regional scales. Among these are studies by Kawabata *et al*. (2001) on a global scale; Jia *et al*. (2003) in Arctic Alaska; Salim *et al*. (2009) in China; Bellone *et al*. (2009) in Africa; Eklundh and Olsson (2003) on Sahel and Eklundh (1998) in East Africa.

2.3 Factors controlling East African rainfall climate

Beside the modifying effect of topography to East Africa weather and climate, East African climate is controlled by an interplay of synoptic (large scale) and mesoscale (local scale) systems (Basalirwa, *et al*. 1999). The synoptic weather systems include Inter Tropical Convergence zone (ITCZ), high pressure cells, mainly the Mascarene and St. Helena highs and sometime the Arabian ridge. Congo air mass and sometimes the teleconnections effects of El Niño Southern Oscillation (ENSO) also play a substantive role. The mesoscale systems include the presence of big water bodies such as Lake Victoria and Indian Ocean. The ENSO effect is further explained in section 2.4, while the brief account of the role played by the other systems on the Tanzania climate is given in the following subsections.

2.3.1 Synoptic systems

(i) Inter Tropical Convergence Zone

The Inter Tropical Convergence Zone (ITCZ) is a zone of low-pressure near the equator formed due to apparent north-south movement of the sun. It is characterized by maximum surface heating and meeting of the two easterly trade winds that originate from the Northern and Southern hemispheres. Thus, convection, cloudiness, and rainfall are enhanced within the ITCZ zone (Camberlin & Okoola, 2003).

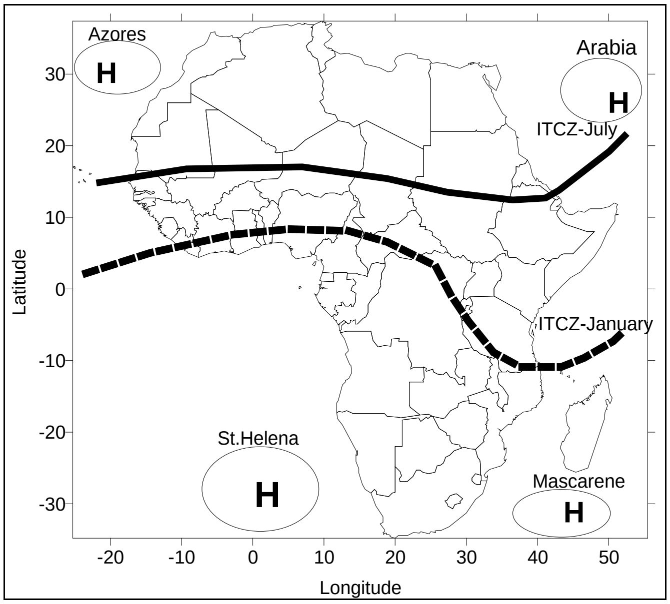


Figure 2.2. *The relative positions of East Africa's climate controlling synoptic systems over Africa. (Modified after Ahrens, 2009)*

Over Central and Eastern Africa, the ITCZ form two components, the zonal and meridional components as the result of the topography mainly the Great Rift Valley and the mountain chains of East Africa (Figure 2.2). The zonal component generally lags the overhead sun by 3-4 weeks and seasonally migrates north and south following the seasonal movement of the overhead sun. The zonal component of the ITCZ is responsible for the bimodality of rainfall pattern over most parts of East Africa. On the other hand, the meridional component account for the unimodal pattern experienced over western, southwestern and southern parts of Tanzania. The meridional component of ITCZ has slightly east to west movement which enhance or lessen the penetration of moisture leaden westerly winds further eastwards (Mapande and Reason 2005).

(ii) Subtropical anticyclones

Unlike the ITCZ, the subtropical anticyclones are quasi-stationary high pressure cells. There are four main anticyclones whose position, strength and orientation may influence weather in East Africa (Figure 2.2). These are Mascarene high located over the Southwest Indian Ocean, St Helena High over the Southeast Atlantic Ocean, Azores High over the North Atlantic Ocean and the Arabian High over the Arabian Peninsula.

These high pressure cells influence weather by forcing the seasonal winds to carry moist/dry air as they move over the oceans/landmass to Eastern Africa in different times of the year. Their differential strength also determines the relative positions of the ITCZ and the associated weather systems. For instance intensification of St. Helena High and weakening of Mascarene High cause the meridional arm of ITCZ to move eastwards. This situation causes wet conditions in most areas over western and as far as central Tanzania as these regions are also influenced by the moist westerlies originating from the Congo tropical forest. The westerlies converge with the easterlies from Indian Ocean resulting to heavy precipitation during long rain season (MAM) especially over the western part of Tanzania (Mapande & Reason, 2005; Sun, *et al*. 1999). Intensification of the Mascarene high around drives the moist south easterlies over the Indian Ocean towards the East African region and well position the ITCZ over Tanzania (Kijazi & Reason, 2009). On the other hand the intensification of the northern hemisphere anticyclones (Azores and Arabia) brings dry north-westerlies and north-easterlies (continental in nature); causing dry spells over most parts of the country especially the Northern parts. Weakening of Arabian high also associated with wet conditions over Lake Victoria and Western Kenya Highlands (Sun, *et al*. 1999).

2.3.2 Meso-scale systems

The mesoscale weather modifying systems over East Africa include Lake Victoria, the East African highlands and Indian Ocean. Lake Victoria modifies the rainfall pattern of the surrounding regions through its circulation pattern which interacts with the larger synoptic systems resulting to frequent thunderclouds and enhanced rainfall activities over the western than eastern sector (Okeyo, 1987). Song, *et al. (*2004) found that, due to shallower warmer southeastern water and deeper colder northeastern water of the lake, there created a lake-atmosphere coupled circulation which results to reduced cloud amounts over Northeastern and enhanced over southeastern. Many studies have incorporated the effect of Lake Victoria on East African climate dynamics and these include Yin and Nicholson (1998); Mukabana and Pielke (1996); Nicholson (1996a, b) and Anyah *et al*. (2006).

Highlands and mountains sometimes hinder eastward penetration of moist air from Congo forest and Lake Victoria or penetration of moist easterlies originating from Indian Ocean from reaching the western side. This results into wetter western or eastern side of the highlands due to orographic lifting (Sun, *et al*. 1999; Oettli and Camberlin, 2005). The proximity to the Indian Ocean contributes to the variability in rainfall seasons over the coastal areas. For example Kijazi and Reason (2005) attributed the western Indian Ocean to be the source of moist easterlies reaching the coastal areas of Tanzania.

The synoptic and mesoscale systems described herein do not act as a single system on the climate and weather of the eastern Africa, rather there is always interaction between them. This situation makes East African weather/climate to be complex and challenging in forecasting.

2.4 Rainfall, Sea surface temperatures and vegetation responses in East Africa.

2.4.1 ENSO background

El Niño/Southern Oscillation (ENSO) is a large-scale ocean-atmosphere interaction over the equatorial Pacific Ocean. It is characterized by the reversal of the sea surface temperature (SST), winds and atmospheric pressure patterns between the eastern and western ocean basins. ENSO comprises of a warm phase (El Niño) and a cool phase (La Niña), which affect the climate in many regions in the world, especially in the tropics via teleconnections (Teleconnection is the phenomenon where the large scale pressure patterns, circulation anomalies and SST affect regions at a distance.). The periodicity of ENSO episodes range from about 2 to 7 years and one episode may last up to a year, depending on the magnitude of the warming of the ocean water in the equatorial Pacific Ocean (Ahrens, 2009; NOAA, 2011).

Based on the observed SSTs and wind pattern over the equatorial Pacific Ocean, scientists divided this region into 5 Niño regions. These regions are named as Niño 1,2,3,4 and 3.4 (an overlap between region 3 and 4), as shown in figure 2.3. These regions over Pacific Ocean are identified as important locations for monitoring winds, SST and rainfall activities. Niño 3.4 is the most commonly used to monitor the beginning and the end of El Niño events (NOAA, 2011).

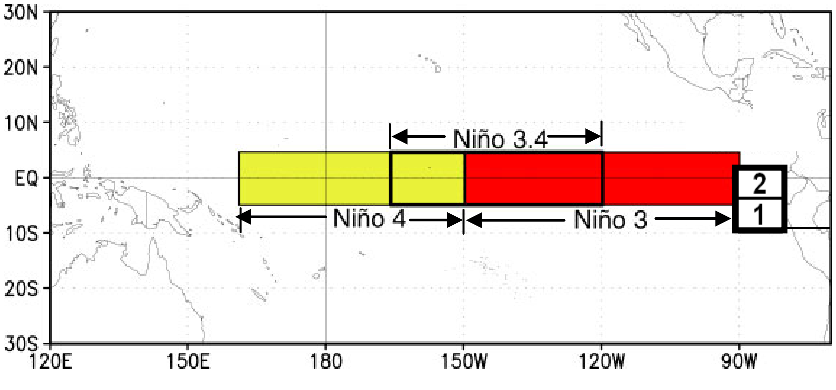


Figure 2.3. *The Niño regions the central Pacific Ocean.*
(Modified from: NOAA, 2011)

Table 2.1. *El Niño and La Niña years*

Strong El Niño	1982/83, 1991/92, 1997/98
Moderate El Niño	1986/87, 1987/88, 1992/93, 1994/95, 2002/03, 2004/05, 2006/07
Strong La Niña	1988/89, 1999/00
Moderate La Niña	1983/84, 1985/86, 1995/96, 1998/99, 2000/01, 2005/06, 2007/08

SST anomaly < -1.5 Strong La Nina; between -0.5 and -1.5-moderate La Nina
SST anomaly > 1.5 Strong El Nino; between 0.5 and 1.5-moderate El Nino
Source: NOAA (2011)

ENSO influences the rainfall and vegetation patterns in East Africa, as observed in the past (Table 2.1), where during strong El Niño phase the region receives higher than normal rainfall, associated with increased vegetation activities. On the other hand, during strong La Niña phase the region receives below normal rainfall associated with decreased vegetation activities. Both increase and decrease in vegetation activities have strong implications to various socio-economic sectors in the region, agriculture being the most affected.

2.4.2 Rainfall responses to ENSO events in East Africa

The teleconnection effect of ENSO to the East Africa rainfall seasons have been widely studied especially for the short rains season (OND). The list is long but some of them are studies by Ogallo (1988); Mutai *et al.* (1998); Indeje *et al*. (2000); Camberlin & Okoola (2003); Ntale (2004); Zorita and Tilya (2002) and Saji *et al*. (2003).

With regards to Tanzania, studies have been done to investigate ENSO effects on Tanzania rainfall as whole country or over different parts (zones) during rainfall seasons. These include studies by Kijazi & Reason (2005) on the relationship between ENSO and interannual rainfall variability over coastal areas and Tilya (2007) on the study of the characteristics of wet and dry spells during the rainy seasons of Tanzania. Both studies found a strong relationship with ENSO events. However for western Tanzania the ENSO influence is minimal (Mapande and Reason, 2005) as these region lies in the transition zone which is between the 'bimodal eastern Africa' and the 'unimodal southern Africa', regions which are strongly impacted during ENSO years (Myeni, 1996; Anyamba *et al*. 2002; Plisner *et al*. 2000). The study by Kijazi and Reason (2005) found that, the circulation patterns associated with floods of October to December (OND) 2006 in northern Tanzania were related to the warm SST over the western Indian Ocean. The warm SST over western Indian Ocean which enhances rainfall activities over East Africa coincided with the 2006 El Niño. Their study further found that, during the same OND rainfall season, Northeastern Highlands received 218% of the expected rainfall, which led to floods, loss of lives and properties.

2.4.3 NDVI responses to rainfall and ENSO events in East Africa

To properly model vegetation growth, it requires combination of many factors which can be environmental or human in nature in addition to rainfall. Many studies on relationship between climate and NDVI in the tropics have mainly focused on the effects of rainfall and temperature but not on other environmental and human factors. Nagai *et al*. (2007) found precipitation and cloud cover during El Niño years to have positive correlations with NDVI while negative correlation with temperature and incoming solar radiation over the Amazon basin and southeastern Asia rainforests. However in their study, the strongest relationship occurred between changes in precipitation and temperature rather than incoming solar radiation and cloud cover. Such result is realistic to these areas since rainfall, temperature and radiation are the main controlling factor for vegetation growth in most parts of the tropics.

The NDVI over East Africa have shown inter-annual variations similar to that of rainfall and seasonal variations similar to rainfall with NDVI lagging behind by 1 to 2 months (Davenport *et al*. 1990; Eklundh, 1996; Ingram, 2005). The reason for lagging is the dependence of vegetation growth on soil moisture more than immediate rainfall as soil moisture is the result of accumulated rainfall. Various studies have been related NDVI to climate, for instance Eklundh (1998) worked on the relationship between AVHRR NDVI and rainfall in East Africa at 10-day and monthly basis. Eklundh found that, for the 10-day time series, only 10 per cent of the NDVI variation could be explained by rainfall while only 36 percent variation for the monthly series. The results are in contrast with earlier findings by other researchers which show a strong relationship between rainfall and NDVI (Nicholson *et al*. 1990; Nicholson and Farrar 1994).

Responses of NDVI to climate episodes such as ENSO events have also been studied by various researchers. Anyamba *et al*. (2001) found that the 1997/98 warm ENSO (El Niño) event resulted in positive NDVI anomaly over most of East Africa, from October 1997 to May 1998. Furthermore, the current study pointed out good correlation between warmer (higher) sea surface temperatures (SST) over the western Indian Ocean (WIO) and warmer than normal SST over Central Pacific Ocean during warm ENSO episodes. This condition lead to enhanced rainfall activities in East Africa, especially in the bimodal rainfall areas (Anyah and Semazzi, 2006), which in turn affect the vegetation growth in the region. Geographically Tanzania land mass is spread over both East Africa and Southern Africa regions. However, politically Tanzania is located in East African region. ENSO events have opposite effect over southern Africa region of which southern part of Tanzania falls under. During El Niño (La Niña) events large part of southern Africa region which are dominated by the unimodal rainfall regime, experience dry (wet) than normal conditions with negative (positive) NDVI anomaly (Myneni *et al*.1996) as opposed to the bimodal regime of Eastern Africa which experience the reverse conditions.

The influence of rainfall and SST variability on vegetation in Tanzania cannot be separated either since one influence the other in a lagged time step. However it is important to understand their individual influences to the vegetation evolution through time which can be useful in establishing an early warning system in regard to the expected vegetation conditions in the country. Furthermore it is difficult to separate the effect of human influence from the climatic variability on the increase or decrease of vegetation greenness in tropics especially in semi-arid areas. This was also pointed out by Diouf and Lambin (2001) when studying land cover changes in semi-arid environment of Senegal using different factor controlling vegetation including rainfall and soil types.

3. Materials and methods

3.1 NDVI data

Variations in vegetation greenness was assessed using NDVI data from the NASA Global Inventory Modeling and Mapping Studies (GIMMS) that was derived from NOAA/AVHRR land dataset from 1981-2008. The data were downloaded from the Global Land Cover Facility (GLCF) website (Tucker, *et al*. 2010). The AVHRR NDVI observations started in August 1981 to present, but the rainfall data were available from 1982 to 2008. To harmonize the data sets, the 1982-2008 period was chosen for this study. The data are at 8 km spatial resolution and at 15-day time composite. The 15- day composite is obtained by employing the maximum value composite (MVC) method which retains pixels with maximum NDVI value in the images taken within 15 days. Further explanation and derivations of the MVC can be found in studies by Diwakar *et al*. (1989) and Tucker *et al*. (2005). This method helps in reducing the clouds' negative effect (lowering) of NDVI. The raw NDVI data were archived as signed 16-bit integer values. To recover the data in to the -1 to +1 range the following formula was used as provided by the GIMMS primary data documentation (GLCF, 2010)

$$NDVI = (raw/10000) \qquad (2)$$

For the purpose of this thesis monthly averages and maximum of NDVI values were computed from the two 15-day composites to match the monthly temporal resolution for the other datasets (climatic and ENSO indices), also to further minimize the effect of 'cloud contamination'. Clouds cover has a tendency of lowering the NDVI value for a certain area through scattering of the electromagnetic radiation (Tucker *et al*. 2005), hence the term cloud contamination. The monthly NDVI anomalies were computed as differences between monthly long-term means (1982-2008) and the monthly values. Further, annual mean NDVI values were calculated by summing up the average monthly NDVI for a given year and divide by 12.

NDVI data set used for this analysis was based on a single pixel (1x1 window) that contains the meteorological stations-64 km2 (8x8km). The study by Eklundh (1996) on the relationship between NDVI and rainfall in East Africa showed 1x1 window to be as good as 3x3 or 5x5 windows in revealing the relationship. Larger sampling windows can introduce errors especially when pixels from large water bodies are included. To minimize the unwanted reflection from pixels near the water bodies in the data, pixels for the stations near large water bodies such as Zanzibar, Pemba, Mwanza and Musoma were shifted inland. The quality of the data was assessed according to the guide (GLCF, 2010) and was found to be good.

3.2 Rainfall data

Total monthly rainfall data for the period 1981-2008 for 29 stations distributed around Tanzania, were obtained from Tanzania meteorological Agency. Geographical location of all the stations is shown in figure 1.1. The quality of the data was assessed and the few missing values (less than 1% for some stations) were either replaced by long time mean for the missing month or values from a nearby station. Majority of the stations had 100% of the data. To match rainfall data with the NDVI data in different time scales, monthly anomalies, seasonal totals, and annual mean rainfall were computed for various analyses in this study.

3.3 Sea Surface Temperatures (SST) data

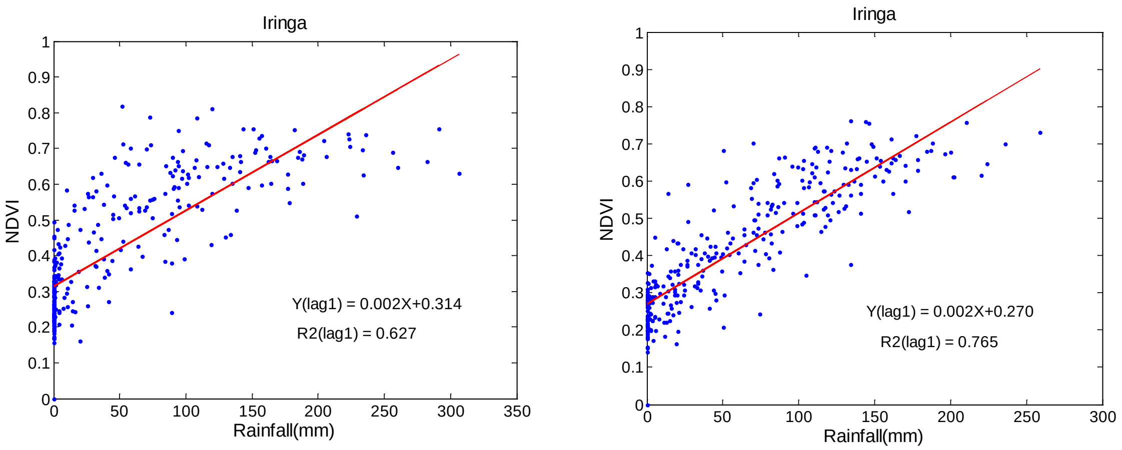
Sea surface temperatures (SSTs) (between 1mm and 20m below sea surface) from Niño 3.4 region, a region used for monitoring ENSO events (El Niño and La Niña) in the central Pacific Ocean (5°N-5°S; 170°-120°W) were used. The data were acquired from the NOAA-Climate Prediction Center (CPC) website (NOAA, 2011).

3.4 Pre-processing procedures.

In order to examine if statistical relationship existed between NDVI and rainfall data, some procedures were undertaken. These includes; (i) analysing the data according to rainfall regimes in Tanzania (i.e. bimodal and unimodal areas) as shown in Figure 1.1 (ii) anaysing according to the zones found in these rainfall regimes. Seven forecasting and climatological zones used by Tanzania Meteorological Agency (TMA) were employed namely; Northern coast (NC), Northeastern Highlands (NEH), Lake Victoria (Lake_V) which are found in the bimodal rainfall regime, while Western (W), Southwestern highlands (SWH), Southern (S) and Central (C) zones are found in the unimodal areas. (TMA, 2011)

Another procedure is (iii) a filtering technique which was used to reduce amount of noise in the data and has proved to be useful in improving the NDVI-rainfall and NDVI-SST relationships. Savitsky-Golay technique in the software TIMESAT was used . the technique employs a moving average window and least- square method on the time series as fully detailed in Eklundh and Jönsson (2009) and Jönsson and Eklundh (2002, 2004).

As an example, analysis of the relationships between unfiltered and filtered NDVI and rainfall data sets were investigated. Figures 3.1a & b show the relationship between mean monthly NDVI and rainfall for Iringa at lag 1 using unfiltered (the original dataset) and filtered respectively. Iringa station was chosen to demonstrate this relationship as it was found to yield the best result among all the stations. Lag 1 was chosen as it resulted to good relationship between NDVI and rainfall as explained in section 3.5. For Iringa station at lag 0 (not shown), R^2 value icreased from 0.40 (before filtering) to 0.57 (after filtering) while for lag 1, R^2 icreased from 0.63 (before filtering) to 0.76 (after filtering). After the application of Savitsky-Golay filtering technique on the raw data the relationship (R^2) was quite improved for 26 stations and 3 stations had slighty changes as it can also be seen in appendix Table B2 & B3. Owing to this improvement due to filtering, filtered dataset was then used in the following analyses for both NDVI and rainfall data.



a

b

Figure 3.1. *Relationship between mean monthly NDVI and rainfall for Iringa (at lag 1) using (a) unfiltered (b) filtered datasets.*

(iv) cross correlation between NDVI and rainfall data was also employed in the analysis as described in the next section (3.5).

3.5 Testing of specific objectives:

Objective 1: To test whether there have been changes (eg. trends) of vegetation greenness and rainfall in Tanzania for the 27 years (1982-2008) period, analysis of NDVI and rainfall trends for different stations, zones and according to rainfall pattern (bimodal or unimodal) was performed. Monthly NDVI data for 27 years at each station were regressed linearly against time to estimate their rate of change (trends). Positive slopes (trends) indicate an increase in vegetation greenness throughout the study time, while negative slopes indicate a decrease in vegetation greenness. These trends were then statistically tested at a significant level of $p = 0.05$.

Due to the high variability in of both the NDVI and rainfall time series, which can result to inconsistency in trends caused by few years, an investigation of the changes of means between two periods, 1982 to 1995 and 1996 to 2008 were carried out using Student t-test. The two periods represent roughly equal halves of the total length of the monthly series and complement the testing of the trends for the whole period. Station NDVI and rainfall data was analyed according to TMA forecasting zones (Figure 1.4).

Student t-test

Student t-test was used to test the changes in means (at 95% confidence interval for the difference between means) with the assumption that the datasets for the two periods (1982 to 1995 and 1996 to 2008) are independent of each other, have equal sample size, normally distibuted and their variance are not significantly different. These are the requirement for this statistical test (Shaw and Wheeler, 1994) and the hypotheses used are described below:

H_0: Null hypothesis: There is no significant difference between the means
(mean 1= mean 2 or mean 1- mean 2 = 0)

H_1: Alternative hypothesis: There is a significant difference between the means
(mean 1 ≠ mean 2 or mean 1- mean ≠ 0)
If the computed t-value is greater than the tabled value (i.e. the difference between the two means is statistically significant), then the null hypothesis is rejected and retain the alternative hypothesis. The degree of freedom is given by 2***n***-2, where ***n*** is the sample size of each dataset.

Objective 2: Attribution of changes in vegetation greenness to rainfall trends was conducted by comparing NDVI and rainfall trends in different time scale (monthly, seasonal and annual), different periods of the time series (1980-1995 versus 1996-2008) and in spatial scale (station, zonal and according to rainfall pattern)

Objective 3: The strength of the relationship between NDVI and rainfall was tested by employing linear correlation and simple linear regression analysis at different time lags. NDVI was considered dependent variable and rainfall an independent variable. Correlation coefficients vary between -1 and +1, which represent the perfect negative relationship or positive relationship between the two datasets. The coefficient is a measure of co-fluctuation between the two datasets, in this study NDVI and rainfall or SST. Statistical significance test was done at 0.05 level for both NDVI-rainfall and NDVI-SST relationships.

Cross correlation

Cross correlation method (eqn.3) was used to estimate the degree of correlation between the two variables given a delay time ‘d’ of one of the variables and is given as:

$$r_{xy}(d) = \frac{\sum_{i=0}^{n-1}(x_{(i-d)} - \bar{x}).(y_i - \bar{y})}{\sqrt{\sum_{i=0}^{n-1}(x_{(i-d)} - \bar{x})^2.(y_i - \bar{y})^2}} \qquad (3)$$

Where;

r_{xy} is the linear correlation coefficient.

$x_{(i-d)}$ are the individual observations of the first dataset (lagged/ delayed by time ‘ d’).
y_i are the individual observations of the second dataset.

$\bar{x}$ and $\bar{y}$ are means for first and second datasets respectively.
n is the sample size.

If equation (3) is computed for all delays d= 0, 1, 2…..n-1, the length of the resulting cross correlation is twice the length of the original series. However it is possible to compute cross correlations with less than the sample size (n) range of delays (Bourke, 1996).

Cross correlation computation between mean monthly NDVI and total rainfall were performed in order to examine the best relationship between the datasets. Figure 3.2 shows an example of cross correlation for Dar es salaam Airport station located within the bimodal rainfall regime. The highest significant correlation (0.58) is found at lag 1. This means rainfall amounts in previous one month (lag 1) than rainfall in the current month (lag 0) and other months of the year, has the greatest correlation with the current month NDVI. Similar findings of 1 to 2 months lags were found by Davenport *et al.* (1990), Eklundh, (1996) and Ingram, (2005) when studying NDVI-rainfall relationship in Eastern Africa region. Cross correlation analysis between NDVI and Nino 3.4 SST had Nino 3.4 SST lagging NDVI between 1 to 3 months. Anyamba *et al*. 2001 found significant increase in correlation at 1 to 4 months lags in East Africa which concur with the findings in this study.

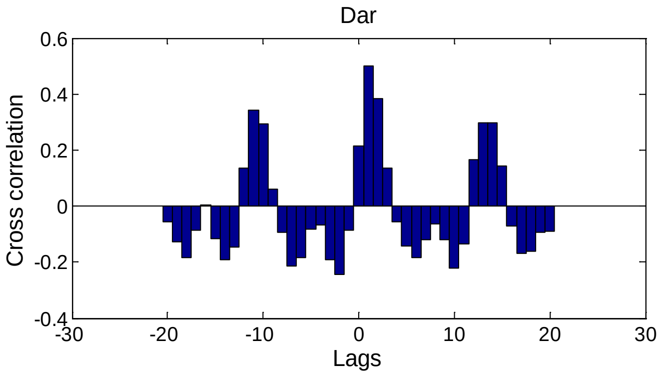


Figure 3.2. *Cross correlation functions between monthly NDVI and rainfall for Dar es Salaam Airport station. (n= 324, p= 0.05 significance level), Positive lags indicate number of months for which NDVI lag behind rainfall.*

Objective 4: The effect of global weather phenomena such as ENSO on vegetation in Tanzania was tested by correlation and simple linear regression analyses between Central Pacific Ocean Sea Surface Temperatures (Nino 3.4 SST) and NDVI.

4 Results

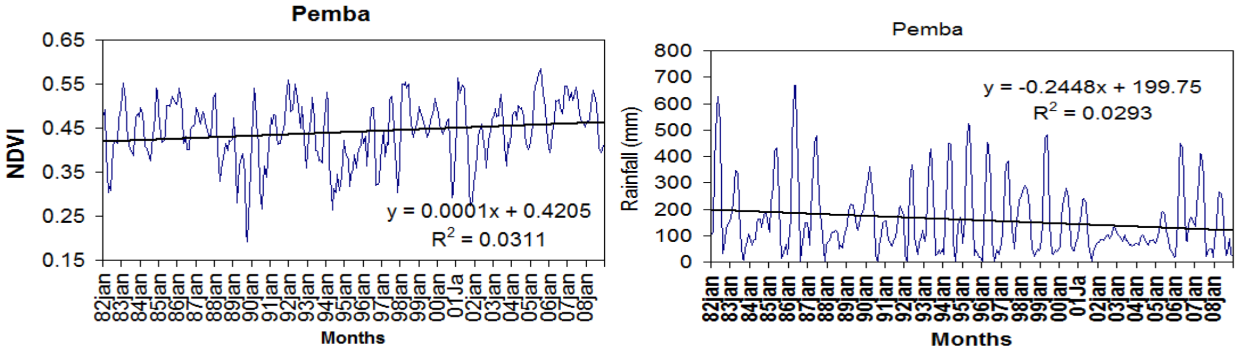
4.1 Trend analysis of rainfall and NDVI time series

4.1.1. Total monthly Rainfall trends, 1982-2008(at station level)

Linear trends (slopes) for total monthly rainfall time series during the period 1982 to 2008 are presented in figures 4.2 and appendix figure C1 . It can be observed that for rainfall, majority (26 statations) of the stations had decreasing trends except for three stations (Iringa, Morogoro and Mwanza) which had increasing trends but statistically not significant. Pemba station observed the largest decreasing trend of -0.2448, while Mwanza obseved the largest increasing trend of 0.0324, though not statistically significant. Further more, upon testing the significance (at p=0.05 significance level) of their corresponding R^2 values, only 5 out of 29 stations (Hombolo, Kilwa, Mlingano, Pemba and Tunduru) had decreased significantly. None of the stations had significant increasing trend. More results are presented in appendices Table B1.

4.1.2 Mean monthly NDVI trends, 1982-2008 (at station level)

NDVI trends (slopes) in figure 4.2 and appendix figure C1, is a mixture of increasing and decreasing trends among the stations, with some stations including Tanga, Zanzibar, Pemba, Morogoro and Dar es salaam (in the bimodal) Mbeya and Mahenge stations (in the unimodal) showing increasing trends despite the their decreasing rainfall trends. In total, trends of 3 out of 29 stations had increased significantly while trends for 8 stations had decreased significantly (Appendix Table B1). Nevertheless the temporal variability of both NDVI and rainfall datasets is high. Pemba station is shown here as an example. (Figure 4.1)



a b

Figure 4.1. *Mean monthly (a) NDVI and (b) total rainfall for Pemba for the period 1982-2008*

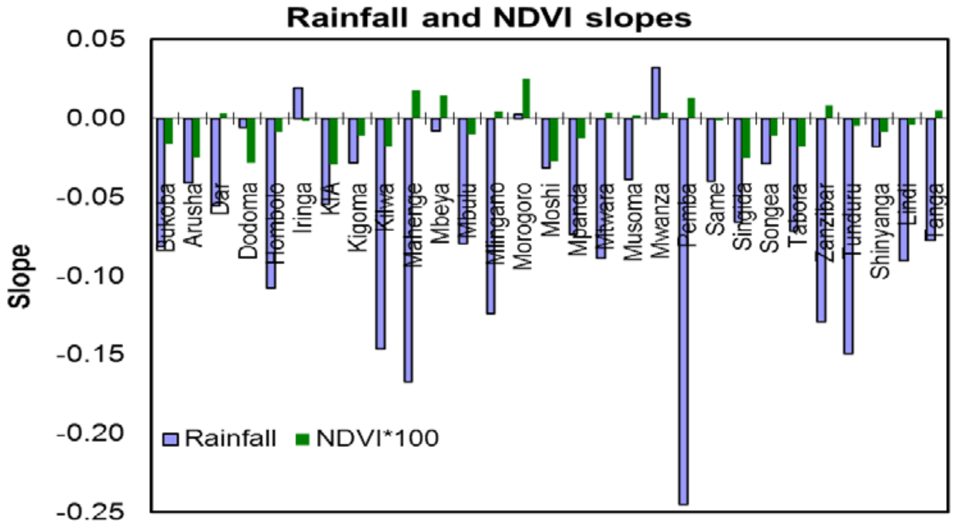


Figure 4.2. *Rainfall and NDVI (multiplied by 100) trends for all the stations.*

4.1.3 Averaged zonal mean monthly NDVI and rainfall trends, 1982-2008

To investigate timeseries trends at the zonal level, mean monthly NDVI and rainfall station data were aggregated in zones acording to figure 1.4 and results are shown in Table 4.1. The rate of change of NDVI indicated that, all of the zones except NC and SWH experienced decreasing NDVI levels which coincide with the observed decresing rainfall trends. For rainfall six out of seven zones had decreasing non significant trends

(Table 4.1). Similarly Northern coast (NC) zone had a decrasing rainfall trend but statistically significant. Annually, NDVI and rainfall trends according to rainfall patterns (bimodal or unimodal) are presented in Table 4.3. The bimodal regions had NDVI and rainfall decreasing by 0.0003/year and 4.31mm/year respectively, while the unimodal regions observed NDVI and rainfall decreasing by 0.0004/year and 3.27mm/year respectively. However only the decrease in NDVI over the Unimodal was found to be statistically significant.

***Table 4.1**. Zonal trends of mean monthly NDVI and rainfall in Tanzania over 1982-2008*

	NDVI			**Rainfall**		
Zone	Slope	R^2	Sig.	Slope	R^2	Sig.
NEH	-0.0002	0.0468	S	-0.0491	0.0081	NS
NC	0.0001	0.0228	S	-0.1045	0.0199	S
Lake_V	-0.00005	0.0031	NS	-0.0263	0.0015	NS
Western	-0.0001	0.0078	NS	-0.0499	0.0041	NS
SWH	0.00004	0.0011	NS	-0.0574	0.0030	NS
Southern	-0.00008	0.0038	NS	-0.1032	0.0125	NS
Central	-0.0002	0.0175	S	-0.0598	0.0087	NS

*In this part the significance threshold for R^2 at 0.05 significance level is taken as R^2 =0.0135 (d.f = 322). **NS**:Not significant and **S**:Significant*

***Table 4.2**. Statistical significance results (t-test) for changes in mean NDVI and Rainfall (mean1:1982-1995 against mean2:1996-2008 periods)*

	NDVI				**Rainfall**			
	mean1	**mean2**	**t-value**	**sig***	**mean1**	**mean2**	**t-value**	**sig***
NEH	0.471	0.432	4.55	S	79.5	70.5	1.58	NS
NC	0.430	0.442	-1.83	NS	145.2	124.4	2.72	S
Lake_V	0.412	0.402	1.07	NS	131.5	123.2	1.18	NS
Western	0.471	0.457	1.03	NS	104.8	96.6	0.97	NS
SWH	0.513	0.514	-0.02	NS	123.2	114.3	0.83	NS
Southern	0.538	0.521	1.32	NS	112 .0	93.0	1.99	NS
Central	0.419	0.385	2.10	S	67.0	59.6	1.11	NS

**For alpha = 0.05 the tabled value is 1.96 for 2 sided test (d.f=322).*
NS:Not significant and S:Significant

***Table 4.3**. Annual trends of mean NDVI and rainfall in Tanzania over 1982-2008*

		Bimodal	Unimodal
Rainfall (mm)	Mean	1052	1030
	Slope	-4.31	-3.27
	R^2	0.039	0.050
NDVI	Mean	0.379	0.464
	Slope	-0.0003	***-0.0004***
	R^2	0.032	***0.116***

Bolded values indicate some significant relationship at p= 0.05 significant level

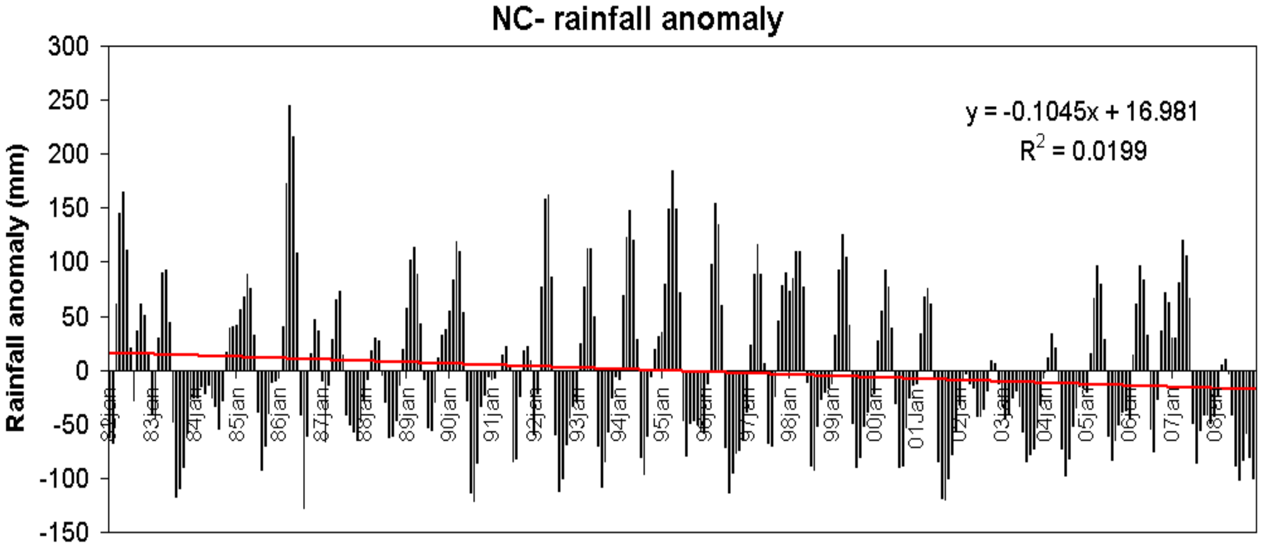


***Figure 4.3.** Monthly rainfall anomaly for Northern Coast (NC) for the period 1982-2008.*

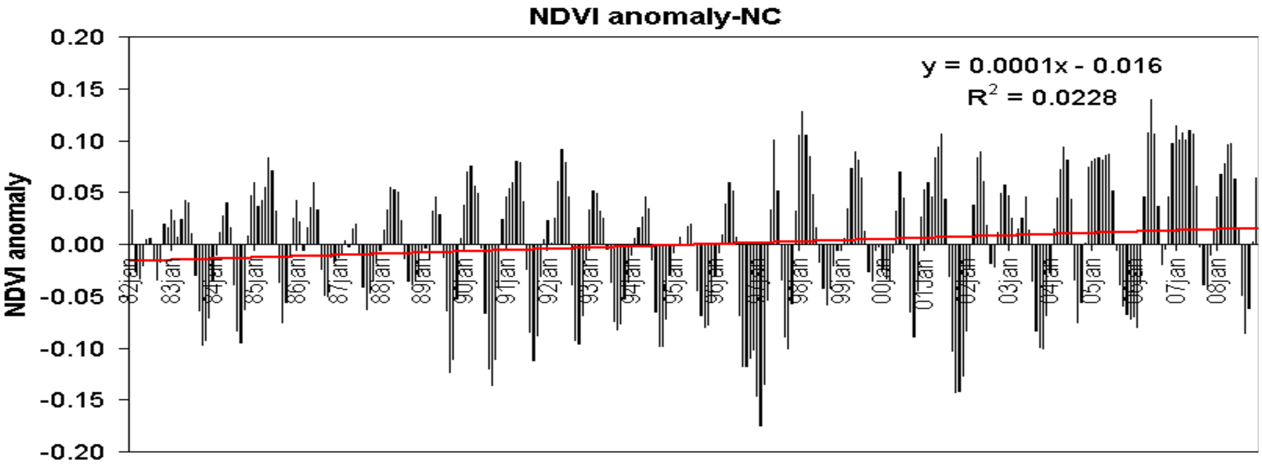


***Figure 4.4.** Monthly NDVI anomaly for Northern Coast (NC) for the period 1982-2008.*

4.1.4 Student t-test at changes in mean NDVI and rainfall between 1982-1995 and 1996-2008 periods

High variability in of both the NDVI and rainfall time series, can result to inconsistency in trends caused by few years. Thus an investigation of the changes of means between two periods,1982 to 1995 and 1996 to 2008 were carried out using Student t-test, and the results from this analysis are presented in Table 4.2. Northeastern highlands (bimodal) and Central (unimodal) zones showed a significant decrease in NDVI mean between the two periods with t-values of 4.55 and 2.10 respectively. The rest of the zones showed no significant changes in the mean NDVI. On the other hand only Northern coast showed a significant change in total rainfall (t-value = 2.72). Results in this part support the ones obtained in part 4.1.3 (Table 4.1) where NDVI had significant decrease in linear trends for NEH and Central zones and a significant decreasing rainfall trend for NC zone.

4.2 Relationship between NDVI and rainfall at different time scales

4.2.1 Monthly relationship

(i) At station level

Figure 4.5 shows the distribution of correlation coefficients between mean monthly NDVI and rainfall at lag 1 and 0. It can be observed the correlation coefficients at lag 1 are higher than lag 0. Thus a higher resposnce of vegetation 1 month later following the rainfall in many stations. The median correlation coefficient for lag 0 is 0.54, and 25% and 75% percentiles are at 0.33 and 0.65 respectively. For lag 1, the median correlation coefficient is 0.73, and 25% and 75% percentiles are at 0.52 and 0.77 respectively.

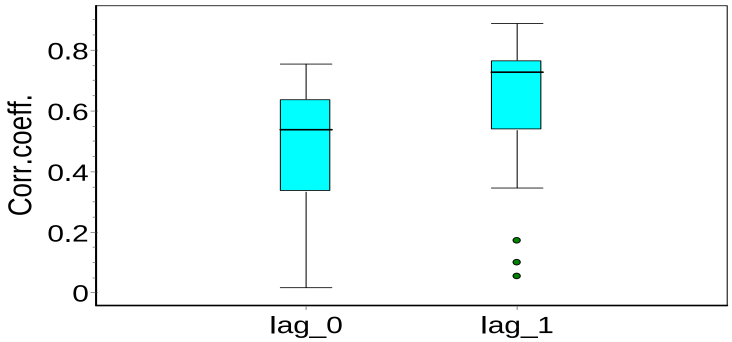


Figure 4.5. *Box plots showing correlation coefficients between mean monthly NDVI and rainfall at lags 0 and 1.*

Figure 4.6 shows coefficients of explanation (R^2 values) from the regression analysis between NDVI and rainfall for all the stations used in this study, at lag 0, 1 and 2 respectively. The highest R^2 values are observed with lag 1 and 2, indicating a close relationship between current NDVI and previous months' rainfall amount than the concurrent months. Also higher R^2 values at lag 1 are observed mostly in the unimodal stations such as Iringa (R^2 = 0.63), Dodoma (R^2 = 0.58), Singida (R^2 = 0.57), Shinyanga (R^2 = 0.61) and Tabora (R^2 = 0.54). In the unimodal stations the median R^2 values is 0.58 at lag 1, while in bimodal stations the median R^2 values is 0.26 at lag 1 (Table B3). Further, spatial distribution of coefficients of explanation are shown in appendix figure C2.

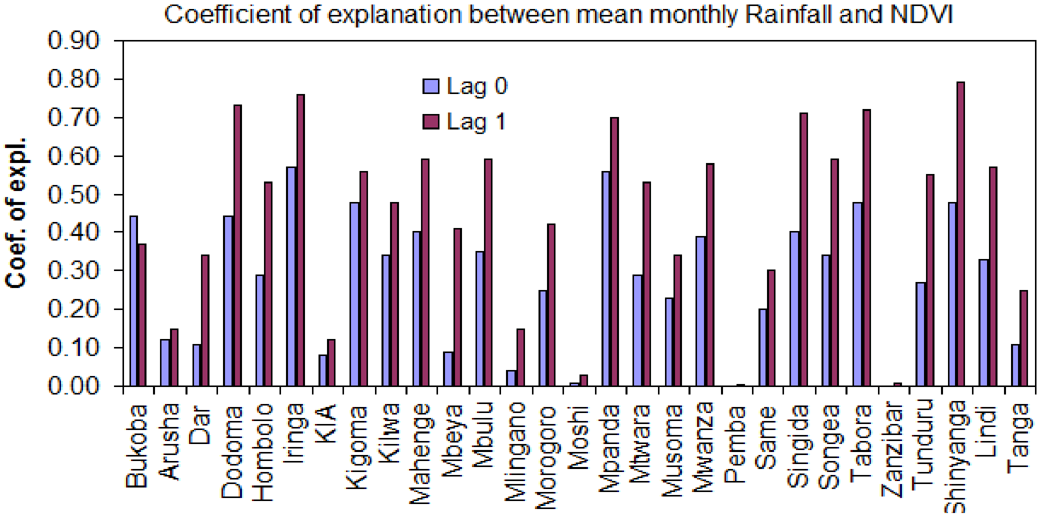


Figure 4.6*. Coefficients of explanation for mean monthly NDVI and rainfall at lags 0 and 1.*

(ii) At zonal level

Correlation coefficients between mean monthly NDVI and rainfall at zonal level are presented in Table 4.4. All seven zones have statistically significant correlation coefficients at p = 0.05 (n=324) significance level. More specifically, Southwestern highlands zone with highest correlation (R^2 = 0.84 at lag 1) and Northern coast having the lowest (R^2 = 0.40 at lag 1) are shown in Figure 4.7.

Table 4.4. *Correlation between Monthly NDVI and Rainfall (Zonal)*

	NEH	NC	LakeV	Western	SWH	South'	Central
r (Lag0)	0.58	0.45	0.78	0.67	0.74	0.63	0.67
r^2	0.33	0.21	0.61	0.45	0.55	0.40	0.45
r(lag 1)	0.68	0.64	0.88	0.86	0.92	0.85	0.89
r^2	0.46	0.40	0.77	0.74	0.84	0.72	0.79

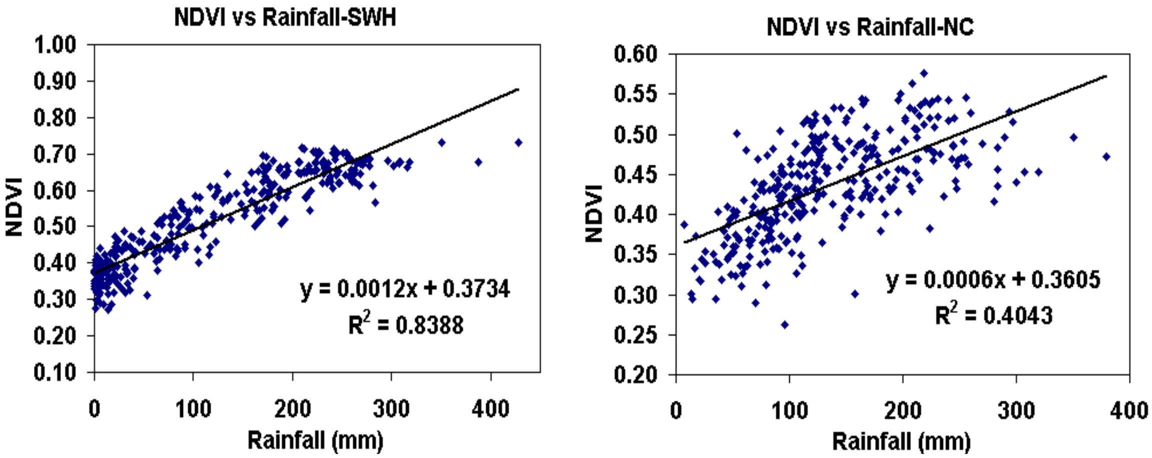


Figure 4.7. *Relationship between mean monthly NDVI versus rainfall for SWH and NC (at lag 1).*

4.2.2 Seasonal relationship

Regression analysis between NDVI and rainfall considering different zones and seasonal time scale revealed the following relationships: (1) Relationship between maximum seasonal NDVI and total rainfall is stronger both within season than at one seasonal rainfall lag. All the same the stronger positive correlation for both mean and maximum NDVI against rainfall was observed with rainfall within the season than with the previous seasons (Figures 4.8 & 4.9). (2) Figure 4.8 show that, zones within unimodal areas had stronger relationships than zones within the bimodal areas. (SWH is located in the unimodal while NEH in the bimodal). (3) Furthermore, at lag 1 relationship as shown in figure 4.9, unimodal zones seem to have negative correlation and this can be observed in their negative slopes.

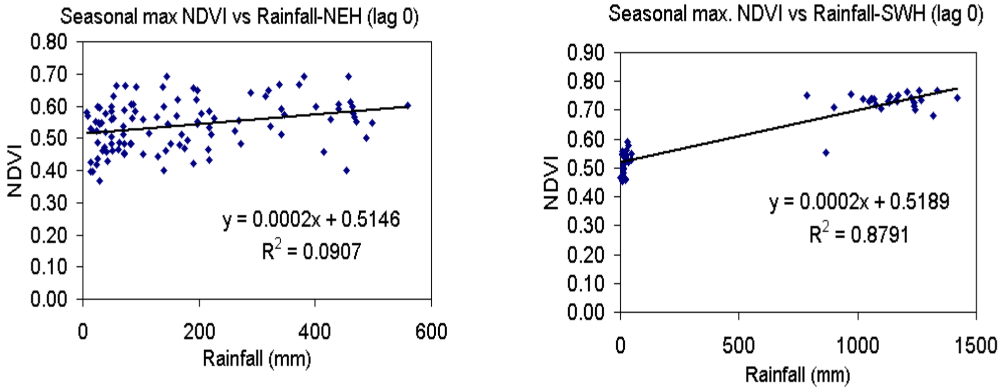


Figure 4.8. *Relationship between seasonal maximum monthly NDVI and rainfall at lag 0 for Northeastern highlands (NEH) and Southwestern highlands (SWH) zones.*

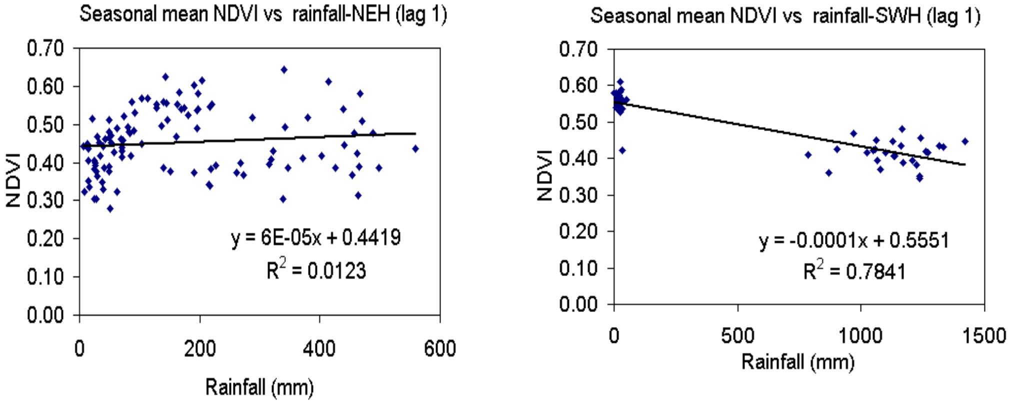


Figure 4.9*. Relationship between mean seasonal NDVI and rainfall at lag 1 for Northeastern highlands (NEH) and Southwestern highlands (SWH) zones.*

4.2.3 Interannual relationship

Figure 4.10 shows a slight inter-annual variability in NDVI and rainfall for both unimodal and bimodal respectively. The general pattern for both NDVI and rainfall is an increase in the period between 80s to early 90s also after 2005 while highly variable in between (late 90s to 2005). However a closer look in to the series show that NDVI annual pattern to some extent coincided with that of rainfall except for some years such as the 1997 (strong El Niño year) when it decreases with high amount of total rainfall received.

An attempt to see the influence of the strong El Niño year of 1997/98 had over the correlation between NDVI and rainfall was made. When 1997 data points were removed, there were improvements in the slope and coefficients of explanations for both bimodal and unimodal areas. For the bimodal regression slope changed from 0.00009 to 0.002 and R^2 changed from 0.008 to 0.046, while for the unimodal slope changed from 0.0002 to 0.003 and R^2 changed from 0.045 to 0.106. A further analysis of the effects of ENSO events on NDVI is presented in section 4.3.

A comparable distribution of monthly, seasonal and annual correlation coefficients is shown in figure 4.12 which shows more decrease in correlation coefficients in the seasonal and annual than in the monthly time scale relationships.

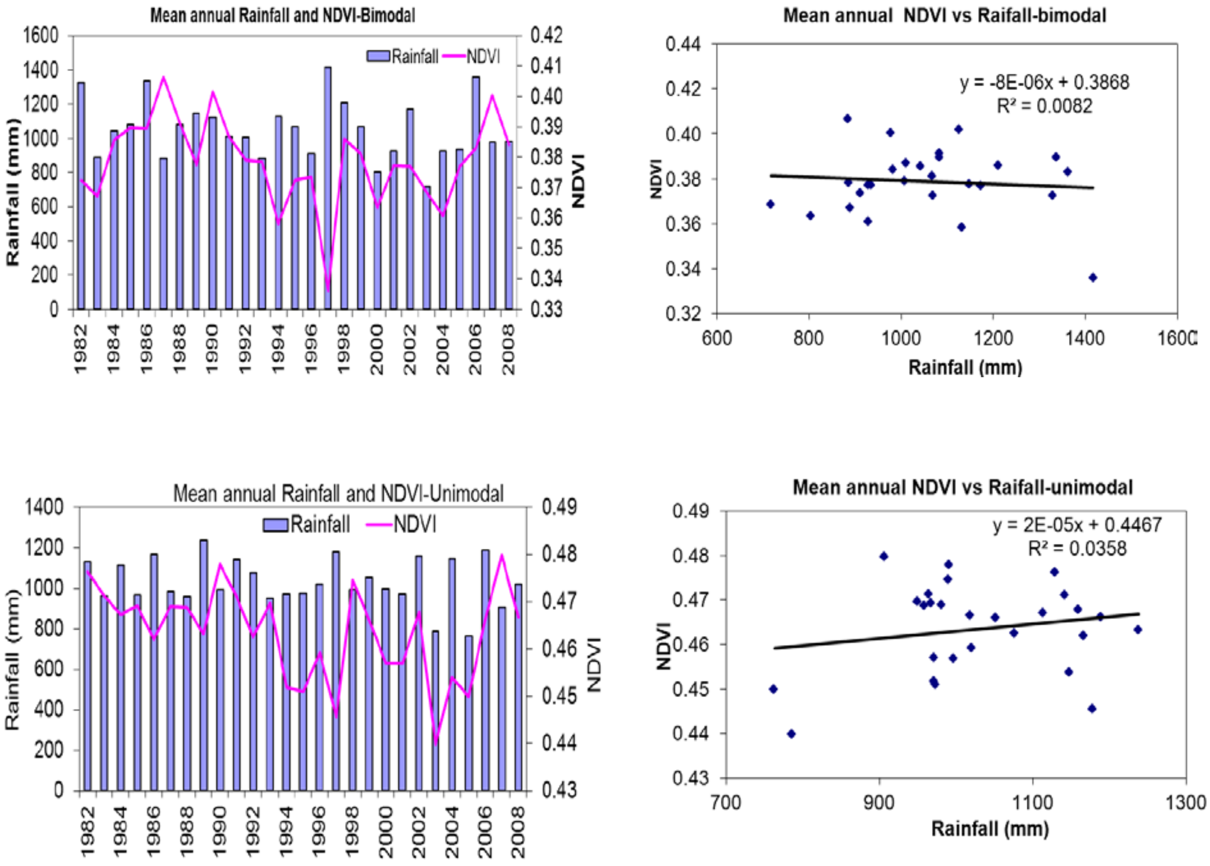


Figure 4.10. *Relationship between annual mean NDVI and rainfall (bimodal rainfall regime 1st row and unimodal 2nd row)*

Correlation coefficients were plotted against the mean annual rainfall for all the station as shown in figure 4.11, for the purpose of investigating the dependence of correlation coefficients on the mean annual rainfall. The relationship did not reveal any defined pattern. Similar findings were obtained by Eklundh (1996) in East Africa.

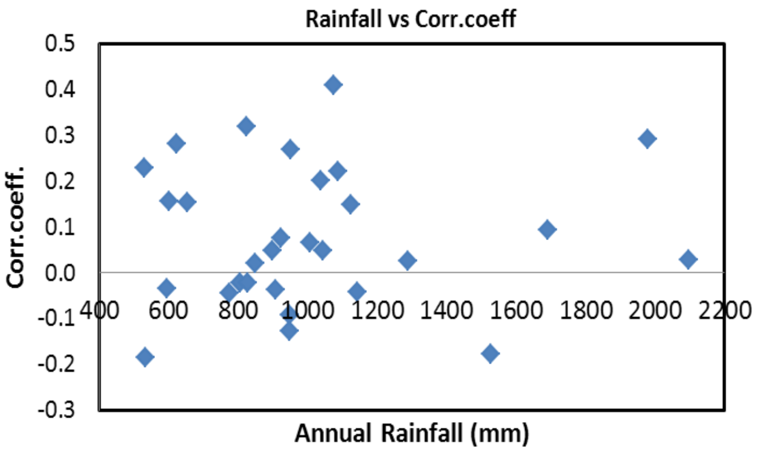


Figure 4.11. *Relationship between mean annual rainfall and stations' correlation coefficients*

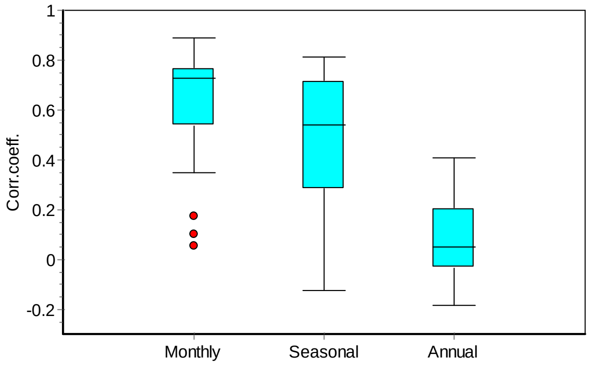


Figure 4.12. *Box plots showing correlation coefficients between mean monthly, seasonal and annual NDVI and rainfall.*

4.3 Relationship between NDVI and SST

4.3.1 Monthly relationship

(i) At zonal level

Correlation analysis between NDVI and Nino 3.4 SST at zero lag are generally low ($r < 0.3$) as shown in Figure 4.13. However there were found significant higher correlations from 1-3 months lags with NDVI lagging Nino 3.4 SST as also explained in section 3.5. The bimodal region has higher correlation coefficients as compared to the unimodal region except for the Southern zone found in the unimodal which has relative highest correlation coefficient (r = 0.27). The relationship for the bimodal and unimodal regions when considering the whole time series and ENSO years separately are shown in table 4.5. The results show a slight increase in the correlation coefficients during ENSO events as compared to the correlation coefficients from the whole time series, ENSO years included. On average correlation coefficients between monthly Nino 3.4 sea surface temperatures (SSTs) and NDVI for the averaged stations over the bimodal region was found to be 0.25, while for the unimodal stations was 0.22.

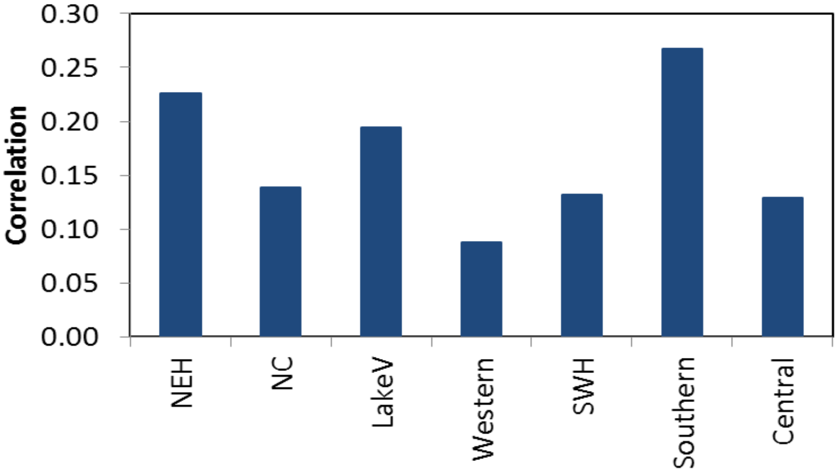


Figure 4.13. *Correlation coefficients between NDVI and Nino 3.4 SST at lag 0*

Table 4.5. *Correlation coefficients between monthly mean NDVI and* Niño *3.4 SST at lag 0.*

	Bimodal			Unimodal			
	NEH	NC	Lake_V	Western	SWH	South’	**Central**
All months(n=324)	***0.226***	***0.138***	***0.194***	0.088	***0.132***	***0.268***	***0.129***
ENSO months **(n=**183)	***0.325***	***0.161***	***0.253***	***0.133***	***0.172***	***0.331***	***0.169***

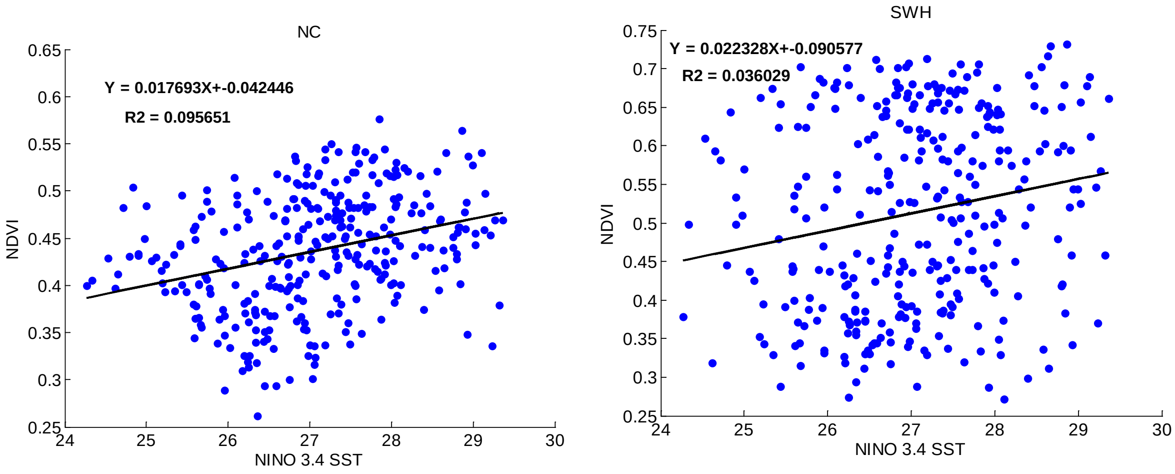
Bolded values indicate some significant relationship at 0.05 significant level.

4.3.2 Regression analysis between monthly NDVI time-series and SST.

Regression analysis between SST and NDVI on a monthly time scale is shown in table 4.6. This result shows a very weak relationship though statistically significant especially more in the bimodal than in the unimodal rainfall regime as further illustrated in figure 4.14. Coefficients of explanation of 6 out of 7 zones are statistically significant at 0.05 level and all have positive slopes.

Table 4.6. *Regression analysis results between monthly mean NDVI and NINO 3.4 SST*

	Zone	**Slope**	**R^2**	**p-value**
Bimodal	NEH	0.0178	***0.0565***	0.0000
	NC	0.0177	***0.0957***	0.0000
	LAKE_V	0.0154	***0.0406***	0.0003
	Average	0.0170	0.0643	
Unimodal	WEST	0.0038	0.0024	0.3815
	SWH	0.0223	***0.0360***	0.0006
	SOUTHERN	0.0318	***0.0868***	0.0000
	CENTRAL	0.0237	***0.0299***	0.0018
	Average	0.0204	0.0388	



a b

Figure 4.14. *Relationship between mean monthly NDVI and Niño 3.4 SST at lag0 for (a) Northern coast (NC) and (b) Southwestern highlands (SWH) zones.*

4.3.3 Seasonal relationship

An attempt to investigate the relationship between NDVI and SST in a seasonal time scale was also made (Table 4.7, figures 4.15 and 4.16). Table 4.7 show the correlation coefficients obtained from the analysis of time series of all seasons and seasons falling in ENSO years separately. During ENSO years the coefficients seem to have improved slightly due to the more pronounced effects (i.e. heavy precipitation or drought events) of ENSO. However the statistically significant correlations were found mainly in the bimodal areas.

Figures 4.15 and 4.16 show the relationship between seasonal averaged NDVI and Nino 3.4 SST during ENSO years covering the study period 1982 to 2008 for Northeastern highlands (NEH) and Western zones respectively. These two zones are chosen to illustrate the opposite effects of ENSO events in different climatological zones of Tanzania. This is easily detected with the fitting of degree 6 polynomials to both NDVI and SST series. The NEH zone representing the bimodal and western represents the unimodal rainfall regimes. For NEH, the interannual variation of seasonal NDVI have significant weak positive correlation (r = 0.312) with Nino 3.4 SST. Furthermore good relationship can be observed in the strong El Niño episodes of 1982/83 and 1987/88 also in the recent La Niña episode of 2008/09. On the other hand the Western zone observed even weaker non-significant correlation (r = 0.119).

Table 4.7. *Correlation coefficients between mean seasonal NDVI and Nino 3.4 SST.*

	Bimodal			Unimodal			
	NEH	NC	LakeV	Western	SWH	South'	Central
All seasons	***0.215***	***0.201***	***0.249***	0.060	0.207	***0.294***	0.167
	n=108			n=54			
ENSO seasons	***0.312***	***0.236***	***0.321***	0.119	0.199	0.410	0.212
	n=60			n=31			

Bold and italic coefficients are significant at 0.05 significant level.

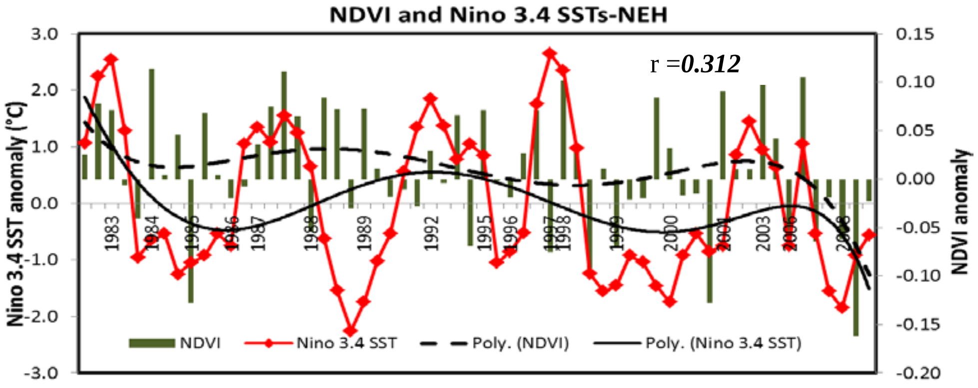


***Figure 4.15**. Time series of seasonal NDVI and Nino 3.4 SST for ENSO years for Northeastern highlands zone at lag 0. (SST positive peak anomalies correspond to El Niño years while negative peaks correspond to La Niña years)*

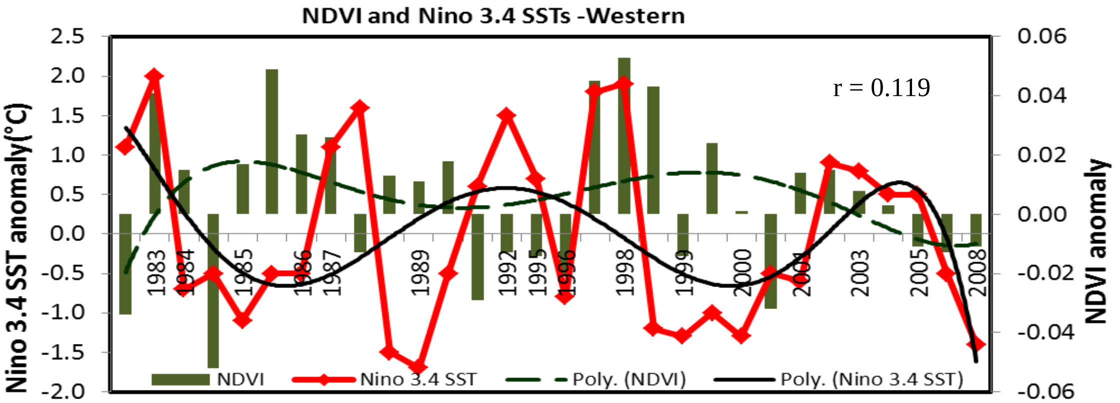


***Figure 4.16.** Time series of seasonal NDVI and Niño 3.4 SST for ENSO years for Western zone at lag 0. (SST positive peak anomalies correspond to El Niño years while negative peaks correspond to La Niña years)*

Table 4.8 shows the results from regression analysis between SST and NDVI on a seasonal time scale. The relationship is weaker than that of the monthly time scale shown in table 4.6. Only 2 zones (NEH and NC) out of 7 are statistically significant at 0.05 level with positive slopes.

Table 4.8. *Regression analysis between seasonal mean NDVI and NINO 3.4 SSTs*

	Zone	**Slope**	**R^2**	**p-value**
Bimodal	NEH	0.0150	***0.0362***	0.0487
	NC	0.0145	***0.0806***	0.0029
	LAKE_V	0.0096	0.0349	0.0529
	Average	0.0130	0.0506	
Unimodal	WEST	0.0050	0.0022	0.5290
	SWH	0.0025	0.0008	0.8435
	SOUTHERN	0.0118	0.0203	0.3042
	CENTRAL	0.0069	0.0031	0.6885
	Average	0.0065	0.0066	

5 Discussion

5.1 Trend analysis of rainfall and NDVI time series

5.1.1. Total monthly Rainfall trends

Increasing as well as decreasing rainfall trends obseved in this study are consistent with previous studies on the climatic trends in the region (Schreck and Semazzi, 2004), also confirm the ongoing climate changes experienced all over the world. The study by Schreck and Semazzi found decreasing rainfall trends for the 1980s and late 1990s but an increasing trends in the mid- 90s over East Africa. However their study was based on the 1961 to 2001 period. This study has observed a further decrease in rainfall trends beyond 2001, which result to overall decreasing trends in the period 1982 to 2008 for most rainfall stations in Tanzania. New *et al*. 2006 studied almost the same time period 1961 to 2000 over southern and West Africa (Tanzania included) and found decreasing averaged total rainfall trends, but with increased daily rainfall intensity which they attributed to the short interval rainfall episodes. Nevertheless this is a general trend and should be confirmed by analysing more stations in smaller spatial scales due to the high spatial and temporal variability in rainfall observations. Such high temporal variability of the stations' rainfall can be seen in figure 4.1b (Pemba). The highest decreasing rainfall trend for Pemba can be attributed to the this high temporal variability (Figure 4.2).

5.1.2 Mean monthly NDVI trends

Most of stations showed more of decreasing trend in NDVI than an increase, this can be partly explained by the observed decreasing trends in station rainfall. Most of the decreasing trends were found over the northern and western parts of the country. Pelkey *et al*. (2000), found similar reults of decreasing vegetation greeness over the west, north and over high altitudes of Tanzania which they attributed to the population pressure in these areas. Their study also found a general increase in vegetation greenness over most parts of the country particulary over the southern part and the increase was more evident when individual vegetation categories were considered. However the time period of their study was between 1981 and 1994 which does not account for the vegetation changes beyond 1994. Serneels *et al*. (2007) on the study of the impact of land use on the land cover change in East Africa found that land use explained about 50% of the variance in vegetation productivity changes at a given landform. A landform in their study was taken as an area with similar characteristics based on slope, soil fertility, soil texture, soil depth, drainage and chemical constraints. All the same as for the rainfall, the temporal variability of NDVI is high (e.g Pemba, Figure 4.1a) and the linear trends obtatined should be interpreted with caution.

5.1.3 Averaged zonal mean monthly NDVI and rainfall trends

Analysis of mean monthly NDVI and rainfall at the zonal level (Table 4.1) revealed that, NEH and Central zones were among the most affected in terms of decreasing NDVI probably due to high frequency of drought events especially in the mid 90s and early 2000s (Yonah *et al*. 2009). Furthermore the analysis of rainfall anomaly show that, dry seasons in these years either were longer and received less rainfall amounts (higher negative anomaly) as compared to the early 80s and early 90s. However many other factors could be playing a significant role as the coefficients of explanation are very low or not significant. Inefficient land use practices such as deforestation over NEH and Southern, overgrazing over Central and Lake Victoria and fire burning (Central, Southern) for agricultural field preparations could be the cause of the decreased NDVI (Schrumpf, *et al*. 2011; Mwanukuzi, 2010, Kangalawe, 2009). Slight increase in NDVI observed in the SWH could be attributed to the fact that , this is the major agricultural area for Tanzania, could suggest an increase in food production resulting to an increased vegetation cover these regions (Mwanukuzi, 2010). This study found a replacement of natural vegetation with the eucalyptus and pine trees and replacement of pyrethrum farms with maize and potato farms mainly over the highlands. The increase in NDVI over Northen coast (NC) in Figure 4.4, while decreasing rainfall trends in Figure 4.3, can be attributed to local climatic influences and land management practices among others. For instance the closure of Mkwaja cattle ranch in the northern coast in year 2000 after 48 years of operation migh have contributed to increased vegetation greeness observed in this zone (Tobler *et al*. 2003). On the otherhand, one of the small scale climatic influences is the maritime type (inluence of the Indian Ocean) where the land strip near coastal areas could be receiving good amount of rainfall which is not recorded in the rainfall measuring stations (Kijazi and Reason, 2009; Basalirwa *et al*. 1999). These land strips shows an increased NDVI even during dry seasons despite low amount of rainfall recorded in the nearby station.

Despite the high interannual variability in both NDVI and rainfall the change in means between the periods 1982-1995 and 1996-2008 for some zones, still their long term (1982-2008) linear trends were statistically significant as can be observed from Table 4.1 and 4.2. For instance statistically significant changes (decrease) in NDVI means between the two periods (1982-1995 and 1996-2008) for NEH and Cetral zones in table 4.2 confirm their statistically significant long term decreasing trends obtained in table 4.1.

5.2 Relationship between NDVI and rainfall at different time scales

5.2.1 Monthly relationship

(i) At station level

Relatively higher correlation coefficients and hence coefficients of explanation were observed in the unimodal than the bimodal stations from the relationship between mean monthly NDVI and total monthly rainfall (Figure 4.6). This could be explained by the fact that rainfall seasons in the unimodal areas are more reliable (less variable) than in the bimodal areas (Basalirwa *et al*. 1999). Rainfall in the unimodal area fall after longer dry months in such a way that vegetation response to the small amounts of rainfall in the beginning and within the season has significant impact to the vegetation growth. Thus rainfall in the unimodal (median R^2 values is 0.58 at lag 1) areas explains the NDVI variability better than in the bimodal. In bimodal stations the median R^2 values is lower (median R^2 values is 0.26 at lag 1), giving an indication that rainfall is not the main controlling factor for NDVI in these areas (Figure 4.6 and Table B3). Eklundh, (1996) found a median value of 0.36 at lag 1 in the similar bimodal areas of East Africa which seem to concur with the coefficients of explanations obtained in the bimodal areas.

Rainfall seasons in the bimodal are highly variable (Zorita and Tilya, 2002) and result to very low or undefined relationships between NDVI and rainfall amounts. In this study stations such as Arusha, Kilimanjaro, and Moshi have R^2 values which are not significant at lag 0, are located in the slopes of East African highlands which are covered by green vegetation most of the year, resulting to saturation of NDVI with or without rainfall.

Stations in the bimodal near the large water bodies such as Mwanza, Bukoba, Musoma, Zanzibar and Pemba also were found to have low R^2 values. Frequency of cloud cover in these areas is high, an influence of Lake Victoria and Indian Ocean (clouds have the effect of lowering NDVI in an area) and part of station pixels may include reflectance from the water, rendering NDVI- climatic factors relationship to be erroneous (Eklundh 1996). For both bimodal and unimodal there were no significant difference in the coefficients of explanation at lag 2 level due to the fact that within two months after the first rains in the season. At this point NDVI might have reached its maximum value when rainfall is no longer a limiting factor for vegetation growth as also found by Davenport and Nicholson (1993).

Furthermore, stations located in semi-arid areas more than in humid areas, regardless of their rainfall regime (bimodal or unimodal) showed relatively higher coefficients of explanations due to higher demands in soil moisture for vegetation growth (Figure appendix C1). As an example of stations located over semi-arid lands and their coefficients of explanations can be seen at Dodoma and Singida in the unimodal, Shinyanga and Same in the bimodal area (Table B1and B2). Similar observations were also reported by Davenport and Nicholson (1993). Filtering of the data produce better relationship between NDVI and climatic variables which are easier to interpret. However the procedure introduces autocorrelation in the datasets and biases to the results as pointed out by Eklundh (1996). Nevertheless both cases using unfiltered (raw data) and filtered data are shown in this study for comparison purposes.

The study of the relationship between NDVI and climatic variables in Tanzania is a complex one. This need to incorporate many other factors which control vegetation greenness; namely influence of human, vegetation and soil types and properties. Other factors could be solar radiation, air temperature, SST over western Indian Ocean, pressure and wind patterns over both Pacific and Indian Ocean to just mention a few (as partly elaborated before in sections 5.1.2 and 5.1.3). A relevant example is the study by Pelkey *et al*. (2000) which investigated the impact of environmental and human impacts to different vegetation types found in Tanzania. In there study forests and woodlands were found to increase in greenness while a decrease in bush lands, grasslands and swamps. If these factors were incorporation in this work they could have improved the results.

(ii) At zonal level

Southwestern highlands is located in the unimodal rainfall regime while Northern coast in the bimodal. The observed decreasing trend in rainfall but a slightly increasing NDVI trend for the Northern coast zone (figures 4.3 &4.4) could explain the observed lowest correlation. (see also part 4.1.3 and 4.1.4). The response of NDVI to rainfall seem to be linear upto about 200mm to 300mm, after which there is slighty or no further increase of NDVI with rainfall. Davenport and Nicholson (1993) found this threshold to be between 100mm and 200mm when studying the relationship between NDVI and rainfall in East Africa. This result confirm the log-linear relationship also found by Nicholson *et al*. (1990) and Eklundh, (1996) though the focus was on the linear trends.

5.2.2 Seasonal relationship

Following the three main relationships obtained from the seasonal relationship between NDVI and rainfall, some explanations could be put forth. The highest amount of biomass production is reached within the current season due to the rainfall amounts within the season (Lag =0), then followed by decrease in biomass amount after rainfall cessation at the end of the season. This is more applicable to the unimodal areas where there are distinct and well-defined start and end of wet or dry rainfall seasons in succession. Hence the negative slope in the unimodal zones at lag 1 (Figure 4.9), the situation when previous wet season are made to correlate to low NDVI season.

Another reason for the differences in the strength of the relationship between the unimodal and bimodal areas is due to the fact that, rainfall seasons in the bimodal area is more variable both start, cessation and within season (Camberline and Okoola, 2003) . Also some areas such as North eastern highlands are evergreen throughout the year, whether the year is wet or dry. This gives an implication that low amount of seasonal rainfall lead to higher NDVI values in these areas. However both unimodal and bimodal areas share the same phenomenon of higher NDVI values with low amount of rainfall since are both located within the tropics where dry seasons are never completely without green biomass and NDVI is relatively greater than 0 throughout the year.

5.2.3 Interannual relationship

First part of the year 1997 experienced drought, which lead to the lowest NDVI registered in the whole period of study, while the last part of the year experienced heavy El Niño rainfall. Vegetation response to the end of the year rainfall might have been slow, hence a shift of maximum response to the year 1998 as also found by Ogutu *et al*. (2007). Another explanation could be that a decrease in the NDVI in the year 1997 was the result of flooding of these areas by rain water and vegetation were destroyed, hence the low NDVI values recorded by the satellite on average. Urban areas where most of the meteorological stations are located are more vulnerable to floods than sub-urban due to their modified environments, including disrupted sewage and rainwater passage systems. The result obtained in this part seems to suggest that a single extreme year in NDVI or rainfall can have considerable effect on their relationship.

Weaker relationship between NDVI and climatic factors were observed in annual and seasonal time scales than with the monthly time scale. This might suggest a climate-vegetation shorter time response rather than accumulated responses.

5.3 Relationship between NDVI and SST

5.3.1 Monthly relationship

At zonal level

Understanding the influence of large-scale ocean-atmosphere phenomena such as ENSO has on vegetation is of great importance to Tanzania. The observed lower correlation coefficients between NDVI and Niño 3.4 SST over the unimodal than in the bimodal areas (figure 4.13) agree with the previous findings. The vegetation response to the ENSO events in the unimodal region of Tanzania is similar to that observed in southern and southeastern Africa regions (Myeni, 1996; Anyamba *et al*. 2001; Anyamba *et al*. 2002; Plisner *et al*. 2000). Anyamba et al. 2001 found the correlation coefficients between NDVI and Niño 3.4 SST at zero lag to be 0.35 and 0.176 in East Africa and South East Southern Africa respectively. The fact that southern zone has the highest correlations could be attributed to its location partly in the Southwestern highlands to the west and its vicinity to the Indian Ocean. Thus warmer/cooler than normal SSTs over the central Pacific Ocean have been associated with the warmer/cooler than normal SSTs over the western Indian Ocean, the condition which enhance/suppress the amount of rainfall received in Tanzania (Kijazi and Reason, 2009; Anyamba *et al*. 2001). Southwestern highlands are one of the areas which receive the highest rainfall amount in the country. The same reasoning follows for the Northeastern highlands (NEH) and Lake Victoria zones which are influenced by the presence of highlands and Lake Victoria respectively.

Western zone observe the lowest correlations between NDVI and Nino 3.4 SSTs. This gives an indication that different climatic system different from the central Pacific SSTs (Nino 3.4) have influence on its rainfall pattern which in turn influence vegetation. For instance Mapande and Reason (2005) found that low level westerly winds originating from southern Congo basin (Congo forest) tend to play a significant role in rainfall seasons over western parts of Tanzania.

5.3.2 Seasonal relationship

From the NDVI-SST seasonal relationship (figures 4.15 and 4.16), it can be observed that, NEH which is within the bimodal region agrees with the previous studies (Pilsner *et al*. 2000 and Propastin *et al*.2010) that Nino 3.4 SST in this region has a positive correlation with NDVI during ENSO events, while over the Western region which is part of the unimodal region, Nino 3.4 SST tends to have weak positive or negative correlations with NDVI. However the correlation observed in figure 4.16 is not negative, but a weak positive one, giving an indication of how the unimodal areas are less influenced by the ENSO events. The fitted degree six polynomials to both NDVI and SST series to some extent illustrate this point where for some of the years NDVI respond in an opposite direction to that of SST.

Overall all the zones for both bimodal and unimodal regions have statistically significant correlations between mean monthly NDVI and Nino 3.4 SST except for the Western zone (Table 4.5), while in a seasonal time scale the significant correlation coefficient are found mostly over the bimodal zones (Table 4.7). This finding suggest that monthly SST over the central Pacific Ocean have greater influence over vegetation evolution in large part of the country, while seasonal SST influence the vegetation mostly over the bimodal zones.

6 Conclusions and possible application of the findings

6.1 Conclusions

In this study climate and vegetation trends, as well as their relationship was studied for Tanzania. The findings can be summarized as follows:

- Most of the station rainfall and NDVI had decreasing linear trends although few were statistically significant.
- The interannual variability in NDVI can be attributed to partly climatic variability mainly rainfall and large scale climatic phenomena such as ENSO.
- Relationship between rainfall and NDVI over the unimodal region was found to be stronger than that in the bimodal region due to differences in the length of the seasons (wet and dry). On the other hand the relationship between Nino 3.4 SST and NDVI was stronger in the bimodal than in the unimodal region due to different rainfall producing synoptic systems involved during ENSO years.
- The finding in this study lie within the range of the previous findings obtained in the broader Eastern and Southern Africa regions. However the correlation coefficients hence the coefficients of explanations from the relationship between NDVI and rainfall/SST are lower at concurrent months and relatively higher at the investigated 1 to 2 months lags, with NDVI lagging rainfall and SST.
- The coefficients of explanation obtained from the relationship between NDVI, rainfall and SST were improved significantly (coefficients of explanation greater than 50% but less than 80%) with the use of noise filtering technique and time lagging of the data sets. Otherwise weak coefficients not exceeding 50% for most stations were observed when using unfiltered and at concurrent months of NDVI and rainfall datasets.
- Relatively better relationship between NDVI and climatic factors were obtained in a monthly time scale than with the seasonal and annual time scales. This gives an indication of climate-vegetation shorter time response rather than accumulated (into seasonal or annual) responses.

6.2 Possible application of the findings.

The usefulness of this study is reflected in the following points.

1. The study will be useful as a basis for assessing the use of early warning system in the country. Occasionally different parts of the country face climate extreme conditions such as droughts and excessive rainfalls associated with floods and these are reflected in the vegetation greenness measures like NDVI.
2. The study will shed light as to what extent has the vegetation greenness been impacted under the changing climate in the recent years. The result can be used as a basis in studying climate changes and climate-vegetation relationships over longer time scale than the period used in this thesis and possibly to forecast the climate variability and changes impacts in future.
3. Vegetation is an important component in the climate system and they are interrelated. Knowing the status of one will help to determine the other, thus the results will be useful for planning purposes in various social economic sectors, such as agriculture and livestock, forestry, wildlife and tourism which are important for the wellbeing of the country.

Appendices

Appendix A. Acronyms and abbreviations

AVHRR	Advanced very high resolution radiometer
C	Central
CEEST	The centre for Energy, Environment, Science and Technology
CPC	Climate Prediction Centre
CO_2	Carbon dioxide
ENSO	El Niño southern oscillation
FAO	Food and Agriculture Organization
FEWS	Famine Early Warning System
GIMMS	Global Inventory Modeling and Mapping Studies
GLCF	Global Land Cover Facility
GHG	Greenhouse gasses
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter tropical convergence zone
KIA	Kilimanjaro International Airport
Lake_V	Lake Victoria
MAM	March to May
NASA	National Aeronautics and Space Administration
NC	Northern coast
NEH	North-eastern highlands
NDVI	Normalized Difference vegetation Index
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration
OND	October to December
PAR	Photosynthetic active radiation
R	Red
S	Southern
SST	Sea Surface Temperature
SWH	Southwestern highlands
TMA	Tanzania Meteorological Agency
URT	United Republic of Tanzania
W	Western

Appendix B

Table B1: Slopes and R^2 values for mean monthly NDVI and rainfall time series (1982-2008).

	Station	Rainfall		NDVI	
		Slope**	R^2	**Slope**	R^2
BIMODAL	Arusha	-0.0407	0.00349	***-0.00024***	***0.03938***
	KIA	-0.0543	0.01021	***-0.00029***	***0.09718***
	Mbulu	-0.0794	0.01071	-0.00010	0.00601
	Moshi	-0.0312	0.00188	***-0.00027***	***0.04100***
	Same	-0.0399	0.00660	-0.00001	0.00016
	Tanga	-0.0771	0.01048	0.00005	0.00215
	Dar es Salaam	-0.0553	0.00424	0.00003	0.00068
	Pemba	**_-0.2448*_**	***0.02935***	***0.00013***	***0.03112***
	Zanzibar	-0.1288	0.01143	***0.00008***	***0.10218***
	Morogoro	0.0026	0.00001	***0.00025***	***0.02479***
	Mlingano	***-0.1236***	***0.03254***	0.00005	0.00351
	Bukoba	-0.0813	0.00628	**_-0.00017*_**	***0.02962***
	Musoma	-0.0387	0.00385	0.00002	0.00032
	Mwanza	0.0324	0.00181	0.00004	0.00205
	Shinyanga	-0.0176	0.00058	-0.00008	0.00491
UNIMODAL	Dodoma	-0.0057	0.00006	***-0.00028***	***0.03328***
	Hombolo	**_-0.1077*_**	***0.02714***	-0.00008	0.00270
	Singida	-0.0659	0.00881	***-0.00025***	***0.02348***
	Iringa	0.0190	0.00088	-0.00002	0.00009
	Mahenge	-0.1668	0.00736	0.00018	0.01285
	Mbeya	-0.0080	0.00007	0.00014	0.01239
	Mpanda	-0.0737	0.00633	-0.00013	0.00849
	Kigoma	-0.0281	0.00158	***-0.00011***	***0.05554***
	Tabora	-0.0717	0.00597	***-0.00018***	***0.01691***
	Mtwara	-0.0887	0.00817	0.00003	0.00069
	Songea	-0.0289	0.00064	-0.00011	0.00995
	Kilwa	***-0.1460***	***0.02504***	-0.00018	0.01053
	Lindi	-0.0905	0.01040	-0.00004	0.00064
	Tunduru	***-0.1494***	***0.02065***	-0.00005	0.00173

*Bolded and italic slopes (R^2) are significant at significance level of p=0.05,n = 324
** Slope here is the same as trend.

Table B2: Regression results from the analysis of mean monthly NDVI versus rainfall (Before filtering).

	Station	Slope**(lag0)	R^2 (lag 0)	Slope**(lag1)	R^2 (lag 1)
BIMODAL	Arusha	0.00001	0.0001	0.0004	***0.04****
	KIA	0.0001	0.01	0.0007	***0.10***
	Mbulu	0.0009	***0.23****	0.0013	***0.43***
	Moshi	0.0001	0.003	0.0003	***0.04***
	Same	0.0005	***0.05***	0.001	***0.24***
	Tanga	0.0002	***0.03***	0.0006	***0.24***
	Dar es Salaam	0.0003	***0.05***	0.0007	***0.26***
	Pemba	0.00001	0.004	0.0001	0.01
	Zanzibar	0.00001	0.005	0.00001	***0.04***
	Morogoro	0.0008	***0.10***	0.0012	***0.26***
	Mlingano	0.0003	***0.03***	0.0007	***0.17***
	Bukoba	0.0005	***0.23***	0.0005	***0.27***
	Musoma	0.0006	***0.12***	0.0009	***0.30***
	Mwanza	0.0004	***0.15***	0.0007	***0.36***
	Shinyanga	0.0009	***0.30***	0.0013	***0.61***
UNIMODAL	Dodoma	0.0011	***0.27***	0.0016	***0.58***
	Hombolo	0.0012	***0.20***	0.0017	***0.43***
	Singida	0.0013	***0.25***	0.0019	***0.57***
	Iringa	0.0017	***0.40***	0.0021	***0.63***
	Mahenge	0.0004	***0.25***	0.0006	***0.39***
	Mbeya	0.0004	***0.07***	0.0008	***0.30***
	Mpanda	0.0011	***0.36***	0.0012	***0.47***
	Kigoma	0.0007	***0.16***	0.0007	***0.24***
	Tabora	0.0009	***0.32***	0.0011	***0.54***
	Mtwara	0.0006	***0.17***	0.0009	***0.38***
	Songea	0.0005	***0.20***	0.0007	***0.36***
	Kilwa	0.0011	***0.24***	0.0014	***0.36***
	Lindi	0.0010	***0.22***	0.0015	***0.42***
	Tunduru	0.0006	***0.18***	0.0009	***0.36***

*Bolded and italic R^2 are significant at significance level of $p=0.05$, $n=324$.

** Slope here is the same as regression coefficient.

Table B3. Regression results from the analysis of mean monthly NDVI and rainfall after filtering using Savitsky-Golay method.

	Station	Slope**(lag0)	R^2 (lag 0)	Slope**(lag1)	R^2 (lag 1)
BIMODAL	Arusha	0.00063	***0.12***	0.0007	***0.15***
	KIA	0.00049	***0.08***	0.0006	***0.12***
	Mbulu	0.00101	***0.35***	0.0013	***0.59***
	Moshi	0.00022	0.01	0.0003	***0.03***
	Same	0.00092	***0.20***	0.0012	***0.30***
	Tanga	0.00049	***0.11***	0.0007	***0.25***
	Dar es Salaam	0.00048	***0.11***	0.0008	***0.34***
	Pemba	0.00001	0.0003	0.00003	0.003
	Zanzibar	-0.00001	0.0003	0.00003	0.01
	Morogoro	0.0008	***0.10***	0.0012	***0.26***
	Mlingano	0.00022	***0.04***	0.0005	***0.15***
	Bukoba	0.00062	***0.44****	0.0006	***0.37***
	Musoma	0.00077	***0.23***	0.0009	***0.34***
	Mwanza	0.00068	***0.39***	0.0009	***0.58***
	Shinyanga	0.00114	***0.48***	0.0015	***0.79***
UNIMODAL	Dodoma	0.00145	***0.44***	0.0019	***0.73***
	Hombolo	0.00135	***0.29***	0.0018	***0.53***
	Singida	0.00148	***0.40***	0.0020	***0.71***
	Iringa	0.00208	***0.57***	0.0024	***0.76***
	Mahenge	0.00050	***0.40***	0.0006	***0.59***
	Mbeya	0.00040	***0.09***	0.0009	***0.41***
	Mpanda	0.00112	***0.56***	0.0013	***0.70***
	Kigoma	0.00045	***0.48***	0.0005	***0.56***
	Tabora	0.00104	***0.48***	0.0013	***0.72***
	Mtwara	0.00070	***0.29***	0.0010	***0.53***
	Songea	0.00057	***0.34***	0.0008	***0.59***
	Kilwa	0.00109	***0.34***	0.0013	***0.48***
	Lindi	0.00111	***0.33***	0.0015	***0.57***
	Tunduru	0.00059	***0.27***	0.0009	***0.55***

*Bolded and italic R^2 are significant at significance level of p=0.05, n=324

Appendix C

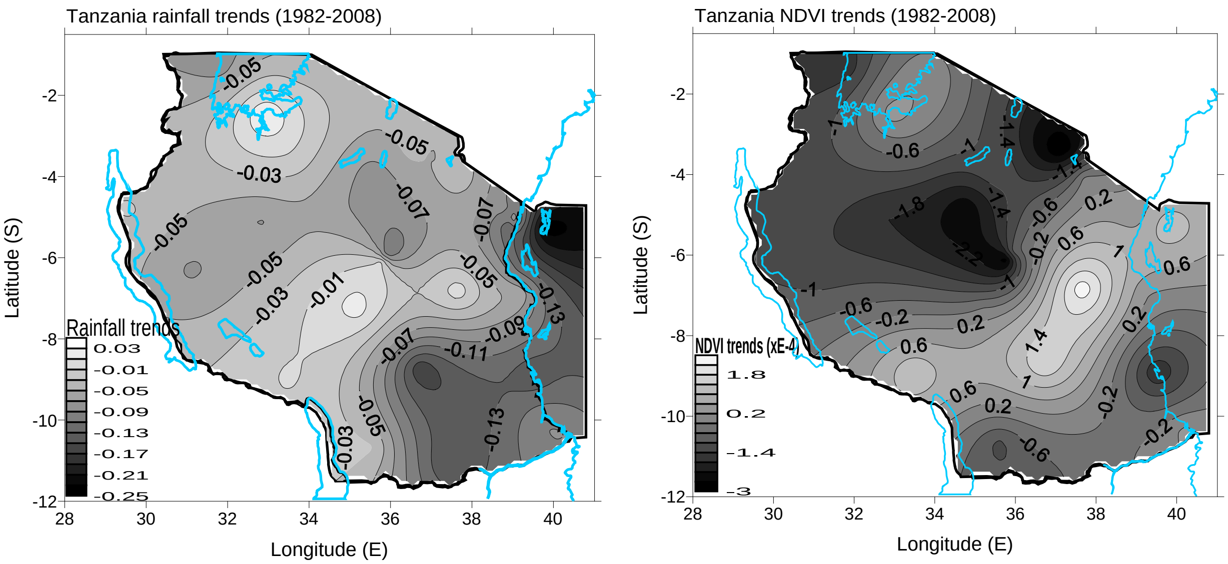


Figure C1. *Rainfall and NDVI (x10-4) trends during 1982 to 2008 period*

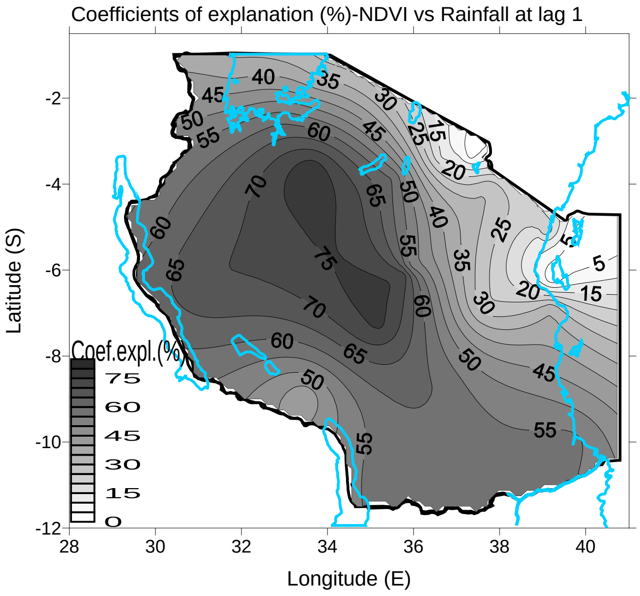


Figure C2. *Coefficients of explanation between mean monthly NDVI versus rainfall at lag 1.*

References.

Ahrens, C. D. (2009). *Meteorology Today* (9th ed.), Brooks/Cole Cengage Learning, Belmont, USA.

Anyah, R.O., Semazzi, F.H.M., and Xie, L. (2006). Simulated physical mechanisms associated with climate variability over Lake Victoria Basin in East Africa. *Mon. Wea. Rev.,* **134**: 3588-3609.

Anyah R.O, Semazzi, F.H. (2006). Climate variability over the Greater Horn of Africa based on NCAR AGCM ensemble. *Theoretical and Applied Climatology*, **86**: 39–62.

Anyamba, A and Tucker, C.J. (2005). Analysis of Sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981–2003. *Journal of Arid Environments,* **63**: 596–614.

Anyamba A., Tucker C.J. and Mahoney, R. (2002). From El Niño to La Niña: Vegetation response patterns over East and Southern Africa during the 1997-2000 period. *Journal of Climate*, **15**:3096-3103.

Anyamba A., Tucker C.J. and Eastman, J.R. (2001). NDVI anomaly pattern over East Africa during the 1997/98 ENSO warm event. *Int. J. Remote Sensing*, **22**(10):1847-1859.

Basalirwa C.P.K., Odiyo, J.O., Mngodo, R.J., and Mpeta, E.J. (1999). The climatological regions of Tanzania based on the rainfall characteristics. *Int.J.Climatol*., **19**: 69-80.

Bellone, T.,Boccardo, P. and Perez, F. (2009). Investigation of vegetation dynamics using long-term Normalized Difference Vegetation Index time series. *American Journal of Enviromental Sciences* **5**(4): 460-466.

Camberlin, P., Moron, V., Okoola, R., Philippon, N. and Gitau, W. (2009). Components of rainy seasons’ variability in Equatorial East Africa: Onset, Cessation, rainfall frequency and intensity. *Theor. Appl. Climatol.,* **98**: 237-249.

Camberlin, P. and Okoola, R. E. (2003). The onset and cessation of the ‘‘long rains’’ in eastern Africa and their interannual variability. *Theor. Appl. Climatol.* **75**: 43–54

CEEST. (1999). Climate change mitigation in southern Africa: Tanzania country study: UNEP collaborating centre on energy and environment, Riso National Laboratory, Denmark (Accessed September 17, 2010) http://uneprisoe.org/EconomicsGHG/Tanzania.pdf

Cracknell, A.P. (2001). The exciting and totally unanticipated success of the AVHRR in applications for which it was never intended. *Advances in Space Research*, **28**: 233–240.

Davenport M.L and Nicholson S.E. (1993). On the relation between rainfall and the Normalized Difference Vegetation Index for diverse vegetation types in East Africa, *Int. J. Remote Sensing*, **14** (12): 2369-2389.

Diouf A., Lambin E. F. (2001). Monitoring land cover changes in semi arid regions: Remote sensing data and field observations in the Ferlo. Senegal, *Journal of Arid Environments* **48** (2):129-148.

Diwakar, P.G., Prabhakar, P., Venkataramana, I., and Devarajan, R. (1989). Derivation of maximum value composite images using multdate NOAA-AVHRR data. *Journal of Indian Society of Remote Sensing*, **17** (1): 1-6.

Eklundh L. (1996). AVHRR NDVI for monitoring and mapping of vegetation and drought in East African environments. *PhD thesis*, Lund University, Sweden.

Eklundh L. (1998). Estimating relations between AVHRR NDVI and rainfall in East Africa at 10-day and monthly time scales, *Int. J. Remote Sensing*,**19**(3): 563-568.

Eklundh, L. & Olsson, L. (2003). Vegetation index trends for the African Sahel 1982-1999. *Geophysical Research Letters*, **30**(8): 1430-1433.

Eklundh, L. and Jönsson, P. (2009). Timesat 3.0 Software Manual, Lund University, Sweden.

Indeje M., Semazzi F. H. M. and Ogallo L. J. (2000). ENSO signals in East African rainfall seasons. *Int. J. Climatol*., **20** (1): 19-46.

Ingram C.J and Dawson T.P. (2005). Climate change impacts and vegetation response on the island of Madagascar. Phil. *Trans. R. Soc. A.*, **363**: 55-59.

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 [Solomon S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. pp. 751.

Jia, G. J., Epstein, H. E. and D. A. Walker. (2003). Greening of arctic Alaska, 1981–2001, *Geophys. Res. Lett.*, **30**(20): 2067.

Jönsson, P., and Eklundh, L. (2002). Seasonality extraction and noise removal by function fitting to time-series of satellite sensor data, IEEE Transactions of Geoscience and Remote Sensing, **40**(8): 1824 – 1832.

Jönsson, P., and Eklundh, L. (2004). TIMESAT - a program for analysing time-series of satellite sensor data. Computers and Geosciences, **30**: 833-845.

Kawabata, A., Ichii, K. and Yamaguchi, Y. (2001). Global monitoring of interannual changes in vegetation activities using NDVI and its relationships to temperature and precipitation. *Int. J. Remote Sensing*. **22**(7): 1377-1382.

Kangalawe, R.Y.M. (2009). Land use /cover changes and their implications on rural livelihoods in the degraded environments of central Tanzania. *Afr. J. Ecol*., **47**: 135–141.

Kanyanga J., Adosi J., Bulane L., Fortunata L., Mdoka M L and Lajoie R. (2006). Evidence of trends in daily climate extremes over southern and West Africa. *Journal of Geophysical research*, **111**, D14102, doi:10.1029/2005JD006289.

Kijazi, A.L. and Reason C.J.C. (2009). Analysis of the 2006 Floods over Northern Tanzania. *Int. J. Climatol*. **29**: 955-970.

Lillesand, T.M., Kiefer, R.W. and Chipman, J.W. (2007). Remote sensing and image interpretation (6th ed.). John Wiley & Sons, Inc. New York.

Marchant, R., Mumbi, C., Behera, S.,Yamagata, T. (2006). The Indian Ocean dipole-the unsung driver of climatic variability in East Africa. *Afr. J. Ecol*., **45**: 4–16.

Mapande A.T and Reason J.C. (2005). Interannual rainfall variability over western Tanzania. *Int. J. Climatol*., **25**: 1355-1368.

Mukabana, J.R, Pielke, R.A. (1996). Investigating the influence of synoptic-scale monsoonal winds and mesoscale circulations and diurnal weather patterns over Kenya using a mesoscale numerical model. *Monthly Weather Review*, 124: 224–243.

Mutai, C.C, Ward, M.N, Colman. A.W. (1998). Towards the prediction of the East Africa short rains based on sea-surface temperature-atmosphere coupling. *Int. J. Climatol.*, 18: 975–998.

Mwanukuzi, P. (2010). Impact of non-livelihood-based land management on land resources: the case of upland watersheds in Uporoto Mountains, South West Tanzania. *The Geographical Journal*. **177**(1): 27–34.

Myneni, R. B., Los, S. O., and Tucker, C. J. (1996). Satellite-based identification of linked vegetation index and sea-surface temperature anomaly areas from 1982-1990 for Africa, Australia and South America. *Geophysical Research Letters*, **23**: 729-732.

Nagai.S.,Ichii,K and Morimoto,H. (2007). Interannual variations in vegetation activities and climate variability caused by ENSO in tropical rainforests. *Int.J. Remote Sensing*. **28**(6): 1285-1297.

New M., Hewitson B., David B., S., Tsiga A., Kruger A., Manhique A., Gomez,B., Coelho A. S.C., Masisi,D.N., Kululanga N., Mbambalala E.,Adesina F., Saleh H.,

Nicholson, S. E., Davenport, M. L., and Malo, A. R. (1990). A Comparison of the vegetation response to rainfall in the Sahel and East Africa, using Normalized Difference Vegetation Index from NOAA AVHRR. *Climatic Change*, **17**: 209-241.

Nicholson, S. E., and Farrar, T. J. (1994). The influence of soil type on the relationships between NDVI, rainfall, and soil moisture in semiarid Botswana. I. NDVI response to rainfall. *Remote Sensing of Environment*, **50:** 107-120.

Nicholson, S.E. (1996a). A review of climate dynamics and climate variability in eastern Africa. In Limnology, Climatology and Paleoclimatology of the East African Lake, Johnson TC, Odada E (eds). Gordon and Breach: Amsterdam; 57–78.

Nicholson, S.E. (1996b). Victoria lake-level modeling aims to predict basin rainfall. *IDEAL Bulletin* (Spring): **5**.

Ntale H.K. and Gan T.Y. (2004). East African rainfall anomaly patterns in association with El Niño/Southern Oscillation. *Journal of Hydrologic Engineering*, **9** (4): 257-268.

Oettli, P., Camberlin, P. (2005). Influence of topography on monthly rainfall distribution over East Africa. *Clim. Res* **28**: 199-212.

Ogallo, L. J. (1988). Relationship between seasonal rainfall in East Africa and southern oscillation. *Journal of Climate*. **8**: 34-43.

Ogutu J.O., Piepho H.P., Dublin H.T., Bhola N. and Reid R.S. (2007). El Niño-Southern Oscillation, rainfall, temperature and Normalized Difference Vegetation Index fluctuations in the Mara-Serengeti ecosystem. *African Journal of Ecology*, **46**(2) : 132-143.

Okeyo, A. E. (1987). The influence of Lake Victoria on the convective activities over the Kenya *Highlands. J. Meteor. Soc. Japan,* 65: 689–695.

Pelkey N.W, Stoner C.J and Caro T.M. (2000). Vegetation in Tanzania: Assessing long term trends and effects of protection using satellite imagery. *Biological Conservation,* **94**: 297-309.

Plisnier, P.D., Serneels, S. and Lambin, E.F. (2000). Impact of ENSO on East African ecosystems: A multivariate analysis based on climate and remote sensing data. *Global Ecology and Biogeography,* **9** (6): 481-497.

Propastin, P., Fotso, L and Kappas, M. (2010). Assessment of vegetation vulnerability to ENSO warm events over Africa. *International Journal of Applied Earth Observation and Geoinformation,***125** : 583-589.

Saji, N.H., Yamagat.T. (2003). possible impacts of Indian Ocean Dipole mode on global climate. *Clim. Res*. **25**:151-169.

Salim H.A., Xiaoling, C., Jianya, G., Haiyan, W and Li, Z. (2009). Analysis of China vegetation dynamics using NOAA-AVHRR data from 1982 to 2001. *Geo-spatial Information Science,* **12**(2). 146-153.

Schreck, C.J and Semazzi, F.H.M. (2004). Variability of the recent climate of the Eastern Africa. *Int.J.Climatol*., **24**: 681-701

Schrumpf, M., Axmacher, J.C., Zech, W and Lyaruu, H. V. M. (2011). Net precipitation and soil water dynamics in clearings, old secondary and old-growth forests in the montane rain forest belt of Mount Kilimanjaro, Tanzania. *Hydrol. Process*, **25**: 418–428.

Serneels, S., Linderman, M., and Lambin, E. F. (2007). A Multilevel Analysis of the Impact of Land Use on Interannual Land-Cover Change in East Africa. *Ecosystems,* **10**: 402–418.

Shaw, G. and Wheeler, D. (1994). Statistical Techniques in Geographical Analysis (2nd Ed.) David fulton Publishers Ltd, London.

Shisanya, C. A., Recha, C. and Anyamba, A. (2011). Rainfall Variability and Its Impact on Normalized Difference Vegetation Index in Arid and Semi-Arid Lands of Kenya. *International Journal of Geosciences,* **2**: 36-47.

Song, Y., Semazzi F. H. M., Xie, L. and Ogallo, L. J. (2004). A Coupled regional climate model for the Lake Victoria basin of eastern Africa. *Int. J. Climatol*., **24**: 57–75.

Sun, L., Semazzi F. H. M, Giorgi, F., and Ogallo, L. (1999). Application of the NCAR Regional Climate Model to eastern Africa 2. Simulation of Interannual Variability of Short Rains, J. Geophys. Res., **104**(6): 6549–6562.

Tilya, F. F. (2007). Characteristics of Wet and Dry Spells in Tanzania during the Rainy Seasons, M.Sc. Thesis. University of Nairobi, Kenya.

Tobler, M.W., Cochard, R and Edwards, P.J. (2003). The impact of cattle ranching on large-scale vegetation patterns in a coastal savanna in Tanzania. *Journal of Applied Ecology*, **40**: 430-444.

Tucker, C.J., Pinzon, J.E., Brown, M.E., Slayback, D., Pak, E.W., Mahoney,R., Vermote, E. and El Saleous, N. (2005). An extended AVHRR 8-km NDVI data set compatible with MODIS and SPOT vegetation NDVI data. *Int.J. Remote Sensing,* **26**: 4485-4498.

Tucker, C.J., Pinzon, J.E and Brown, M. E. (2010), Global Inventory Modeling and Mapping Studies, Global Land Cover Facility, University of Maryland, College Park, Maryland. http://glcf.umiacs.umd.edu/data/gimms/.

Yin, X. and Nicholson, S.E. (1998). The water balance of Lake Victoria. *Hydrological Sciences Journal,* **43**: 789–811.

Yonah.,I.B, Kikwasi, W.K, and Timiza,W.M. (2009). Implication of the acute drought in Tanzania during 2005 cropping season. *Reserch Journal of Tanzania Meteorological Agency*. **2.**

Zorita, E. and Tillya, F.F. (2002). Rainfall variability in Northern Tanzania in the March-May season (long rains) and its links to large scale climate forcing. *Clim. Res*. **20:** 31-40.

Internet Resources

Bourke, (1996) Cross correlation. <http://paulbourke.net/miscellaneous/correlate/ -viewed 23Jan 2011>

FAO (2002) Africover <http://www.africover.org/webmap.htm>(Accessed February 23, 2011)

Global Land Cover Facility (GLCF) http://www.glcf.umd.edu/library/guide/GIMMSdocumentation_NDVIg_GLCF.pdf, 2010

Kauzeni A.S., Kikula, I.S., Mohamed, S.A., Lyimo, J.G. and Clayton D.B.D. (1993) Land Use Planning and Resource Assessment in Tanzania: A case study. *IRA Research Paper No. 35 <http://pubs.iied.org/pdfs/7751IIED.pdf>*

NOAA (2011), Cold and warm episodes by season, *Climate Prediction Center* <http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml>(Accessed February 2, 2011).

TMA (2011) Weather forecasting and data. <http://www.meteo.go.tz/>(Accessed, 2011)

URT (2011) Country profile < http://www.tanzania.go.tz/landsf.html>(Accessed March 5,2011)

Previous reports

Lunds Universitets Naturgeografiska institution. Seminarieuppsatser. Uppsatserna finns tillgängliga på Naturgeografiska institutionens bibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på http://www.geobib.lu.se/

The reports are available at the Geo-Library, Department of Physical Geography, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden.
Report series started 1985. The whole complete list and electronic versions are available at http://www.geobib.lu.se/

157 Öberg, Hanna (2009): GIS-användning i katastrofdrabbade utvecklingsländer
158 Marion Früchtl &Miriam Hurkuck (2009): Reproduction of methane emissions from terrestrial plants under aerobic conditions
159 Florian Sallaba (2009): Potential of a Post-Classification Change Detection Analysis to Identify Land Use and Land Cover Changes. A Case Study in Northern Greece
160 Sara Odelius (2009): Analys av stadsluftens kvalitet med hjälp av geografiska informationssystem.
161 Carl Bergman (2009): En undersökning av samband mellan förändringar i fenologi och temperatur 1982-2005 med hjälp av GIMMS datasetet och klimatdata från SMHI.
162 Per Ola Olsson (2009): Digitala höjdmodeller och höjdsystem. Insamling av höjddata med fokus på flygburen laserskanning.
163 Johanna Engström (2009): Landskapets påverkan på vinden -sett ur ett vindkraftperspektiv.
164 Andrea Johansson (2009): Olika våtmarkstypers påverkan på CH_4, N_2O och CO_2 utsläpp, och upptag av N_2.
165 Linn Elmlund (2009): The Threat of Climate Change to Coral Reefs
166 Hanna Forssman (2009): Avsmältningen av isen på Arktis - mätmetoder, orsaker och effekter.
167 Julia Olsson (2009): Alpina trädgränsens förändring i Jämtlands- och Dalarnas län över 100 år.
168 Helen Thorstensson (2009): Relating soil properties to biomass consumption and land management in semiarid Sudan – A Minor Field Study in North Kordofan
169 Nina Cerić och Sanna Elgh Dalgren (2009): Kustöversvämningar och GIS - en studie om Skånska kustnära kommuners arbete samt interpolationsmetodens betydelse av höjddata vid översvämningssimulering.
170 Mats Carlsson (2009): Aerosolers påverkan på klimatet.
171 Elise Palm (2009): Övervakning av gåsbete av vass – en metodutveckling
172 Sophie Rychlik (2009): Relating interannual variability of atmospheric CH_4 growth rate to large-scale CH_4 emissions from northern wetlands
173 Per-Olof Seiron and Hanna Friman (2009): The Effects of Climate Induced Sea Level Rise on the Coastal Areas in the Hambantota District, Sri Lanka - A

geographical study of Hambantota and an identification of vulnerable ecosystems and land use along the coast.

174 Norbert Pirk (2009): Methane Emission Peaks from Permafrost Environments: Using Ultra–Wideband Spectroscopy, Sub-Surface Pressure Sensing and Finite Element Solving as Means of their Exploration
175 Hongxiao Jin (2010): Drivers of Global Wildfires — Statistical analyses
176 Emma Cederlund (2010): Dalby Söderskog – Den historiska utvecklingen
177 Lina Glad (2010): En förändringsstudie av Ivösjöns strandlinje
178 Erika Filppa (2010): Utsläpp till luft från ballastproduktionen år 2008
179 Karolina Jacobsson (2010):Havsisens avsmältning i Arktis och dess effekter
180 Mattias Spångmyr (2010): Global of effects of albedo change due to urbanization
181 Emmelie Johansson & Towe Andersson (2010): Ekologiskt jordbruk - ett sätt att minska övergödningen och bevara den biologiska mångfalden?
182 Åsa Cornander (2010): Stigande havsnivåer och dess effect på känsligt belägna bosättningar
183 Linda Adamsson (2010): Landskapsekologisk undersökning av ädellövskogen i Östra Vätterbranterna
184 Ylva Persson (2010): Markfuktighetens påverkan på granens tillväxt i Guvarp
185 Boel Hedgren (2010): Den arktiska permafrostens degradering och metangasutsläpp
186 Joakim Lindblad & Johan Lindenbaum (2010): GIS-baserad kartläggning av sambandet mellan pesticidförekomster i grundvatten och markegenskaper
187 Oscar Dagerskog (2010): Baösberggrottan – Historiska tillbakablickar och en lokalklimatologisk undersökning
188 Mikael Månsson (2010): Webbaserad GIS-klient för hantering av geologisk information
189 Lina Eklund (2010): Accessibility to health services in the West Bank, occupied Palestinian Territory.
190 Edvin Eriksson (2010): Kvalitet och osäkerhet i geografisk analys - En studie om kvalitetsaspekter med fokus på osäkerhetsanalys av rumslig prognosmodell för trafikolyckor
191 Elsa Tessaire (2010): Impacts of stressful weather events on forest ecosystems in south Sweden.
192 Xuejing Lei (2010): Assessment of Climate Change Impacts on Cork Oak in Western Mediterranean Regions: A Comparative Analysis of Extreme Indices
193 Radoslaw Guzinski (2010) Comparison of vegetation indices to determine their accuracy in predicting spring phenology of Swedish ecosystems
194 Yasar Arfat (2010) Land Use / Land Cover Change Detection and Quantification — A Case study in Eastern Sudan
195 Ling Bai (2010) Comparison and Validation of Five Global Land Cover Products Over African Continent
196 Raunaq Jahan (2010) Vegetation indices, FAPAR and spatial seasonality analysis of crops in southern Sweden

197 Masoumeh Ghadiri (2010) Potential of Hyperion imagery for simulation of MODIS NDVI and AVHRR-consistent NDVI time series in a semi-arid region

198 Maoela A. Malebajoa (2010) Climate change impacts on crop yields and adaptive measures for agricultural sector in the lowlands of Lesotho

199 Herbert Mbufong Njuabe (2011) Subarctic Peatlands in a Changing Climate: Greenhouse gas response to experimentally increased snow cover

200 Naemi Gunlycke & Anja Tuomaala (2011) Detecting forest degradation in Marakwet district, Kenya, using remote sensing and GIS

201 Nzung Seraphine Ebang (2011) How was the carbon balance of Europe affected by the summer 2003 heat wave? A study based on the use of a Dynamic Global Vegetation Model; LPJ-GUESS