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Spatial Assessment of NDVI as an Indicator of Desertification in Ethiopia using Remote Sensing and GIS

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By

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Master degree thesis in

Physical Geography and Ecosystem Science

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Abbreviations

a.s.l	Above sea level
AVHRR	Advanced Very High Resolution Radiometer
EO	Earth Observation
EPA	Environmental Protection Authority
FAO	Food and Agriculture Organization of United Nations
FEWS	Famine Early Warning System
GIMMS	Global Inventory Modeling and Mapping Studies
GPM	Global Precipitation Measurement
MODIS	Moderate Resolution Imaging Spectroradiometer
MVC	Maximum Value Composite
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NMSA	National Meteorology Services Authority
NOAA	National Oceanic and Atmospheric Administration
n.d.	No date
TRMM	Tropical Rainfall Measuring Mission
UN	United Nations
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization

Abstract

Desertification is a serious environmental and socio-economic problem occurring at global, regional and local scale. According to Article 1(a) of the United Nations Convention to Combat Desertification (UNCCD), define the term "desertification" means "land degradation in arid, semi-arid and dry sub-humid (dry lands) areas resulting from various factors, including climatic variations and human activities". If a trend of vegetation cover is negative, then it can be a sign of ongoing desertification processes. The Normalize Differences in Vegetation Index (NDVI) derived from the long term (1982-2006) NOAA AVHRR satellite's sensor and observed rainfall data at climate stations are used and analyzed to monitor desertification processes through NDVI and rainfall trends over time in Ethiopia. Vegetation cover naturally depends on precipitation. The suggested methodology called linear regression has been validated using vegetation trends as a proxy for degradation processes.

Results show that at climate stations level, more than 80% of the stations have strong correlation(r) between NDVI and rainfall. A majority of the stations have no trend of NDVI and rainfall over time. Sixteen percent of the stations have experienced an increase and four percent of the stations a decrease both in NDVI and rainfall. The NDVI trend map, which is derived from 8_km AVHRR GIMMS satellite's sensors, shows that a majority of the study area has no significant NDVI trend ($p<0.05$). More than 40% of the area has experienced a positive trend in vegetation cover ("greening") and less than 6% of the area has experienced a decrease in vegetation. This over all positive trends is not in line with the previous study acclaiming widespread and irreversible degradation in Ethiopia.

Keywords:
Climate Change, Land Degradation, Desertification, Land Cover, NOAA AVHRR, NDVI Rainfall.

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CHAPTER 1

1.Introduction

1.1 Background

Desertification is a serious environmental and socio-economic problem occurring at different scale (global, regional and local). The process of desertification and its consequences are devastating for the environments, socio-economic and political stability of the countries where they occur. More than one billion people globally, most of them among the poorest in the world are affected by desertification. These people, accounting to approximately one quarter of the world's population, are vulnerable for different challenges including soil degradation and vegetation loss, which might lead to deterioration of arable land and eventually to chronic food insecurity.

Rainfall in Ethiopia is highly erratic and most of very high intensity and its distribution varies spatially and temporally (Fig 1, right side). Such variability is a threat to an agricultural industry that relies heavily on rain feed agriculture since it has been very vulnerable to phenomena caused by rainfall extremes such as annual droughts and intra-seasonal dry spells as well as floods particularly in the lowland areas (FAO, 1986).

Common crops in central, north and southeastern highland area of Ethiopia are (Figure 1, left side): wheat, teff, barley, oats, maize, sorghum, millet, pulse and oil seeds. In the southern and southwestern areas, dominating crops are enset, coffee, chat, yams, taros, sweet potatoes, potatoes, tobacco, vegetables and maize (EPA, 1998). Highlands and lowlands represent the topographical elevation of an area above and below 1500 meters a.s.l respectively (NMSA, 2001). The main causes of land degradation in Ethiopia are: Overgrazing, deforestation, and poor sustainable land management practices. More than 90% of the population and cultivated lands are located in highland of Ethiopia (Hawando, 1997). Desertification is the continual degradation of dry land ecosystems by climate variations and human activities.

According to Reining (1978) indicators are useful to assess and monitor desertification. They can be grouped into the following: physical (measurement) indicator, biomass (vegetation) indicator and social (settlement) indicators. This study has been limited to use of the common vegetation index from remote sensing dataset called Normalized Difference Vegetation Index (NDVI) and rainfall data that have been collected from 25 climate stations in order to visualize the spatial patterns of natural vegetation. Therefore, this study will contribute towards identifying areas under desertification using trend of NDVI and to rainfall distribution in Ethiopia. The report of the result can be used as a background document for further study.

Normalized Difference Vegetation Index (NDVI) and rainfall have been considered as indicators to study desertification. The two growing seasons in Ethiopia are the “Belg” and the “Meher” seasons, which receive rainfall from February to June and from June to October, respectively. The “Meher” season is the main season and produces more than 90% of the national’s total cereals products, and the “Belg” provides the remaining cereal products.

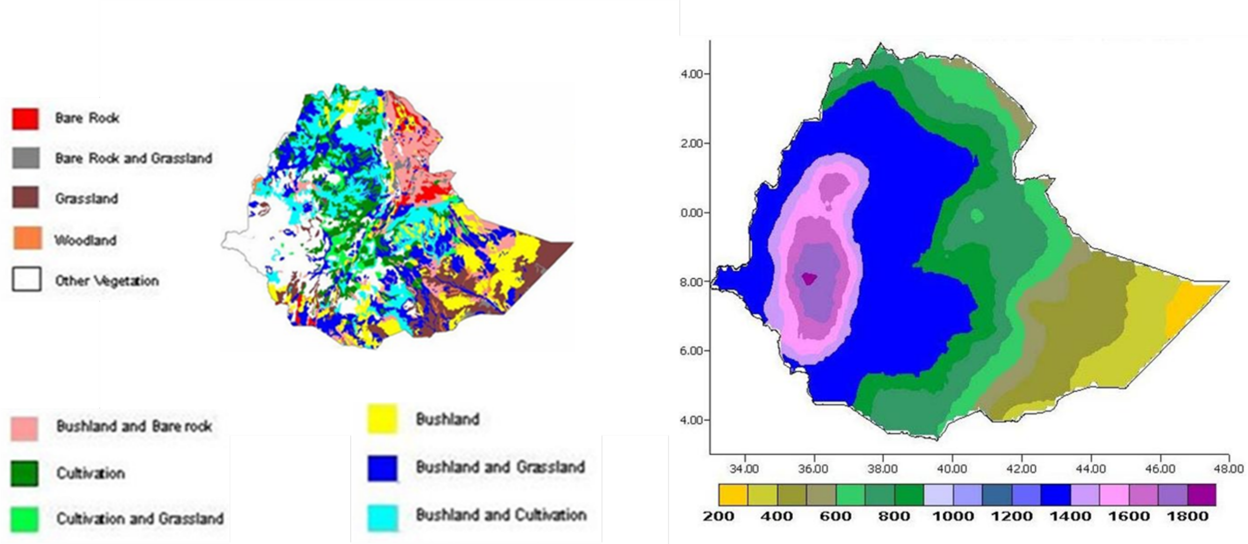

Figure 1: Long-term average annual rainfall distribution in mm (right) as adapted from FAO (1984a) in Mengistu (2000) and vegetation cover (left) as modified after White (1983) in Mengistu (2000).

1.2 Study Area

The study has been carried out in Ethiopia with special emphasis given to the dryland part of the country. Ethiopia is located in the eastern part of Africa between 3°-15° N latitude and 33°-48° E longitude (Figure 2). In 2013 census, the country has a population size of 86.6 million and about 85 percent of the total populations are engaged in small-scale agriculture. Irrigation system has not yet been well developed, so that the farmers depend on rain fed agriculture system. It has a tropical monsoon climate with wide elevation variation. There are three climatic zones. These zones are: a cool zone in the central part across the western and eastern section of the highland from 2400 to 4620 meters above mean sea level; a temperate zone lies between 1,500 and 2,400 meter altitude a.s.l and the hot low lands below 1,500 meters (NMSA, 2001). The annual average temperature varies from less than 7 - 12ºC in the cool zone to above 25ºC in the hot lowlands (NMSA, 2001).

According to Hawando (1997), the total area of Ethiopia at risk of desertification is approximately 71.5% of the country. Due to differences in topographical altitude, which ranges between the peak 4560 meters above sea level at Ras Dashen mountain to 220 meters below sea level at Afar depression in the north east (EPA, 1998), the dryland of Ethiopia is categorized into different climatic zones called arid, semi-arid & dry sub-humid area. It covers approximately 75% of the whole area (FAO, 2010). The dry sub-humid areas from 1200-2700 meters a.s.l in altitude and receives of annual rainfall from 642-1117 mm with a corresponding evapo-transpiration from 1312-1790 mm per year, whereas the arid and hyper-arid receive range of annual rainfall between 28 to 406 mm (Hawando, 1997).

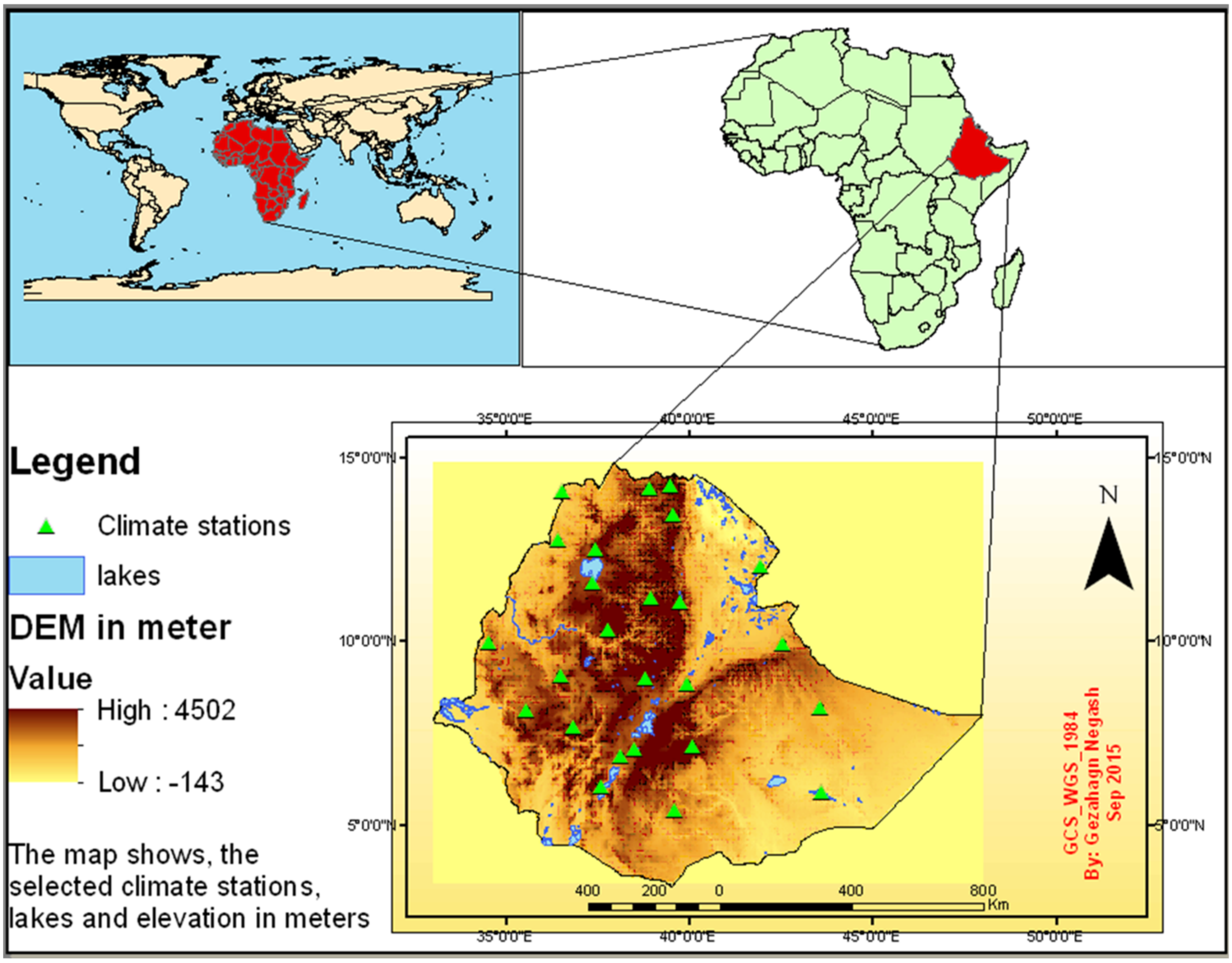

Figure 2: Study Area.

1.3 Statement of the problem

Africa has a great potential to undertake both large and small-scale activities in order to maintain food security and sustainable development, which is directly related to the environment and socio-economic issues. However, many challenges limit the potential of this continent such constraints are: climate change and variability, extreme weather event such as drought & floods, lack of sustainable land use management, land degradation and desertification. “A further threat to Africa realizing the full potential of its land resource is desertification (UNEP, 2008)”.

“The Ethiopian highlands cover 44% the country’s total area and some of 27 million ha representing approximately 50% of the highlands are already significantly degraded (Hawando, 1997, pp: 76)”. If this trend keeps in this way, then production yield per head will be decrease by 30% in highlands area in 20 years (FAO, 1984b). Land degradation and desertification are the main challenges of this country and have resulted in vulnerable to drought and famine in 1972/73 and 1984/85 (Hawando, 1997).

1.4 Objectives

The main aim of this study is to assess desertification in Ethiopia using remote sensing and rainfall data during the study period 1982-2006. In order to reach the main aim, the following specific objectives are studied:

1. Investigate significant spatial trends in NDVI over the study period 1982-2006.
2. Investigate significant spatial trends in rainfall over the study period 1982-2006.
3. Investigate the correlation between NDVI and rainfall at climate station level.
4. Analyze whether trends in NDVI and rainfall indicate widespread desertification in Ethiopia.

1.5 Scope and limitation of the study

This study is limited to NDVI and rainfall datasets analysis in relation to desertification. So, due to financial limitation, it does not includes others climate factors and human involvement as indicators of desertification. The analysis is based on monthly Maximum Value Composite of NDVI with respect to three-month cumulative rainfall data in mm at 25 selected sample climate stations.

CHAPTER 2

2. Theory

2.1 The Concept of desertification

Aubreville (1949), defined desertification as the changing of productive land into a desert as the result of an irrecoverable state of devastation and destruction of land by man-induced soil erosion. The researcher at that time concluded that desertification in tropical Africa was due to man's activity and not as a result of the Sahara spreading or climatic causes. In the 1960s, the term "desertification" has been connected with exceptional and terrible drought situation in Sahelian Africa and the scientific community and international cooperation at that time also considered desertification as a local development problem, requiring local solutions (Requier & Caron, 2005). Afterwards, desertification was often understood by the media to mean desert advance. Satellite data information in the early 1980s showed an increase in the photosynthetic activity in African Sahel region (Eklundh & Olsson, 2003; Olsson et al., 2005; Hermann et al., 2005; Seaquist et al., 2006; & Heumann et al., 2007). Recent research has evoked re standing debate about the direct impact of people on Sahel regions (Hein & de Ridder, 2006; & Prince et al., 2007). Even more recent finding using data from the same satellite sensor showed that there is no significant evidence to support that people have had impact on vegetation dynamics across the Sahel for the period of 1982-2002 (Seaquist et al., 2009).

The term land degradation and desertification are sometimes used interchangeably but the two terminologies are distinct. According to Article 1(a) of the United Nations Convention to Combat Desertification, define the term "desertification" means "land degradation in arid, semi-arid and dry sub-humid (dry lands) areas resulting from various factors, including climatic variations and human activities (UNCCD, 1994; UN, 1994; Reynolds & Stafford, 2002)." Since 1990 this debate has been changed. Desertification is now considered to be an issue of sustainable development and global environment. In reality, it is a multi-dimensional (climatic, biophysical and social) complex process, which leads to both decreasing natural environment fertility and expanding poverty. Besides, desertification is not limited to arid areas, but also affects the semi-arid and sub-humid regions of the earth. Desertification is a global issue, which are both a natural phenomenon and a process induced by human activities (Brabant, 2010). According to the same source, desertification is a process involving soil erosion and/or land degradation that occurs in environments under low rainfall conditions. Desertification consequently describes an irreversible decline or destruction affecting the biological potential of lands and their capacity to sustain or feed the populations. Brabant (2010) defined land degradation "as a process that diminishes or destroys the agricultural crop or livestock and forest production capacity of land. It is induced by human activities or can be natural phenomenon aggravated by the effects of human activities."

According to UNEP and FAO, desertification (degradation) categorized in three group (severe, moderate, and slight) depends on the degree of causes of land degradation, which includes water & wind erosion, water logging, salinization, pesticide as part of desertification. The measurement related to these indicators requires assessments of land degradation in arid, semiarid and sub-humid area and the status of this methodology is under revision by Land Degradation Assessment in Dryland (LADA) program and FAO (UN, 2008). Since the ratio of rainfall to potential evapo-transpiration is less than 0.65, the large areas of highlands falling under UNEP's definition of desertification (UNEP, 2008).

Desertification stages may be categorized as reversible, severe and irreversible. Degradation of natural resources leading to desertification is more pronounced in Africa and Asia than any other contents of the world (FAO, 1997). The total aridity cover in Africa (Hyper-arid, arid, semi- arid and dry sub-humid) is 21.2 million hectares. About 38% of the total aridity land is occupied by the hyper-arid category and largely located in Northern Africa regions that comprise dry land areas without vegetation, low annual rainfall (less than 100mm) with a few shrubs and an ideal area for nomadic pastoralism (FAO, 1997). The three regions of Africa (Northern, Western, and Eastern) have almost equal coverage of aridity but central Africa is largely forested and covers only 1% the total aridity zone in Africa. From eastern African countries, Sudan, Djibouti, and Somalia are largely occupied by hyper-arid, arid, and semi-arid. Kenya and Ethiopia have large area occupied by the arid and semi-arid zones. Fig 3, adapted from UNESCO teacher's guide, shows world map of aridity zones.

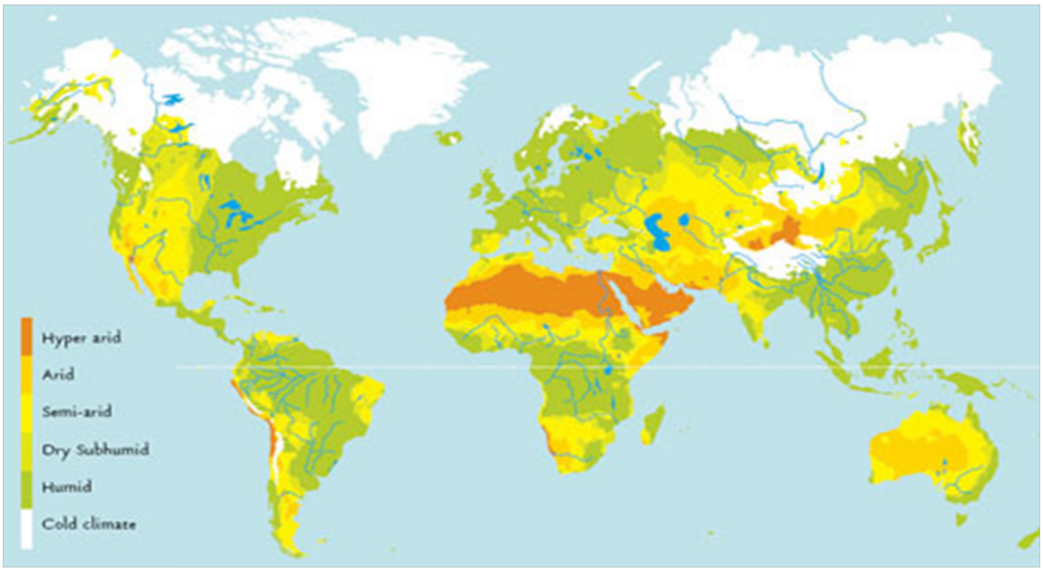

Figure 3: World map of aridity zones (UNESCO & UNCCD, n.d.)[1].

The complexity of the causes of desertification and diversity of its effects make it difficult to evaluate its magnitude with accuracy. The causes and processes that lead to desertification vary according to geographic areas and the complex interaction between climate variability and human activities. Desertification was first dealt with as a biophysical issue and nowadays, it is considered as a complex problem that involves many human-induced factors (Requier-Desjardins & Caron, 2005). According to the United Nations Convention to Combat Desertification report (UNCCD, 2004), the cause may vary from region to region on account of economic conditions, population density, agricultural practices (e.g. overgrazing, degradation of soil fertility and structure), erosion, deforestation, climate change, migration and politics.

Climate variability is one of the factors of desertification. Rainfall which vary greatly during the year and with wider fluctuations occurring over the years and decades usually resulted in insufficient moisture for vegetation growth. This ultimately leads to drought and in addition prolonged rainfall levels below average recorded levels are one of the factors for desertification. A human activity that involves lack of soil and water management practices, for example deforestation, degrades soil structure and fertility, hindrances water infiltration, and causes soil dryness promoting desertification. Population growth and its demand on agricultural resources have promoted the desertification process. Desertification brings about immediate consequences often described as the vicious circle: Land impoverishment,

[1]. Available at: http://wa1.www.unesco.org/mab/doc/ekocd/index_learning.html

agricultural production insufficient to feed all the resident population, increased social tensions and conflict and then migration.

2.2 Remote sensing and GIS

Earth observation (EO) technologies play an important part in studies, modeling and monitoring of environmental phenomena, at various spatial and temporal scales. These technologies are used for implementation of early warning and decision support systems for decision-makers to set out relevant strategies for natural resources management and sustainable development. Remote sensing is a tool; techniques and methods to observe the Earth's surface at a distance and to interpret the images to acquire information of the particular object on the Earth (Buiten & Cleavers, 1993). It is usually understood as a tool that allows studying phenomena involving only electromagnetic waves, mainly detected and recorded by sensors onboard planes or satellites. Vegetation, lands, rivers, water-covered areas, and buildings, are located on the Earth surface and interacting with electromagnetic radiation, are considered as objects. Satellite-based remote sensing is used to collect detailed information anywhere on Earth, thus enabling also to monitor environmental pollution, forest fires, earthquakes, floods, desertification, etc.

A remote sensing system is not self sufficient to generate information directly to end users. It is a tool for acquisition of spatial and temporal data in global, national and local scale. And then these data have to be analyzed together with ancillary data on the ground in order to derive understandable useful information likely to be integrated into information and decision support system is called Geographical Information System (GIS). GIS is required for creating awareness of environmental condition for varies applications including decision making towards sustainable development. It allows to follow-up and monitors the environment in the long term, to detect risk areas, to support decision-makers in defining relevant indicators, and to assess their impacts. This involves the use of data input, storage and retrieval, manipulation and analysis and output and reporting. These are accomplished using different software developed by different venders. The final product of GIS applications includes suitability maps for various land uses, resources availability and vulnerability maps.

2.3 Indicators

Once the researchers understand the processes and identified the indicators that characterize the phenomenon in a given area. Then these indicators allow warning and helping local or national authorities in undertaking relevant actions of environmental management after pass through analytical techniques of spatial and temporal datasets in GIS. Within this scope, remote sensing enables to assess physical and ecological indicators.

2.3.1 NDVI

NDVI is the most common combinations of spectral bands of remotely sensed imagery for estimating green vegetation cover (Tucker, 1979; Goward et al., 1985; & Justice et al., 1985). The importance of remote sensing in assessing and monitoring desertification in arid and semi-arid regions is widely recognized and well developed in a variety of field. It involves the recording of reflected or emitted electromagnetic radiation at or from earth's surface by sensors on board an aircraft or a satellite. Electromagnetic energy can be transmitted, absorbed, scattered or reflected in the interaction process with the matter. Different features on the earth surface respond differently to incoming electromagnetic radiation. The type and condition of the feature determine the proportions of the energy reflected, absorbed and transmitted in particular wavelengths. Figure 4 shows typical reflectance curves for three basic types of earth features. These are healthy green vegetation, dry soil and clear water.

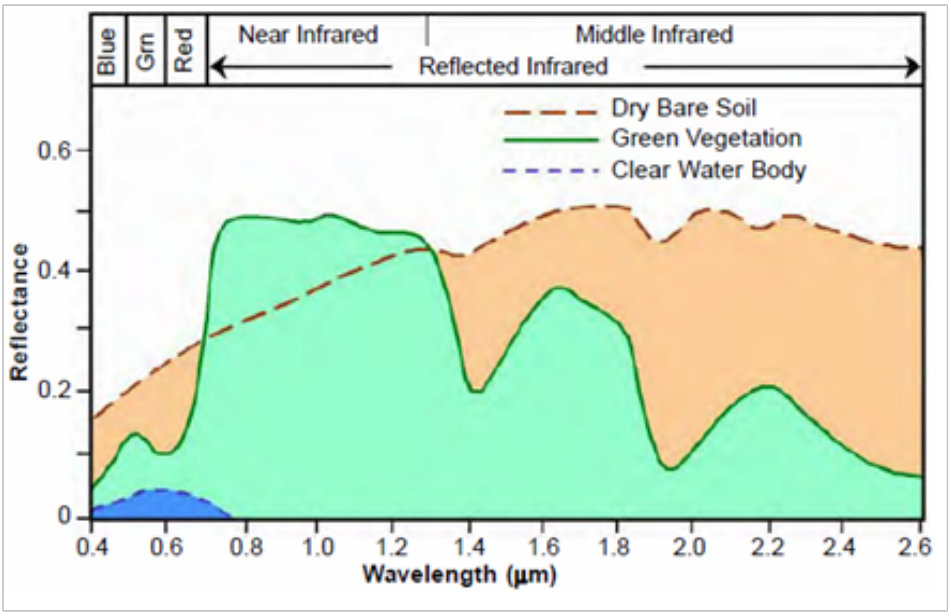

Figure 4: Spectral reflectance curves of dry soil, green vegetation and water[2].

Generally, there is a relationship between objects and their reflectance in different wavelengths or bands. This important property of objects makes it possible to identify

2. REMOTE SENSING: Fundamental Concepts Detailed information is available at: http://remote-sensing.net/concepts.html

different characters of surface substances and allows for separation by analysis of their spectral signatures. Reflection, absorption and transmission of vegetation canopy are dependent upon the leaves chlorophyll content, physiological structure and water content and the reflectance of healthy vegetation varies with soil type, sun angle and sensing angle, vegetation cover and non-vegetation components. Clear water has a low spectral reflectance (< 10%) in the visible range (0.4-0.7µm). At wavelengths longer than 0.75 µm, water absorbs all the incoming energy. Vegetation basically has three reflectance valleys, at the red spectral wavelength region (0.65 µm) is caused by high absorptance of energy by chlorophyll a and b in the leaves. The other regions at wavelength 1.45-1.55 µm and 1.90-1.95 µm are caused by high absorptance of energy by water in the leaves. Dry soil has more or less a flat reflectance curve. When it is wet, its spectral reflectance is reduced due to the absorption nature of water. The absorption of plant leaves in the red allows for photosynthesis and amounts 70% to 90% of the incoming radiation (Campbell, 1996).

The NDVI derived from satellite-based optical sensor images allow us to monitor the development of green vegetation in land surfaces over wide areas. NDVI is a quantitative indicator of the relative abundance and activity of green vegetation. It is well correlated with several biophysical characteristics of vegetation like leaf area index, green cover, green biomass and chlorophyll content (Goward et al., 1985; Justice et al., 1985; & Prince et al., 1995). NDVI employs the red (R) and infrared (NIR) wavelengths.

$$NDVI = (NIR - R) / (NIR + R)$$

NDVI data allow monitoring seasonal variations in surface moisture and plant biomass. Some studies examining seasonal and inter-annual behavior of different vegetation types have demonstrated usefulness of NDVI in arid and semi-arid environments. For example, research conducted in southern New Mexico, Peters and Eve (1995) differentiated shrub, grass, and mixed shrub and grass vegetation of incomplete canopy coverage in a Chihuahuan Desert site (Peters et al., 1997). Other studies of semi-arid vegetation canopies have successfully used these vegetation indices for land use classification, but also for biomass estimation (Kennedy, 1989). Dense vegetation shows up very strongly in the imagery, and areas with less or no vegetation are also clearly identified. Based on the vegetation cover information alone, one can’t infer the desertification process since other factors could affect the vegetation cover which are not related to desertification process, including phenology, natural variation in rainfall and cropping seasons.

According to Sameonakis and Dranke (2004), although NDVI is important indicators to monitor desertification process, combining effect with other indicators more accurate, such as evapo transpiration, rain use efficiency, the run-off coefficient and erosion to determine the land degradation and desertification. Their study reported the result that combined indicators showed that there are desertification prone areas in the arid and semi-arid parts of Ethiopia and Eritrea. Hellde'n and Tottrup (2008) also reported that a strong general positive relationship between NDVI and rainfall over time since rainfall is a major factor for vegetation in dry lands of Africa. Fensholt and Proud (2012), suggested from comparing GIMMS and MODIS, GIMMS NDVI is a basis for detecting long term trend in NDVI in most of the world's semi-arid, dry sub-humid and sub-humid areas. There is more research related to land degradation monitoring in arid and semi arid areas based on long term trend of NDVI (Dent et al., 2008; & Olsson et al., 2005).

NDVI is also used to monitoring vegetation conditions and provide early warning on drought and famines, so that helping local or national authorities in undertaking relevant actions of environmental management. The Famine early warning system network (FEWS NET)[3], uses different satellite image products like NDVI, in order to monitor the crop in range land of semi-arid sub-Saharan Africa (Hutchinson, 1991).

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[3]. Recent information available at: http://www.fews.net/east-africa

CHAPTER 3

3. Data and methods

3.1 Data

3.1.1 NDVI

The NDVI dataset was derived from the Advanced Very High Resolution Radiometer (AVHRR) sensor series 7, 9, 11, 14, 16 and 17 of National Oceanic and Atmospheric Administration (NOAA) satellite. This datasets was processed and had been corrected from aerosols and other effects which are not related to vegetation change by the Global Inventory Monitoring and Modeling Studies group (GIMMS) at the National Aeronautical and Space Administration (NASA) (Tucker, Pinzon & Brown, 2004). It has spatial resolution of 8 km and available every 15 days (bimonthly) for the period of 25 years (1982 – 2006). The total number of raw NDVI image dataset downloaded was (25 years) *(12 months) *(2 weeks) = 600.

Table 1: Range of reflectance for NDVI and water[4].

Value	Object
0 – 1	NDVI
-0.1	Water
-0.05	Null

3.1.2 Rainfall

For the rainfall dataset (Table 2), in total, 25 sample climate stations were selected randomly and used in this study from different location (longitude, latitude) in decimal degree from east, west, north, south and central part of Ethiopia. For this study acquired monthly total rainfall (in mm) for each climate station for period of 25 years (1982 – 2006). The data were collected from National Meteorological Center at Addis Ababa. Some data were missed (13%). The Microsoft-EXCEL interpolation function supports four different methods and the missed data were estimated using linear interpolation method.

[4] . http://glcf.umd.edu/data/gimms/, this time offline.

Table 2: Climate stations with its location in decimal degree latitude and longitude.

Numbers	Station Name	Latitude	Longitude
1	Robe	7.13	40.05
2	Arba Minch	6.06	37.56
3	Gondar	12.52	37.43
4	Bahir Dar	11.60	37.32
5	Debre Markos	10.33	37.74
6	Dire Dawa	9.97	42.53
7	Gode Met	5.90	43.58
8	Gore	8.13	35.53
9	JIMMA	7.67	36.82
10	Addis Ababa	8.99	38.79
11	Debre Zeit	11.20	38.93
12	Metehara	8.86	39.92
13	Awassa	7.06	38.48
14	NEGELLE	5.42	39.57
15	Mekele	13.47	39.53
16	Nekemte	9.08	36.46
17	Combolcha	11.08	39.72
18	Humera	14.10	36.52
19	Metema	12.77	36.41
20	Assosa	10.00	34.52
21	Yabello	6.88	38.10
22	Degahabur	8.22	43.55
23	Elidar	12.07	41.92
24	Adigrat	14.28	39.45
25	Adwa	14.18	38.88

3.1.3 Other Data

Ethiopian administrative boundary shape file has been used in order to visualize its boundary in reference of world geographic coordinate system (GCS_WGS_1984). For this study, the main software programs were used: R, SPSS, Microsoft-Excel and Arcgis 10.2.

3.2 Data Analysis

A method for desertification assessment was developed in two steps in Figure 5. In the first step, after the 600 NDVI raw image dataset were imported and visualized, and then pixel-wise trend analysis was estimated by linear regression from 1982 – 2006 using free software R. The NDVI satellite images were used as the dependent variable and the time (every two weeks) as independent variables. The regression slope for each pixel (8 km by 8 km) was mapped based on indicating value in different colors, green (positive), yellow (approach to zero from both side) and red (negative) trends and adapting this technique and procedure following by Eklundh and Olsson (2003). Depending on the p-values, the significance of the NDVI trend was further analyzed at 95% confidence interval and p- values greater than 5% was masked by the software. Finally, the country boundary had been overlay and the significance NDVI Trend map of Ethiopia has been extracted in ArcMap 10.3.

First the original GIMMS 15-day data were re-sampled to monthly data by taking the maximum value of each monthly pair of data. This resulted in 300 images. Then for each of the 25 stations time series of NDVI were extracted and regressed against rainfall total for the concurrent plus two antecedent months using SPSS and MS- EXCEL (Nicholson et al., 1990; & Herrmann et al., 2005). Since the response of vegetation to rainfall is not immediate, so that lagged regression is best approach. Hence, this study focused on a natural change in NDVI driven by rainfall change.

The NDVI bimonthly raw datasets are used in the first stage of analysis without having deseasonalized the time series, in order to estimate the trend coefficient. So, the trends are partially a function of factors, which are not related to vegetation. These factors include: (1) atmospheric noise such as clouds and aerosols, which can cause variation in NDVI values (Tucker et al., 2005; & Brown et al., 2006). (2) Soil reflectance naturally depends on the soil type. The effect of soil reflectivity on NDVI (Huete, 1989) in sparse vegetative areas has shown that the soil background acts to produce higher and lower NDVI over dark and light soils respectively. (3) Variation of NDVI signals due to change in orientation of sensor position in response to light source and topographic effect of land surface (Epiphanio & Huete, 1995). (4) Variation in vegetation phenology and length of growing season leads to time series auto-correlation (Bai, 2008b).

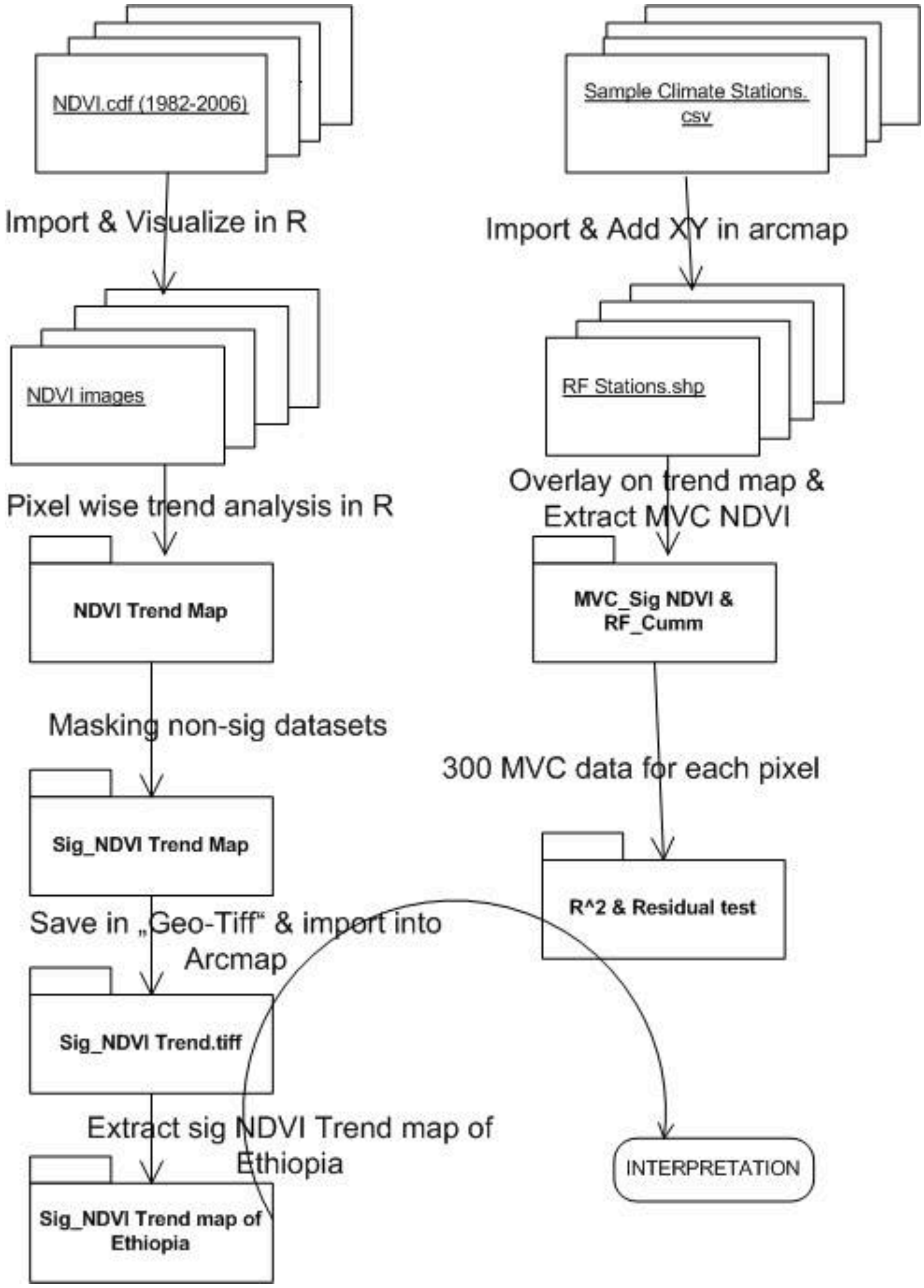

Figure 5: Two steps analysis of NDVI and rainfall at stations

CHAPTER 4

4. Results

4.1 NDVI

According to the methodology, pixel-wise (8km by 8km) significance NDVI linear trend analysis was estimated using R. The regression gain coefficient (ß) (Figure 6) was plotted in a map. The result shows in general, small changes in NDVI over the area. This spatial trend map of NDVI that accounts 41.75% of the total area of Ethiopia had a very small positive trend (ß > 0) and 5.37% had a negative trend (ß < 0) over time in the study period (1982-2006). From the total area (17,569 cells), only 47.12% were statistically significant and more than 50% of the area was not significant (gray in color). The NDVI change, at the end of the study period for the area ß = 0.0003 is equal to 0.18 NDVI units and for ß = -0.0002, is equal to -0.12 NDVI units respectively.

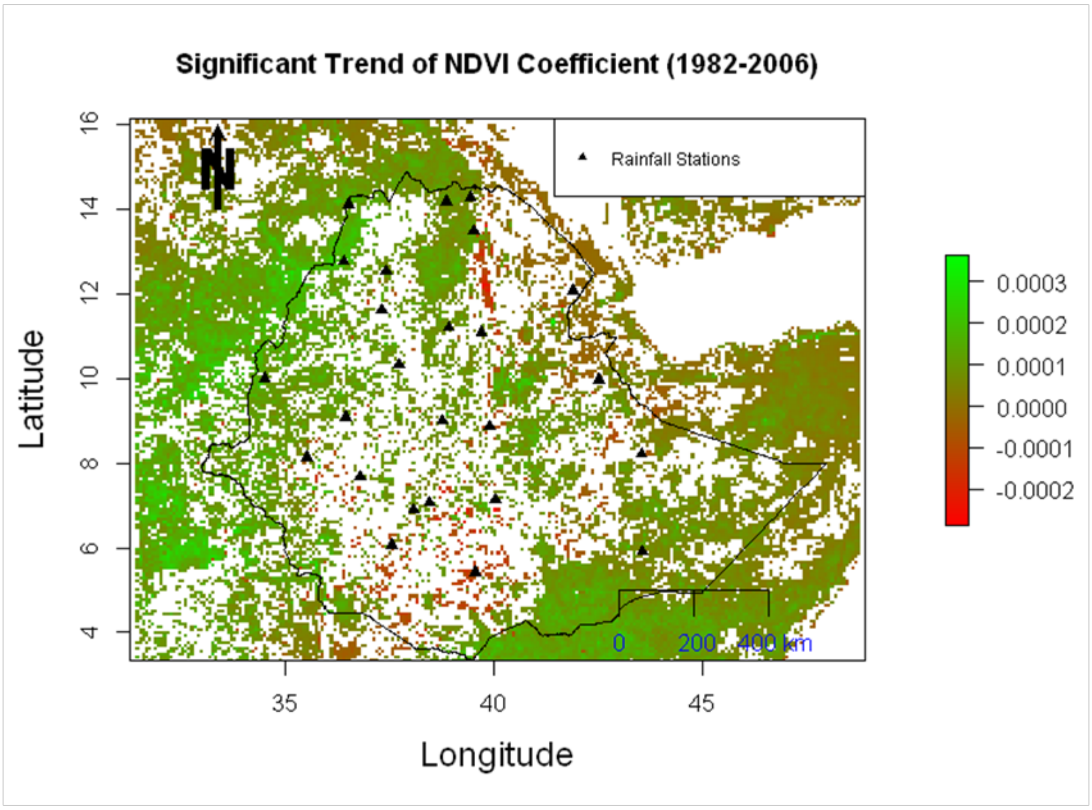

Figure 6: Regression gain coefficient of the NDVI trend line (1982-2006).

4.2 NDVI and Rainfall at station level with respect to time

Most of the climate stations lie within the area where NDVI was not significant. Since a climate station could represent an area with a radius of 20 km roughly, so that the analysis has been considered by extracting the nearest significance NDVI trend at maximum distance of a radius of 2.5 cells around the station. The trend of NDVI and rainfall with respect to the time series is shown below (Tab 3). It represented as "+", "-"or "0" for positive, negative and no trend respectively. Sixty percent of the station has no trend and only 32% has positive and 8 % negative trend of NDVI. For rainfall, 80% of the station has no trend and only 16% has positive and 4 % negative trend.

Table 3: Trend of NDVI and rainfall at station level.

Stations	NDVI Trend	Rainfall Trend	Stations	NDVI Trend	Rainfall Trend
Robe	0	0	NEGELLE	0	0
Arba Minch	0	0	Mekele	+	0
Gondar	0	+	Nekemte	0	0
Bahir Dar	0	0	Combolcha	+	0
Debre Markos	0	0	Humera	0	0
Dire Dawa	0	0	Metema	0	+
Gode Met	+	0	Assosa	+	0
Gore	+	0	Yabello	+	0
JIMMA	0	0	Degahabur	-	0
Addis Ababa	0	0	Elidar	-	+
Debre Zeit	0	0	Adigrat	+	0
Metehara	0	-	Adwa	+	+
Awassa	0	0			

4.2.1 Graph of NDVI and cumulative Rainfall

For Addis Ababa climate station, central part of Ethiopia, the trend of rainfall had increased and the NDVI trend also increased but very small rate as shown below (Figure 7). The 300 sample of MVC_NDVI values near to the Addis Ababa climate station were significantly and positively correlated with Rainfall ($r = 0.48$) at $p < 0.01$. The variability of NDVI accounted by the variability of Rainfall at $R^2 = 23\%$ and the rest are explained by other factors and the residual plots has no pattern. The same is true with strong R^2 for more than 80% of the stations. On the other hand, Metahara station has only 16% (R^2), due to irrigation system; the NDVI has no significant trend in time series, and negative rainfall trend (Figure 8).

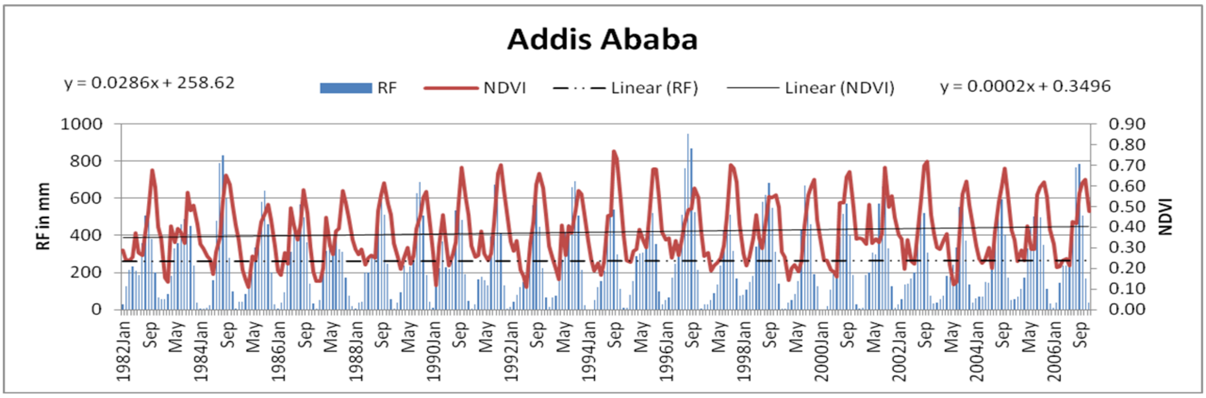

Figure 7: Graph of NDVI and rainfall at Addis Ababa station.

Metahara climate station is located about 200km apart from capital Addis Ababa to East direction. It lies in the rift valley region; low land and semi arid area with average temperature and rainfall per month are 30°c and 48.35 mm respectively. It has no NDVI trend but has weak negative rainfall trend (r = -0.232, sig = 0.00) (Tab 3). The correlation between NDVI and rainfall is weak positive (r=0.162, sig=0.005) (Tab 4). In this area there is a large-scale production of sugar from sugar plant based on irrigation system throughout the year.

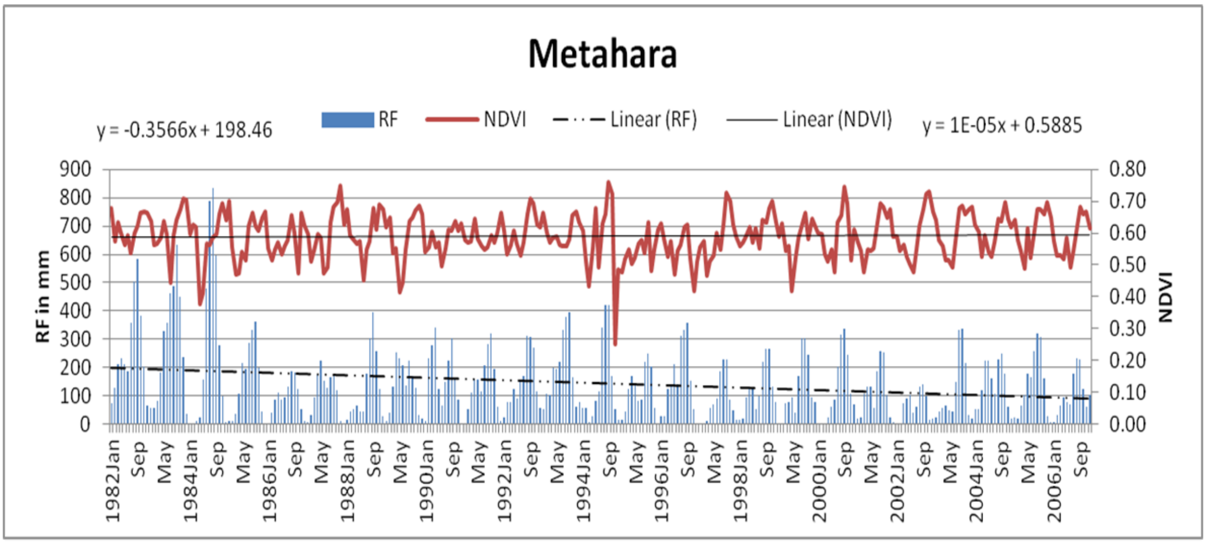

Figure 8: Graph of NDVI and rainfall at Metahara station.

The correlation of NDVI and rainfall at station level is shown in below (Table 4). More than 80% of the station has strongly positive correlation of NDVI with rainfall.

Table 4: Correlation of NDVI and rainfall at station level.

Climate Stations	*Pearson Correlation (r)*	*Climate Stations*	*Pearson Correlation (r)*
Addis Ababa	+0.482	Gonder	+0.705
Adigrate	+0.718	Gore	+0.323
Aduwa	+0.643	Humera	+0.849
Arbaminch	+0.489	Jimma	+0.705
Assossa	+0.771	Mekele	+0.627
Awassa	+0.171	Metahara	+0.162
Combolcha	+0.652	Metema	+0.818
Debrezeit	+0.616	Negelle	+0.619
Debremarkos	+0.690	Nekemte	+0.705
Degehabour	+0.610	Yabellow	+0.156
Gode	+0.622		

CHAPTER 5

5. Discussion

This study aims to analyze vegetation trend using NDVI from AVHRR sensor and their relationship with three month observed cumulative rainfall in order to monitoring desertification in Ethiopia from 1982-2006. The analysis has been accomplished in the following manner. First, map the linear trend coefficient (ß) of NDVI and change in NDVI for 25 years. Second, MVC -NDVI values per month have been extracted and trends were calculated for 25 climate stations. Thirdly, the correlation between NDVI and three month total rainfall (concurrent and two previous months) has been estimated at stations level.
In response to thesis aim 1, investigation of spatial NDVI trends, the map of trends (Figure 6) was summarized. The map shows that the majority of the area has no NDVI trend over time and the change of NDVI is small (Figure 6). However, large areas of significant positive trends of NDVI have been identified. Generally, the North Eastern part (Afar region) along with rift valley area to Southern part of Ethiopia has a strong negative trend of NDVI. Recent study, using NDVI as indicator by Moges (2014), the result conformed that less vegetation density in Northern part of Ethiopia during 2000-2005.

There are distinct red patches of long term negative trends in NDVI in the Northern part of Ethiopia (Figure 6) at location from (39.72, 13.152) to (39.88, 11.86) in decimal degree latitude and longitude (Table 5). The upper parts of these patches lie on the boundary between Southern Tigray and Afar region. The lower parts lie on the boundary between Northern Wollo and Afar region. Figure 9 shows monthly rainfall distributions near to the upper part of the red patch area, Mekel stations. The station has no significant trend.

Table 5: Location of red patch in decimal degree.

Red Patch	**Longitude**	**Latitude**
Red Patch1 **(Upper)**	39.72	13.152
Red Patch2	39.70	12.90
Red Patch3	39.77	12.50
Red Patch4	39.80	12.23
Red Patch5 **(Lower)**	39.88	11.86

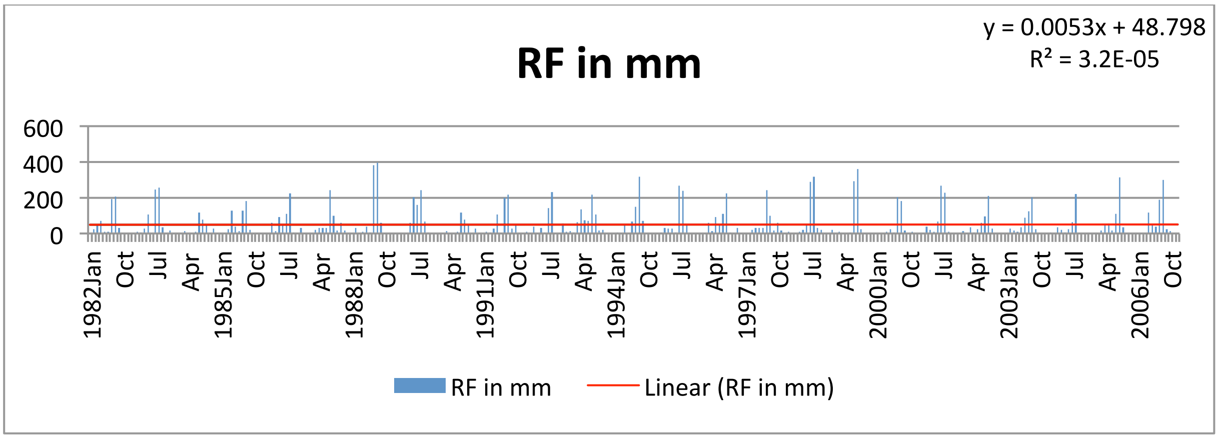

Figure 9: Monthly rainfall distribution at Mekele station.

On the other hand, in the Central north, from North Western down to Western part of Ethiopia along the boundary area and South Western part of Somali have showed positive trend. According to Hawando's (1997) classification of dryland area of Ethiopia, based on precipitation and potential evapo-transpiration, both Afar and Somali lie in arid and hyper-arid region in the low land areas and Western Ethiopia belong to Semi arid and dry humid in highland areas.

The second aim, detection of rainfall trends, was met by time-series analysis, and generally indicated that the time-series of rainfall had no trend. The trends of NDVI and rainfall over time have been calculated and the result shows majority of the stations have showed no trend since most of the climate station lie within the area where NDVI was not significant. Most of the stations have weak to strong positive correlation between NDVI and rainfall (Tab 4). This agrees with early results by Helldén and Eklundh (1988). For example, Gore climate station lies in the highland of Western Ethiopia and vegetation practice varies from a mixture of evergreen rainforest and seasonal cultivation. It has an average rainfall 157.37mm/ month. It has no rainfall trend but has weak positive NDVI trend (r = 0.226, sig = 0.00). The correlation between NDVI and rainfall is weak positive (r=0.323, sig=0.00).

If the trend of vegetation cover is decreasing, this may be an indication of ongoing desertification process in the study area. The long-term degradation of vegetation as monitored by NDVI is an indicator of desertification (Hill et al., 2008). For instance, the trend of rainfall increased and the NDVI decreased over time in Arbamich climate station. This inverse relationship indicated that, there could be human involvement for example deforestation and urbanization due to population density in the Southern part of Ethiopia. On the other hand, the trend of rainfall decreased and the NDVI is also decreased over time in Arbamich climate station. This direct relationship indicated that, there could be climate-induced desertification.

The analysis of correlations between NDVI and rainfall (aim3) indicated that NDVI and rainfall at most stations (84%) were significantly positively correlated (Table 4). This is the pre condition for detecting the area under climate-induced desertification. But there is no case (stations) for both trends of NDVI and rainfall decreased at the same time. There is no significant negative correlation between NDVI and rainfall as well for detecting the area where human induced desertification. This study deals with desertification using the relationship (correlation) between NDVI and Rainfall as indicator and their trend as well. So, the result shows, both indicators at 84% of the stations have positive correlation (r), increased trend of vegetation cover in large area (41.75%) but majority of the stations (80%) have neither positive nor negative rainfall trend. Some stations (16%) have shown a positive trend of rainfall and a few stations have experience of negative trend in both NDVI (8%) and rainfall (4%).

As mentioned in section 2.3.1, there are many research studies performed successfully on monitoring green vegetation using NOAA AVHRR satellite sensor image data through the common vegetation index called NDVI (Tucker, 1979; Goward et al., 1985; Justice et al., 1985; Dent et al., 2008; & Olsson et al., 2005). There are also many more studies in Sahel showing that slightly increasing in NDVI trend due to increasing rainfall since 1990s (Be′gue′ et al., 2011; Anyamba & Trucker, 2005; Hermman et al., 2005; Hicker et al., 2005; & Anyamba et al., 2014). The result of this study in line with most Sahels' studies that shows “re-greening”. The suggested methodology in this study is reliable and validated to assess desertification process using vegetation trends (Helldén & Tottrup, 2008).

Concerning the fourth thesis objective, the results do not confirm the previously published worries of widespread vegetation degradation possibly leading to desertification. In 1980s, both UNEP and FAO recognized the importance of indicators to monitors desertification at different scales (local, regional and global). They developed provisional methodology for assessment and mapping of desertification using 22 indicators (Symeonakis & Drakes, 2003). These indicators include primarily causes of soil erosion and the ratio of precipitation to potential evapotranspiration.

However, there are some limitations on acquisition of data using remote sensing satellite sensor. These are; the availability of time series data is relatively short to analyze the trend. According to WMO (2010), 30 years is the minimum length of an observational data records required in order to compare the severity of current drought with the previous event. Secondly, mixing of reflectance due to atmospheric noise, coarse resolution and soil background may significantly affect the NDVI value (Treitz & Rogan, 2004; & Todd & Hoffer, 1998). Coarse resolution data do often not detect what is going on at more local scale. There might be a lot of degradation, but also some very green areas, and these are mixed in the coarse resolution (8 km) pixel and may be the green areas hide the degraded areas (Mbow et al., 2015). Thus NDVI trend images derived from coarse AVHRR GIMMS sensor could be affected by these limitations. Moreover, Yin et al. (2012) and Mbow et al. (2015) mentioned that as result of different pre- processing techniques and coarse spatial resolution of AVHRR GIMMS, the NDVI trend image map might not reflect the true vegetation change.

CHAPTER 6

6. Conclusion and Recommendation

The study shows, at climate stations level, more than 80% of the stations have strong correlation(r) between NDVI and rainfall. Majority of the stations have no trend of NDVI and rainfall over time. Some stations have experience increase and a few stations decrease both in NDVI and rainfall. The NDVI trend map, which is derived from the 8km AVHRR GIMMS satellite data shows the majority of the study area has no NDVI trend. More than 40% of the area experience positive trend in vegetation covers ("greening"). And less than 6 % of the area experiences a decrease in vegetation, which includes linear red patch (hot spot) in Northern and some cluster forms in Southern part of Ethiopia. In both cases, the change in NDVI and rainfall per pixel (64 km^2) is very small in magnitude over time (25 years).

This study needs further studies in order to understand in detail situation at local scale by estimating trend map of NDVI using high-resolution sensors. In addition to that there is also lack of archive long time series of observed rainfall dataset in the study area. So that, TRMM (Tropical rainfall measuring mission) / GPM (Global precipitation measurement) satellite datasets are an option concerning to acquisition of rainfall data. These satellite have varies sensors onboard for instance Precipitation Radar (PR), TRMM Microwave Image (TMI), Visible and Infrared Scanner (VIRS), Cloud and Earth Radiant Energy Sensor (CERES) and Lightning Imaging Sensor (LIS) to get rainfall estimate of the tropics[5]. The TRMM mission has been ended but the archive data is still available.

The discrepancies between the previous study and the findings of this study may be related to methodological issues including the temporal scale and the coarse spatial resolution of the applied NDVI data. However, the example of the Sahel has shown that, in spite postulated irreversible degradation, a re-greening is possible. Further research and detailed field studies are needed to better understand these differences.

[5]. http://trmm.gsfc.nasa.gov/

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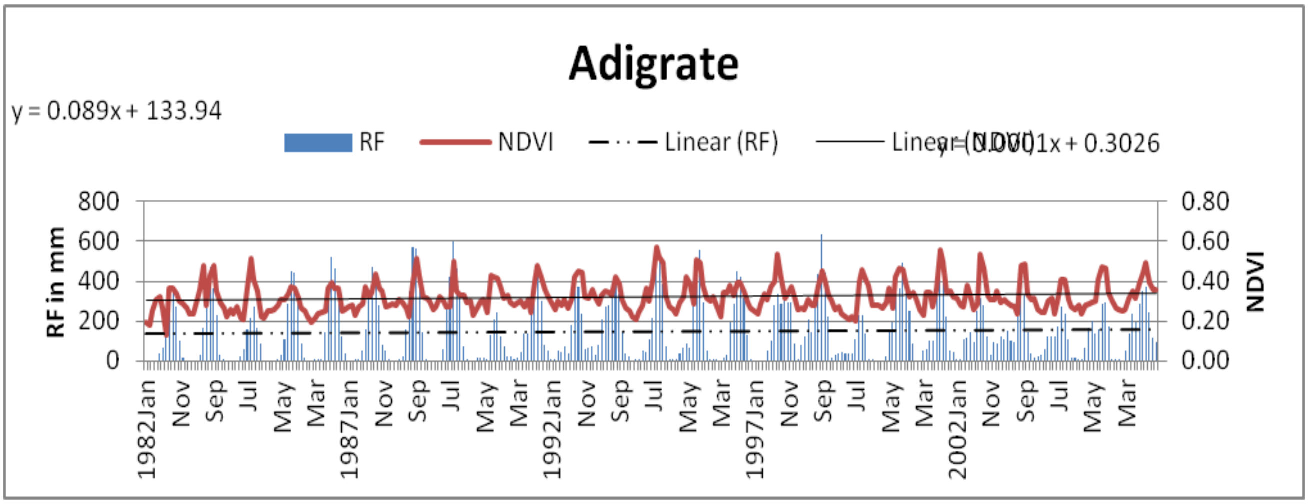
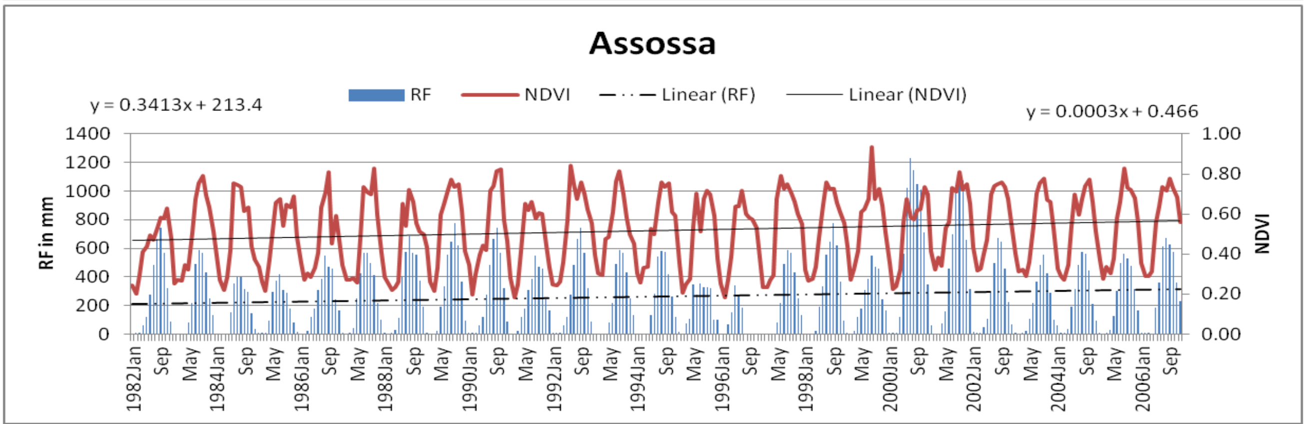
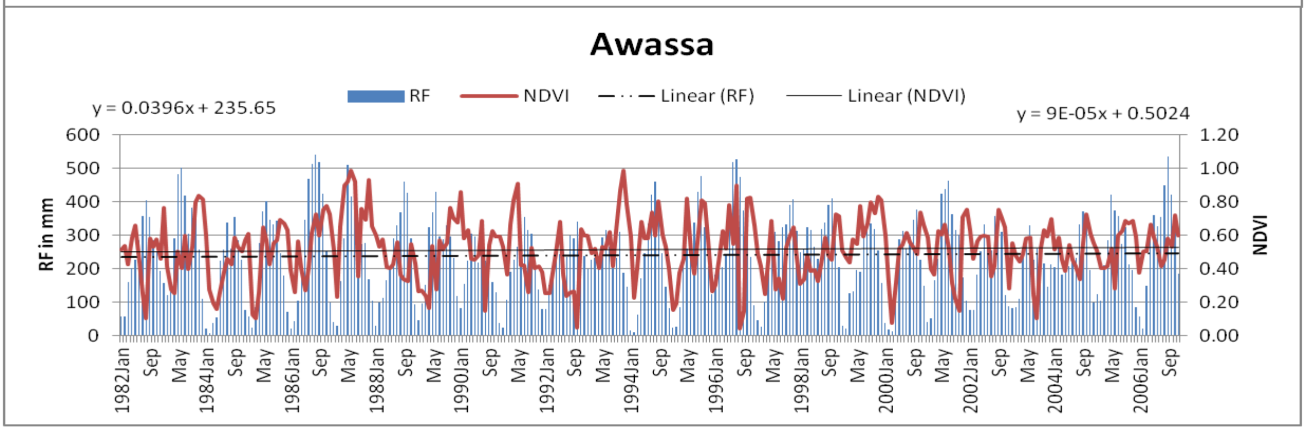
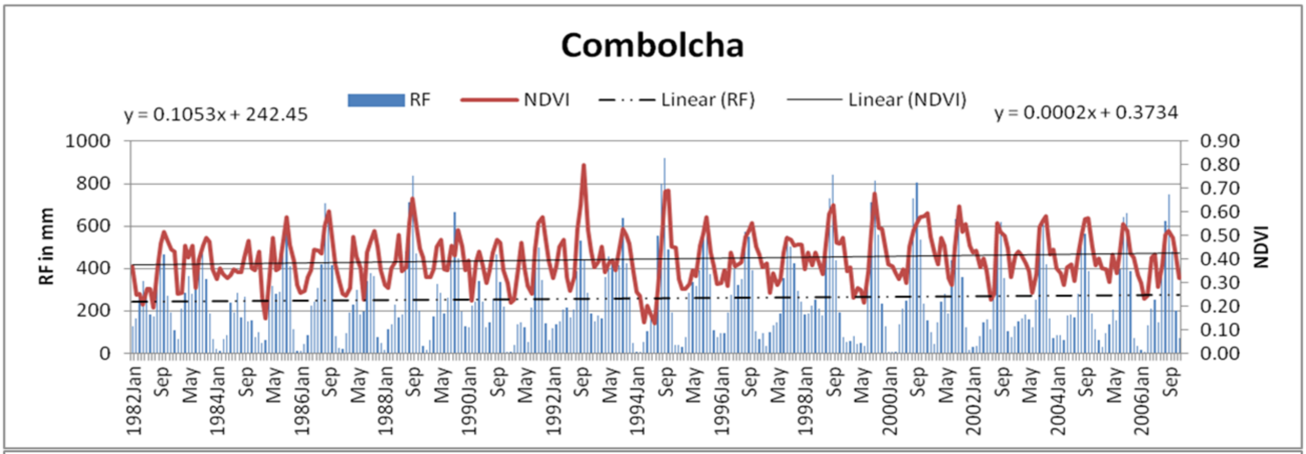
Appendices

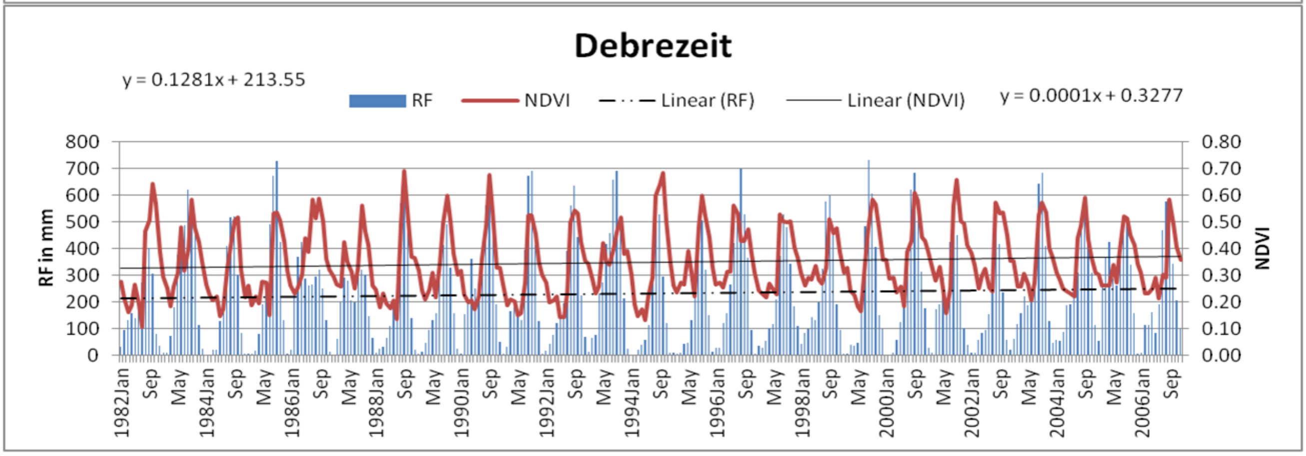
I. Graphs of NDVI and Rainfall at Station Level

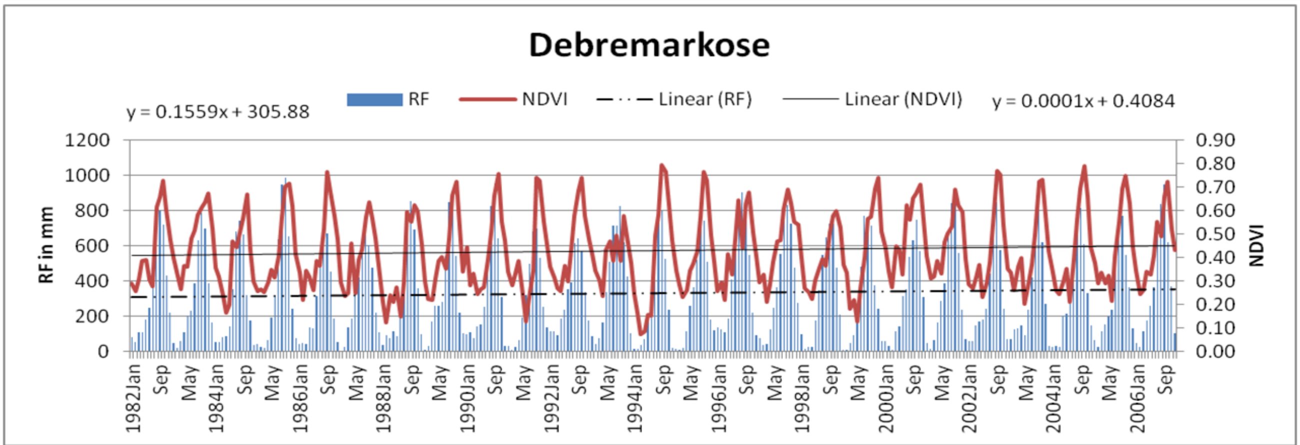


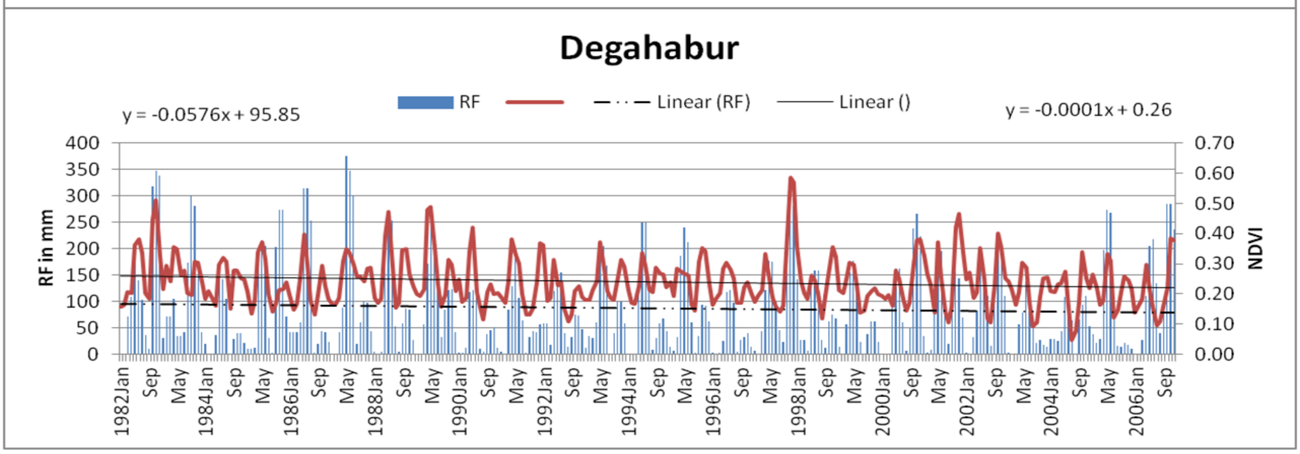


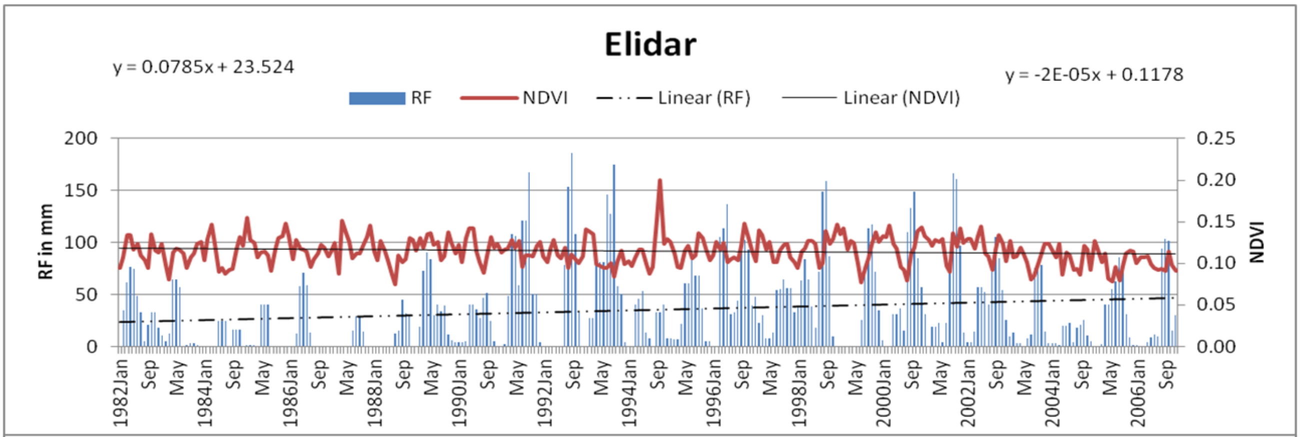


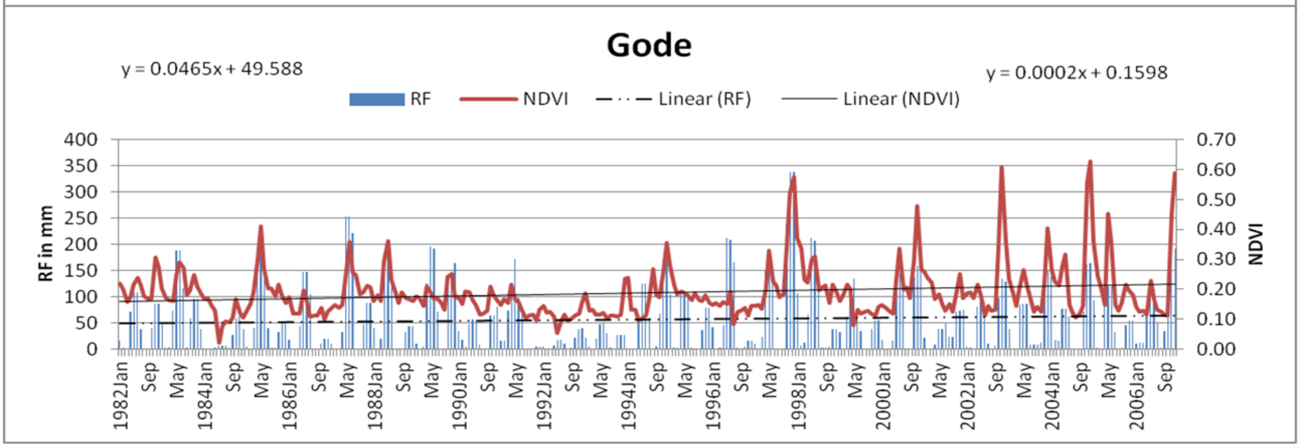

Combolcha
RF
NDVI
Linear (RF)
Linear (NDVI)
y = 0.1053x + 242.45
y = 0.0002x + 0.3734
RF in mm
NDVI
1000
800
600
400
200
0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

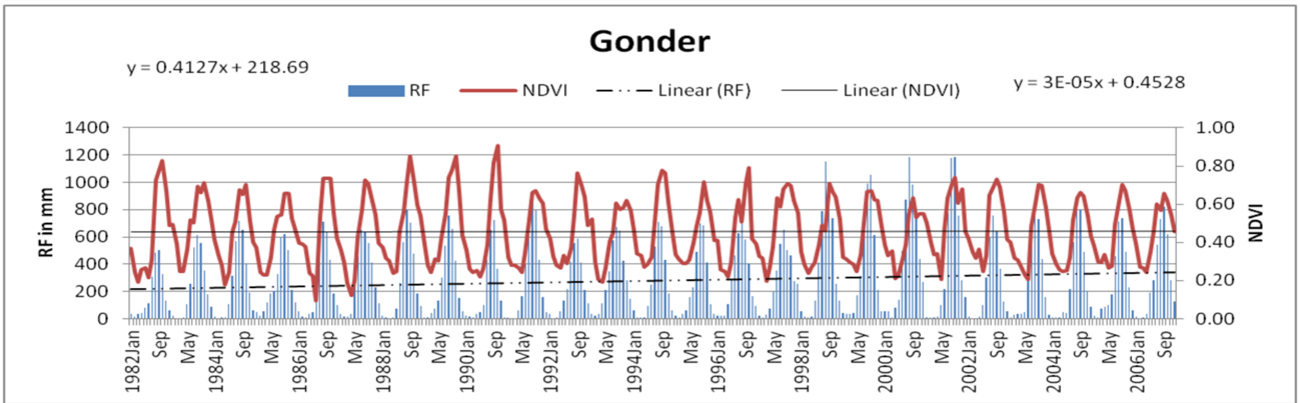

Debrezeit
y = 0.1281x + 213.55
RF
NDVI
Linear (RF)
Linear (NDVI)
y = 0.0001x + 0.3277
RF in mm
NDVI
800
700
600
500
400
300
200
100
0
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

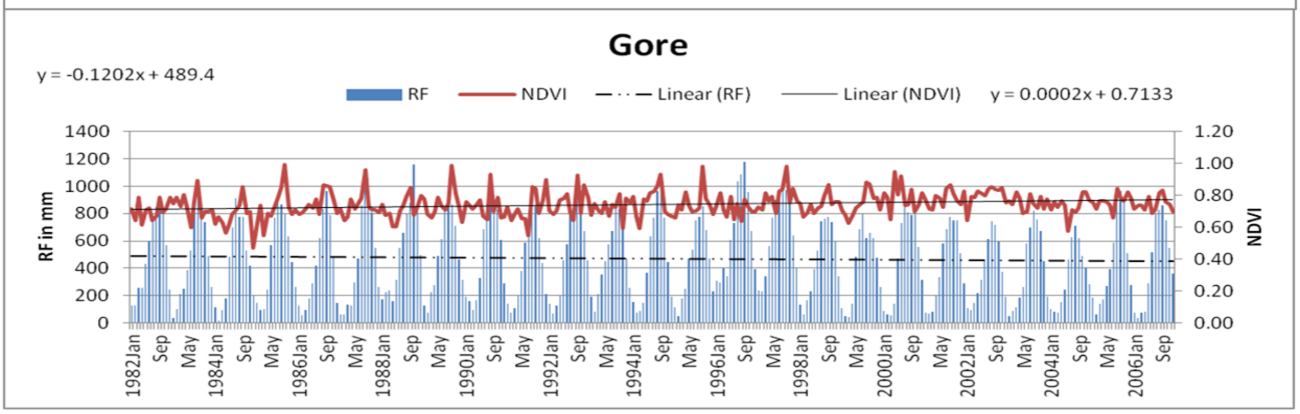

Debremarkose
RF
NDVI
Linear (RF)
Linear (NDVI)
y = 0.1559x + 305.88
y = 0.0001x + 0.4084
RF in mm
NDVI
1200
1000
800
600
400
200
0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

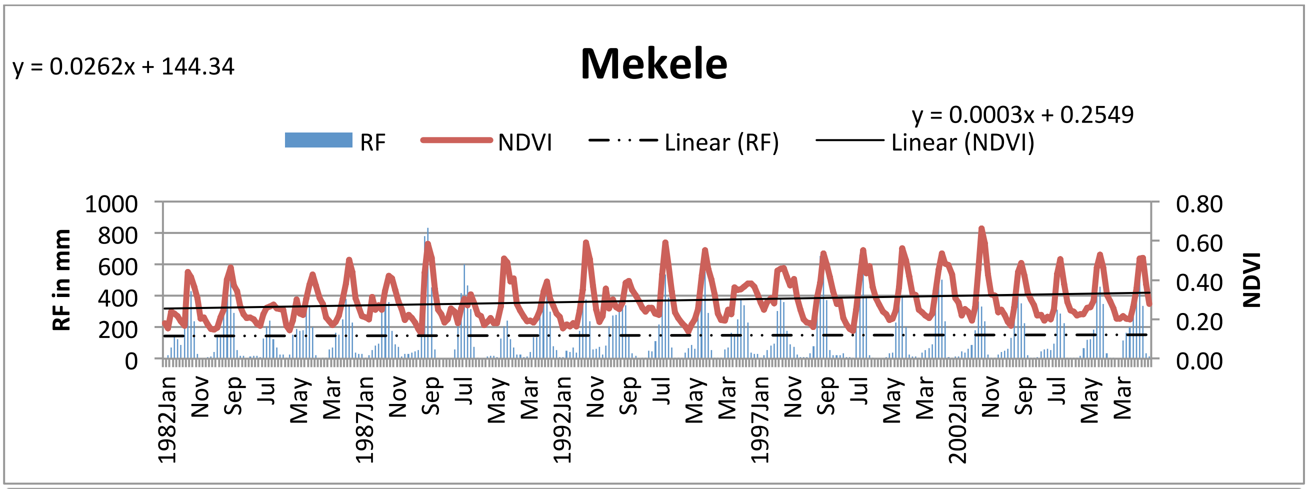

Degahabur
RF
Linear (RF)
Linear ()
y = -0.0576x + 95.85
y = -0.0001x + 0.26
RF in mm
NDVI
400
350
300
250
200
150
100
50
0
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00

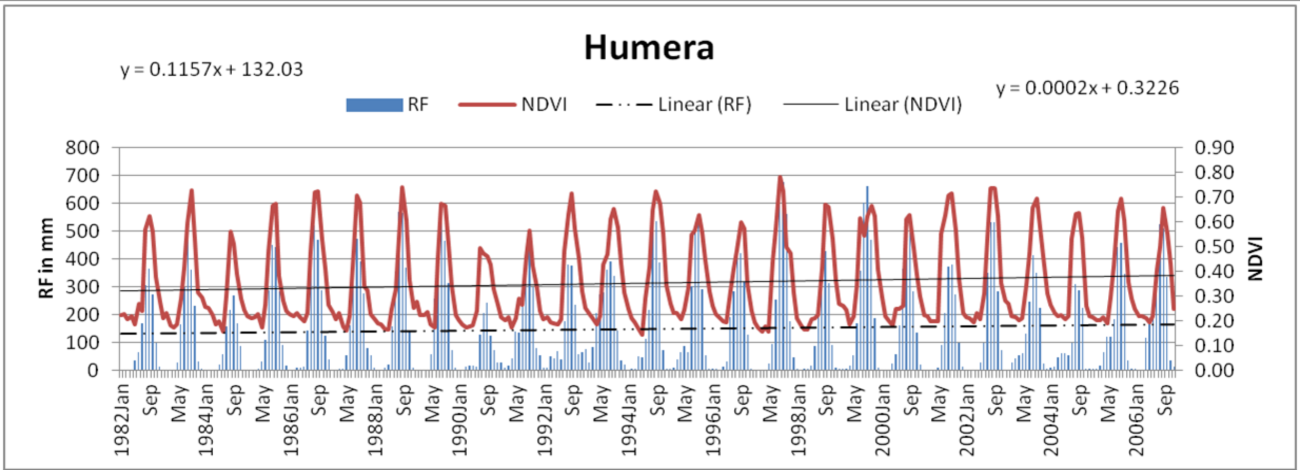

Elidar
y = 0.0785x + 23.524
y = -2E-05x + 0.1178
RF
NDVI
Linear (RF)
Linear (NDVI)
RF in mm
NDVI
200
150
100
50
0
0.25
0.20
0.15
0.10
0.05
0.00
1982Jan
Sep
May
1984Jan
1986Jan
1988Jan
1990Jan
1992Jan
1994Jan
1996Jan
1998Jan
2000Jan
2002Jan
2004Jan
2006Jan

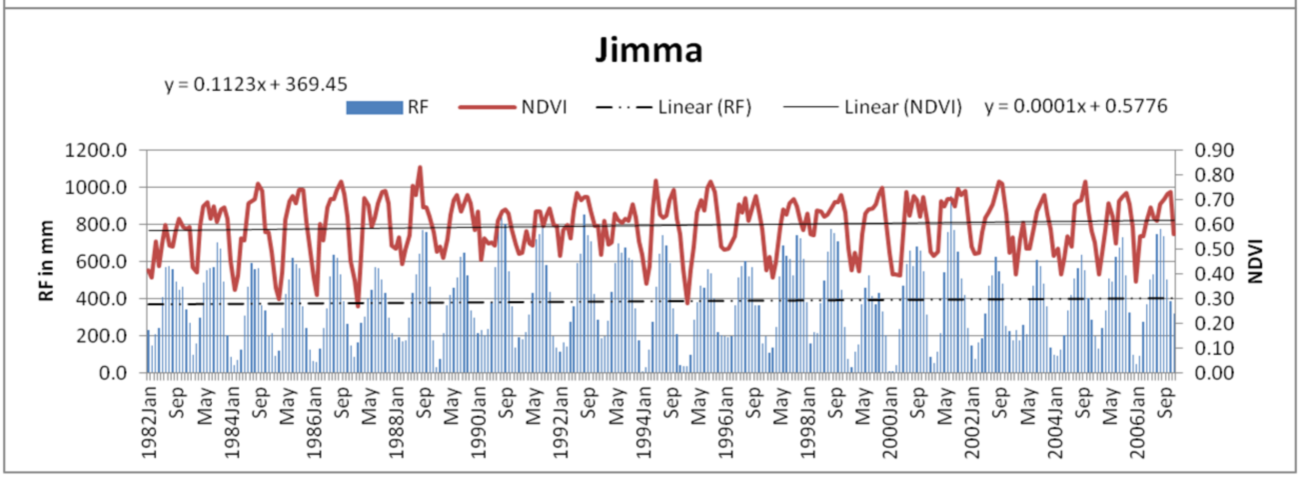

Gode
y = 0.0465x + 49.588
y = 0.0002x + 0.1598
RF
NDVI
Linear (RF)
Linear (NDVI)
RF in mm
NDVI
400
350
300
250
200
150
100
50
0
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1982Jan
Sep
May
1984Jan
1986Jan
1988Jan
1990Jan
1992Jan
1994Jan
1996Jan
1998Jan
2000Jan
2002Jan
2004Jan
2006Jan


Gonder
y = 0.4127x + 218.69
y = 3E-05x + 0.4528
RF
NDVI
Linear (RF)
Linear (NDVI)
RF in mm
NDVI
1400
1200
1000
800
600
400
200
0
1.00
0.80
0.60
0.40
0.20
0.00
1982Jan
Sep
May
1984Jan
1986Jan
1988Jan
1990Jan
1992Jan
1994Jan
1996Jan
1998Jan
2000Jan
2002Jan
2004Jan
2006Jan


Gore
y = -0.1202x + 489.4
y = 0.0002x + 0.7133
RF
NDVI
Linear (RF)
Linear (NDVI)
RF in mm
NDVI
1400
1200
1000
800
600
400
200
0
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1982Jan
Sep
May
1984Jan
1986Jan
1988Jan
1990Jan
1992Jan
1994Jan
1996Jan
1998Jan
2000Jan
2002Jan
2004Jan
2006Jan


Mekele
y = 0.0262x + 144.34
y = 0.0003x + 0.2549
RF
NDVI
Linear (RF)
Linear (NDVI)
RF in mm
NDVI
1000
800
600
400
200
0
0.80
0.60
0.40
0.20
0.00
1982Jan
Nov
Sep
Jul
May
Mar
1987Jan
Nov
Sep
Jul
May
Mar
1992Jan
Nov
Sep
Jul
May
Mar
1997Jan
Nov
Sep
Jul
May
Mar
2002Jan
Nov
Sep
Jul
May
Mar


Humera
y = 0.1157x + 132.03
y = 0.0002x + 0.3226
RF
NDVI
Linear (RF)
Linear (NDVI)
RF in mm
NDVI
800
700
600
500
400
300
200
100
0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1982Jan
Sep
May
1984Jan
Sep
May
1986Jan
Sep
May
1988Jan
Sep
May
1990Jan
Sep
May
1992Jan
Sep
May
1994Jan
Sep
May
1996Jan
Sep
May
1998Jan
Sep
May
2000Jan
Sep
May
2002Jan
Sep
May
2004Jan
Sep
May
2006Jan
Sep


Jimma
y = 0.1123x + 369.45
RF
NDVI
Linear (RF)
Linear (NDVI)
y = 0.0001x + 0.5776
RF in mm
NDVI
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1982Jan
Sep
May
1984Jan
Sep
May
1986Jan
Sep
May
1988Jan
Sep
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1990Jan
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May
1992Jan
Sep
May
1994Jan
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1996Jan
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2000Jan
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2002Jan
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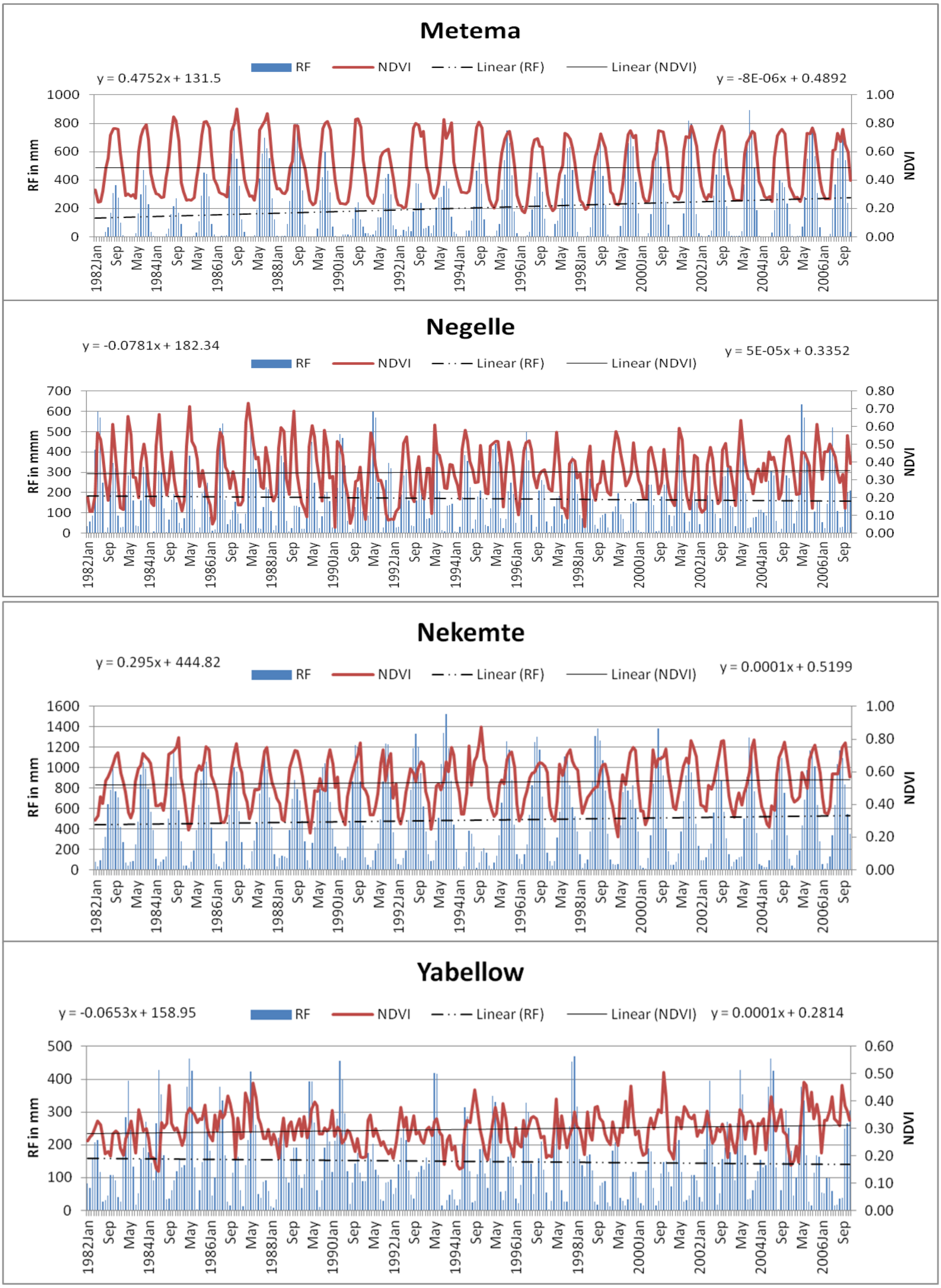
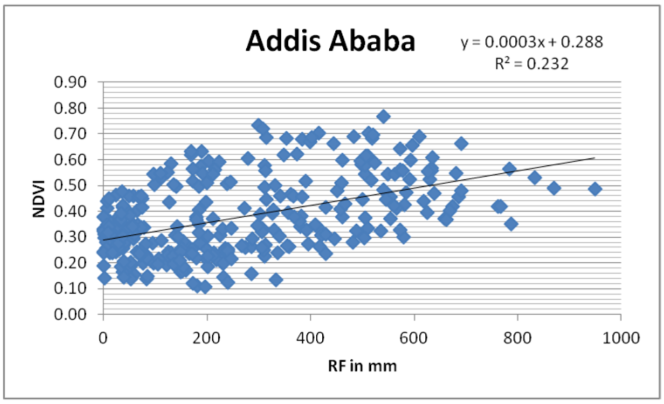
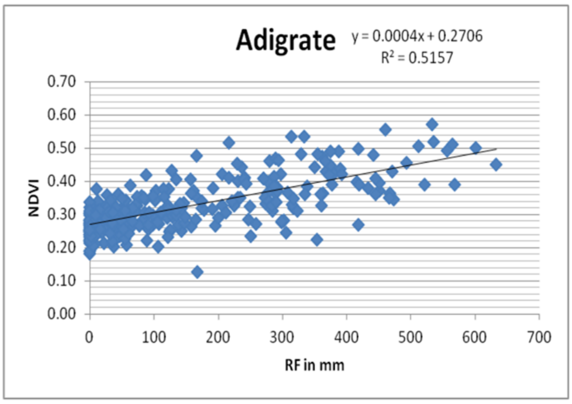
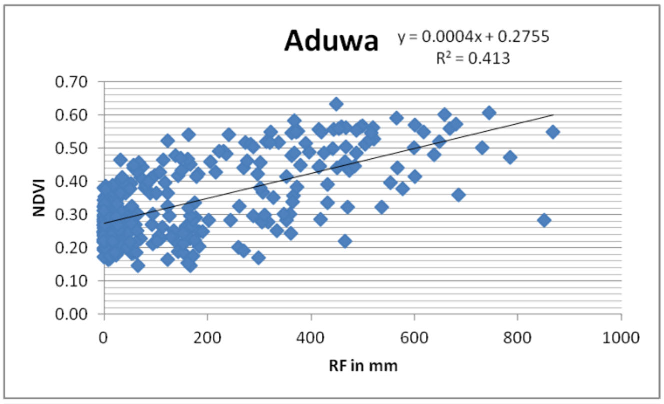
May
2004Jan
Sep
May
2006Jan
Sep

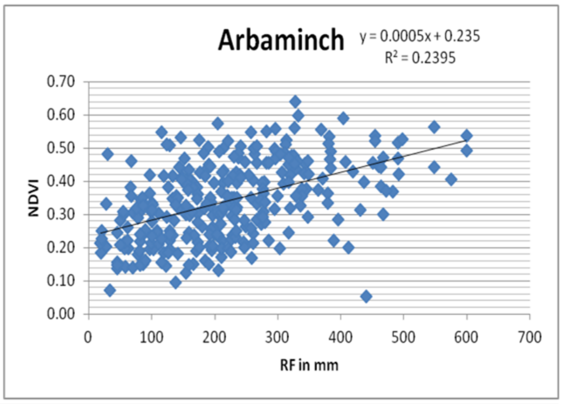

Metema
RF
NDVI
Linear (RF)
Linear (NDVI)
y = 0.4752x + 131.5
y = -8E-06x + 0.4892
RF in mm
NDVI
1982Jan
Sep
May
1984Jan
1986Jan
1988Jan
1990Jan
1992Jan
1994Jan
1996Jan
1998Jan
2000Jan
2002Jan
2004Jan
2006Jan
Negelle
y = -0.0781x + 182.34
y = 5E-05x + 0.3352
RF in mmm
Nekemte
y = 0.295x + 444.82
y = 0.0001x + 0.5199
RF in mm
Yabellow
y = -0.0653x + 158.95
y = 0.0001x + 0.2814
RF in mm

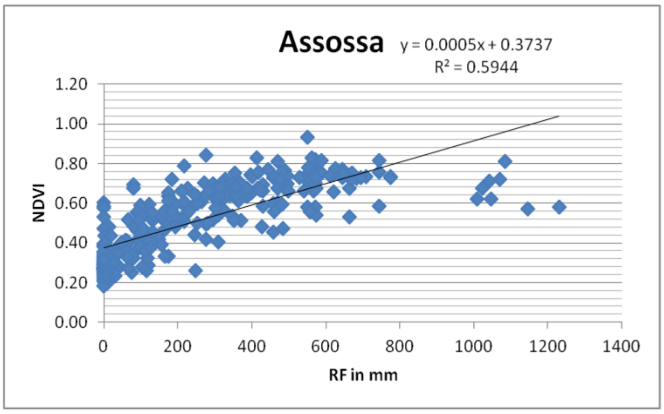
II. Correlation of NDVI and Rainfall

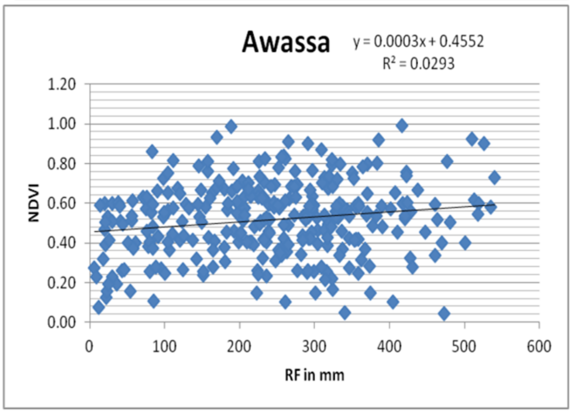


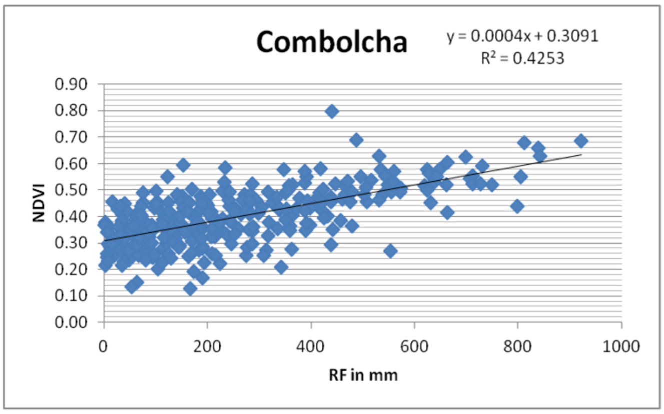


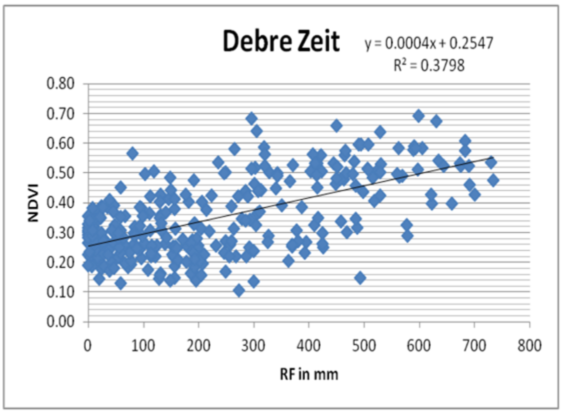


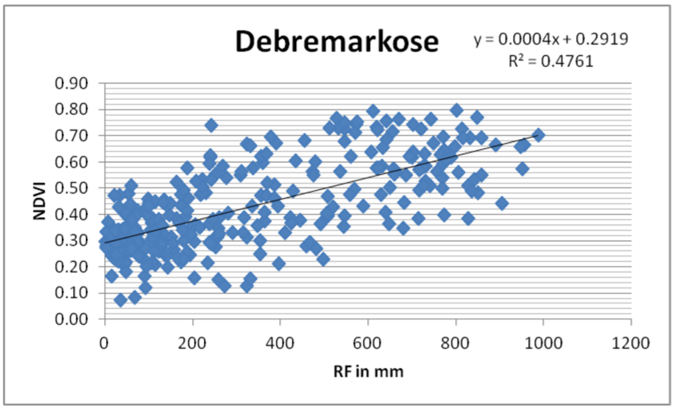


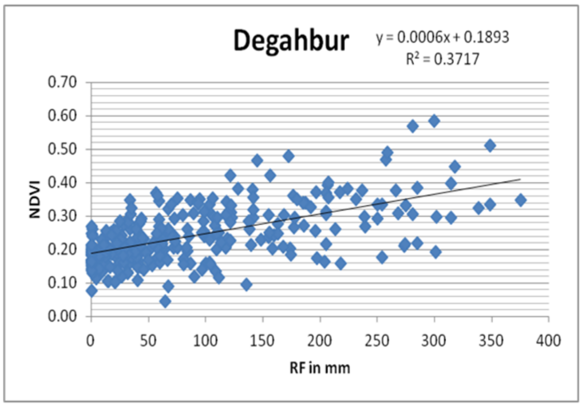


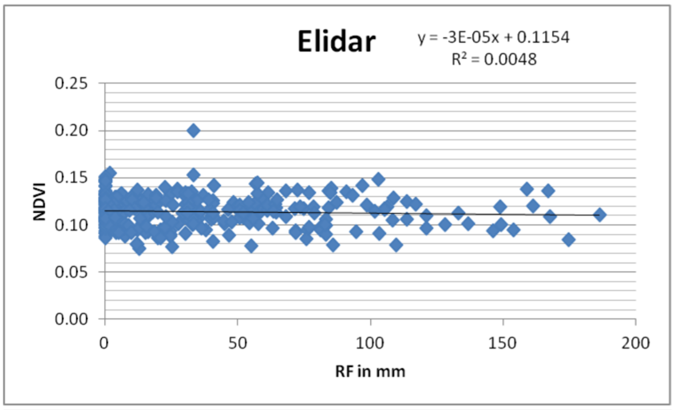


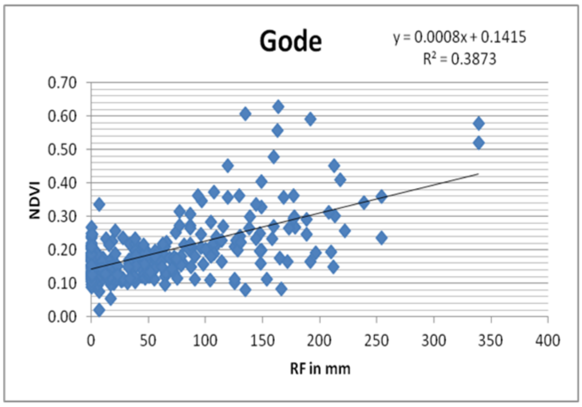


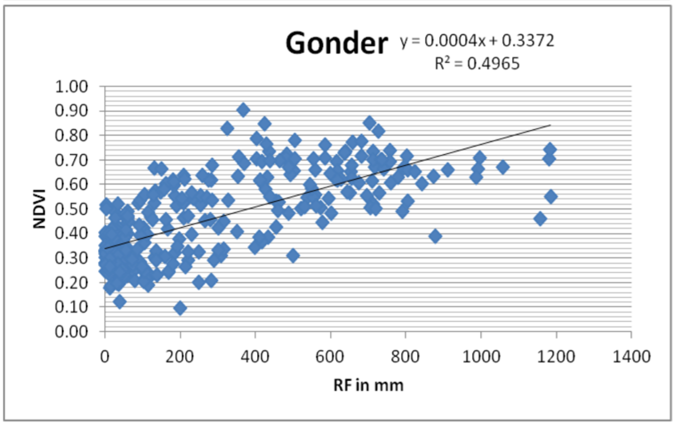


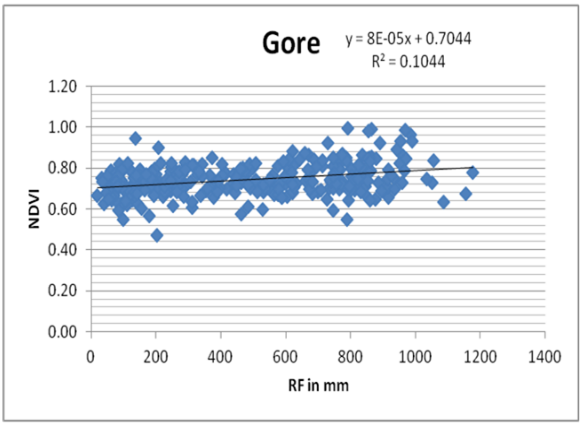

Debremarkose
y = 0.0004x + 0.2919
R² = 0.4761
NDVI
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90
0 200 400 600 800 1000 1200
RF in mm

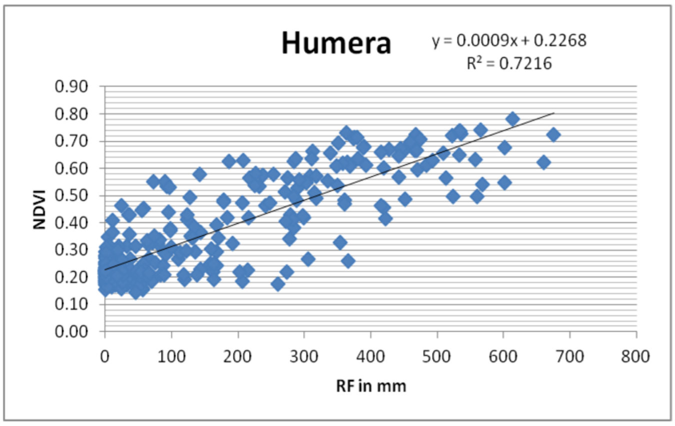

Degahbur
y = 0.0006x + 0.1893
R² = 0.3717
NDVI
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70
0 50 100 150 200 250 300 350 400
RF in mm

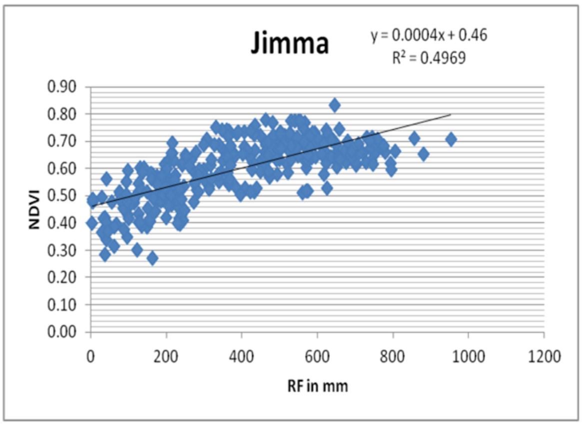

Elidar
y = -3E-05x + 0.1154
R² = 0.0048
NDVI
0.00 0.05 0.10 0.15 0.20 0.25
0 50 100 150 200
RF in mm

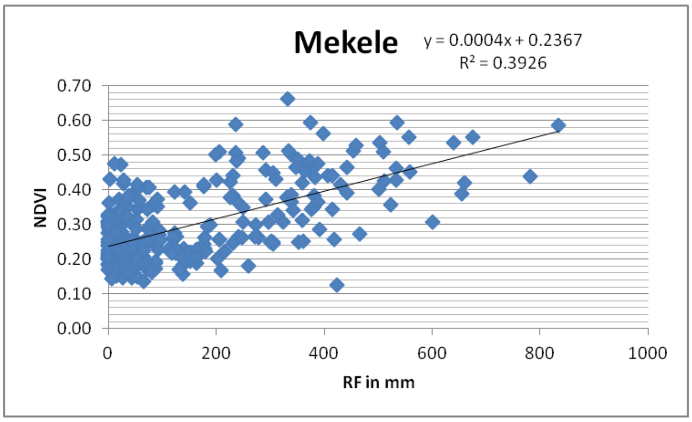

Gode
y = 0.0008x + 0.1415
R² = 0.3873
NDVI
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70
0 50 100 150 200 250 300 350 400
RF in mm

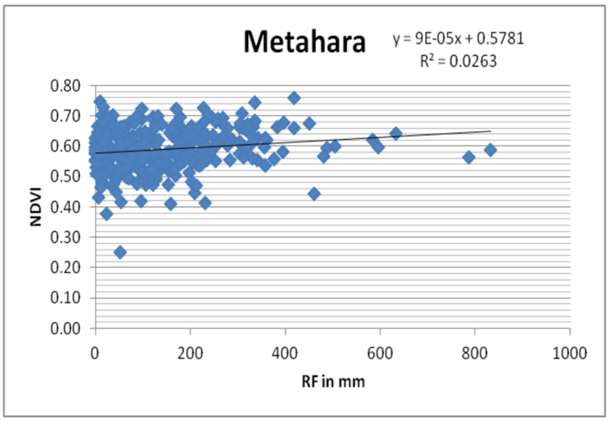

Gonder
y = 0.0004x + 0.3372
R² = 0.4965
NDVI
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90 1.00
0 200 400 600 800 1000 1200 1400
RF in mm

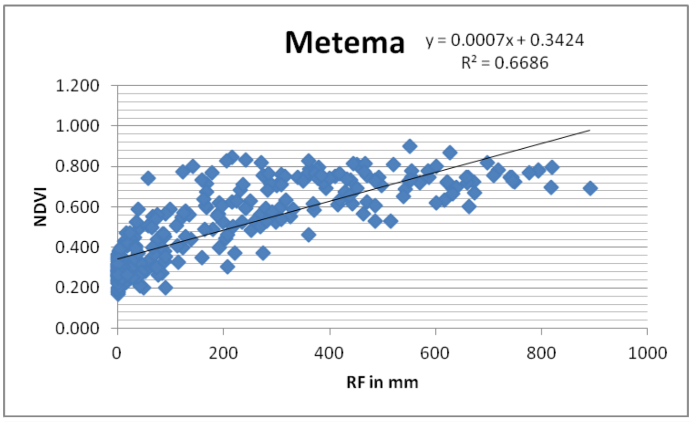

Gore
y = 8E-05x + 0.7044
R² = 0.1044
NDVI
0.00 0.20 0.40 0.60 0.80 1.00 1.20
0 200 400 600 800 1000 1200 1400
RF in mm

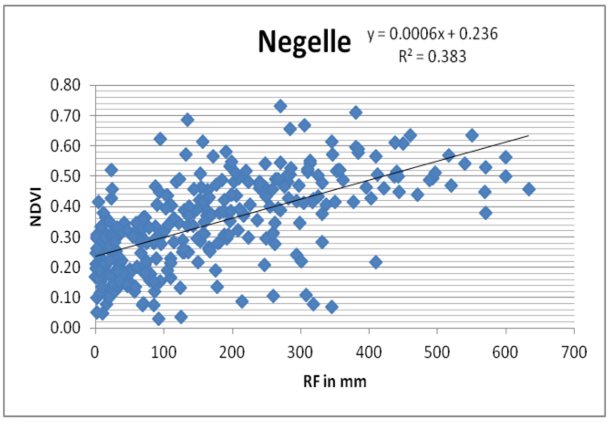

Humera
y = 0.0009x + 0.2268
R² = 0.7216
NDVI
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90
0 100 200 300 400 500 600 700 800
RF in mm

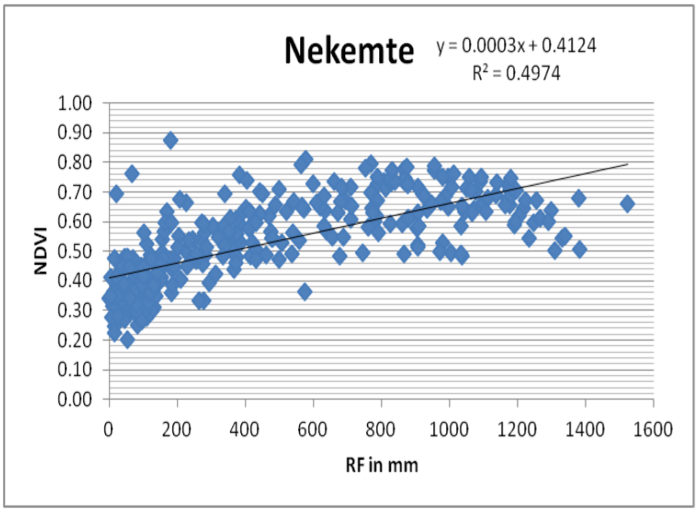

Jimma
y = 0.0004x + 0.46
R² = 0.4969
NDVI
0.00 0.10 0.20 0.30 0.40 0.50 0.60 0.70 0.80 0.90
0 200 400 600 800 1000 1200
RF in mm

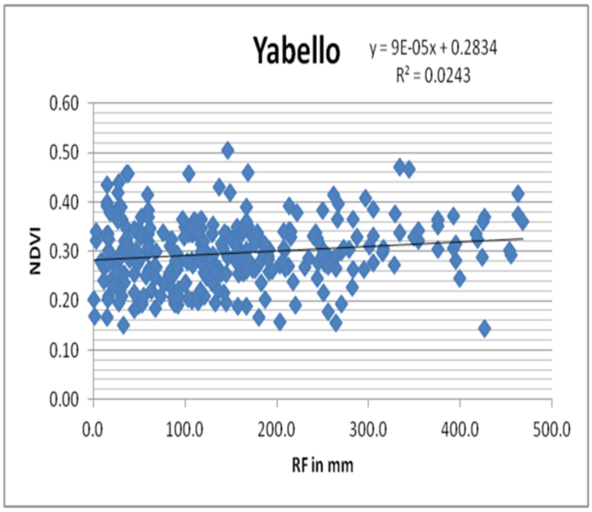

Mekele
y = 0.0004x + 0.2367
R² = 0.3926
NDVI
RF in mm


Metahara
y = 9E-05x + 0.5781
R² = 0.0263
NDVI
RF in mm


Metema
y = 0.0007x + 0.3424
R² = 0.6686
NDVI
RF in mm


Negelle
y = 0.0006x + 0.236
R² = 0.383
NDVI
RF in mm


Nekemte
y = 0.0003x + 0.4124
R² = 0.4974
NDVI
RF in mm


Yabello
y = 9E-05x + 0.2834
R² = 0.0243
NDVI
RF in mm

III. R^2 Test of Results

Table i: The coefficient of determination (R^2) of NDVI as dependent and RF independent variables.

Climate Stations	R^2	*Climate Stations*	R^2
Addis Ababa	0.232	Gonder	0.496
Adigrate	0.516	Gore	0.104
Aduwa	0.413	Humera	0.722
Arbaminch	0.239	Jimma	0.497
Assossa	0.594	Mekele	0.393
Awassa	0.029	Metahara	0.026
Combolcha	0.425	Metema	0.669
Debrezeit	0.380	Negelle	0.383
Debremarkos	0.476	Nekemte	0.497
Degehabour	0.372	Yabellow	0.024
Gode	0.387	Elidar	0.005

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