Geospatial Analysis to Study Environmental Change: Climate Variability and Vegetation Cover Dynamics in Ethiopia and the Horn of Africa

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Ephrem Gebremariam Beyene

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Berlin, September 2010

For my son Leul and my wife Adey

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Tag der Disputation: Nov 15 2010

Selbständigkeitserklärung

Hiermit erkläre ich, die vorliegende Arbeit ohne fremde Hilfe verfasst und nur die angegebene Literatur und angegebenen Hilfsmittel verwendet zu haben.

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Zusammenfassung

Viele Länder sind in den letzten Jahrzehnten von Schwankungen des Niederschlags und langfristigen Veränderungen sowohl in der Niederschlagsmenge als auch -verteilung betroffen. Dieser Zustand wirkt sich signifikant auf das Muster der Vegetationsbedeckung aus (Funk 2009). Um Variabilität und Trends der saisonalen Niederschläge in Ostafrika im Allgemeinen und Äthiopien im Speziellen kennen zu lernen, sind eingehende räumliche und zeitliche Analysen erforderlich. Normalized Difference Vegetation Index (NDVI)-Karten ermöglichen Vergleiche der räumlichen und zeitlichen Variabilität von Vegetationsmenge und -zustand. Diese können verwendet werden, um die landwirtschaftliche Produktion und Trends der Desertifikation in Gebieten, die auf Regenfeldbau angewiesen sind zu beurteilen. Um die Millennium Development Goals (MDGs) zur Beseitigung von extremer Armut und Hunger zu erreichen, ist eine angemessene Planung notwendig, basierend auf der Kenntnis aller Zusammenhänge.

Folgende Fragen stellten sich: Können die RFE Daten zuverlässig eingesetzt werden, um die Variabilität saisonaler Regenfälle zu analysieren? Wie gut korrelieren die Niederschlagsschätzungen (Rainfall Estimates, RFE) des National Oceanic Atmospheric Administration-Satelliten (NOAA) und die National Meteorological Agency (NMA) von Äthiopien-Aufzeichnungen ? Wie sehen Trends und Variabilität der saisonalen Niederschläge und der Vegetationsbedeckung aus? Die Studie analysierte die monatlichen Niederschlagsschätzungen (RFE) von (NOAA) und die monatlichen Niederschlagsauf-zeichnungen (Januar 1996 - Dezember 2006), die Wetterstationen der (NMA) sammelten. Weiterhin analysierte die Studie saisonale Entwicklungen der Vegetationsbedeckung, unter Verwendung des Normalized Difference Vegetation Index (NDVI) des Advanced Very High Resolution Radiometer (AVHRR) zwischen 1982 und 2008 (27 Jahre).

Nach räumlich-zeitlichen Analysen der satellitengestützten RFE- und der monatlichen Niederschlagsaufzeichnungen der Wetterstationen wird festgestellt, dass die beiden Datensätze während der wichtigen Regenzeiten, Sommer und Frühling, gut korrelieren. Viele Wetterstationen haben Korrelationswerte über 0,5 und 0,75. Damit sind RFE-Bilder zuverlässig genug, um für die rechtzeitige räumlich-zeitliche Analyse von Katastrophen in Zeiten von spät einsetzendem Regen (late inception), Trockenperioden innerhalb der Regenzeit (dry spells) und vorzeitiger Beendigung des Niederschlags (early cessation) genutzt zu werden. Daher können die RFE-Bilder verlässlich für Frühwarnsysteme im Land eingesetzt werden und um Entscheidungsträgern die Folgen zu verdeutlichen, die Veränderungen der Niederschlagsmenge, des zeitlichen Ablaufes, der Dauer und der Häufigkeit der Niederschlagsdefizite auf unterschiedlichen räumlichen und zeitlichen Ebenen mit sich bringen.

Um die Entwicklungen der Vegetationsbedeckung zu betrachten und um vergangene und aktuelle Entwicklungen zu vergleichen, wurde die Untersuchungs-Periode, welche von 1982 bis 2008 ging, in zwei Abschnitte aufgeteilt. Der erste Teil geht von 1982 bis 1995, der zweite von 1995 bis 2008. Während der ersten Hälfte befand sich in den meisten Teilen Ostafrikas die gesamte Vegetation in ständigem Rückgang. Eine Ausnahme bildete der Sudan, wo eine relative Stabilität beobachtet werden konnte. Während der zweiten Hälfte war die gesamte Vegetationsentwicklung besser als in der ersten Hälfte. Obwohl relativ stabil, gibt es Gebiete mit schnellem Rückgang, vor allem am westlichen Steilhang des äthiopischen Rift Valley, in Süd-Kenia und in West-Uganda.

Der Trend zeigte einen höheren Rückgang der Vegetation im Sommer und Frühling. So gibt es eine zunehmende Verschlechterung der Vegetationsbedeckung in und um die Victoria-Region, im größten Teil von Zentral- und Nord-Tansania, in einem erheblichen Teil des südlichen Äthiopiens und im nördlichen Teil des Rift Valley-Steilhangs. Die Veränderungen des aktuellen Niederschlags wurden mit der durch Trendanalysen prognostizierten Niederschlagsmenge verglichen und es zeigte sich eine Abnahme der Niederschlagsmenge in den meisten Teilen Ostafrikas, besonders im Winter und Frühling. Dies zeigte sich auch im relativ schlechten Zustand der Sommer-Vegetation. Für mehr als 90% der Fläche Kenias wird in einem Zeitraum von 10 Jahren ein Rückgang des Frühjahrsniederschlags um 7% oder mehr erwartet. Auf der anderen Seite zeigen die Herbst- und Frühjahrs-Niederschlagsmengen im Süd-Sudan eine steigende Tendenz, welche um bis zu 10% weiter anwächst, vor allem rund um den zentralen Teil des südlichen Sudan.

Abstract

Rainfall variability and changes in long term amounts and distributions is a condition currently affecting many countries over recent decades. This situation controls the vegetation pattern significantly. In order to understand the existing variability and trends of the seasonal rainfall in east Africa at large and Ethiopia in specific, an in depth spatio temporal analyses is required. Spatial data on rainfall and vegetation cover can be used make quick assessments. Normalized Difference Vegetation Index (NDVI) maps have a good allow comparisons of the spatial and temporal variability in the amount and condition of vegetation. These can be used to assess agricultural production and trends in desertification in areas that rely on rainfed agriculture. Rainfall Estimates (RFE) can be used to asses trends in rainfall. To meet the Millennium Development Goals (MDGs) of eradicating extreme poverty and hunger, such tools can be used to enable proper planning.

The main research questions are: Can the RFE data be used reliably to analyse seasonal rainfall variability? How well NOAA satellite rainfall estimates (RFE) and NMA rainfall records are correlated? How does the seasonal rainfall and vegetation cover trends and variability look like? The study analysed monthly satellite rainfall estimates (RFE) from NOAA (National Atmospheric and Oceanic Administration) and monthly rainfall records (January 1996–December 2006) collected from weather stations by NMA (National Meteorological Agency of Ethiopia). The study further analysed seasonal trend of vegetation cover using Normalized Difference Vegetation Index (NDVI) from Advanced Very High Resolution Radiometer (AVHRR) between 1982 and 2008 (27 years).

After doing spatio-temporal analyses of the satellite RFE and monthly weather stations rainfall records, it is found that the two datasets correlated well during the important rainy seasons; summer and spring. Many weather stations have correlation values above 0.5 and 0.75. As a result RFE images are reliable enough to be used for timely spatio-temporal analyses of disasters in times characterized by late inception, dry spells and early cessation of rainfall. Therefore, the RFE images can be recommended for early warning systems in the country and to inform decision makers on the consequences of changes in the magnitude, timing, duration, and frequency of rainfall both temporally and spatially

For vegetation cover trend the study period that is from 1982 to 2008, it was assessed in two time slices. The first part is between 1982 and 1995 and the 2nd part which is from 1995 to 2008. During the first half, the overall vegetation cover was in constant decline in most parts of east Africa with the exception of Sudan where relative stability was observed. During the second half, the overall vegetation trend was better than the first half. Though relatively stable, there are areas with fast decline particularly in western escarpment of the Ethiopian rift valley, southern Kenya and western Uganda.

The trend showed higher decline of Vegetation during summer and spring seasons. There is an increasing deterioration of vegetation cover near and around Victoria region, most part of central and northern Tanzania, significant portion of southern Ethiopia and northern part of the rift-valley escarpment. The changes in the current rainfall with a rainfall amount forecasted using trend analyses were compared and it showed a decrease in the rainfall amount in most parts of east Africa particularly during winter and spring. For example, in more than 90% of the total area of Kenya, the rainfall amount in spring after 10 years of time is expected to decrease by 7 % or more. On the other hand, in southern Sudan autumn and spring rainfall amounts show an increasing trend that will increase by up to 10% particularly around the central southern Sudan.

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1. Introduction

1.1 Background

Ethiopia has a tropical monsoon climate with wide elevation-induced variation. Three climatic zones can be distinguished: a cool zone in the central part crosscutting the western and eastern section of the high plateaus above 2400 up to 4620 meters above mean sea level a temperate zone between 1,500 and 2,400 m.a.s.l, and the hot lowlands below 1,500 m. Mean annual temperature varies from less than 7 - 12ºC in the cool zone to over 25ºC in the hot lowlands (NMSA 2001).

Rainfall in Ethiopia is highly erratic, and most rain falls as intensive, often convective storms, of very high intensity and varies extremely spatially and temporally. Such variability is a threat to an agricultural industry that relies heavily on rainfed agriculture since it will be 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).

Ethiopia is mainly an agricultural country with limited forest cover. (MoA, 1993) Less than 3% of the entire country is now covered with trees, compared to the 40% of a century ago and 16% in the early 1950s, prompting fears of an impending environmental disaster in this country which is home to coffee and one of the biodiversity hotspots of the world, now with large areas exposed to heavy soil erosion (MWR 2001).

Ethiopian land which falls within the UNEP's definition of desertification is estimated to cover 71.5% of the country's total land area. Overgrazing, deforestation, poor farming practices and using dung for fuel are the major causes of land degradation in Ethiopia. The recorded annual soil erosion (surface soil movement) in Ethiopia ranges from low of 16 tons/ha/yr to high of 300 tons/ha/yr depending mainly on the slope, land cover, and rainfall intensities (UNEP 2008). The total estimated annual soil loss (surface soil movement) from the cultivated, range and pasture lands (780,000 km) in Ethiopia is estimated to range from low of 1.3 to an average of 7.8 billion metric tons per year (MEDaC, 1999)

Food insecurity in Ethiopia, due to amongst others persistent drought, has been the order of the day for a very long period Even during good years, the survival of some 4-6 million people depends on international food assistance annually (Devereux, 2000). HIV/AIDS poses the foremost threat to poverty reduction and is a major source of vulnerability. In 2001, 6.6% of adults were estimated to be infected, with 3.7% in rural and 13.7% in urban areas and 15.6% in the capital Addis Ababa (UNAIDS 2002).

Ethiopia has been structurally food deficit since at least 1980's. The food gap rose from 0.75 million tons in 1979/80 to 5 million tons in 1993/94, falling to 2.6 million tons in 1995/96 despite a record harvest (Befekadu, 2000). Even in that year, 240,000 tons of food aids were delivered, suggesting that chronic food insecurity afflicts millions of Ethiopians in the absence of transitory production shocks.

1.2 Statement of the problem

Rural development stalled and rural poverty expanded during the 1990s in most part of Africa. Population growth remains very high. According to the 2007 Ethiopian census pollution growth is 2.9 % at national level and declining per-capita agricultural capacity retards progress toward Millennium Development Goals (MDGs) set by the United Nations. The overall biomass productions during main growing-season have diminished in countries with food shortage clustered along the western rim of the Indian Ocean.

Since 1980, the number of undernourished people in eastern and southern Africa has more than doubled. Many countries have been affected by rainfall variability and long-term changes in both rainfall amount and distribution over recent decades (Funk 2009). This condition affects the vegetation cover pattern significantly. In order to know the level of variability and trends of the seasonal rainfall in east Africa at large and Ethiopia in specific, an in depth spatio temporal and analyses are required. It is also relevant to do the analyses on vegetation cover to study its impacts on biomass production. To analyse the patterns of rainfall and vegetation cover variability and trends will help to better understand the food security situations and prospect of the country as well the region.

The number of rain gauges throughout African countries is small and unevenly distributed, and the gauge network is deteriorating due to economic or political instability. Satellite rainfall estimates are increasingly being used widely in place of gauge observations or to supplement gauge observations (Dinku et al. 2007). The National Meteorological Agency of Ethiopia (NMA) keeps records of rainfall data from above 600 stations in the country since early 1950’s. Characterization of rainfall variation in time and space is an indispensable part of crop monitoring for food security. In order to compensate for sparse and late reporting of rain gauge stations, early warning systems often rely upon indirect estimates of precipitation (Funk & Verdin 2003).

1.3 Research Questions and Objectives

- The questions we seek to answer are how well NOAA satellite rainfall estimates (RFE) and NMA rainfall records are correlated?
- Can the RFE data be used reliably to analyse seasonal rainfall variability?
- How does the seasonal rainfall and vegetation cover trends and variability look like?

The specific Objectives are:

1. To map, quantify as well as depict the trends and variability of vegetation cover change
2. To analyse the trends of rainfall and calculating of rainfall variability
3. To observe the relation between the global change in climate and vegetation cover dynamic of the region in comparison with food security problems in the country.

4. To forecast the overall spatio temporal rainfall amount and vegetation cover patterns

1.4 Materials and Methods

The research uses Normalized difference Vegetation Index (NDVI) and Rainfall Estimates (RFE) data captured through National Oceanic and Atmospheric Administration (NOAA) satellites as well as rainfall records collected from various meteorological stations. The spatial resolution of the satellite images that will be used for the study is 8 km by 8km. The data is available in BIL file format.

The NDVI and RFE data is derived from the NOAA satellites data and processed at the National Aeronautical and Space Administration (NASA). RFE uses cold cloud duration, or CCD (derived from cloud top temperature), and station rainfall data. Meteosat 7 geostationary satellite infrared data are acquired in 30-minute intervals, and areas depicting cloud top temperatures of less than 235K are used to estimate convective rainfall. Two new satellite rainfall estimation instruments are incorporated into RFE 2.0, namely, the Special Sensor Microwave/Imager (SSM/I) on board Defence Meteorological Satellite Program satellites, and the Advanced Microwave Sounding Unit (AMSU) on board NOAA satellites. SSM/I estimate are acquired at 6-hour intervals, while AMSU rainfall estimates are available every 12 hours. RFE 2.0 obtains the final daily rainfall estimation using a two part merging process, then sums daily totals to produce dekadal estimates (ADDS 2005).

The research considered 10 days (dekadal) RFE 1.0 images dated between Jan 96 and Dec 00 and RFE 2.0 images from Jan 01 to Dec 06 from NOAA. RFE 1.0 used an interpolation method to combine Meteosat and Global Telecommunication System (GTS) data, and included warm cloud information for the dekadal estimates. RFE 2.0 uses additional techniques to better estimate precipitation while continuing the use of cold cloud duration, or CCD (derived from cloud top temperature), and station rainfall data (FEWSNET 2008).

NDVI provides a measure of the amount and vigour of vegetation on the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater amounts of vegetation. NDVI values for vegetated land generally range from about 0.1 to 0.7, with values greater than 0.5 indicating dense vegetation. The NDVI data acquired for the research is at dekadal (10 days) level for a 27 year time period, (1982-2009). These raster dataset has a resolution of 8 km so the data is good enough to study the vegetation condition at national level. Evaluation of this data set enables vegetation trends in variability over the time period to be deduced.

2. The Study Area

2.1 Location and Administrative Structure

2.1.1 Location

Ethiopia is a highly elevated mountainous East African country. The relief is influenced by the East African rift valley that cuts across the country creating high and rugged mountains; flat topped plateaux, deep gorges, valleys and plains (Figure 2.1).

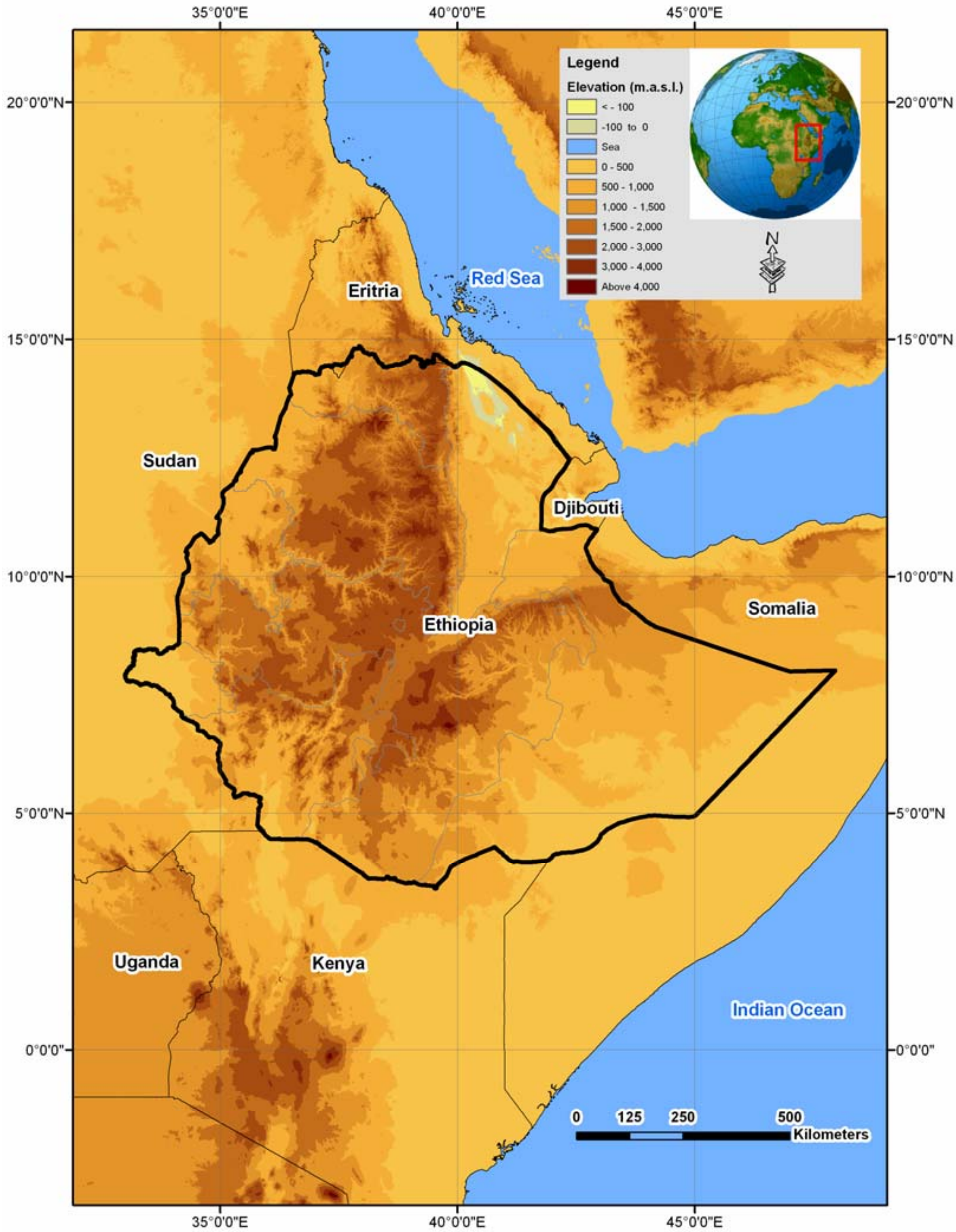

Fig 2.1 Elevation and Location Map of the study Area (Basic Data: GTOPO USGS) (Map by EGB)

2.1.2 Administrative Structure

Ethiopia is classified in four hierarchical administrative levels, from regional states, to Zones, to Woredas and then kebele associations. In most cases statistical data, reports similar documents are aggregated using these administrative levels however boundaries are highly dynamic.

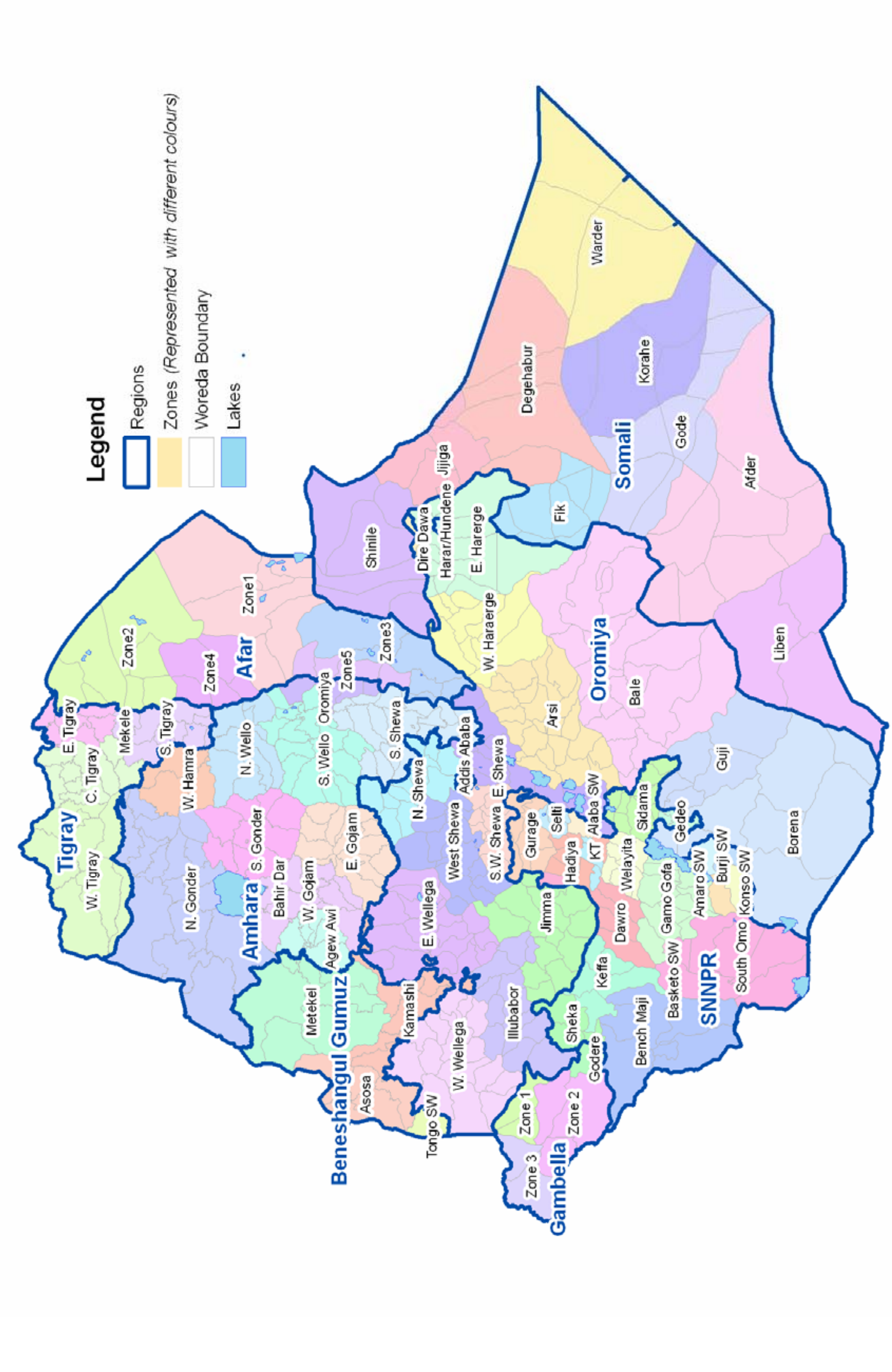

Fig 2.2 Regional Sates and Zonal map of Ethiopia with woreda boundary overlay. (Basic Data Source: Ethiopian Mapping Task Force)(Map by EGB)

Never-ending division and merging of Administrative units like *woredas* and Zones is very common which bring challenges to carry out uniform time series analyses based on these socio-economic datasets.

2.2 Physical Parameters

2.2.1 Elevation and Slope

The altitude ranges from the highest peak at Ras Dashen (4,620 meters above sea level), in the Northwest, down to the Danakil depression (120 meters below sea level), one of the lowest dry land points on the earth, in the Northeast part of the country. The highlands constitute around 45% of the total area of the country.

There is an essential difference between the highlands and the lowlands in terms of climate, population distribution, economic activities, lifestyle, etc. The important factor that determines the climate of Ethiopia is elevation. It influences temperature and rainfall. Elevation is a fundamental dimension of the geographical context in which agriculture and other rural activities take place (IFPRI 2006). The most basic understanding of Ethiopian land use and agricultural practices is defined by a distinction between highlands and lowlands, traditionally defined at 1,500 meters above sea level (m.a.s.l.).

Slope could be defined as a measure of terrain steepness, that is, the degree to which land deviates from horizontal plane. Slope affects the agricultural suitability of different areas: steep slopes are more difficult to cultivate and more likely to lose soil and nutrients through erosion faster than gentle slopes. Ethiopia being a mountainous country has steep terrain in many areas (See Fig 2.3). On the map, slope is measured as percentage rise. A slope of zero indicates flat ground, while a slope of 100 percent is equivalent to a 45 degree angle. However, while land may be irregular and precipitous in some areas (a cliff, for example), what is measured is the average slope over an area of about 3.3 hectares. So within any given area, some steeper areas will be found. In this map, average slopes of even 8-10 percent include very steep terrain (IFPRI 2006).

2.2.2 Climate

The climate of Ethiopia is mainly controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) and associated atmospheric circulations. The complex topography and existence of large water bodies further modifies the climate creating microclimates in regions. This climate ranges from semi-arid desert type in the lowlands to humid and warm (temperate) type in the southwest. Mean annual rainfall distribution has a maximum of 2000 mm over the south-western highlands and a minimum of <300 mm over the south-eastern & north-eastern lowlands. Mean annual temperature ranges from < 15^0C over the highlands to > 25^0C in the lowlands (NMSA 2001).

Mean annual rainfall ranges from about 2000 mm over some pocket areas in the Southwest to about less than 250 mm over the Afar lowlands in the Northeast and Ogaden in the Southeast. Rainfall decreases northwards and eastwards from the high rainfall pocket areas in the Southwest (Fig 2.4). Rainfall during the year occurs in different seasons. There are two rainfall seasons in Ethiopia, namely, *Belg* (February-May), a short rain season, and Kiremt (June-September), a long rain season (NMSA 2001).

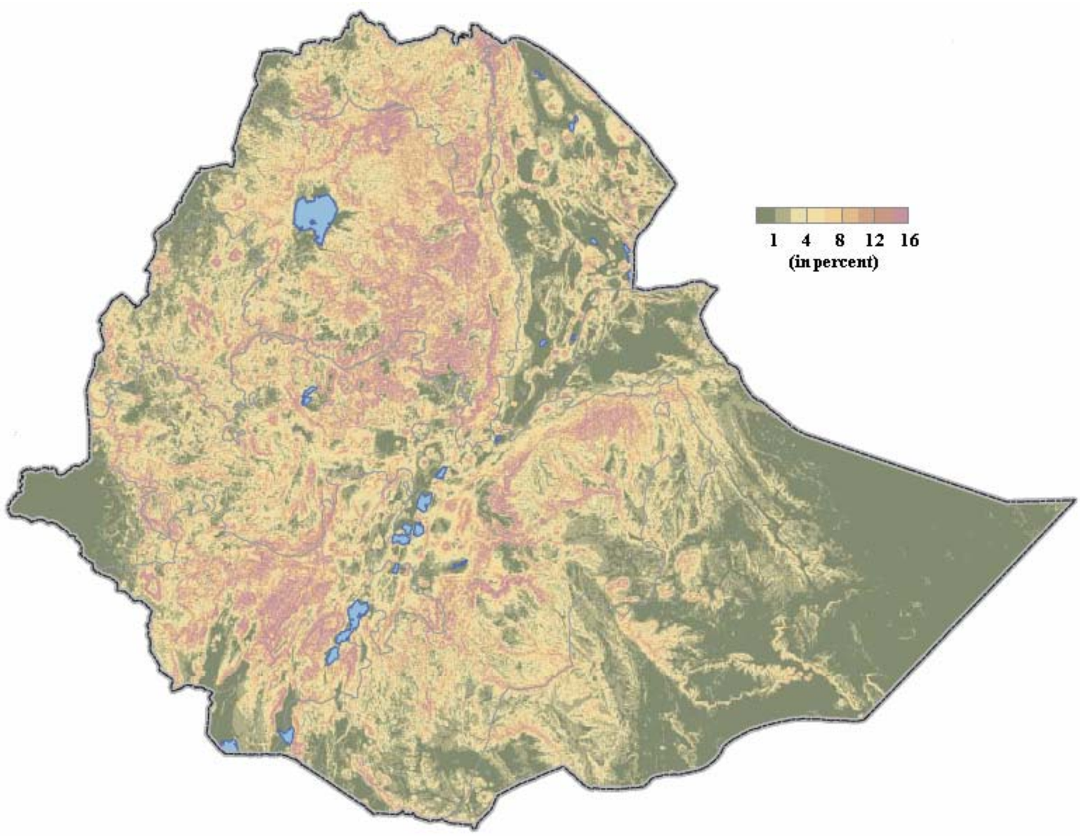

Fig 2.3 Slope map of Ethiopia (Source: IFPRI, 2006 based on Shuttle Radar Topography Mission elevation data, NASA)(Modified by EGB)

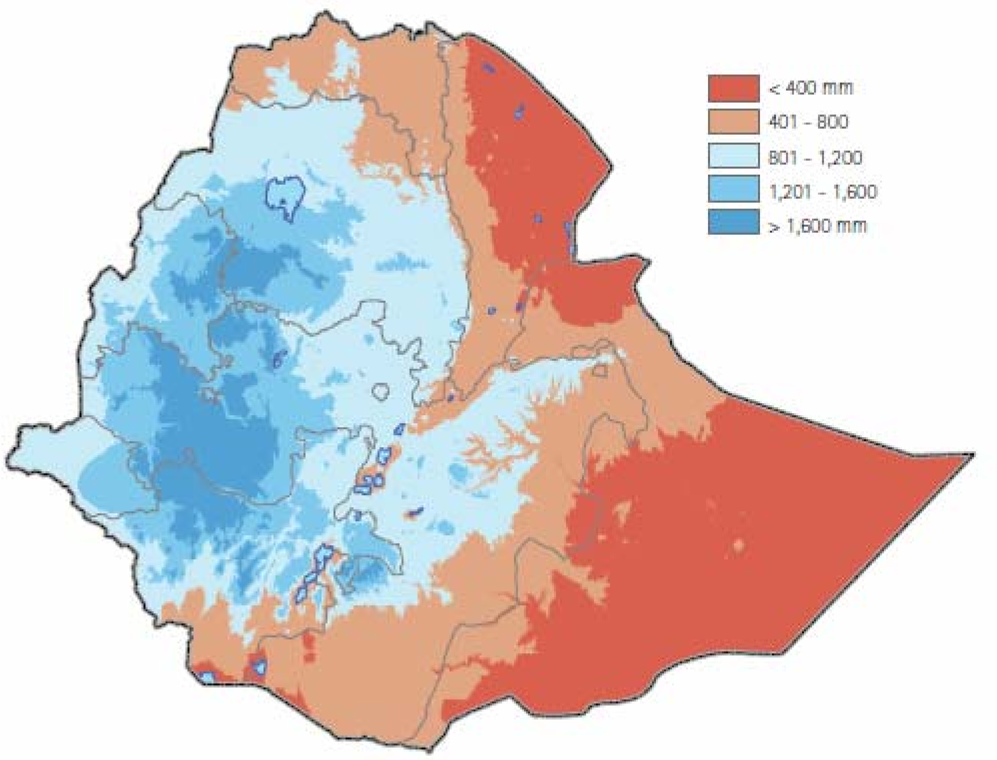

Fig 2.4 Map of mean annual rainfall (Source: IFPRI 2006, based on WorldClim, University of California, Berkeley)

The major growing seasons in the Ethiopian highlands are associated with annual rainfall patterns. Crop cultivation practiced regularly on most parts of Ethiopian highlands. Most areas in the country experience both the Kiremt and Belg rains with the exception of some areas in the northwest. In the north, *Kiremt* rains tend to fall earlier around the end of June, while in the south, they start as late as October. Although most crop production in the highlands is associated with the *Kiremt* rains, many communities depend on the *Belg* season to meet their food needs. Note that the south-western highlands get more than seven months of heavy rainfall, while the eastern lowlands get less than two months light rains (IFPRI 2006).

Maps shown on Fig 2.5 depict the long-term mean monthly temperatures calculated from average daily temperatures for the 12 months based on the past 35 years of available data. It is immediately apparent that variation between different parts of the country at any one time is likely to be much greater than variation for a single location over time. Variation in temperature is dependent on altitude. Because of Ethiopia's location near the Equator, seasonal changes in day length and incoming solar radiation are minimal and, consequently, have little impact on annual average temperature range (IFPRI 2006).

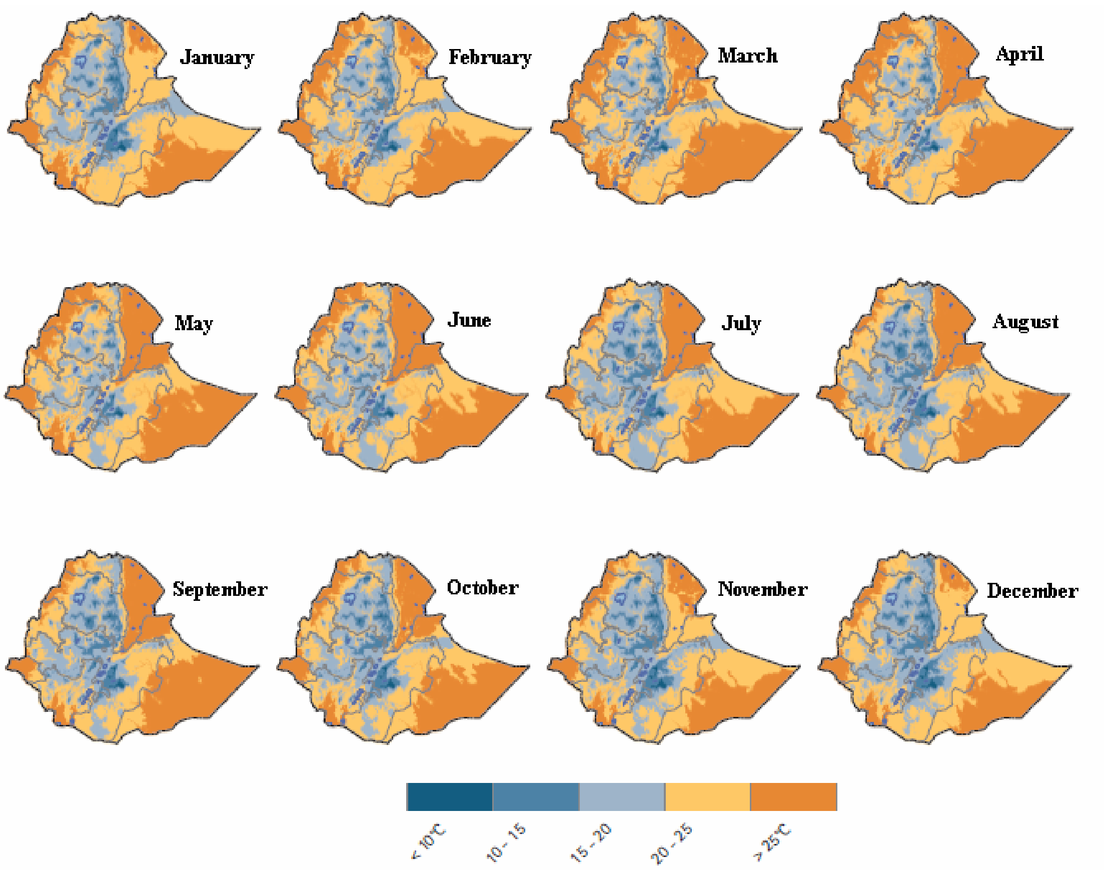

Fig 2.5 Mean monthly temperature (Source: IFPRI 2006, based on data from WorldClim, University of California)

According to NMSA, Mean annual temperature varies from about 10^0C over the high table lands over Northwest, Central and Southeast to about 35^0C over North-eastern edges (Figure 2.6). Daily maximum temperature varies from more than 37^0C over the lowlands of Northeast (Afar Triangle) and Southeast (Ogaden) to about 15^{0}C over the highlands of Central and northern Ethiopia. The elevation map is depicted on Fig 2.1. The daily range of temperature is always high. Generally speaking the months of March through May are the hottest during the year. Lowest annual minimum temperatures occur over the highlands particularly between November and January. Minimum temperatures that reach frost point during the *Bega* season are not uncommon over the highlands. Also temperatures lower than 5^{0}C occur during high rainfall months (July & August) over the plateaux in Northwest, Central and Southeast due to high cloud cover.

Agro-ecological zones are defined differently in different parts of the world, reflecting the most important local conditions in determining agricultural options. Altitude is the primary determinant of agricultural land-use options in Ethiopia due to its influence on rainfall and temperature. Other important factors vary across the country. The Ministry of Agriculture and Rural Development developed a system of agro-ecological zonation in which 18 major zones were defined for the country based on both temperature and moisture regimes. Each of these zones has characteristic crops found within its boundaries. Some crops are found within several zones; others are restricted to only one or two. Fig 2.6 depicts the complex mosaic of temperature and moisture patterns across the country; this map highlights fundamentally different production environments across the arid eastern and humid western lowlands and across the highlands, which are moister in the west than in the north (IFPRI 2006).

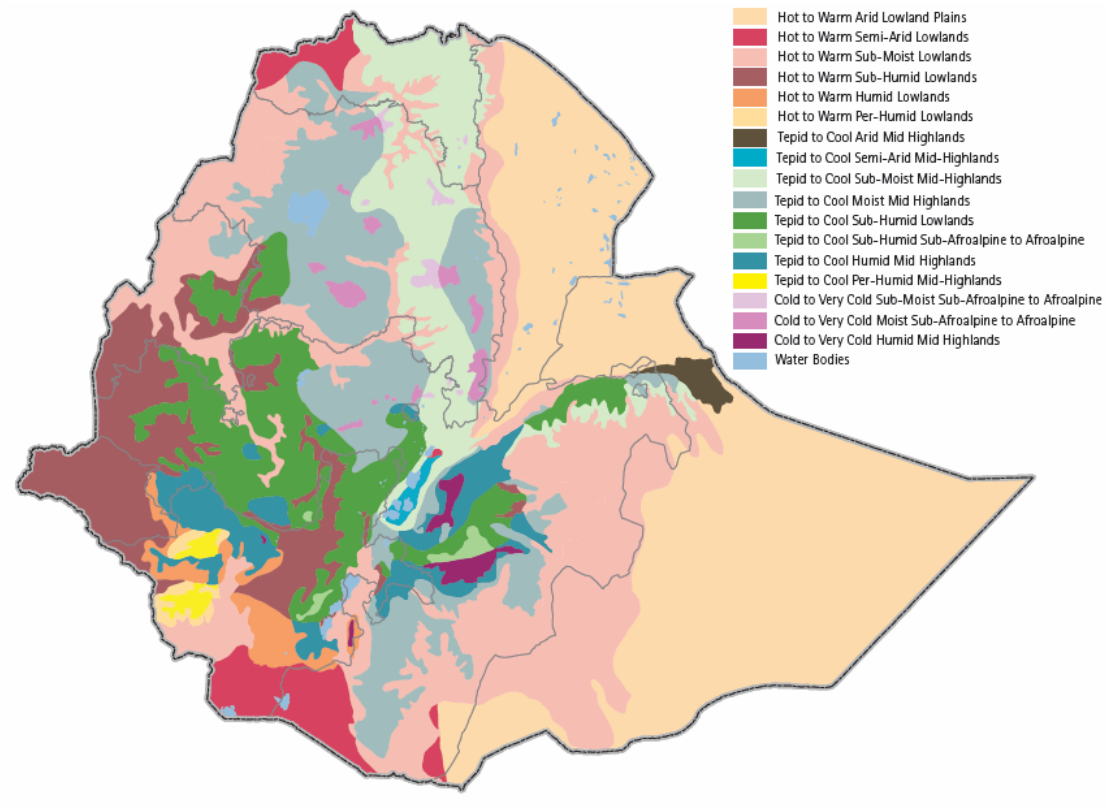

Fig 2.6 Agro-ecological zones for Ethiopia based on temperature and rainfall regimes (Source: IFPRI 2006 based on Natural Resource Management and Regulatory Department, Ministry of Agriculture and Rural Development.)

2.2.3 Land Use / Land Cover

More than 50% of Ethiopia's land is utilised for grazing and browsing. It has to be noted here that grazing and browsing occurs in cultivated areas, in woodlands and forests, bushlands, shrub lands, grasslands and in not usable lands. Cultivation forms the second largest (nearly 23%) land use while forests and woodlands cover about 7 percent of the country. Over 16% are bare land, in the form of exposed rock, salt flats and sand. Table 2.1 shows the distribution of land use in the country (EMA, 1988).

Land Use / Land Cover	Percent
Intensively cultivated land	10.3
Moderately cultivated land	12.5
Afro-alpine and sub-afro-alpine vegetation	0.2
High forest	4.4
Woodland	2.5
Riparian wood land and shrub	0.6
Bush land and shrub land	21.4
Grass land	30.5
Water bodies	0.5
Others	17.5

Table 2.1 Landuse / Landcover Distribution in Ethiopia. Source: Ethiopian Mapping Authority (EMA, 1988)

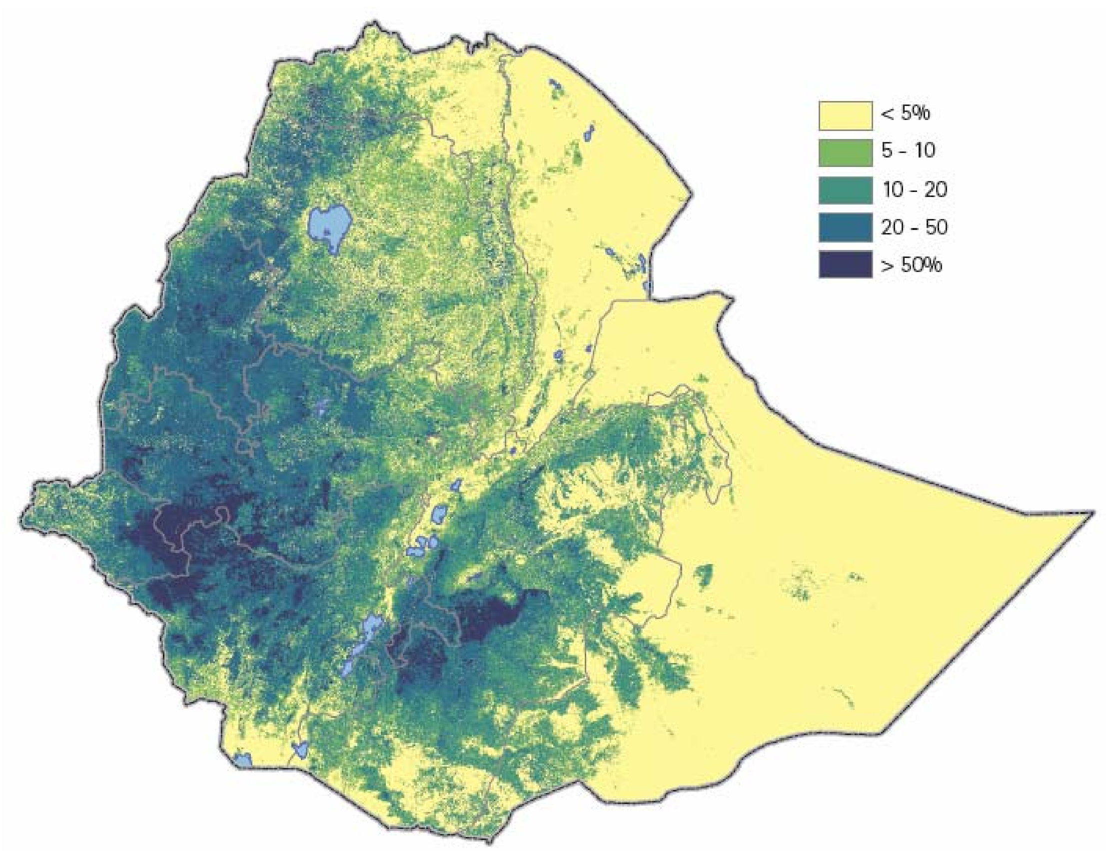

Fig 2.7 Tree cover map of Ethiopia (Source: IFPRI 2006 based on Moderate Resolution Imaging Spectroradiometer (MODIS) sensor 2001, Global Land Cover Facility, University of Maryland)

Tree cover is shown on Fig 2.7 as a percentage of total ground cover. Some of the patterns in the map reflect moisture availability. Note the general pattern of higher values in the moister areas of the country. Lower values in moist areas show where agricultural activity has displaced natural forest, particularly in the cereal-producing areas of the central and northern highlands. The tree cover map is based on moderate-resolution satellite data, which does a good job of capturing biomass (the density of vegetative material) but not different types of trees. Consequently, the map does not distinguish among different types of tree cover, such as natural forest, woodlot plantations, agroforestry, and tree crops such as coffee and fruit trees.

2.2.4 Soil

Together with climate and terrain, soil conditions determine what agricultural production possibilities exist in a given area from a biophysical perspective. Major soil associations are classified on the basis of predominant chemical and physical properties, derived from parent geological material and modified by weathering and other transformative processes. Leptosols (29.8 percent of total land area) are mostly found in the north, are very shallow (< 30 cm), and have somewhat limited agricultural potential. Nitosols (12.5 percent) are mostly found in the west and are deep, well-drained soils. Despite low pH and low levels of phosphorus, they have relatively good agricultural potential. Vertisols (10 percent) have wider distribution. They are heavy, black clay soils that are difficult to work; and have poor drainage. Although they have good chemical properties, their use is limited due to water-logging. Other soils including Cambisols (9.4 percent), Calcisols (9.3 percent), and Luvisols (7.8 percent) have relatively good physical and chemical properties for agricultural production. Gypsisols (7.6 percent) in the eastern lowlands have limited agricultural potential (IFPRI 2006).

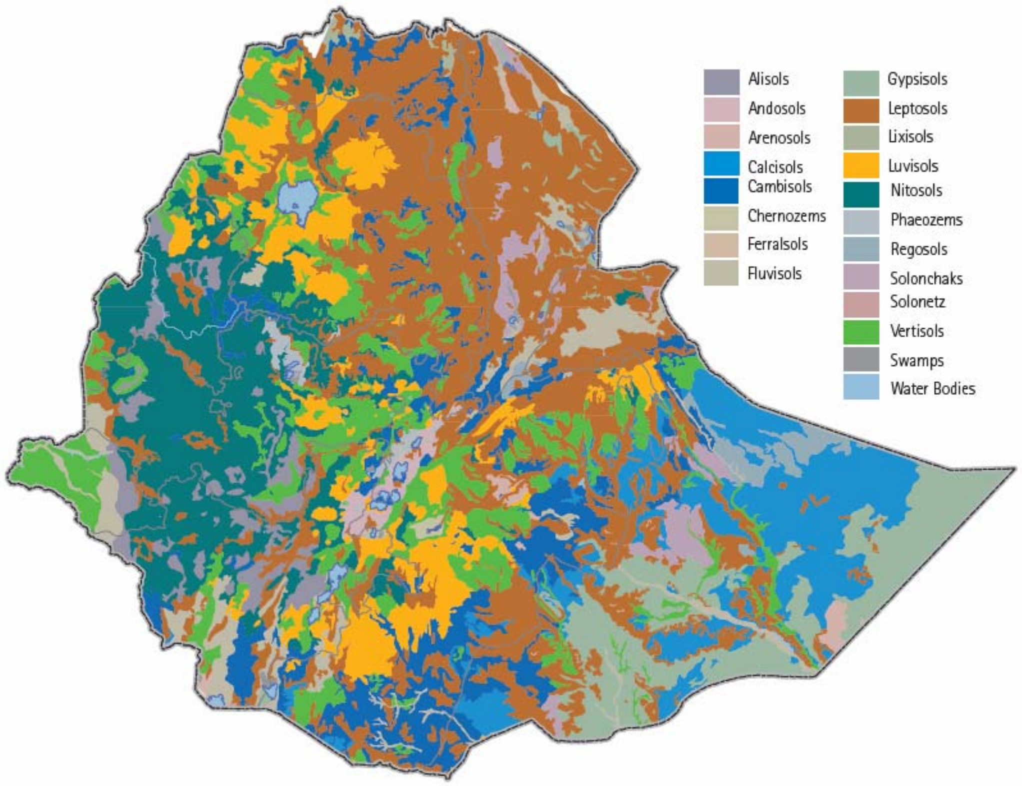

Fig 2.8 Soil map of Ethiopia (Source: IFPRI 2006 based on FAO Global Soil and Terrain Database (SOTER) 1997.)

2.2.5 Water Resources and Irrigation

Natural water resources represent a vital biosphere component. The development of water resources for agricultural purposes on the one hand and rural water supply schemes on the other are the focus of our discussion in this section. Until recently, the water potential of the country was not accurately known, and even today this is still a contentious area. There have been different estimates of the irrigation potential of the country, and the issue has not been satisfactorily resolved. One of the earliest estimations was made by the World Bank in 1973, which suggested a figure between 1.0 and 1.5 million hectares. Recent estimates, however, place the figure somewhat higher.

According to the Ministry of Agriculture (1986), the total irrigable land in the country measures 2.3 m. h. (million hectares). The International Fund for Agricultural Development (IFAD 1987), on the other hand, gives a figure of 2.8 m. h., while the Office of the National Committee for Central Planning’s 1990 figure, which is based on WRDA's estimations, is 2.7 m. h.. The Indian engineering company Water and Power Consulting Services’ 3.5 m. h. is the highest estimate so far. Most of these figures are derived by adding up the irrigation potential of the country's eight river basins as shown in Table 1 below. Except for the Awash River and the Rift Valley lakes, all the other basins are part of the major trans-boundary river systems that drain out of the Ethiopian highlands and flow into the neighbouring countries of Sudan, Kenya and Somalia.

In the 1960s and 1970s, comprehensive reconnaissance and feasibility studies were carried out on the Abbai (Blue Nile), Awash and Wabe Shebelle river basins (See Fig 2.9). In 1962, a German engineering team, and in 1964, the U.S. Bureau of Reclamation undertook extensive studies of the water resource potential of the Abbai River basin, the largest basin in the country. Both reports maintained that there were high hopes for the development of irrigated agriculture in the basin. The German study (Lahmeyer 1962), which was confined to the Gilgel Abbai basin, a much smaller area, suggested that the production of oil seeds, pulses and fodder crops, using the waters of the Gilgel Abbai, would be very profitable and earn high foreign exchange. The U.S. study recommended that small-scale irrigation should be greatly encouraged but that large-scale schemes would be too costly. It argued that without a co-ordinated water development program in the basin there would be no prospects for agricultural development in north-west Ethiopia (MWR, 2001).

On the other hand, the Awash River basin attracted a good deal of local and international investment, and was the subject of numerous studies and surveys in the 1960s and 1970s (Dessalegn 1986). By the beginning of the 1970s, 100,000 *ha.* of land was under modern irrigation in the country of which about 50 percent was located in the Awash Valley (Wetterhal 1972). An extensive survey of the Wabe Shebelle basin, which began at the end of the 1960s, was completed in 1972. About the same time, a reconnaissance survey of the Tekezze and Mereb and Gash Rivers in the north of the country was under way. In brief, the imperial regime was keen to determine the water resource potential of the country's river basins and to invite foreign capital to invest in agro-industrial enterprises in these areas. Table 2.2 shows area and percentage of potentially irrigable land and utilized areas.

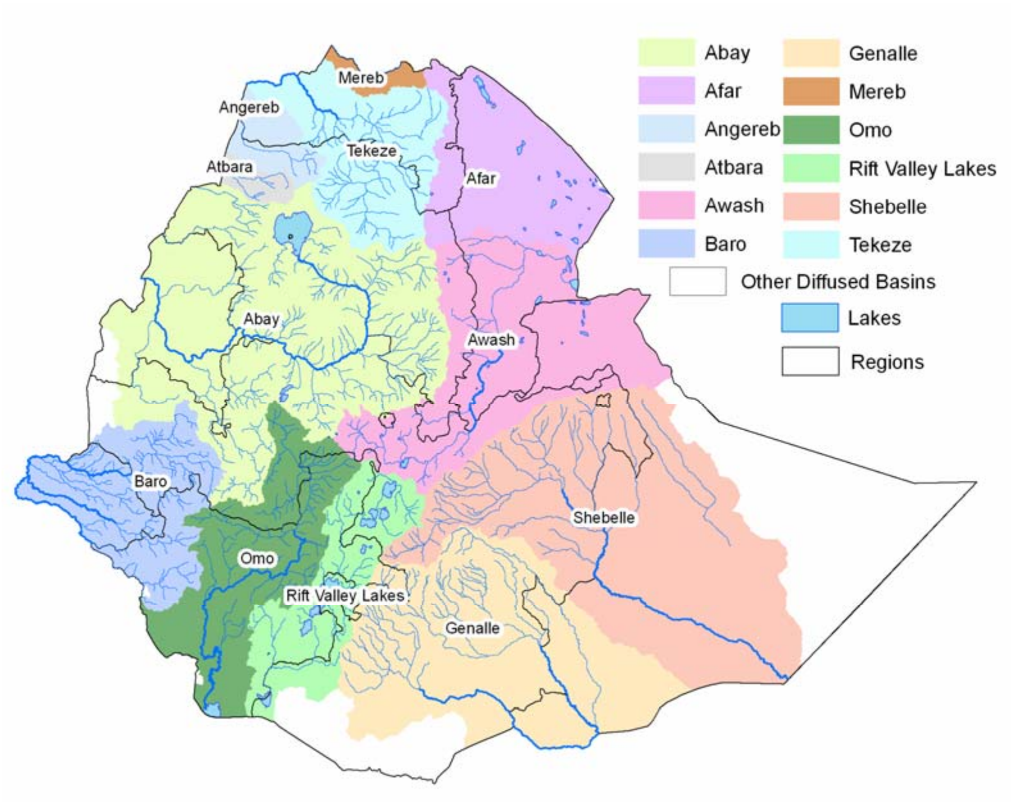

Fig 2.9 River Network and Basins of Ethiopia (Basic Data Source: Ministry of Water Resources)(Map by EGB)

	Basins	Potential irrigable area (ha.)	Actual irrigated area (ha.)	% Utilized
1	Abay (Blue Nile)	977,915	21,010	2.1
2	Rift Valley Lakes	122,300	12,270	10
3	Awash	204,400	69,900	34.2
4	Omo-Ghibe	450,120	27,310	6.1
5	Genale-Dawa	435,300	80	0.02
6	Wabi-Shebelle	204,00	20,290	9.9
7	Baro-Akobo	748,500	350	0.05
8	Tekeze	312,700	1,800	0.57
9	Afar	3,000	-	-
10	Mereb	37,560	8,000	21.3
	Total	3,291,795	161,010	4.07

Table 2.2 Potential and actual irrigated areas in Ethiopia (Source: Ministry of Planning and Economic Development)

According to recent Ministry of water resources data (cited in MEDaC 1999), some 30 large and medium-scale irrigation projects with a combined command area of over 600,000 hectares have been identified in various parts of the country for development by the state since the 1980s. Of these, about 15 percent have already been completed. Feasibility studies have been completed on another 25 percent of the projects and the rest have been the subject of reconnaissance studies. These projects are separate from the large river basin projects for which comprehensive master plans are now being prepared.

Ethiopia's use of its water resources is very limited. Less than 6 percent of the country's irrigable land is now under irrigation. The distribution of irrigation schemes in the country is quite skewed. Almost 74 percent of the irrigated area served by large and medium schemes is located in the Awash valley (MWR, 2001). However, as shown in Table 1 above, the Awash River basin contains less than 7 percent of the irrigable area of the country. In contrast, large and medium irrigation covers less than one percent of the Abbai basin, the largest basin in the country (ONCCP, 1990).

Traditional irrigation is a complement to rain-fed agriculture, and the crops grown are often horticultural crops and fruit trees. Peasants have awareness of the benefits of irrigation and are willing to invest their labour in the construction and maintenance of the schemes. In parts of north Shoa, north Wollo, east Gojjam and the highlands of Harrage zones, the traditional systems still being utilised by peasants date back to the last century. Many of these schemes are managed by elected elders known as "water fathers" or "water judges" and this traditional management system has proved effective in many instances. In some cases, the irrigation schemes are managed by PAs. It is thus evident that peasants have proven ability to organise themselves and to manage small-scale irrigation systems. The labour and discipline necessary to maintain these systems over many decades is evidence of a high level of practical knowledge of water management in the rural areas (ONCCP, 1990).

2.3 Crop and Livestock Production

Agriculture activities mainly crop production and animal husbandry remains by far the most important sector of the country for the following reasons: it supports about 85% of the population directly in terms of employment and livelihood, and it is the source of 90% of the export earnings and 40-50% of the national GDP. Food crops, industrial crops, export crops (e.g. coffee), livestock and livestock products are the main components of the Ethiopian agriculture. Subsistence mixed farming (cultivation and livestock rearing) and nomadic pastoralism are widely practiced in the highlands and lowlands respectively. It supplies around 70% of the raw material requirement of agro-based domestic industries (MEDaC, 1999). Agriculture is also the major source of food for the population of the nation and hence the prime contributing sector to food security. In addition agriculture is expected to play a key role in generating surplus capital to speed up the overall socio-economic development of the country (MWR, 2001).

The farming system in Ethiopia can be classified into five major categories namely: the highland mixed farming system, the lowland mixed agriculture, the pastoral system, shifting cultivation and commercial agriculture (Degefe, 2000). According to MEDaC crop production is estimated to contribute on average about 60%, livestock accounts close to 27% and forestry and other sub-sectors around 13% of the total agricultural value.

In Ethiopia, there are seasonal rainfall patterns that vary in number, intensity, duration, and timing, depending on location. Fig 2.10 shows the level of importance of the *Belg* season for the production of temporary crops. This is determined by dividing the amount of crop area cultivated for temporary crops during the short rains *(Belg)* by the crop area cultivated for the same crops in the main rainy season (*Meher).* The higher the mapped value, the more important the short rain season is for agricultural production. Note the strong north-south gradient. The southern part of the country has the most pronounced and economically important *Belg* season, although there is also an important secondary season in the eastern parts of Amhara region. In this area the *Belg* rains fall some weeks earlier than that further south. (IFPRI, 2006)

More than 63 percent of all crop holders in Ethiopia have less than 1 hectare of land (See Fig 2. 11). Geographically, some patterns are readily apparent. Average land holdings in the southern lowlands and highlands of SNNP, as well as the eastern highlands and eastern fringe of the northern highlands, are strikingly smaller than elsewhere in the country. In contrast, relatively few crop holders in broad areas of the central highlands of Oromiya and Amhara have less than 1 hectare of land.

2.3.1 Crops

It is estimated that 12.9 million ha (around 12 % out of the total area of the country) farmed in 2008 to produce cereals, pulses, oil-seeds and root, stem, tuber and tree crops in one of the most diverse sets of agro-ecologies in the world. Only some 200 000 ha are irrigated, therefore the nation’s annual harvests depend on the quality and quantity of the variable annual rains. Consequently, production at the national level varies dramatically from year-to-year. This is particularly the case in the marginal areas located predominantly in the north and east of the country and in low-lying valleys and rain-shadows throughout the main production zones of the central highland plateau.

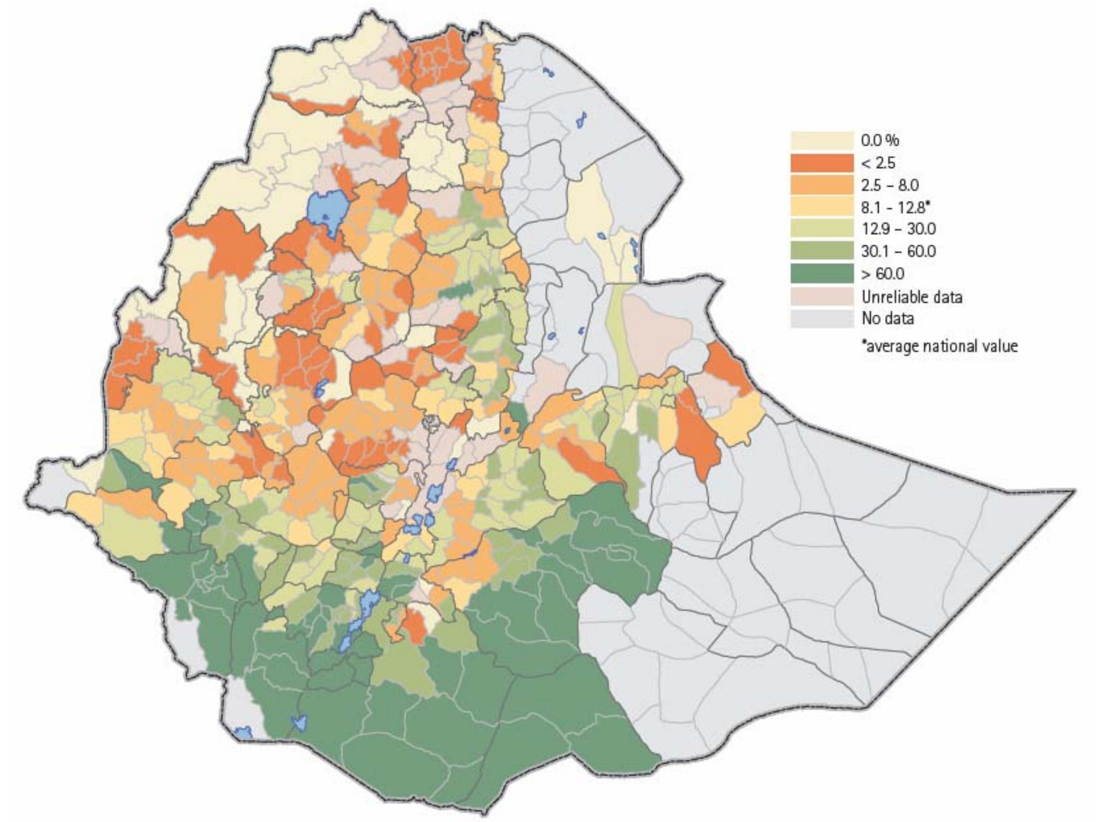

Fig 2.10 Cropped Area in Belg Season as a Proportion of Cropped Area in Meher Season (Source: IFPRI 2006, based on Ethiopian Agricultural Sample Enumeration 2001/02, CSA)

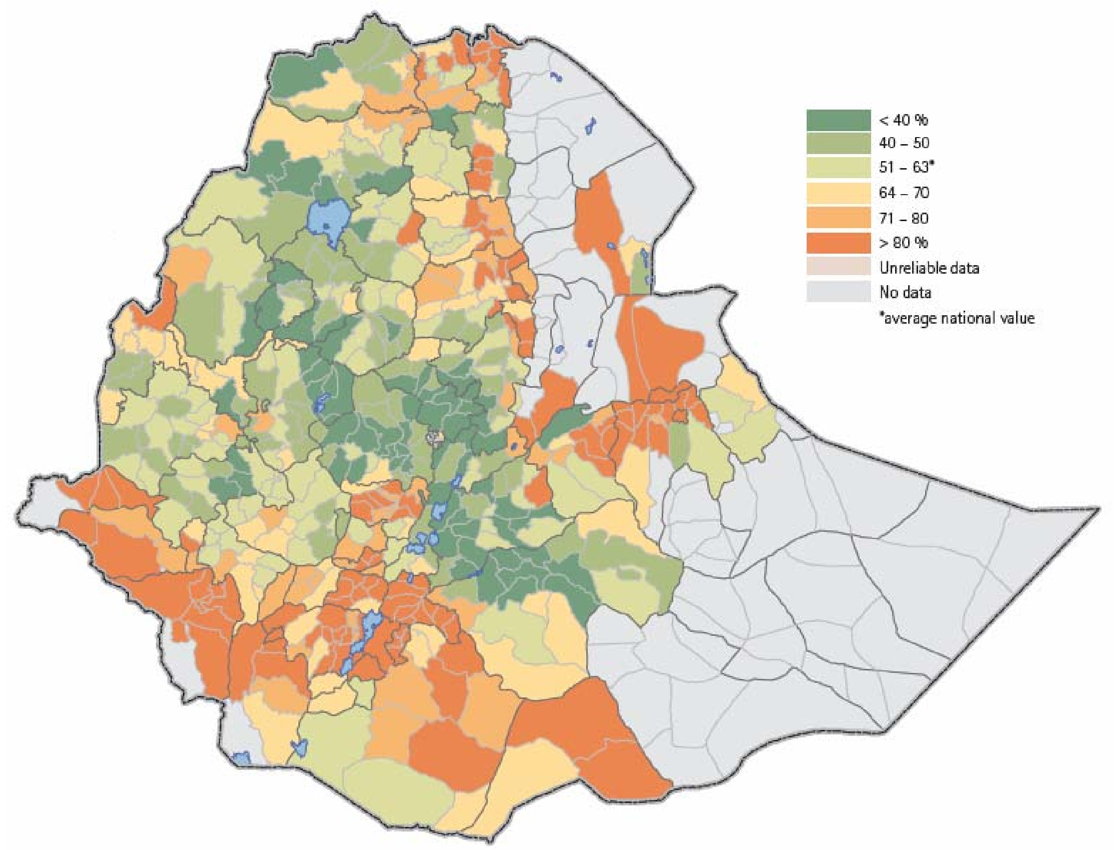

Fig 2.11 Proportion of Crop Holders with Holdings of One Hectare or Less (Source: IFPRI 2006, based on Ethiopian Agricultural Sample Enumeration 2001/02, CSA)

The crops are grown during two seasons; the minor season, *Belg*, planted from early February onwards and harvested from late March up to and including August; and the major season, *Meher*, planting both during and after the *Belg* season and harvested from September up to and including the following February (FAO, 2009).

Regions	Item	Teff	Barley	Wheat	Maize	Sorghum	Finger Millet	Other	Cereals	Total Pulses	Total cereals
Tigray	Area	191.8	99.4	112.0	77.9	168.0	79.5	-	729.8	71.8	801.1
	Yield	0.9	1.2	1.5	18	1.5	11	-	-	-	-
	Production	164.7	117.9	169.9	143.9	259.1	85.8	-	942.7	60.5	1 003.1
Afar	Area	2.7	-	-	12.5	2.0	-	-	17.2	0.5	17.7
	Yield	0.7	-	-	1.0	1.9	-	-	-	-	-
	Production	1.8	-	-	12.5	3.8	-	-	18.1	0.3	18.4
Amhara	Area	1 062.4	316.9	442.2	434.3	532.4	195.5	35.2	3 018.7	604.5	3 623.2
	Yield	1.2	1.5	1.9	2.7	1.8	1.5	1.17	-		-
	Production	1 256.6	482.7	848.2	1 173.9	957.6	284.1	61.4	5 064.6	665.0	5 729.5
Oromiya	Area	1 069.3	456.0	836.3	1 048.1	637.0	90.0	20.8	4 160.7	577.2	4738.0
	Yield	1.1	1.7	2.3	2.5	1.7	1.3	1.1			-
	Production	1 215.1	771.9	1 937.6	2 588.7	1 073.8	119.7	22.9	7 735.7	621.2	8 356.8
Somali 1/	Area	-	1.7	3.0	37.0	34.0	-	-	75.7	1.0	76.7
	Yield	-	1.0	1.2	1.0	1.0	-	-	-	-	-
	Production	-	1.7	3.6	37.0	33.1	-	-	79.7	0.6	80.3
Benl-gmuz	Area	17.7	1.1	1.8	34.0	60.3	29.9	-	145.0	9.5	154.5
	Yield	0.8	1.0	1.1	2.1	1.6	1.2	-	-		-
	Production	13.7	1.1	1.9	69.9	98.7	35.9		221.7	7.6	229.3
SNNPR	Area	200.1	75.6	107.3	324.4	102.3	6.3	1.9	818.0	167.3	985.4
	Yield	0.9	1.4	1.7	2.4	1.7	1.2	1.1	-	-	-
	Production	187.3	108.1	178.2	780.3	169.5	7.7	2.2	1 443.5	177.2	1 620.7
Gambella 1/	Area	-	-	-	6.8	3.0	-	-	9.8	0.1	9.9
	Yield	-	-	-	1.5	1.1	-	-	-		-
	Production	-	-	-	10.5	3.3	-	-	13.8	0.5	13.9
Harari	Area	-	-	0.1	2.4	5.9	-	-	8.5	-	8.5
	Yield	-	-	1.5	1.2	1.3	-	-	-	-	-
	Production	-	-	0.2	2.9	7.7	-	-	10.8	-	10.8
A. Ababa	Area	3.6	0.1	3.9	-	-	-	-	7.6	1.2	8.8
	Yield	1.4	1.6	2.3	-	-	-	-	-	-	-
	Production	5.2	0.2	9.2	-	-	-	-	14.5	1.3	15.8
Dire Dawa	Area	-	-	-	-	0.3	7.7	-	8.0	0.5	8.5
	Yield	-	-	-	-	1.2	1.1	-	-	-	-
	Production	-	-	-	-	0.4	8.5	-	8.9	0.4	9.3
TOTAL	**Area**	**2 547.6**	**951.0**	**1 506.6**	**1 977.6**	**1 552.8**	**401.16**	**62.5**	**8 999.3**	**1 433.6**	**10 432.9**
	Yield	**1.1**	**1.6**	**2.1**	**2.4**	**1.7**	**1.3**	**1.5**	**-**	**-**	**-**
	Production	**2 844.6**	**1 483.8**	**3 148.9**	**4 829.8**	**2 619.4**	**533.2**	**94.2**	**15 554.1**	**1 534.1**	**17 082.3**

1/ Incomplete.

Table 2.3. Ethiopia: Area ('000 ha), Production ('000 tonnes) and Yield (tonnes/ha) of Cereals and Pulses in 2008 Meher Season for Peasant Holdings (Source: FAO 2009)

Out of the total cropped area in Ethiopia, 92.5 percent is dedicated to temporary crops. Of this, cereals account for 80 percent of the temporary crop area. Pulses follow in importance, accounting for almost 13 percent. Oilseeds cover a little less than 5 percent of the temporary crop areas, while vegetables and root crops account for only 1 and 3 percent, respectively. As it is depicted on Fig 2.12, in terms of distribution, cereals have the most uniform patterns, being found throughout the country, especially in highland areas. There are concentrated areas of pulse production in several parts of the highlands, as well as in some transitional areas of the south. Root crops are sparsely cultivated everywhere, with some areas of denser cultivation seen in the highlands of SNNP regional state. Oil seeds are more prevalent in the central and northern highlands than elsewhere. Note that in these and subsequent maps showing crop areas, woredas with “no data” can usually be understood to have insignificant or no production (IFPRI 2006).

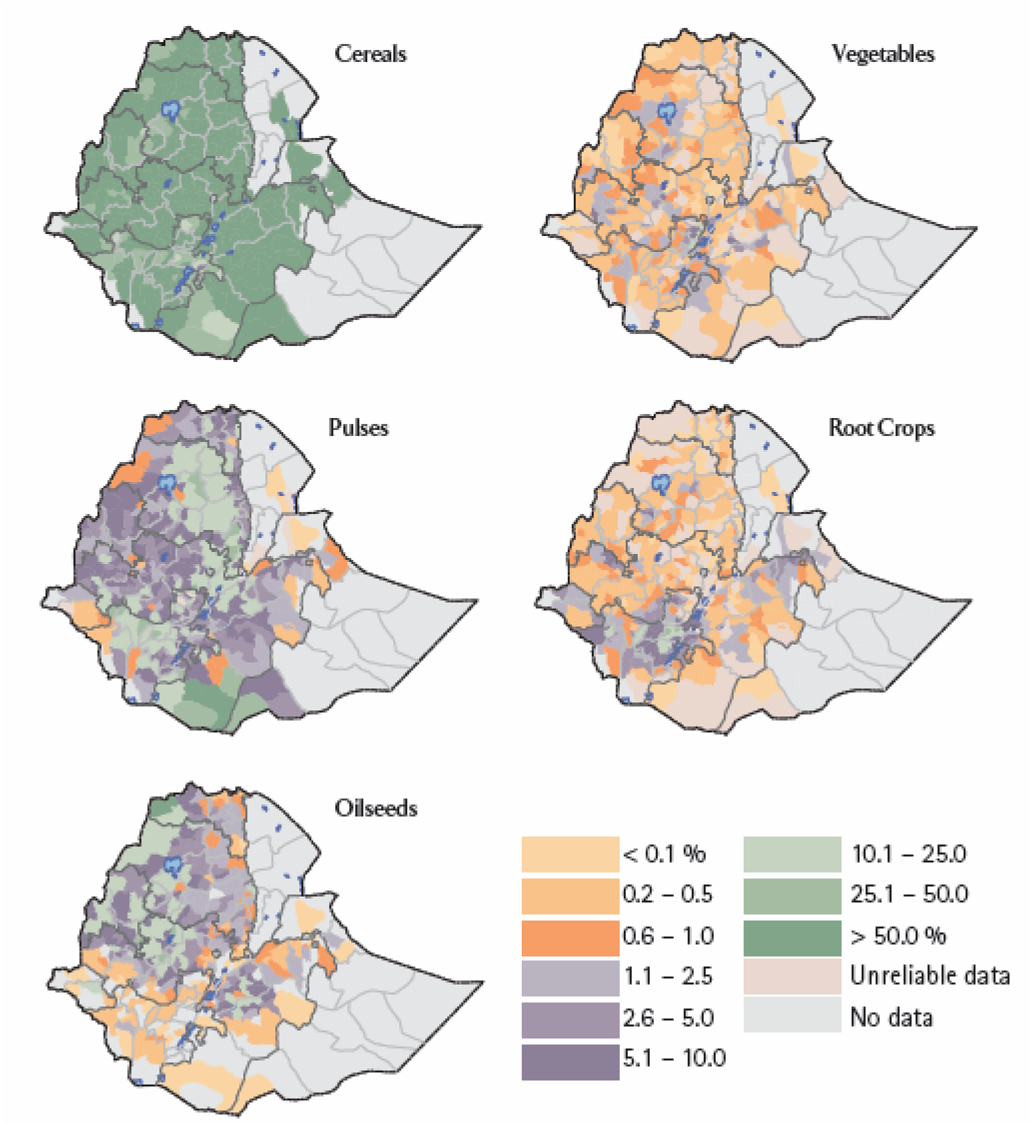

Fig 2.12 Proportion of temporary crops (Source: IFPRI 2006, based on Ethiopian Agricultural Sample Enumeration 2001/02, CSA)

Crop diversity follows the complicated mosaic of agro-ecologies derived from a combination of the usual rainfall for the locality, soil types ranging from vertisols to sand; and altitudes ranging from more than 3 000 meters to less than 600 meters above sea level. The main cereal staples are ‘teff’, wheat, barley, maize, sorghum and finger millet and they are grown in varying proportions according to the parameters noted above conditioned by the traditional culture and prevailing market conditions (FAO, 2009).

Cereals account for almost 80 percent of all temporary crops grown in Ethiopia. Of these, ‘teff’ constitutes a little more than a quarter of total cultivated area (26 percent), followed by maize (24 percent), sorghum (17 percent), wheat (15 percent) and barley (13 percent). The distribution of these cereals is strongly influenced by elevation. ‘Teff’ is grown throughout the highlands, predominating at elevations of 1,500-2,300 m.a.s.l. Maize and sorghum, while also grown throughout the highlands, do better at lower and warmer altitudes, while wheat and barley are grown in higher and cooler environments (IFPRI 2006).

Carbohydrate sources other than cereals include the stem of ‘enset’ or false-banana (*Enset ventriculosum*), cassava, sweet-potatoes and potatoes all of which are found in either the middle altitude or highland areas of the southern and central regions of the country (FAO, 2009).

A variety of oilseeds are commonly grown throughout the highlands, with distinctive geographical distributions. ‘Neug’, or Niger seed (Guizotia abyssinica), is by far the most dominant, accounting for more than half of all oilseed cropland. It is grown primarily in Amhara and Tigray but is also widespread in some parts of Oromia. Linseed accounts for about a third of all oilseed cropland and is grown over a much broader area, with the highest allocation of cropland in the Arsi and Bale regions of Oromia. Sesame is grown in some highland areas but is most common in the lowland areas bordering Sudan in the far west (IFPRI 2006).

	Commercial Farms 2007			Commercial Farms 2008		
	Area (ha)	Yield (t/ha)	Production (tonnes)	Area (ha)	Yield (t/ha)	Production (tonnes)
Total Grains	299 993		470 965	287 194		439 131
Cereals & Pulses	178 290		410 965	141 315		350 943
Total Cereals	158 031		380 965	139 984		349 456
Teff	4 577	1.7	7 613	109	0.8	89
Barley	614	1.9	1 150	1 481	1.7	2 549
Wheat	33 494	2.0	66 141	19 544	2.6	51 445
Maize	53 780	3.6	190 989	4 640	4.3	165 270
Sorghum	65 508	1.8	114 994	80 210	1.6	130 103
Finger Millet	58	1.3	78			
Oats						
Rice - Other						
Pulses	20 259	1.5	30 000	1 331	1.1	1 487
Oil Seeds	121 703	0.5	60 000	145 879	0.6	88 188

Table 2.4. Ethiopia: Area ('000 ha), Production ('000 tonnes) and Yield (tonnes/ha) of Cereals and Pulses in 2008 Meher Season for Commercial Farms (Source: FAO, 2009)

Cash crops include oilseeds, sugar-cane, coffee, tea, chat, eucalyptus, citrus, mangoes and spices. The tree crops are grown in forests and plantations and on-farm as hedgerows, woodlots and orchards throughout the country located in the middle altitude and highland farms. By far the most important is the ubiquitous eucalyptus which serves as the basic commodity for the construction of rural houses and furniture and provides a sustainable flow of fuel wood for both domestic and rural agro-industrial use (FAO, 2009).

2.3.2 Livestock

National livestock production from pastoral areas is augmented by the settled agro-pastoralism of peasant farmers throughout the central plateaux. Grasslands, comprising indigenous grasses and clovers, provide intensively grazed pasture, which, coupled with browse and crop residues provide the feed for the livestock in mixed farming systems producing sheep, goat and beef and dairy cow products for sale and home use. The sedentary livestock also include the ubiquitous oxen that provide the draught power for major peasant farming operations like ploughing, secondary cultivation, and threshing and some transportation of goods and commodities (FAO, 2009).

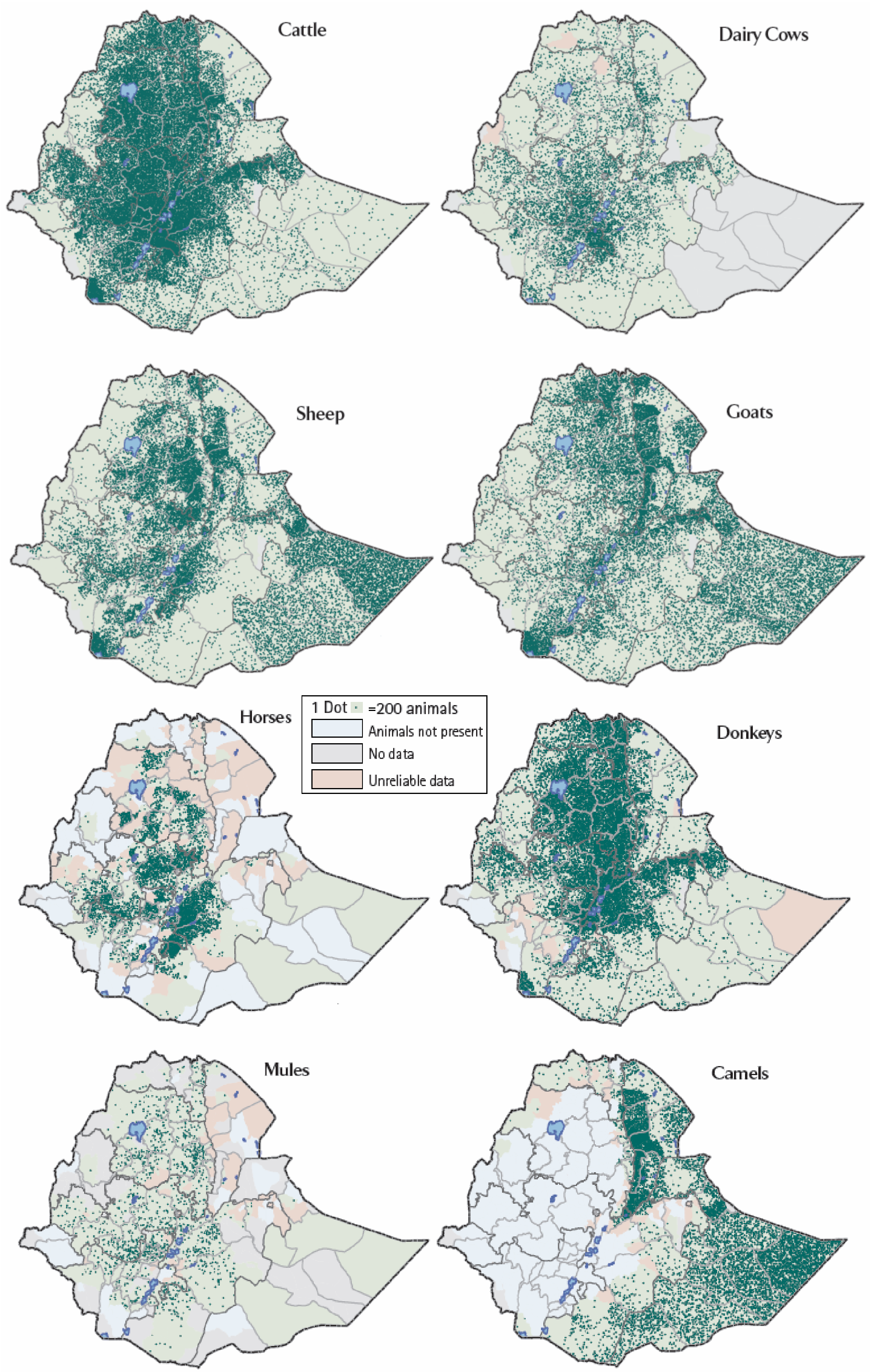

Fig 2.13 Livestock population dot map (Source: IFPRI 2006, based on Ethiopian Agricultural Sample Enumeration 2001/02, CSA)

Livestock densities vary throughout the country depending, in part, on the type of environment found and farming system used. Fig 2. 13 shows the densities of the livestock most commonly held by smallholders. Cattle used for dairy and meat production, as well as farm traction, are found throughout the highlands. Moreover it shows densities of draught animals, which clearly shows that horses, mules, and donkeys are all found predominantly in highlands, while camels are almost exclusively found in the lowlands (IFPRI 2006).

Of these cattle, dairy cows are most common in the central highlands and transitional areas in and around the Rift Valley, while other cattle are found in high densities throughout the highlands. Goats and sheep are used in both highland and lowland environments, with goat populations somewhat more uniformly dispersed than sheep. All types of livestock have relatively low densities in the humid lowlands of the west, which is primarily due to the increased prevalence of tsetse flies (IFPRI 2006).

Looking more closely, studies suggest some important variations in this pattern: donkeys have both the greatest density and widest distribution, being found even in many lowland areas. Horses are most prevalent in Oromia and eastern Amhara, where they have longstanding cultural associations as well as economic uses. Mules also have a wide distribution in the highlands but are far less numerous overall. All types of livestock have relatively low densities in the humid lowlands of the west, primarily due to the increased prevalence of tsetse flies (FAO 2002).

2.4 Population size and growth

The 2007 Population and Housing Census results showed that the total population of Ethiopia is around 74 million and estimated to be 80 million in the year 2010. The data show that there are significant variations in the distribution of population by regions. As shown in Table 2, the largest proportion of the country's population was found in Oromia Region, followed by Amhara and SNNP Regions. The lowest proportion was in Harari Regional State (CSA, 2009).

The same patterns of overall population distribution by regions were observed in the 1994 census. However, there were slight changes in the percentage of population distribution over the last 12 years: the percentage shares for Oromia and SNNP Regions have slightly increased since 1994, whereas the percentage share of the national population in Amhara Region has declined from 25.9 to 23.3 percent. Around 80% of the population of the country was found in the three biggest regional states namely: Oromia, Amhara and Southern Nations and Nationalities and Peoples (SNNP) both in 1994 and 2007. For the rest of the regions, distribution of the national population expressed in terms of percentages remained nearly the same (CSA, 2009).

The 2007 Population and Housing Census results show that the population of Ethiopia grew at an average annual rate of 2.6 percent between 1994 and 2007—a decrease of 0.2% from the annual growth rate during the previous period (1984-1994). The highest annual growth rate for the period 1994-2007 (Fig 2.14) is observed for Gambella Region (4.1), followed by Benishangul-Gumuz (3.0%), SNNP and Oromia (2.9 %).

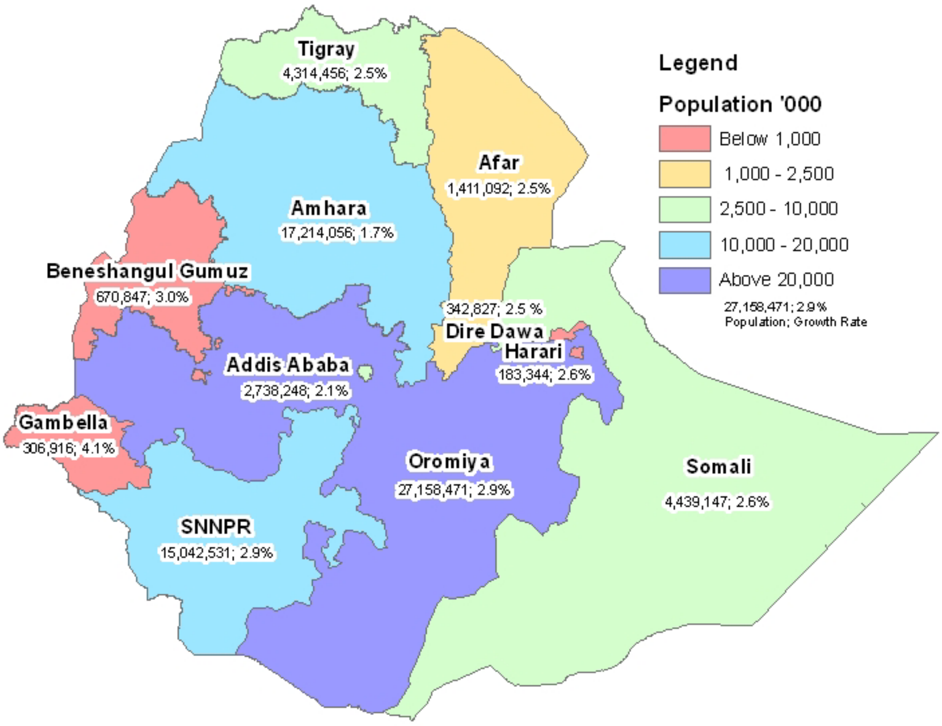

Fig 2. 14. Population and growth rate map of regions. (Basic Data: 2007 Census Report)(Map by EGB)

The annual rates of population growth for Somali, Harari and Tigray Regions and Dire Dawa City Administration are almost the same as the national rate. The lowest annual growth rate in the country is for Amhara Region (1.7%), while overall, annual growth rates in four other regions are higher than the national average.

Region	1994		Growth Rate in %	2007	
	Number	% share		Number	% Share
Tigray	3,136,267	5.9	2.5	4,314,456	5.8
Afar	1,060,573	2.0	2.2	1,411,092	1.9
Amhara	13,834,297	25.9	1.7	17,214,056	23.3
Oromia	18,732,525	35.0	2.9	27,158,471	36.7
Somali	3,198,514	6.0	2.6	4,439,147	6.0
Benishangul Gumuz	460,459	0.9	3.0	670,847	0.9
SNNP	10,377,028	19.4	2.9	15,042,531	20.4
Gambella	181,862	0.3	4.1	306,916	0.4
Harari	131,139	0.2	2.6	183,344	0.2
Addis Ababa	2,112,737	4.0	2.1	2,738,248	3.7
Dire Dawa	251,864	0.5	2.5	342,827	0.5
Special Enumeration				96,570	0.1
Country Total	53,477,265	100.0		73,918,505	100.0

Table 2.5 Regional population size, share and growth rate (Source: CSA 2007)

Age data is useful for demographic analysis and for various types of socio-economic development planning. The age-sex structure of a population is usually depicted graphically by a population pyramid. It is determined by the effects of past fertility, mortality and migration. Though age data have many uses, it is usually very difficult to obtain reliable data on age in developing countries. This is mainly due to high illiteracy, which limits individuals' awareness and capacity to record their children's and their own age. Moreover, the lack of a complete and sound vital registration system has a negative impact on the quality of age data. Such is the case in Ethiopia. To mitigate this problem, alternative methods, such as using lists of historical events, have been used to assist respondents and enumerators in estimating a person's age during census surveys (CSA, 2009).

The broad base of the population pyramid depicted below shows that a significant proportion of the national population is below age 15 the 2007 census a pattern also observed in the 1994 census.

The impact of population growth on development is not inherently negative or positive. When accompanied by rapid economic and technological advances, population growth can actually contribute to national development (Birdsall, Kelley, & Sinding, 2001).

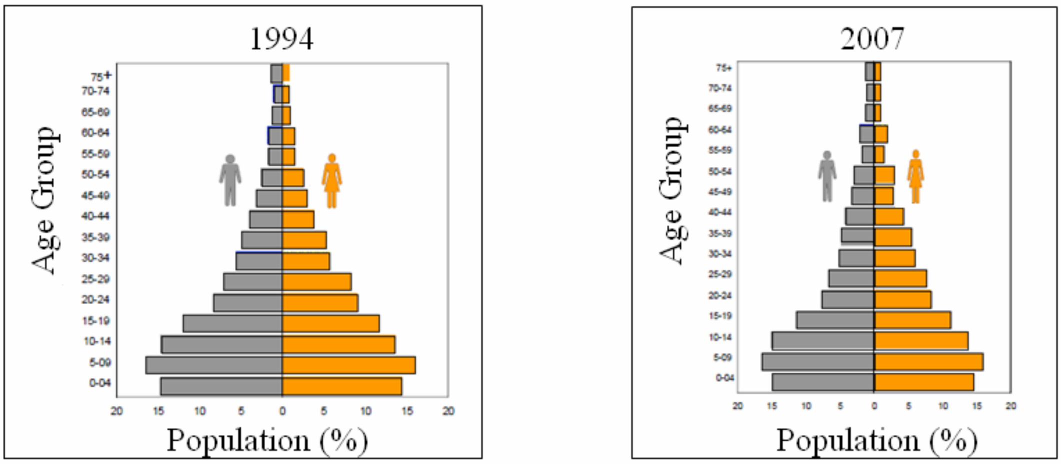

Fig 2.15. Population Pyramid of Ethiopia 2007 and 1994 (Source: CSA 2007)

Ethiopia's economic and social indicators are declining with population growth. The majority of Ethiopia's population is economically inactive. Over half are under the age of 18, which is too young, or above the age of 65, which is too old to work and only half of the working-age population is employed full time (See Fig 2.15). Therefore, a small working population must provide for a large number of unemployed young people, creating a disproportionately high dependency level that inhibits investment in the future.

Life expectancy is 42 years at birth, infant mortality is 114 per 1000 live births, and the mortality rate for children under age five is 171 per 1000 live births (World Bank, 2004).

Malnutrition is a chronic problem: more than half of children under five years are stunted, while 47 percent are underweight (UNICEF, 2004). The average daily calorie intake of the population (2,037 per day) lags behind the minimum recommended intake of 2,300 calories.

Ethiopia's unsustainable population growth contributes not only to its dire economic and social situation, but also to the country's environmental degradation, especially in the densely populated highlands. These sloping lands, occupied for centuries, are severely deforested, over cultivated, eroded, and nutrient-poor.

Population growth rate in urban areas is much higher than in rural areas: while the national population growth rate is 2.46 percent, the urban centres grow at a rate of 4.1 percent as drought and famine in the rural areas force people to seek alternative livelihoods in the cities (UNPD, 2003).

2.5 Early Warning System

With a plethora of rainfall driven problems, an effective early warning system, would provide sufficient lead time between prognosis and actual occurrence of food shortages or surpluses and enables the government to face sudden or chronic food crises on the one hand and ensure supply-demand balance through necessary intervention in the market on the other. According to ECOSOC (United Nations Economic and Social Council), early warning system is an essential management tool for safeguarding and improving food security. A national early warning system needs to be integrated with the global early warning system to assess the domestic food availability situation by adjusting domestic production/stock with import/export of the essential food items.

Information systems are critical for ensuring that government is able to uphold its responsibilities to the citizenry in an accountable fashion. However, research indicates that the relationship between policy, information and action is not as direct in practice as it is in theory (Hendrie, 1997).

In Ethiopia, there is an abundance of institutions engaged in disaster early warning, baseline information and food security surveillance activities. Sandford's Review of Assessments Undertaken in Ethiopia (Sandford, 2002) includes 33 different types of assessments throughout the country. The management of early warning entails an impressive array of government, donor, UN and NGO bodies (Lautze, 2003).

The National Early Warning Committee is chaired by the DPPA (Disaster Prevention and Preparedness Agency) and consists of the MoARD, NMSA, CSA and EMA. The Early Warning Department of the DPPA serves as its secretary. Early Warning Committees exist in most regions, zones and woredas. Government officials per woreda are responsible to complete a monthly reporting format. In pastoral areas, for example, the monthly data collection form includes the following eleven indicators of production, consumption and welfare.

- Rainfall (amount, distribution, timeliness)
- Pasture and water (availability and livestock density)
- Livestock (condition, population, mortality and causes, disease types and outbreaks, measures taken)
- Human and livestock migration patterns (usual, unusual, distance)
- Crop (major crops, timing of cultural practices, deviations, crop condition, pests and diseases, measures taken)
- Food and feeds deficiency
- Other sources of income (labor, charcoal production, etc.)
- Market situation (supply and price patterns, variations and causes for all livestock species,
- grains, other food crops and food items)
- Coping strategies (distress migration, distress disposal of jewelry and other household items, sale of oxen, excess marketing of livestock, seeking unskilled labor, begging and crisis appeal to the authorities)
- Relief food (availability and distribution)
- Human health (outbreaks, persons affected, measures taken, results, mortality and causes)

The Livestock Early Warning System (LEWS) is currently in a pilot phase in Borana (near Yabello) with plans to hand over the system to the DPPC in the near future. LEWS is specifically designed to assess risks in pastoral areas and is intended to provide monthly projections of developing situations (Seleshi, 2003). The program combines predictive and spatial characterization technologies with a network of collection and measurement sites. The Ethiopian Agricultural Research Organization (EARO) is currently testing the system. The LEWS system is based on near infrared spectroscopy (NIRS) and faecal profiling technology, supported by advanced grazing land and crop models. Its main products are:

- spatial analysis of weather, soils, terrain conditions and human and livestock populations,
- nutritional analysis of free-ranging animals (through faecal samples)
- analysis of the impact of weather on forage supply and crop production among selected groups of households (Smith, 2001).

The objective of the NMSA is to provide weather forecast information for government agencies engaged in civil aviation, agricultural and weather dependent activities. The NMSA provides short-term (3 day), medium-term (10 day), monthly, and seasonal forecasts. Maps are produced along with descriptive forecasts. The forecasts of the NMSA indicate the amount of precipitation and are not designed to monitor soil moisture in the soil. Daily forecasts are disseminated by radio and television. The NMSA is reputed to provide fairly adequate forecasts that are widely used by government offices, other early warning systems, NGOs and farmers.

The Ministry collects data on crop production by using such indicators as land preparation, timing of planting, seed availability, germination rate, dry planting, area coverage, market prices, etc. Prior to the federal government’s program of decentralization, the zonal bureaus served as sources of data. The MoA has not yet implemented a plan to collect data from the approximately 512 woredas since communication equipment is generally not available in most woredas. Whenever there is drought MoARD collects weekly assessment reports from crisis-affected regions, although it is unclear how this system is linked to the DPPA’s system of routine data collection.

CSA is responsible for the data collection of the WMS and plays key roles in designing questionnaires. Indicators monitored include household assets, income sources, access to facilities, education levels, health status, consumption and production. The Welfare Monitoring Unit assumes responsibility for most of the analysis on these indicators. The analysis is conducted by highly skilled analysts. The resulting documents are much demanded by donors and government institutions. They are used for influencing policy, although they also assist with upward accountability. The key users are the Ministry of Finance and Economic Development (MoFED), the Prime Minister’s Office, Donors, Regional Councils and Regional BoFEDs.

FEWS-NET relies heavily on the convergence of independent variables generated through the Early Warning Working Group consisting of DPPC, SC-UK, WFP/VAM, CARE, SC-US, UN-EUE, MOH, NMSA, MOA and NGOs. This reliance on secondary sources is both a strength (in that it strives to conduct a form of meta-analysis on existing data) and a weakness (in that it has no capacity for independent verification). Its similarity to both the WFP/VAM and DPPA Early Warning Systems makes it difficult at times to distinguish the particular contributions of each system.

FEWS-NET makes use of satellite imagery for spatial analysis (NDVI and Meteosat/Rainfall Estimation), which it receives directly from NASA and NOAA every ten days. FEWS-NET staffs undertake frequent field trips to assess food security (availability and access) conditions in collaboration with WFP, government partners and NGOs. FEWS-NET produces a monthly food security report that is widely distributed. They also issue alerts and harvest assessment reports. Located on the same compound as the USAID/Addis Ababa mission, FEWS enjoys a high level of access and influence to USG relief and development decision makers. Looking ahead, FEWS-NET is shifting its focus from food security hazards to closer monitoring of food security outcomes, using livelihoods-based frameworks.

The annual FAO/WFP Crop and Food Supply Assessment mission (October / November) estimates national cereal and pulse production, import requirements and needs for emergency food aid (FAO/WFP, 2002). The assessment is designed to calculate the "food balance," i.e., the overall staple food (cereals and pulses only) surplus or deficit. The food balance is an estimate of the total quantity of cereals and pulses produced nationally minus 160 kg per person per year. Livestock and root and cash crop performance are not considered.

The main multi-agency post-harvest assessment (WFP and other UN agencies, donors, NGOs and regional authorities) determine the number of people requiring food assistance at district level and the duration of assistance for the following year. Around 20 teams participate in the multi-agency assessment with approximately 80 assessors from over 15 agencies.

The WFP/VAM department uses state of the art mapping technologies to identify areas where people are most vulnerable to hunger and to estimate their needs. It is one of several systems WFP manages. (Others include site and project monitoring and woreda profiles.) The role of WFP's VAM unit in early warning can be divided into three categories: (1) assessments for triggering intervention, (2) analysis for advocacy and resource mobilization, (3) contingency to strengthen preparedness.

The VAM unit uses a range of monitoring indicators including satellite imagery of rainfall and crop conditions and food prices in local markets. WFP obtains food security information from WFP field officers based in the regions and external sources, e.g. DPPC-EWS, FEWS-NET, UN-EUE and NGOs. Through the WFP field offices, VAM collects data on pastoral areas using such indicators, *inter alia*, as pasture and rainfall condition and market prices through its field offices with an aim to generating data for food requirements.

3. Seasonal Rainfall and Vegetation Patterns

3.1 Spatio-temporal Distribution of Ethiopian seasonal rainfall

The National Meteorological Services Agency has identified six major rainfall zones based the seasonal distribution of rainfall (See Fig 3.1).There are three types Mono-modal classes. Mono-modal I areas receive rainfall during the boreal summer June, July, August and also September and particularly in the southern part of this rainfall zone. The dry period is longer, particularly in the eastern margin of northern Ethiopia as compared to that of other parts of the country. Central Highlands of north Ethiopia experiences rainfall up to 1400mm while the reverse is true when we go towards the east, which is less than 200 mm.

The southwest part of the country where the rainfall amount high classified as mono-modal II and it receives rainfall during summer, spring and autumns seasons. According to NMSA (1989), the mean annual rainfall reaches up to 2800 mm in the southwest and the minimum mean annual rainfall below 600 mm over the margin of western tip. The moist period lasts nine months from February to October in the southwest and it decreases gradually towards the west. The six-month humid period from April to September is suitable for the production of perennial like coffee and others without the risk of sever water stress.

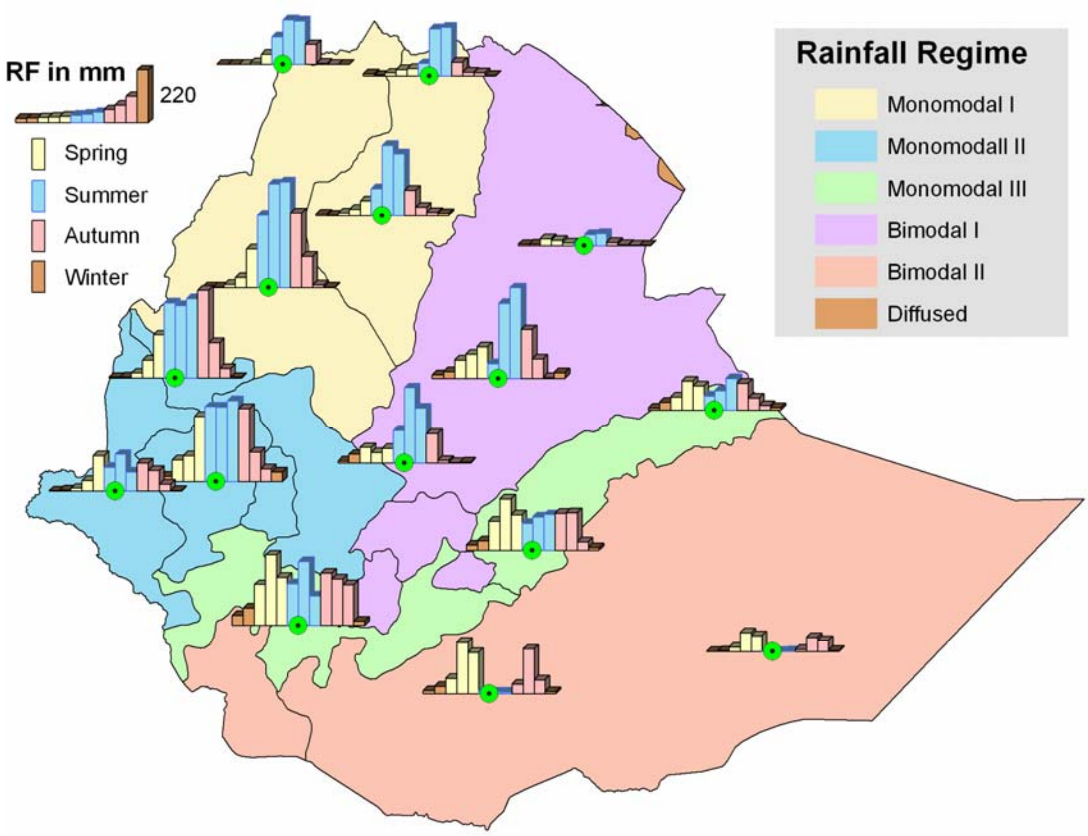

Fig 3.1 Zones of seasonal rain (Basic Data Source: NMA)(Map by EGB)

The third type of mono-modal rainfall regime is a strip of land stretching from south west part of the country to south eastern part of the country and the rainfall amount also decreases as one goes further to the east. However in this zone all the three seasons namely summer, spring and autumn are equally important.

There are two types of bi-modal rainfall regimes. The first one which is classified as Bimodal I receives rainfall during spring and summer. The spring rains are shorter in time frame and small in amount. The mean annual rainfall ranges from 400mm in the Rift Valley to 1600 mm towards the West.

The other type bi-modal type of rainfall zone is found in the south eastern lowlands Ethiopia. The spring and autumn rains are important here. The eastern highlands receive mean annual rainfall up to 1000 mm whereas there is a decrease towards the southeast of up to 200 and less than that. The main dry period lasts five months, from October to February. The spring rains brings higher amount of rain to this zone. In the north-eastern lowland area where the great east African lift valley gets its widest part the rainfall pattern is diffused.

Rainfall varies throughout the country, not only spatially but also temporally (See Fig. 3.2). Some parts of the western highlands experience rainfall for most of the year, while most of the rest of the country experiences rainfall within either the main rainy season (Kiremt, roughly July through Sept) or possibly also the short rains (Belg, roughly March through May).

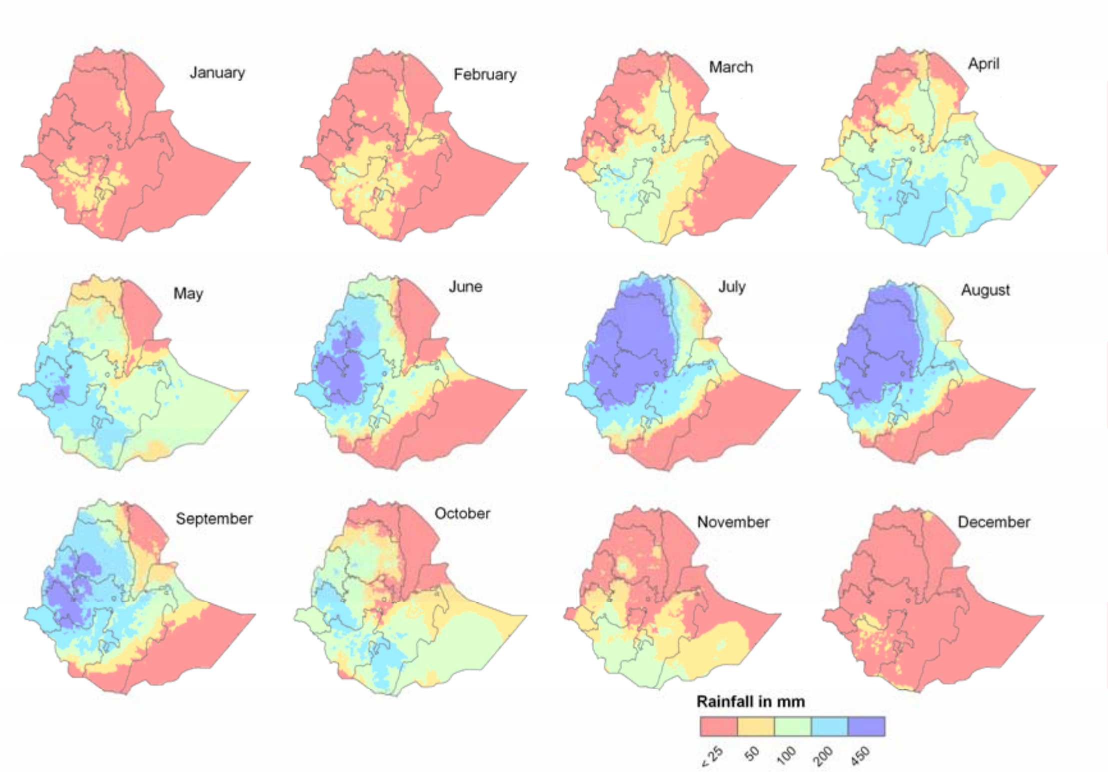

Fig. 3.2 Mean monthly rainfall in mm (Basic Data Source: NOAA RFE) (Map by EGB)

The Maps in Fig 3.3 illustrate the contribution of individual months compared to the total mean annual rainfall. It is possible to see clearly that the month of April for the south eastern part since the area receives above 50 % of the rain during this month.

Some pockets areas receive up to 70% during this month. At the national scale the months of January and February are less important in terms of their contribution since their contribution is less than 10 %. Rainfall during the month of December is also less important for most parts of the country with the exception of southern tip of SNNPR.

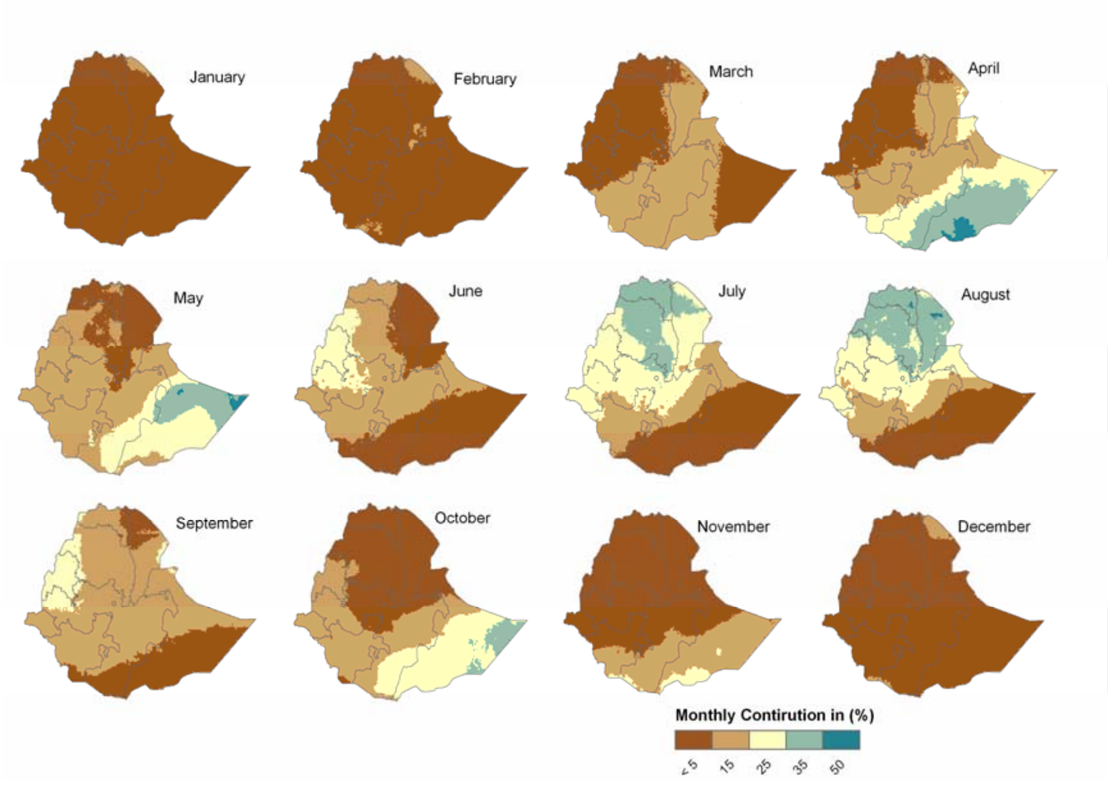

Fig 3.3 Percental monthly contribution out of total annual rainfall (Basic Data Source: NOAA RFE) (Map by EGB)

The rainfall amount and its inter- and intra-annual variability are the limiting factors in most parts of northern, eastern and southern parts of the country. The variability of rainfall has not only shaped the farming systems in these areas, but has greatly influenced the public policies and programs for these areas. The onset, distribution and amount of rainfall are very important to perform proper agricultural activities.

Since the weather phenomenon varies year to year, and the effect of that specific phenomenon could vary area-to-area, comparing and identifying the areas with different duration of records may be misleading. For instance for Addis Ababa the CV value for the duration of 1964-2000 is 21% while during 1981 – 2000 it is 24%. In case of Arba Minch, from 1970-2000 the CV is 30% while during 1981-2000 it was 20%. So the variability could vary with the reference of different time frame even in case of the same station, let alone different areas. Since the weather phenomenon varies year to year, the effect of that specific phenomenon could vary area to area (Demissie, 2002).

As can be seen from Figure 3.4, the variability increases towards the north, north-eastern, south and south-eastern parts of the country and these areas are not suitable for cultivation. As a result, through diversification and flexibility of farming systems, the farmer tries to adapt both to good and to bad rainfall situations. Besides, the erratic nature of the rainfall could favour the occurrence of pest and disease in these areas. As a result, crop yield is poor in these areas.

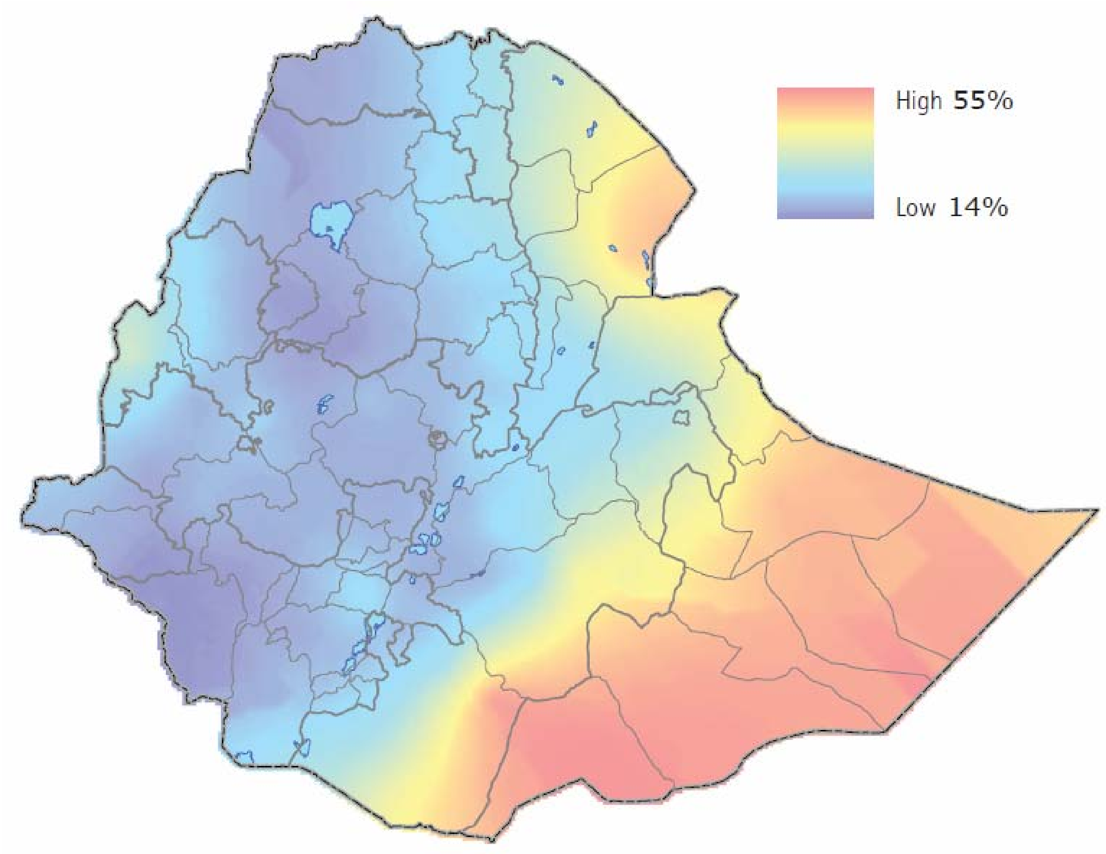

Fig 3.4 Coefficient of variation of mean annual rainfall of Ethiopia (Source: IFPRI 2006, based on WorldClim, University of California)(Map by EGB)

The CV value of south and south-eastern lowlands reaches up to 57%. In northern Ethiopia, the higher variability is 40% around Mekele. The south-western and central Rift Valley area shows the CV value 37 and 36%, respectively. In case of central highlands, the variability is higher over south-eastern Amhara region. These areas, particularly with the CV value greater than 30%, are subjected to recurrent drought. Crop damage and livestock losses due to moisture stress are common and frequent phenomena over these areas.

3.2 Rainfall pattern in East Africa

We need to briefly review normal conditions. Fig 3.5 shows satellite-observed Mean Annual rainfall distribution of East Africa. Rainfall amount vary significantly in the region. In some areas like southern Uganda and south western part of Ethiopia, the annual rainfall is more than 1500 mm per year and it also exceeds 2000 mm. Elevation remains to be very important factor to determine the amount of rainfall in most part of east Africa. Ethiopian highlands are highly dominated by orographic effects particularly by moisture bearing trade winds coming from the west during boreal summer.

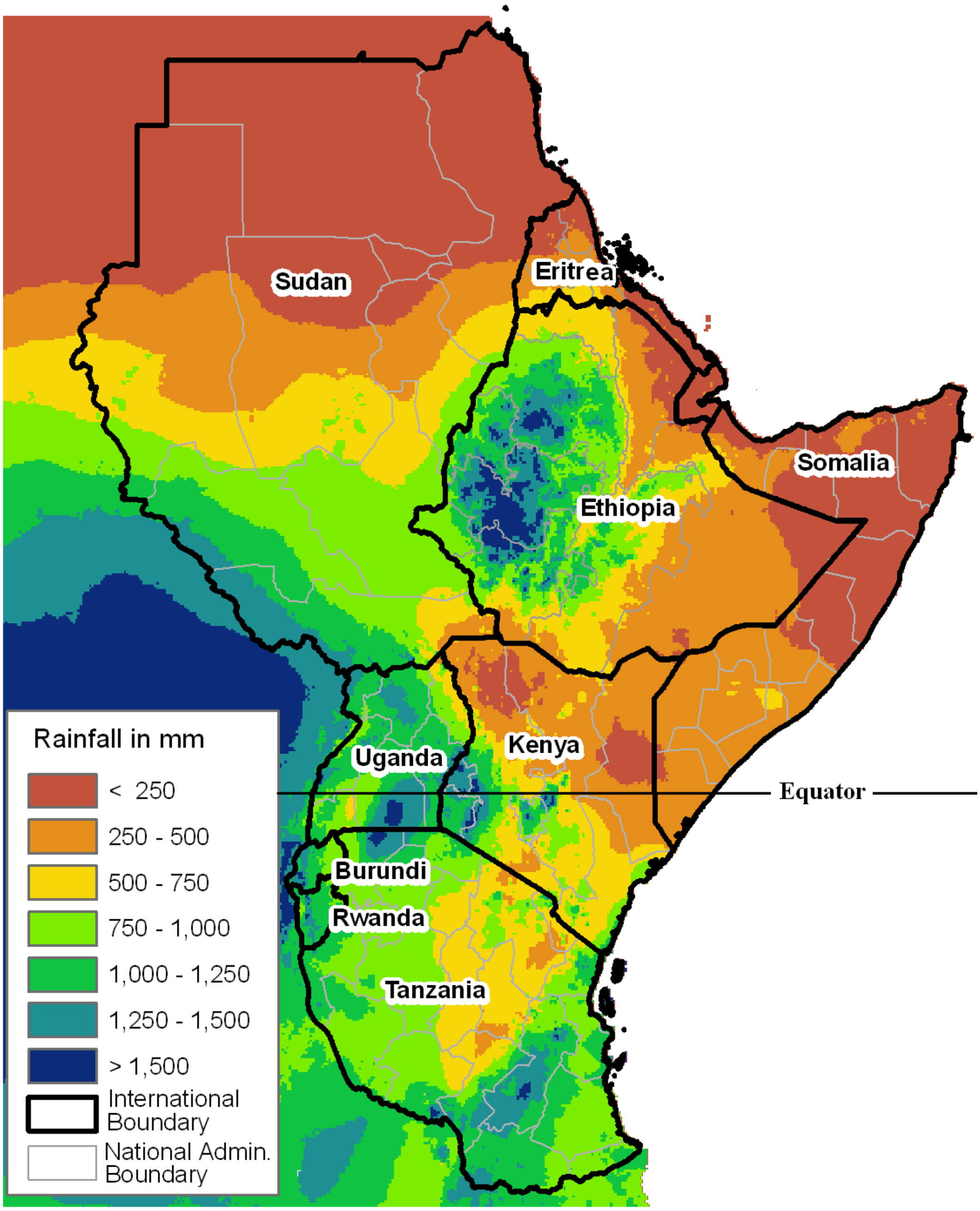

Fig 3.5 Mean Annual rainfall distribution of East Africa (Basic Data source: NOAA RFE) (Map by EGB)

Significant parts of western highlands Ethiopia receiving rainfall of more than 750mm of rain during summer season (See Fig 3.6). Northern Sudan, Eastern Ethiopia, Somalia and northern half of Kenya are generally arid area with rainfall less 500 mm of rain and in the drier parts is less than 250mm of rainfall which qualifies the definition of desert. Spring and summer also bring rain to most parts of Uganda and Kenya. In Somalia and south eastern part of Ethiopia, even if the amount of rainfall is relatively lower, these seasons are two main rainy seasons (See Fig 3.7).

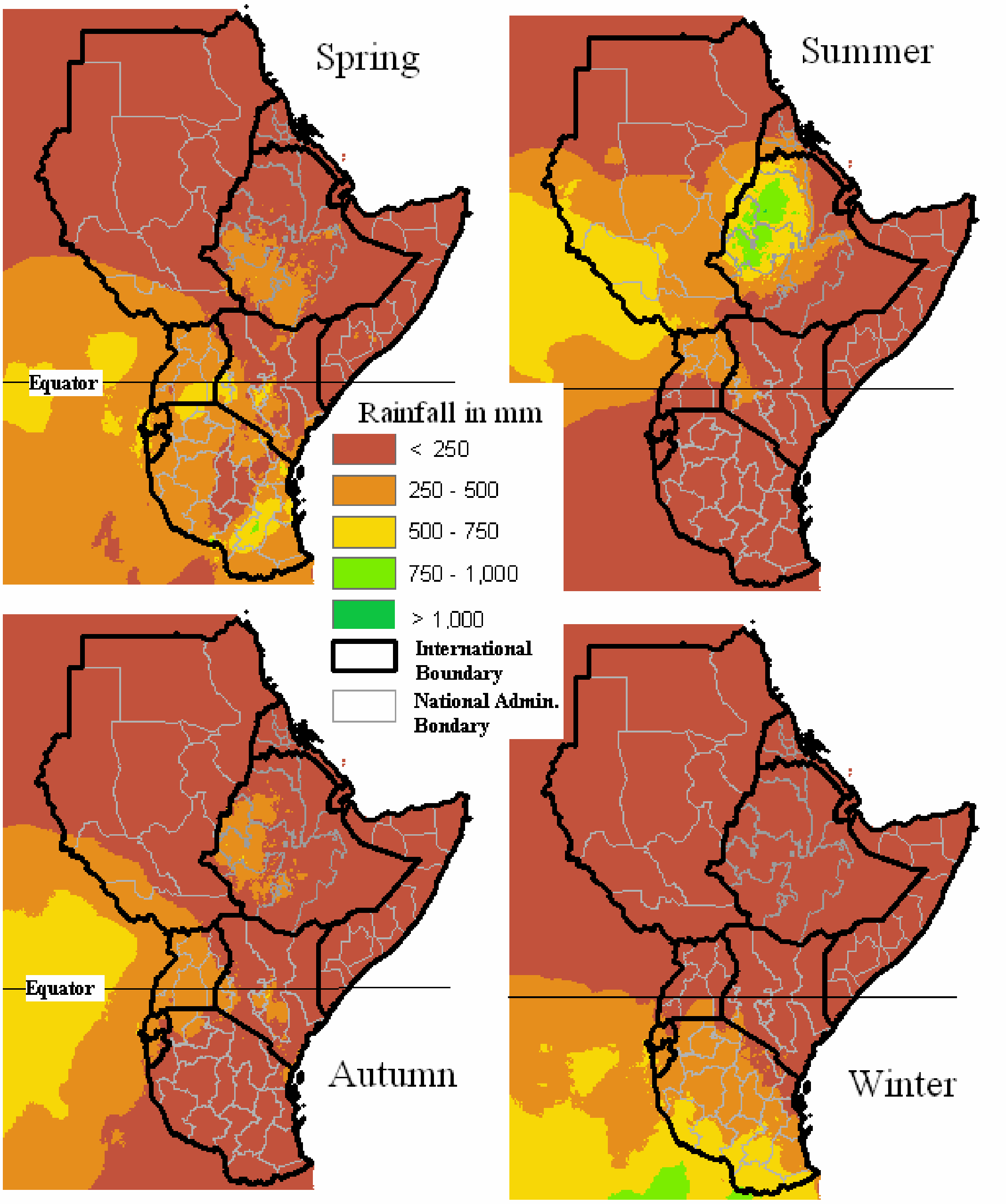

Fig 3.6 Seasonal rainfall distribution in East Africa (Basic Data source: NOAA RFE)(Map by EGB)

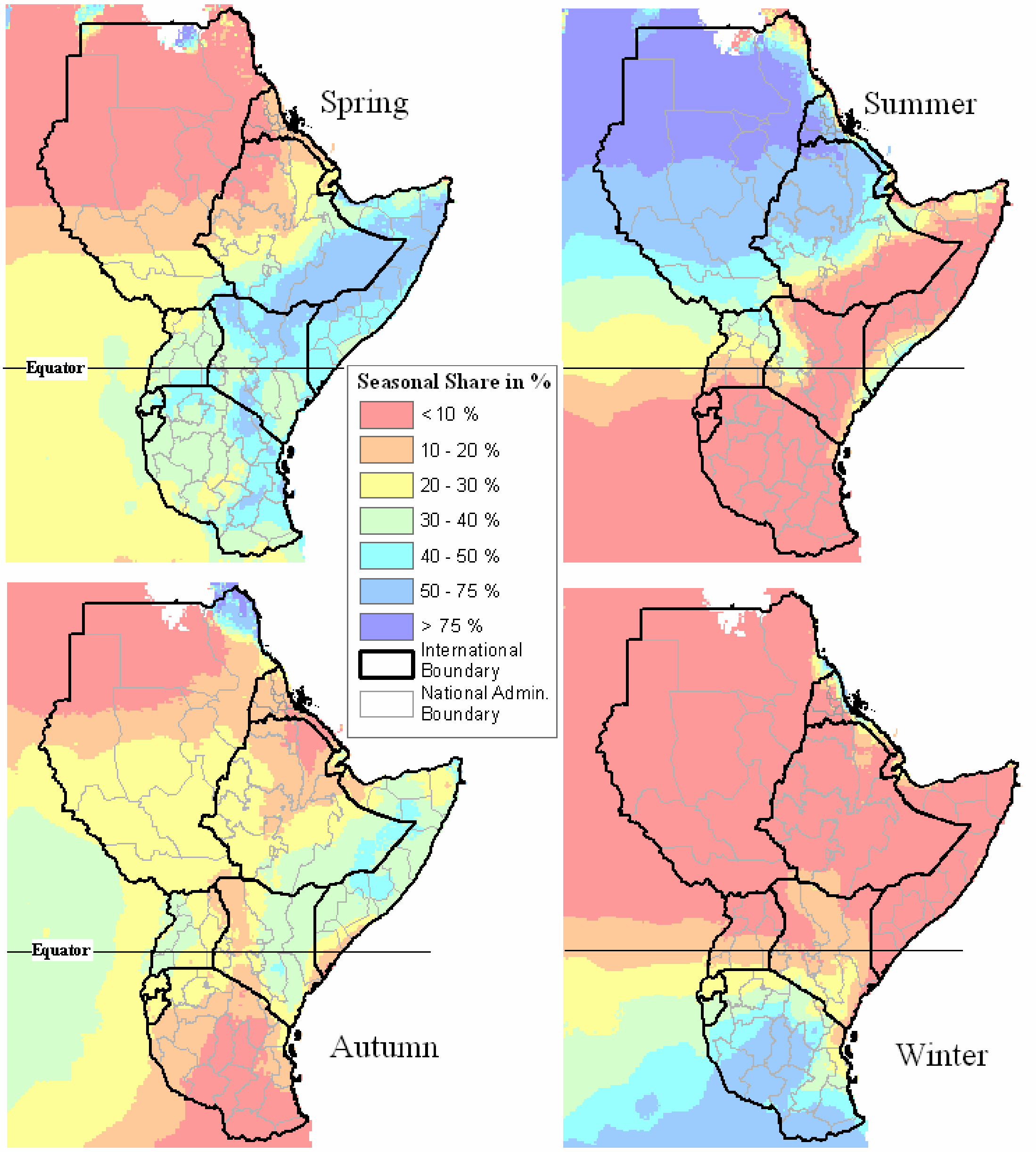

Fig 3.7 Seasonal proportion compared the annual rainfall amount (Basic Data source: NOAA RFE) (Map by EGB)

As Haile (1987, cited in Climatic and Agroclimatic Resources of Ethiopia, 1989) has pointed out, the seasonal and annual variability of rainfall is associated to the macro-scale pressure systems and monsoon flows related to the changes in the pressure systems. Major systems affecting Ethiopian weather are the Inter Tropical Convergent Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Sub Tropical Jet (STJ), Tropical Easterly Jet (TEJ) and the Somalia Jet.

3.3 Inter Tropical Convergence Zone

As it is graphically described on Fig 3.8, on or near the equator, where average solar radiation is greatest, air is warmed at the surface and rises. This creates a band of low air pressure, centred on the equator. This rising air comprises one segment of a circulation pattern called the Hadley Cell. The rising air is replaced by the trade winds approaching the equator from north and south. As the trade winds meet near the equator, surface convergence and uplift take place. For this reason, the equatorial band of low pressure is called the Equatorial Trough, Intertropical Convergence Zone, or the *ITCZ*.

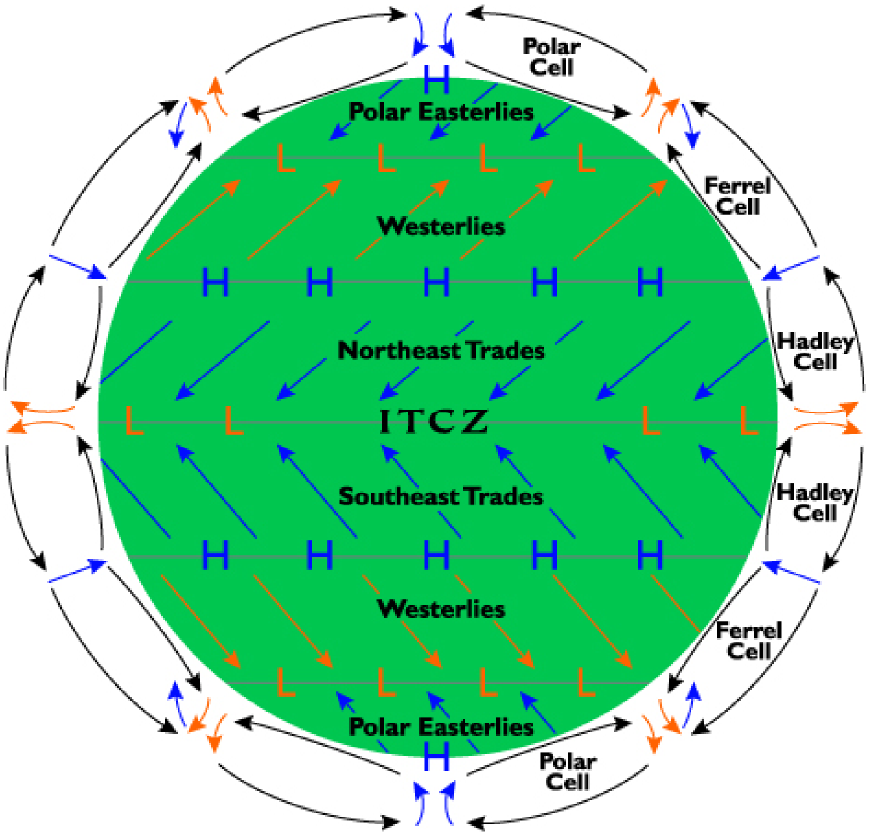

Fig 3.8 Global belts of high and low pressure, and major prevailing winds on Earth. (Pidwirny, 2006)

The ITCZ moves northward during the high-sun season of the Northern Hemisphere, and south during the high-sun season in the Southern Hemisphere (See Fig 3.2). These movements are not perfectly symmetrical above and below the equator, because of the influence of land masses, among other factors.

When the ITCZ lies north of the Geographic Equator (See Fig 3.2 C), the Southeast Trade Winds acquire a south-westerly direction after crossing the equator and again the convergence pattern favours the formation of a Tropical Depression.

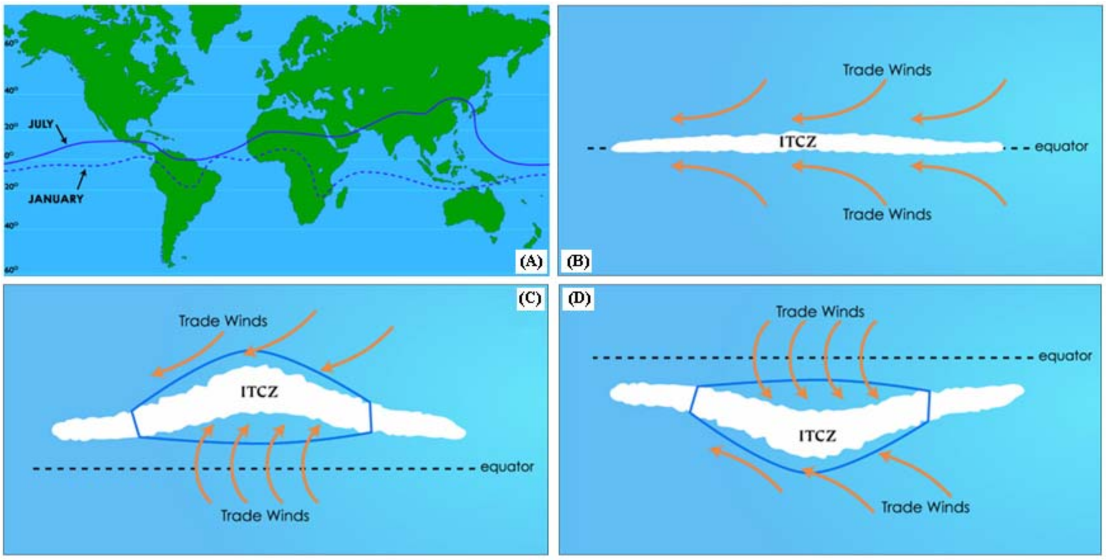

Fig 3.9 (A) The seasonal meandering of the ITCZ. (B) Trade winds converging parallel to the ITCZ. (C) A tropical depression on the ITCZ north of the geographical equator. (D) A tropical depression on the ITCZ south of the geographical equator. (Pidwirny, 2006)

When the ITCZ lies south of the Geographic Equator (See Fig 3.9 D), as it does in the Western Pacific and Indian Oceans, the Northeast Trade Winds acquire a north-westerly direction after crossing the equator (because the Coriolis force changes direction below the equator!) In this situation, the convergence is strong and favours the formation of a Tropical Depression. In Fig 3.9 D, note that the direction of the winds entering the low encourages clockwise rotation, which is cyclonic in the Southern Hemisphere.

We are interested in the ITCZ because the migration of the inter-tropical convergence zone (ITCZ) in Africa drives seasonal precipitation patterns across the continent. Most area in the Ethiopian highland receives rainfall during summer *(kiremt)* season when high pressure cell develop over Asian land mass in general and Arabian Peninsula in specific. Precipitation which results from the lifting of moist air over an orographic barrier such as a mountain range; strictly, the amount so designated should not include that part of the precipitation which would be expected from the dynamics of the associated weather disturbance, if the disturbance were over flat terrain. Also known as relief rainfall, this forms when moisture-laden air masses are forced to rise over high ground. The air is cooled, the water vapour condenses, and precipitation occurs. Some authors maintain that relief merely intensifies the precipitation caused by convection or formed at fronts. The term orographic intensification is, therefore, used occasionally.

It has been long recognized that clouds dispel greater amounts of moisture over highland areas, due to a phenomena known as “orographic lifting”, shown schematically in Fig 3.10 Orographic effects cause much higher volumes of precipitation to accumulate at higher elevations, while rainfall “shadows” develop in areas down-wind of these same highlands. The shadow zones may receive as little as a quarter or less of the highland precipitation. It rains and snows in the mountains and it’s dry in the desert on the leeward side (Chow 1977).

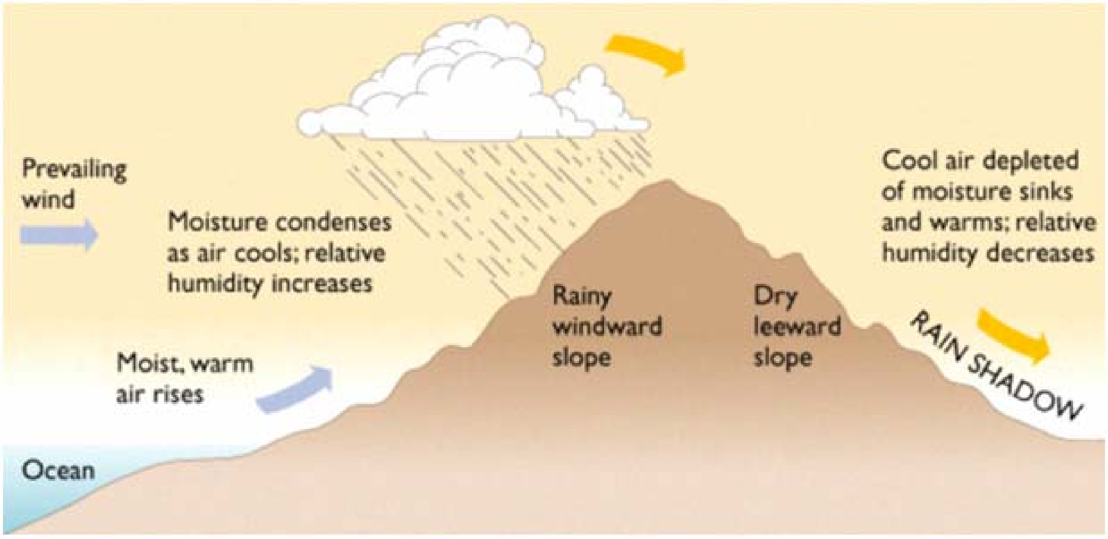

Fig 3.10 Diagram illustrating orographic lifting of clouds over steep-sided mountains and the rain shadow that tends to develop on the leeward side of the range (Source: Chow 1977).

Funk (2009) in his research pointed out that the rainy intertropical front typically stretches from Southern Africa east across the southern tropical Indian Ocean, with rainfall peaks near Indonesia and Madagascar. Across the northern Indian Ocean the monsoonal winds blow from north to south (black arrows pointing toward the Equator in Fig 3.11). Along the southern Indian Ocean steady easterly trade winds (another black arrow in Fig 3.11) bring moisture into Southern Africa, feeding the main rainy season. In recent years, surface winds have tended to flow southward (grey arrows in Fig 3.11), into the warming south-central Indian Ocean and away from Africa. This climate shift tends to draw moisture away from Africa, reducing December–January rains in parts of Southern Africa and March-May rains in parts of Eastern Africa.

The large connected white dots in Fig 3.11 indicate a second important source of climate variation in these regions: the Indian Ocean Dipole. When sea surface temperatures are relatively warm in the north-western Indian Ocean and cold in the south-eastern Indian Ocean, Eastern Africa is relatively wet and Southern Africa is relatively dry—and vice versa. Taken together, the warm south-central Indian Ocean and Indian Ocean Dipole patterns can tell us much about December–January–February rainfall in Eastern and Southern Africa. Some seasons are affected by warming in both the south-central and south-eastern Indian Ocean (Funk 2009).

A study done at university of reading stated collation of observed Sea surface temperature and rainfall data shows that excessively strong short rains are associated with positive Sea Surface Temperature (SST) anomalies in the western Indian Ocean and negative anomalies in the eastern part of the ocean – a pattern similar to the Indian Ocean dipole or zonal mode (IOZM). Comparison between the time series of Pacific Ocean SST and the DMI (dipole mode index – a measure of strength of the IOZM) suggests that, in certain circumstances, the IOZM and consequent strong rainfall in East Africa can be triggered by an El Nino event. Composites of SST during the October and November preceding an El Nino show a generalised warming of the Indian Ocean. There are several strong El Ninos which do not trigger an IOZM and are not associated with strong rainfall in East Africa. Analysis of individual events suggests that both the phase and strength of the El Nino are important.

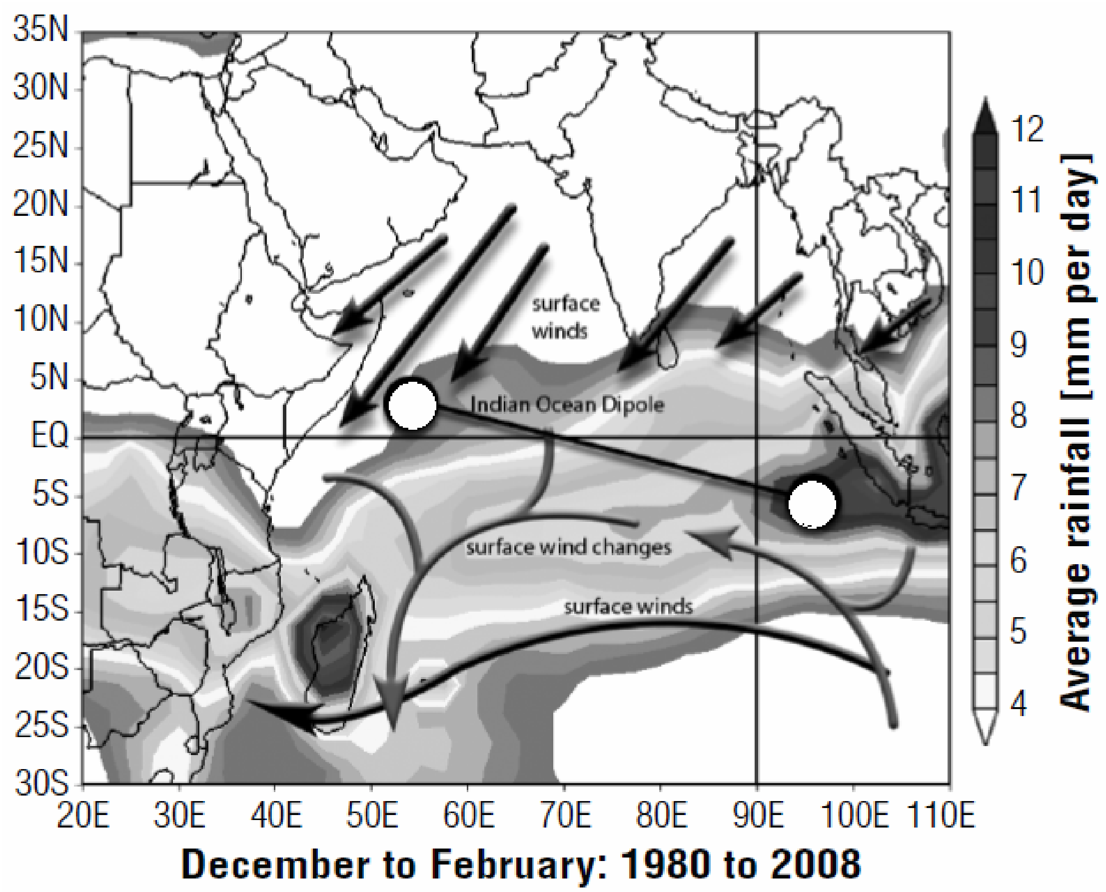

Fig 3.11 Average daily rainfall (shading) and surface wind conditions (black arrows) for December-January-February. Also shown are recent changes (1993-2007 minus 1979-2002) in surface winds. Images were obtained from the Climate Diagnostic Centre. (Source: Funk 2009)

3.4 Vegetation Cover Pattern of Ethiopia and the greater horn of Africa

Rainfall variability and long-term changes in both rainfall amount and distribution has affected many countries over recent decades. While rainfall is only one factor in a complex tableau of factors that are influenced by the global climate, it plays an important role in regulating the growth and vegetation cover dynamics of Eastern and Southern Africa significantly. NDVI provides a measure of the amount and vigour of vegetation on the land surface. The magnitude of NDVI is related to the level of photosynthetic activity in the observed vegetation. In general, higher values of NDVI indicate greater vigour and amounts of vegetation. The NDVI data used to prepare Vegetation cover map (See Fig 3.12) is at dekadal (10 days) level for a 27 year time period, from the 1982-2009.

East African Vegetation cover shows seasonal variation. There are areas that show less seasonal variation like the forest areas as well as permanently arid areas. In general (See Fig. 3.12) the vegetation cover in autumn and summer is relatively higher. Uganda, Western tip of Kenya and south western Ethiopia are under higher vegetation cover throughout the year. There is thin or no vegetation cover in areas near the Red Sea coast and Indian Ocean as well as northern part of Sudan, north eastern Ethiopia and north western Kenya.

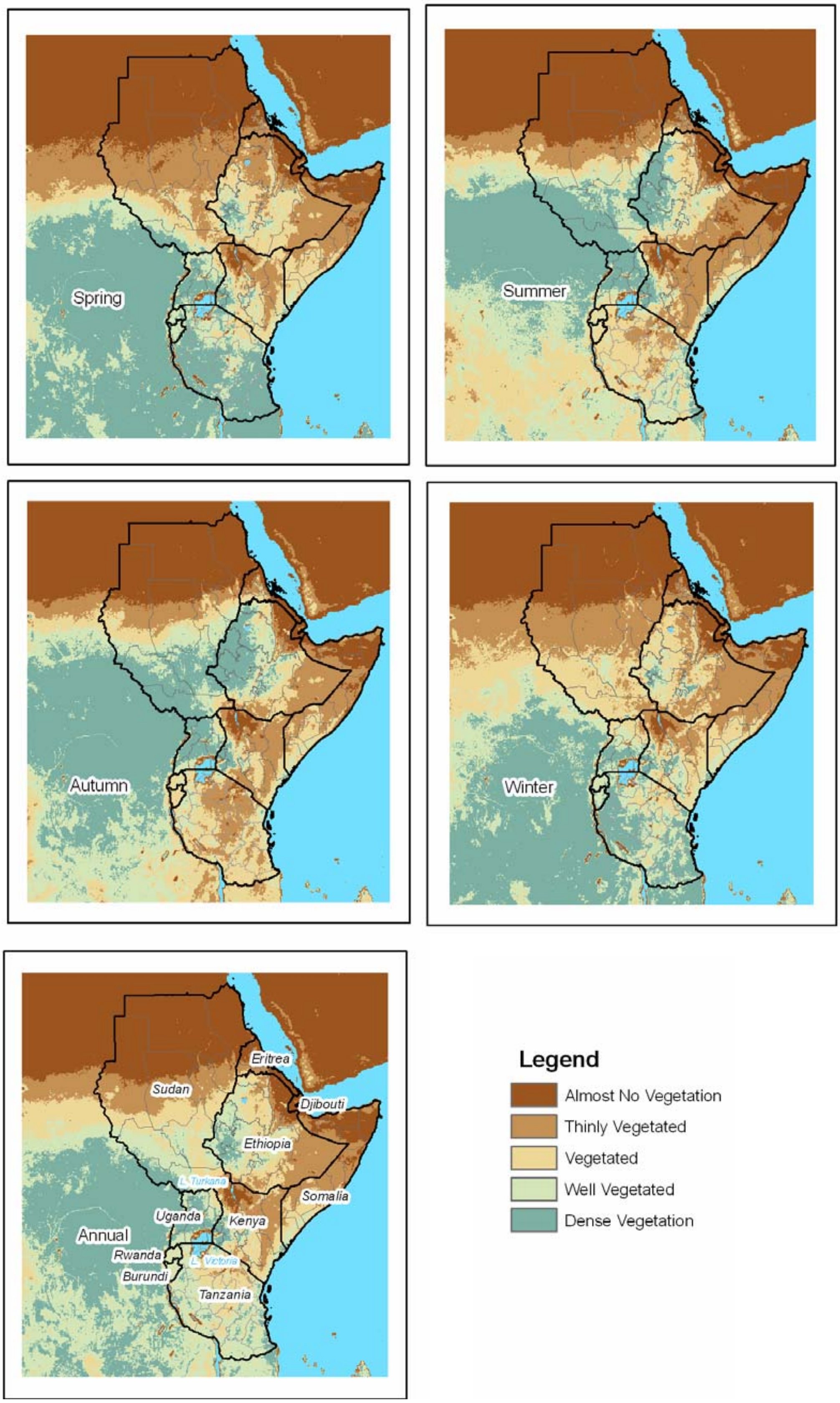

Fig 3.12 Seasonal distribution of vegetation cover map based on NOAA NDVI (Map by EGB)

Summer vegetation in western Ethiopia is abundant since there is enough moisture in the soil caused by summer rain. Summer rainfall results good vegetation cover for most parts of western and central Ethiopia. The vegetation cover is higher during autumn. The vegetation cover in parts such as around Turkana in North Western Kenya, Afar triangle in north eastern Ethiopia, northern Sudan and Somalia is almost non existent.

All in all the vegetation cover reduces during winter time in the region. For example in winter the Ethiopian natural forests located in the central & western parts are clearly identifiable since the seasonal vegetation cover reduces in other parts of the country and the forests remain green (See Fig 3.12). Applying same procedure the forest cover in the southern Uganda and western Kenya near Lake Victoria are clearly identifiable.

Higher density of vegetation in the southern portion in the spring, progresses northward in the summer and autumn and moves back southwards in the south. Both movements are similar with the movement pattern of ITCZ which is driven by the position of the sun. The proportions of thinly vegetated areas are reduced during summer and autumn. The desert areas remain the same apart from the margins that recede and progress.

4. Spatio-temporal Correlation, Variability and Trend Analyses

4.1 Geospatial Information Science and Technology

Geospatial technologies combine a suite of software products to create, manage and analyze digital geographic data sets. Geospatial technologies combine various aspects of computer science with Geographic Information Systems (GIS), remote sensing, photogrammetry, cartographic visualization, spatial statistics, and Global Positioning Systems (GPS). Scientists, municipal employees and a variety of business practitioners utilize geospatial technologies for resource and emergency management, land use planning, and crime prevention.

Remote sensing is defined as the instrumentation, techniques and methods to observe the Earth's surface at a distance and to interpret the images or numerical values obtained in order to acquire meaningful information of particular objects on Earth. Although remote sensing data can be interpreted and processed without other information, the best results are obtained by linking remote sensing measurements to ground (or surface) measurements and observations. Some of these products that can be used in Ethiopia to improve the early warning system are described below.

NOAA-CPC products are CMAP, RFE, ARC and CMORPH. RFE is produced specifically for United States Agency for International Development (USAID) Famine Early Warning Systems (FEWS) to assist in drought monitoring activities over Africa. The latest version, RFE version 2.0 (RFE2) has been operational since January 2001. It replaced the previous version, RFE1 (Herman et al. 1997), which was operational from 1995 to 2000. The inputs for the RFE2 algorithm include estimates from NOAA sensors, data from METEOSAT, and daily rainfall data from Global Telecommunication System GTS reports. This algorithm produces daily rainfall estimates. RFE 2.0 uses additional techniques to better estimate precipitation while continuing the use of cold cloud duration, or CCD (derived from cloud top temperature), and station rainfall data (FEWSNET 2008). The main difference between RFE1 and RFE2 is that RFE2 uses PM estimates while RFE1 includes a procedure to estimate warm orographic rain.

For the analysis of Vegetation cover, NDVI data is an important data set. A useful data set has been made available by NASA which is sensed by the AVHRR instrument onboard on the NOAA (National Oceanographic and Atmospheric Administration) satellite platform. The AVHRR (Advanced Very High Resolution Radiometer) sensor is designed to monitor climate systems in five spectral channels. However one of the bands was placed in the red part of the spectrum and another one in the near infrared (NIR), making vegetation monitoring additionally feasible. The long time series available (since 1982), the high temporal repetition (daily – 10-day – month), the ready-to-use format (calibrated), the global coverage, the free-of-charge availability, the possibility to transfer the data over the Internet etc. makes the NOAA Pathfinder satellite images a much used data set.

LEAP (Livelihood, Ethiopia, Assessment, and Protection) is software environment for drought indexing, designed specifically for the local context and co-developed by WFP, World Bank and FAO. It is a powerful tool and once fully developed, could greatly improve early warning as well as support agricultural decisions regarding planting time, irrigation and implementation of water harvesting programs. LEAP is free, simple and an open source. It mainly developed to project agricultural yields based on weather parameters and water requirement satisfaction index. Moreover is designed to estimate potential costs of intervening against acute (crop failure related) livelihood stress.

LEAP provides a good proxy estimate of the costs of protecting transient food insecure peoples' livelihoods at the time of shock. It is independent, objective, verifiable and replicable and conveys information in near real-time to ensure timely and effective response to livelihood stress. It provides early warning of livelihood stress levels. It signals an amount of financial resources required for early livelihood protection at regional levels. LEAP can be applied to crops and Pasture monitoring, irrigation needs assessments, agro-meteorological zoning, and climate change adaptation needs assessments.

4.2 Correlation between Remotely Sensed and Weather Stations' Data

4.2.1 Rainfall Observations

The 'best' product depends on the specific application. For example for operational agricultural monitoring, a simple system that does not depend on real-time gauge input and that is accurate for low rainfall may be needed (DINKU et al. 2007). The research considered RFE 1.0 images dated between Jan 96 and Dec 00 and RFE 2.0 images from Jan 01 to Dec 06 from NOAA. The other datasets are the monthly rainfall rain gauge records collected from different stations by NMA of Ethiopia. There are over 600 rain gauge stations found in Ethiopia that are classified in to four different classes as synoptic, principal, 3rd and 4th class stations (See Fig 4.1 and Fig 4.2).

In fact NMA's rainfall records have a higher temporal coverage than RFE and they record the actual rainfall amount on the ground. About 150 of them are provided with better equipment and are surveyed by well trained workers. These are referred to as synoptic and principal weather stations. Data from these stations were considered for the analyses of this research. The gauge data have undergone routine quality checks by the NMA.

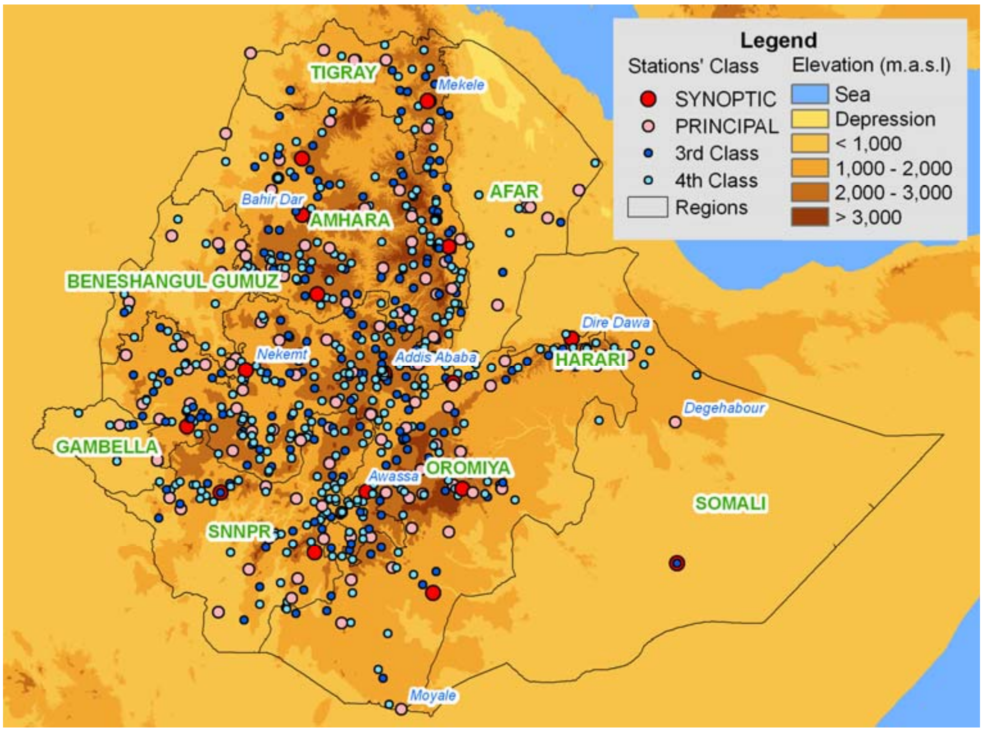

Fig 4.1 Distribution of Meteorological stations in Ethiopia. (See Annex for Larger Map) (Map by EGB)

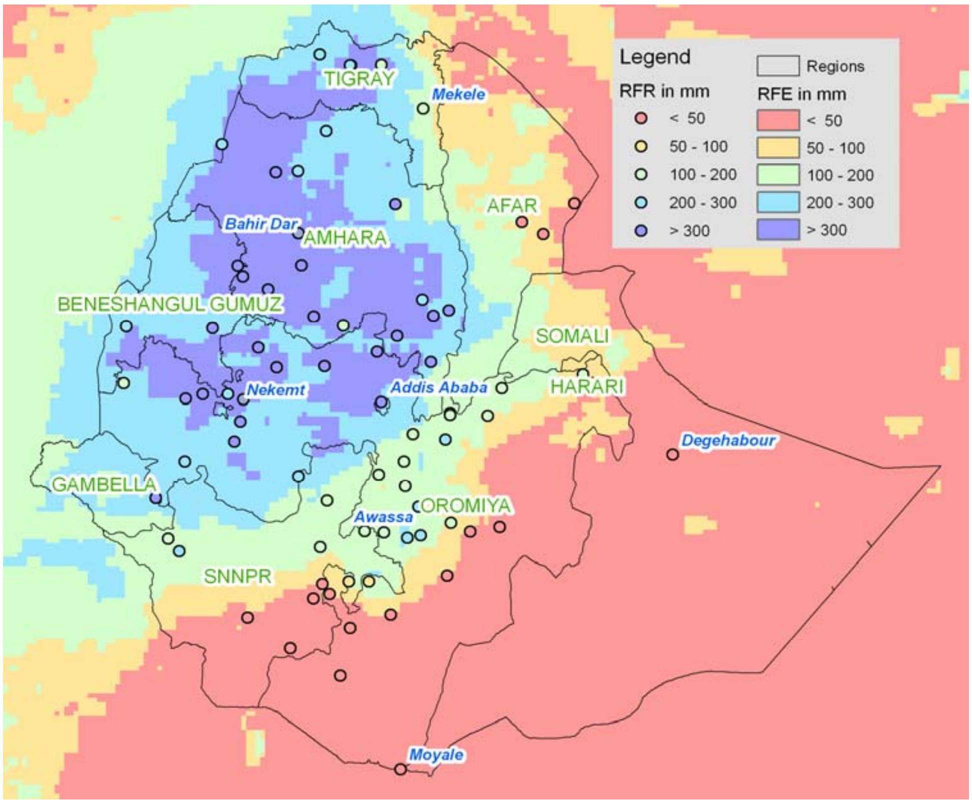

Fig .4.2 Overlay of RFE and Weather Stations Rainfall Records (RFR) in July 2006. (Map by EGB)

4.2.2. Techniques of calculating spatio-temporal correlation

The monthly rainfall data from the NMA meteorological stations were entered into a GIS system and all the necessary set of shapefiles were created with data on the amount of rainfall and distribution of stations. The layers were georeferenced and transformed in order to have the same spatial parameters as the RFE images. Then the Shapefiles were converted to raster data layers. On the other hand the dekadal images from NOAA were converted from '.BIL' (Band Interleaved by Line Format) to ArcGIS GRID format and the dekadal images were summed up to develop monthly rainfall images. Rainfall values were extracted from the RFE images for all weather stations.

These pairs of monthly raster layers, station's data and RFE, were combined using the 'combine' function available in the Spatial Analyst extension of ArcGIS and 132 images were produced to cover all months found between January 1996 and December 2006. The images' table contains rainfall values of the two data sources in two columns. Based on these tables, Pearson's coefficient of correlation values, Standard Deviation (SD) and Mean were calculated using SPSS. Fig 4.3 shows the methodological work flow.

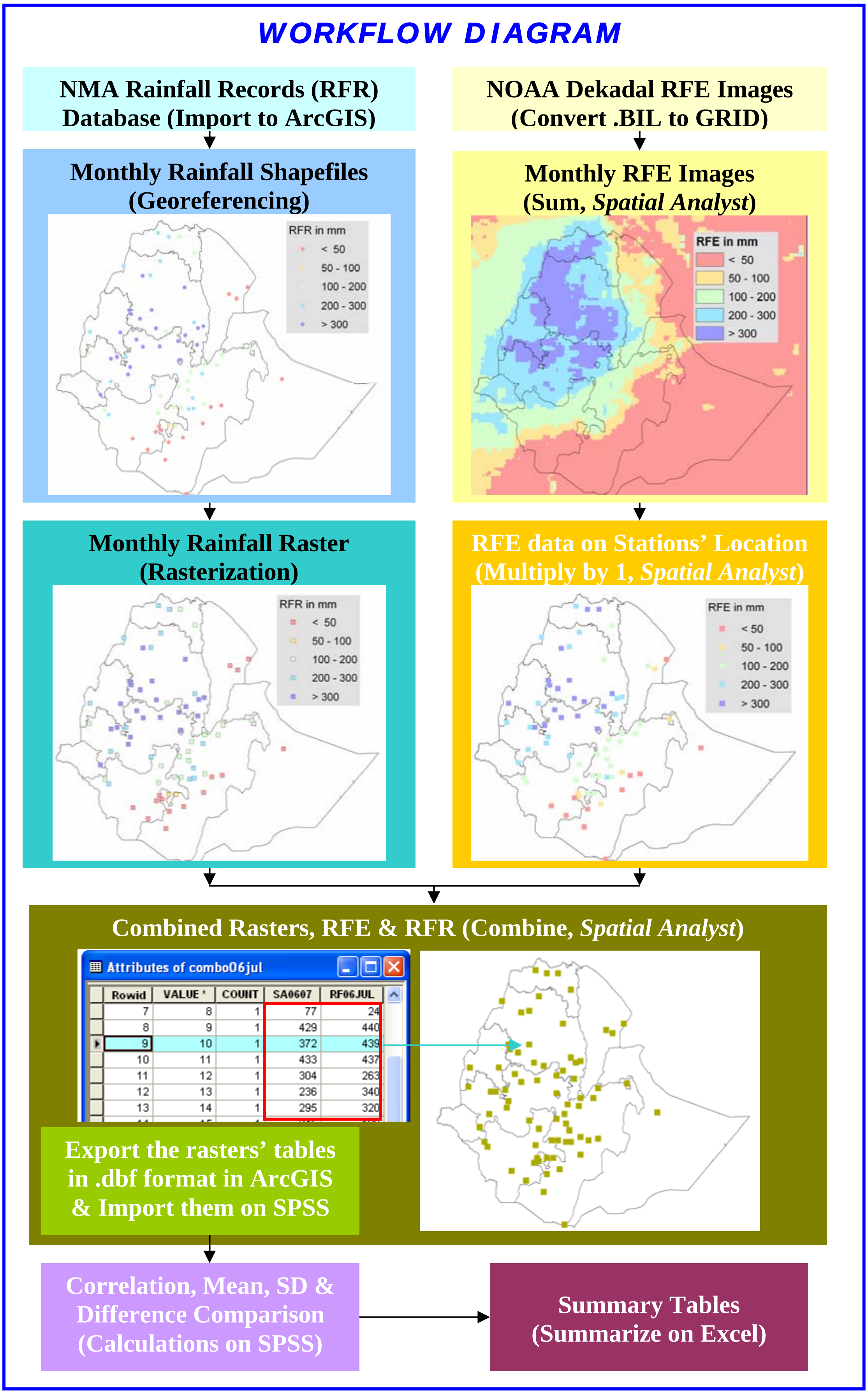

Fig 4.3 Workflow diagram showing steps followed during data analyses

In order to show the pattern graphically NMA rainfall records and NOAA RFE are extracted for some selected towns (See Fig 4.4). Each graph depicts 132 monthly rainfall data for the period January 96 to December 2006. Moreover the series of scatter diagrams in Fig 4.5 and Fig 4.6 show vividly the patterns of RFE and Rainfall records in the four seasons. In order to plot the diagrams four months were selected to represent the four seasons. These are January, April, June and October to represent winter, spring, summer and winter respectively. The diagrams show that the observations are well distributed during July and poor distribution in winter. Further more it possible to see from Fig 4.6 that rainfall values taken from RFE 2.0 images underestimate rainfall values

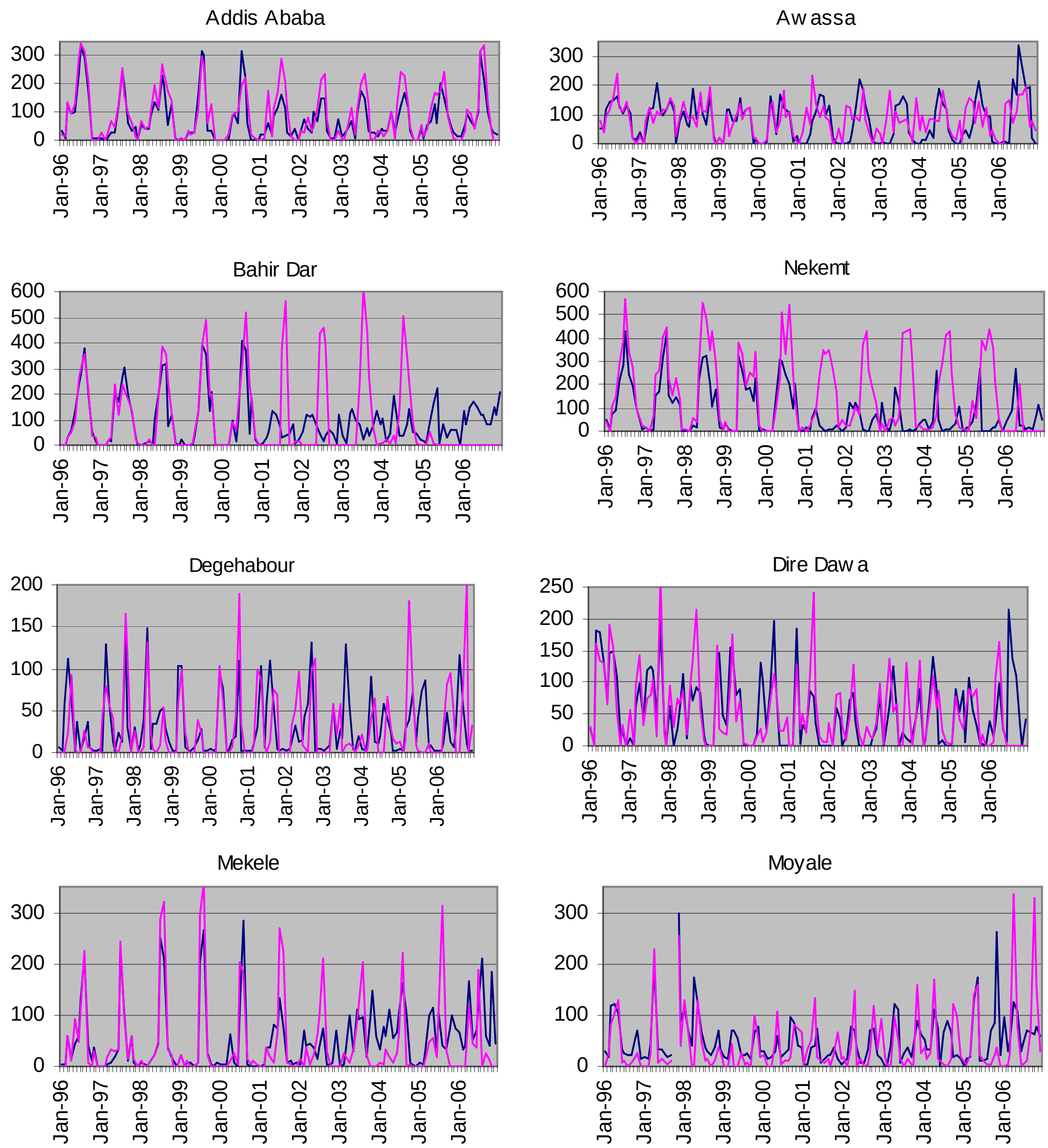

Fig 4.4 Rainfall Estimates (RFE) ______ and NMA Rainfall Records (RFR) ______ (rain in mm)

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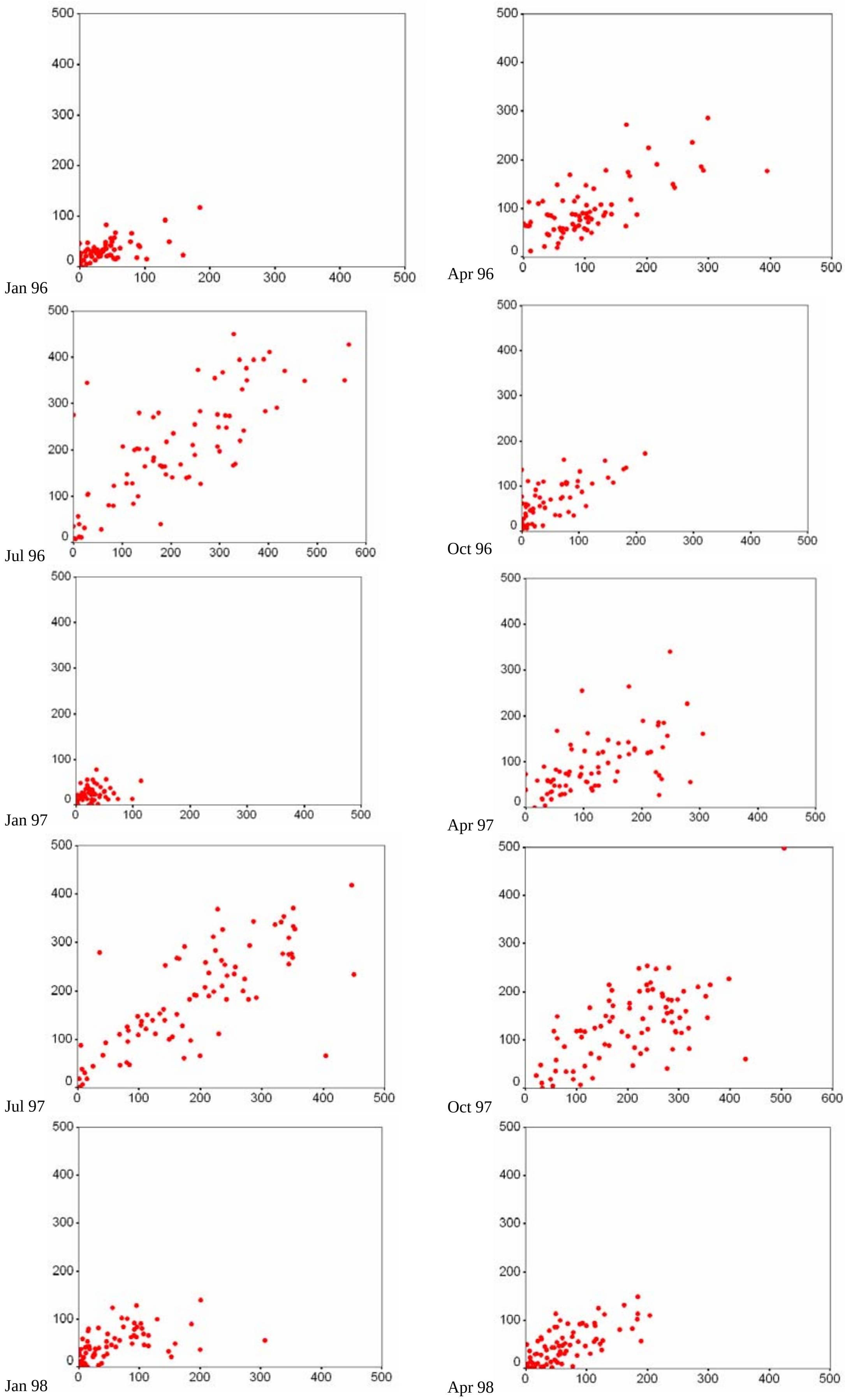
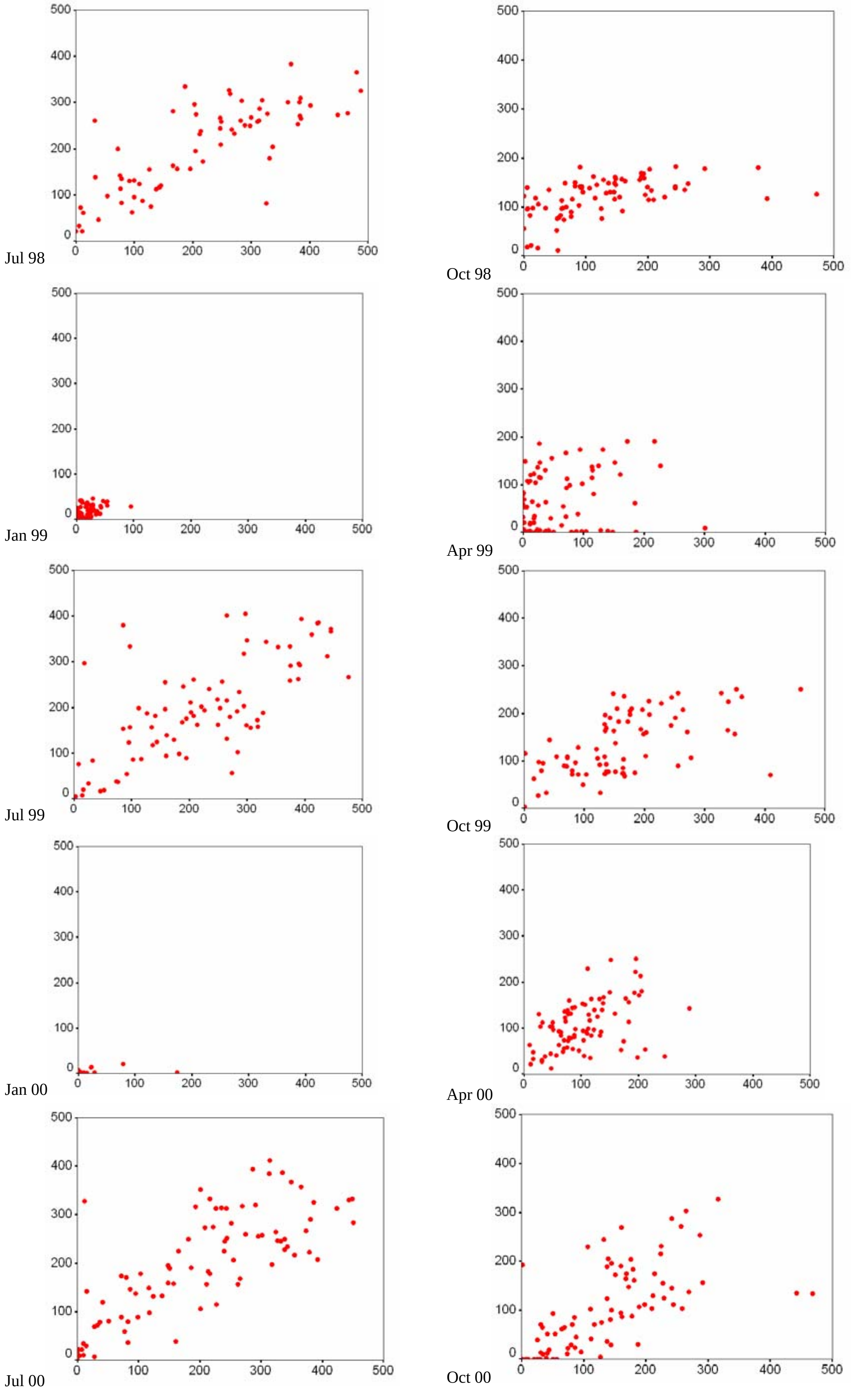


Fig. 4.5 Scatter Plot of RFE (x-Axis) and Stations' rainfall records (Y- Axis) RFE 1.0

…Continued from Fig 4.5 Scatter Plot of RFE (x-Axis) and Stations' rainfall records (Y- Axis) RFE 1.



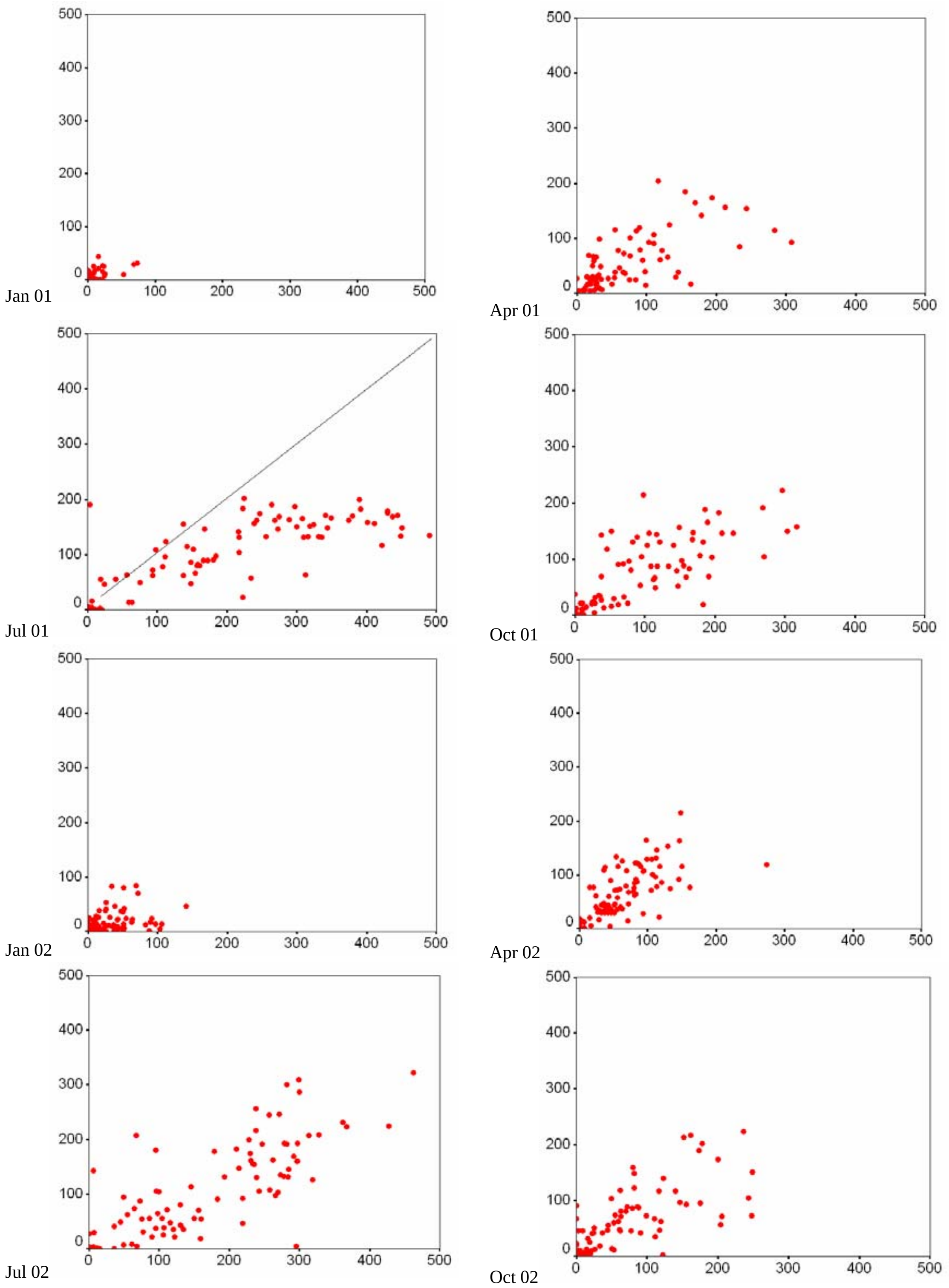
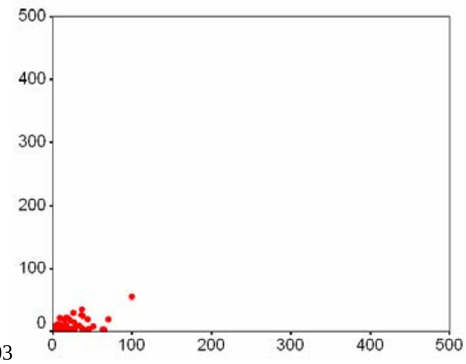
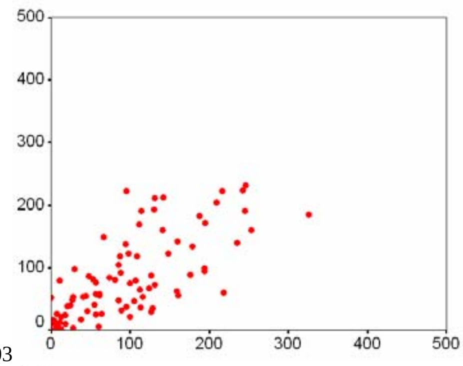
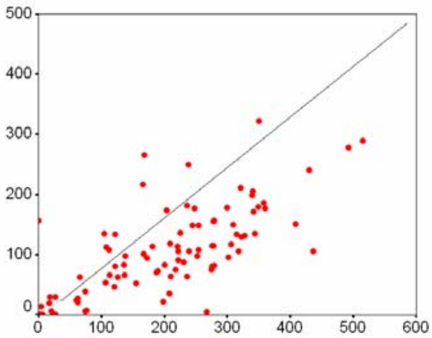


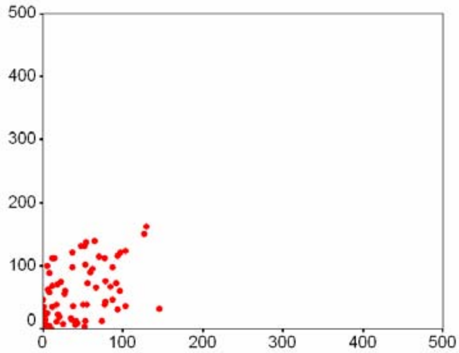
Fig. 4.6 Scatter Plot of RFE (X-Axis) and Stations' rainfall records (Y-Axis) RFE 2.0

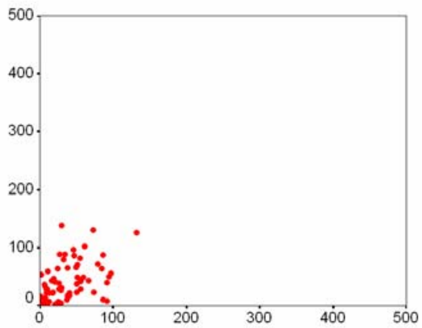
…Continued from Fig. 4.6 Scatter Plot of RFE (X-Axis) and Stations' rainfall records (Y-Axis) RFE 2.0

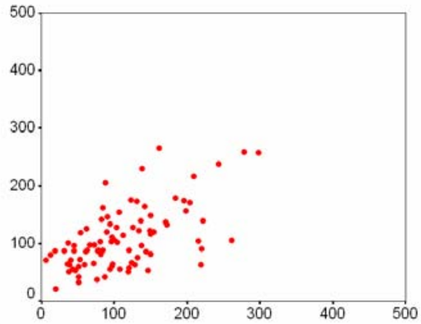

Jan 03


Apr 03


Jul 03


Oct 03


Jan 04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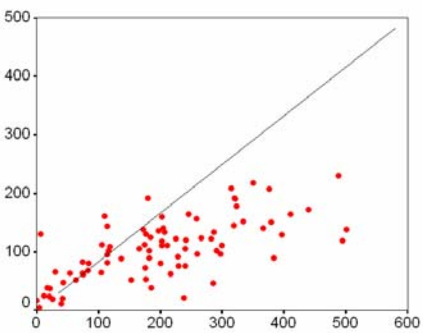
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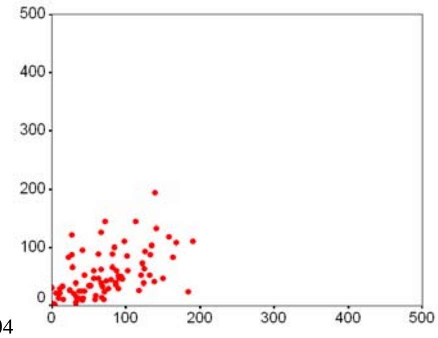
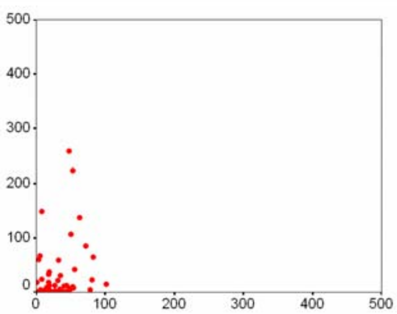
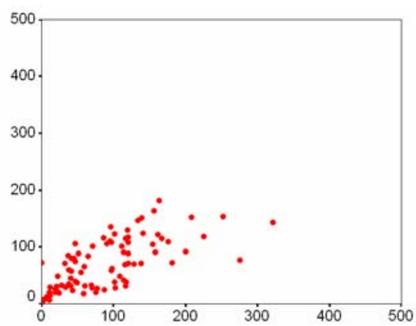
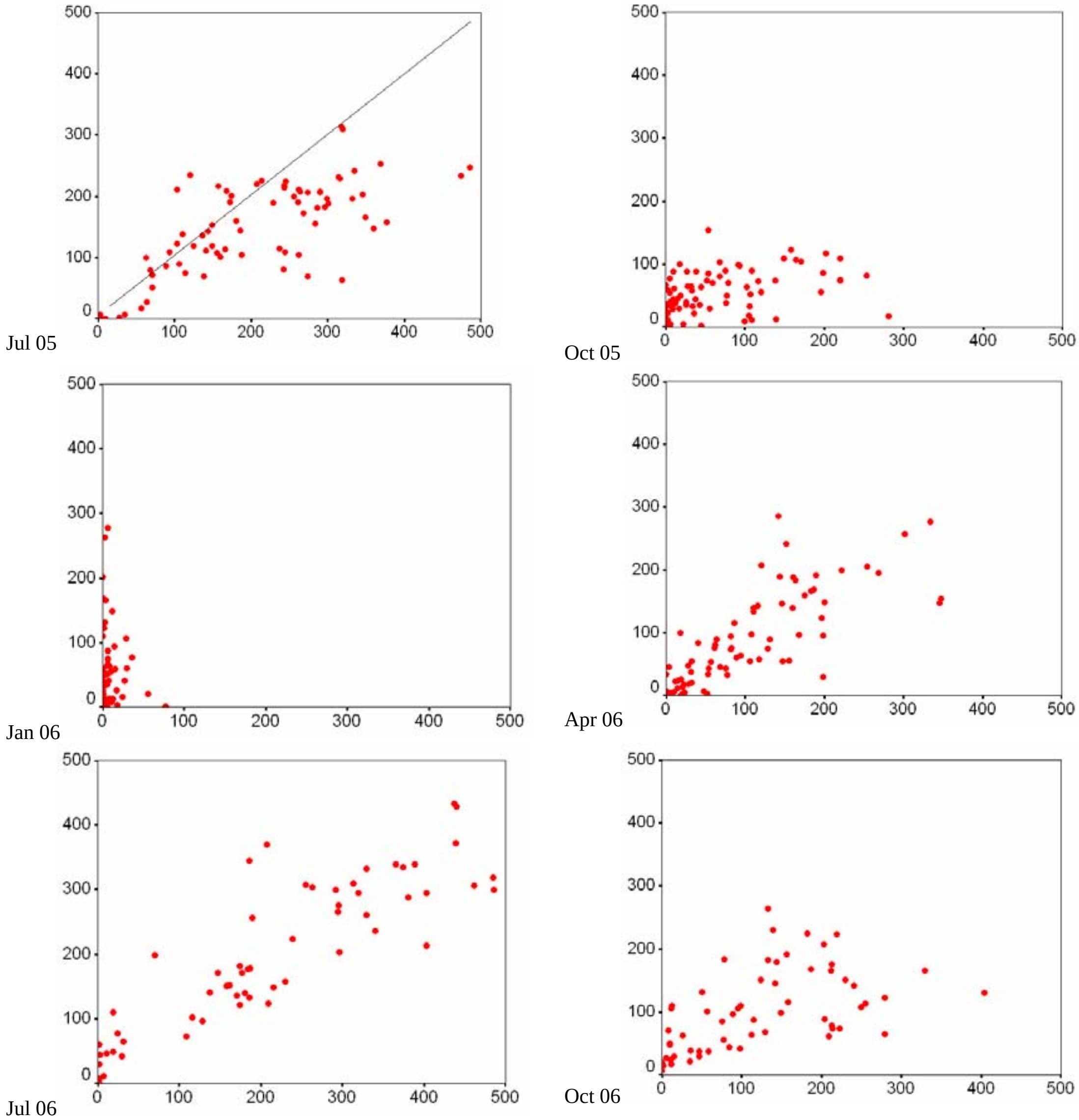

Oct 04


Jan 05


Apr 05

…Continued from Fig. 4.6 Scatter Plot of RFE (X-Axis) and Stations' rainfall records (Y-Axis) RFE 2.0



4.2.3. Correlation results and discussion

The analyses showed correlation values, Standard Deviation (SD), mean as well as percental differences of the mean rainfall between satellite RFE and stations' rainfall records on a monthly basis for the time period 1996 to 2006. An explanation of the temporal analyses can be given based on Table 4.1 and Table 4.2. For example in Table 4.1 it is depicted that during the month January in 1996 rainfall data from 79 stations (N) were considered giving a correlation (r) of 0.57. The average rainfall of all observed stations was 39 mm with 39 SD and the mean of RFE was 30 mm with 21 SD. So the estimated values of RFE showed only 76% as compared to the actual values of the rainfall stations.

		1996				1997				1998			
		Mean	SD	N	r	Mean	SD	N	r	Mean	SD	N	r
Jan	RFE	30	21	79	0.57	22	16	77	0.37	45	36	95	0.56
	RFR	39	39	79		23	22	77		52	56	95	
	Difference	76%				93%				86%			
Feb	RFE	16	17	69	0.16	3	5	21	-0.19	43	46	78	0.49
	RFR	18	48	69		5	13	21		47	42	78	
	Difference	90%				55%				91%			
Mar	RFE	101	46	85	0.66	24	20	87	0.45	35	29	89	0.60
	RFR	107	49	85		54	38	87		49	42	89	
	Difference	95%				45%				71%			
Apr	RFE	100	56	91	0.68	92	63	94	0.61	47	37	95	0.74
	RFR	111	81	91		117	78	94		64	55	95	
	Difference	90%				79%				73%			
May	RFE	124	52	89	0.52	89	73	96	0.80	117	58	89	0.63
	RFR	158	75	89		106	93	96		124	70	89	
	Difference	78%				84%				95%			
Jun	RFE	145	81	92	0.68	167	123	102	0.76	125	93	91	0.87
	RFR	159	100	92		128	87	102		129	128	91	
	Difference	92%				130%				97%			
Jul	RFE	204	115	93	0.78	188	104	99	0.75	206	93	91	0.70
	RFR	210	132	93		189	109	99		225	142	91	
	Difference	97%				99%				92%			
Aug	RFE	201	98	92	0.75	161	101	98	0.72	167	82	97	0.64
	RFR	199	116	92		172	104	98		219	127	97	
	Difference	101%				94%				76%			
Sep	RFE	116	89	89	0.73	92	86	102	0.64	74	38	99	0.48
	RFR	123	87	89		101	78	102		148	107	99	
	Difference	94%				91%				50%			
Oct	RFE	62	45	86	0.72	128	77	99	0.617	120	39	96	0.53
	RFR	46	51	86		198	99	99		125	93	96	
	Difference	135%				65%				96%			
Nov	RFE	36	19	94	0.37	68	60.08	98	0.61	18	10	74	0.43
	RFR	33	25	94		94	77.74	98		20	21	74	
	Difference	111%				72%				90%			
Dec	RFE	7	6	57	0.68	17	31	54	0.62	6	5	35	0.57
	RFR	12	16	57		35	47	54		6	10	35	
	Difference	63%				49%				103%			

Table 4.1. Coorelation Results, SD, Mean, Difference of RFE1.0 and rainfall records

Table 4.1 Continued

		1999				2000			
		Mean	SD	N	r	Mean	SD	N	r
Jan	RFE	18	13	85	0.45	4	6	23	0.29
	RFR	18	18	85		18	38		
	Difference	100%				20%			
Feb	RFE	7	8	32	-0.07	5	8	13	0.52
	RFR	10	23	32		6	10	13	
	Difference	66%				71%			
Mar	RFE	78	60	82	0.74	10	18	59	0.76
	RFR	64	60	82		16	16	59	
	Difference	121%				62%			
Apr	RFE	61	60	95	0.25	106	53	101	0.48
	RFR	57	61	95		102	56	101	
	Difference	108%				103%			
May	RFE	110	108	97	0.81	120	103	99	0.76
	RFR	111	111	97		133	101	99	
	Difference	98%				90%			
Jun	RFE	112	104	104	0.84	92	108	100	0.81
	RFR	119	109	104		129	127	100	
	Difference	94%				72%			
Jul	RFE	196	108	98	0.73	195	108	106	0.78
	RFR	217	124	98		194	127	106	
	Difference	90%				100%			
Aug	RFE	181	97	100	0.76	187	107	107	0.68
	RFR	224	134	100		215	127	107	
	Difference	81%				87%			
Sep	RFE	81	58	100	0.71	77	67	105	0.63
	RFR	135	90	100		145	90	105	
	Difference	60%				53%			
Oct	RFE	139	65	91	0.58	104	85	98	0.66
	RFR	162	94	91		139	93	98	
	Difference	85%				75%			
Nov	RFE	10	15	72	0.61	18	22	93	0.28
	RFR	18	19	72		43	28	93	
	Difference	60%				43%			
Dec	RFE	12	12	70	0.57	4	7	62	0.05
	RFR	15	18	70		29	28	62	
	Difference	82%				14%			

RFE data and weather stations' rainfall data register significantly similar values during summer seasons. In most parts of the highlands where agriculture is important for livelihood, summer rains followed by spring rains are the main source of water for agriculture. The correlation values are higher for the months with higher rainfall and lower during the period of little rain. It is possible to associate better estimations with higher rainfall and vice versa. However it needs an in-depth study on the algorithm of RFE to know exactly why it shows such kind of seasonal variation of correlation values.

Funk and Verdin compared satellite rainfall estimates and reanalysis precipitation fields in 2003 with station data for western Kenya. Their regression analysis yielded a coefficient of determination of 0.8. They further noted that there are several good reasons for satellite RFE favourable performance in tropical areas. Satellite RFE fields should be reasonably accurate because they are based on observations of cloud top temperatures, which in turn are related to vertical motion and convection. Moreover it incorporates daily station observations to correct potential bias and to leverage the utility of sparse gauge networks. In addition RFE has a spatial scale of approximately 10 km which is consistent with the convective nature of tropical rainfall.

		2001				2002				2003			
		Mean	SD	N	r	Mean	SD	N	r	Mean	SD	N	r
Jan	RFE	12	13	43	0.38	18	20	94	0.34	9	11	75	0.38
	RFR	16	19	43		33	28	94		22	20	75	
	Difference	75%				54%				40%			
Feb	RFE	11	12	82	0.27	10	10	69	0.26	23	20	98	0.71
	RFR	18	18	82		14	14	69		28	24		
	Difference	61%				71%				82%			
Mar	RFE	44	33	106	0.61	67	37	102	0.60	45	32	104	0.59
	RFR	81	59	106		76	50	102		52	37	104	
	Difference	55%				87%				86%			
Apr	RFE	56	49	97	0.69	70	43	106	0.61	82	69	107	0.77
	RFR	75	73	97		67	45	106		96	79	107	
	Difference	74%				105%				86%			
May	RFE	105	69	97	0.76	66	49	103	0.65	60	61	105	0.76
	RFR	130	86	97		69	58	103		55	64	105	
	Difference	81%				97%				109%			
Jun	RFE	88	69	100	0.78	84	87	106	0.84	116	101	109	0.82
	RFR	138	104	100		120	113	106		153	117	109	
	Difference	64%				70%				75%			
Jul	RFE	115	63	102	0.76	112	87	109	0.78	110	76	109	0.74
	RFR	223	145	102		173	117	109		207	128	109	
	Difference	52%				65%				53%			
Aug	RFE	102	65	106	0.63	109	62	105	0.64	148	81	110	0.60
	RFR	215	116	106		192	108	105		215	110	110	
	Difference	48%				57%				69%			
Sep	RFE	55	47	86	0.76	79	56	109	0.76	73	59	107	0.73
	RFR	122	85			114	74	109		148	107	107	
	Difference	45%				69%				49%			
Oct	RFE	54	47	105	0.74	60	57	97	0.71	49	44	100	0.55
	RFR	121	84	105		67	67	97		39	37	100	
	Difference	45%				91%				126%			
Nov	RFE	30	38	80	0.57	12	13	63	0.69	61	55	103	0.45
	RFR	28	34	80		15	17	63		31	40	103	
	Difference	106%				81%				199%			
Dec	RFE	10	17	72	0.39	40	49	96	0.69	38	37	98	0.40
	RFR	24	44	72		53	49	96		33	33	98	
	Difference	43%				76%				116%			

Table 4.2. Correlation Results, SD, Mean, Difference of RFE2.0 and rainfall records

Table 4.2 Continued

		2004				2005				2006			
		Mean	SD	N	r	Mean	SD	N	r	Mean	SD	N	r
Jan	RFE	34	34	97	0.61	26	52	74	0.25	53	59	67	-0.10
	RFR	31	30	97		28	23	74		8	13	67	
	Difference	109%				96%				630%			
Feb	RFE	24	18	96	0.28	8	9	65	0.05	34	30	74	0.51
	RFR	18	31	96		15	30	65		29	26	74	
	Difference	135%				55%				118%			
Mar	RFE	31	20	101	0.35	64	34	103	0.67	65	49	84	0.76
	RFR	39	45	101		79	44	103		67	56	84	
	Difference	79%				82%				96%			
Apr	RFE	109	53	104	0.64	70	44	102	0.71	88	76	88	0.58
	RFR	112	65	104		88	71	102		106	106	88	
	Difference	97%				79%				83%			
May	RFE	76	73	101	0.85	141	71	99	0.59	125	89	78	0.82
	RFR	70	77	101		143	100	99		120	88	78	
	Difference	109%				98%				104%			
Jun	RFE	59	47	105	0.78	73	82	98	0.86	103	70	80	0.81
	RFR	123	104	105		132	118	98		133	106	80	
	Difference	48%				55%				77%			
Jul	RFE	102	55	86	0.71	148	77	91	0.75	199	117	73	0.86
	RFR	194	128			206	117	91		214	146	73	
	Difference	52%				72%				93%			
Aug	RFE	141	62	88	0.67	98	56	91	0.66	179	83	85	0.76
	RFR	199	113			192	113	91		231	122	85	
	Difference	71%				51%				77%			
Sep	RFE	105	63	104	0.64	84	54	89	0.70	131	91	76	0.80
	RFR	136	98	104		150	101	89		140	98	76	
	Difference	77%				56%				94%			
Oct	RFE	51	39	99	0.53	54	33	94	0.40	104	62	69	0.55
	RFR	71	46	99		69	68	94		126	98	69	
	Difference	72%				79%				83%			
Nov	RFE	36	42	97	0.77	43	41	74	0.44	88	84	62	0.67
	RFR	49	54	97		33	33			49	61	62	
	Difference	74%				129%				180%			
Dec	RFE	21	31	67	0.69	17	17	35	-0.09	77	87	67	0.61
	RFR	23	30	67		4	12	35		41	41	67	
	Difference	94%				433%				185%			

To enhance interpretation, summary tables were prepared based on table 3.3. The results are summarised for spring (March – May), summer (June -Aug), autumn (Sep – Nov) and winter (Dec – Feb) seasons as shown in Tables 3.3 and 3.4. The analyses showed that there is higher correlation or ‘r’ during summer and spring seasons and weak correlation during winter. The summer average value of ‘r’ for RFE 1.0 is 0.75 and the max and min values are 0.87 and 0.64 respectively, while the winter value is 0.38 on average with a minimum of -0.19. For RFE 2.0 images the summer average ‘r’ value, max and min of summer are 0.75, 0.86 and 0.60 respectively. The datasets also showed satisfactory correlation in autumn which is around 0.57 for RFE 1.0 and 0.64 for RFE 2.0 images.

Rainfall amount is better estimated on RFE 1.0 images. It is found that RFE 1.0 images recorded the rainfall amount 7% lower than NMA records of summer rains in average. However RFE 2.0 images estimate 36% lower rainfall than NMA's records in average. (See table 4.4) DINKU et al. (2008) compared RFE 1.0 and RFE 2.0 in Ethiopia and Zimbabwe. His findings showed that RFE 2.0 underestimates rainfall amount in Ethiopia, but on the other hand RFE 2.0 gives a better estimation than RFE 1.0 in Zimbabwe. It is stated that the problem of underestimation may partly be ascribed to the complex topography of the country and the associated orographic rain process. Cloud development may start as a result of orographic lifting of moist air. This may lead to precipitation while the cloud top is still relatively warm. With release of latent heat, this cloud system could then develop to deep convection allowing sensors to detect the rainfall from the deep convection.

Thus, the satellite products may only detect part of the rainfall. This might partially explain the underestimation. Comparison was also made between the previous (RFE 1.0) and current (RFE 2.0) versions of RFE. It was shown that RFE1.0 which includes an algorithm that specifically deals with orographic warm rain processes, performed much better than RFE2.0 over Ethiopia (DINKU ET al. 2008).

		Min		Max		Average
RFE 1.0	Spring	0.25	Apr '99	0.81	May '99	0.63
	Summer	0.64	Aug '99	0.87	Jun '98	0.75
	Autumn	0.28	Nov '00	0.73	Oct '96	0.57
	Winter	-0.19	Feb '97	0.68	Jan '96	0.38
						0.58
RFE 2.0	Spring	0.35	Mar '04	0.85	May '04	0.67
	Summer	0.60	Aug '01	0.86	Jul '06	0.75
	Autumn	0.40	Oct '05	0.80	Nov '04	0.64
	Winter	-0.10	Jan '06	0.71	Feb '03	0.37
						0.61

Table 4.3. Summary of Correlation Values

		Min		Max		Average
RFE 1.0	Spring	45%	Mar '97	121%	Mar '99	86%
	Summer	72%	Jun '00	130%	Jun '97	93%
	Autumn	43%	Nov '00	135%	Oct '96	79%
	Winter	14%	Dec '00	103%	Jan '99	65%
RFE 2.0	Spring	55%	Mar '01	109%	May '03	89%
	Summer	48%	Jun '04	93%	Jun '06	64%
	Autumn	45%	Sep '01	199%	Nov '03	92%
	Winter	40%	Jan '03	135%	Jan '04	77%
	** The calculations Excluded 2006 Winter*					

*Table4.4 Summary for Comparison of rainfall Amount (RFE / Stations' Data)*100*

In order to see the vegetation response during the months that has showed significant differences in rainfall, the research compared NDVI values with long term monthly NDVI averages. This helped to determine the rainfall during that time was above or bellow normal condition. Fig. 4.7 depicts the difference between 2006 RFE and Long term average of rainfall in winter season in southern part of Ethiopia. It shows that the rainfall condition is above normal for most part of SNNPR and the surrounding. Long term rainfall data is provided from NOAA is prepared based on stations rainfall data interpolation and RFE averages. For some parts the difference in rainfall amount is above 150 mm. In fact in some areas it show bellow normal situations like southern part of Bench Maji zone and eastern Borena.

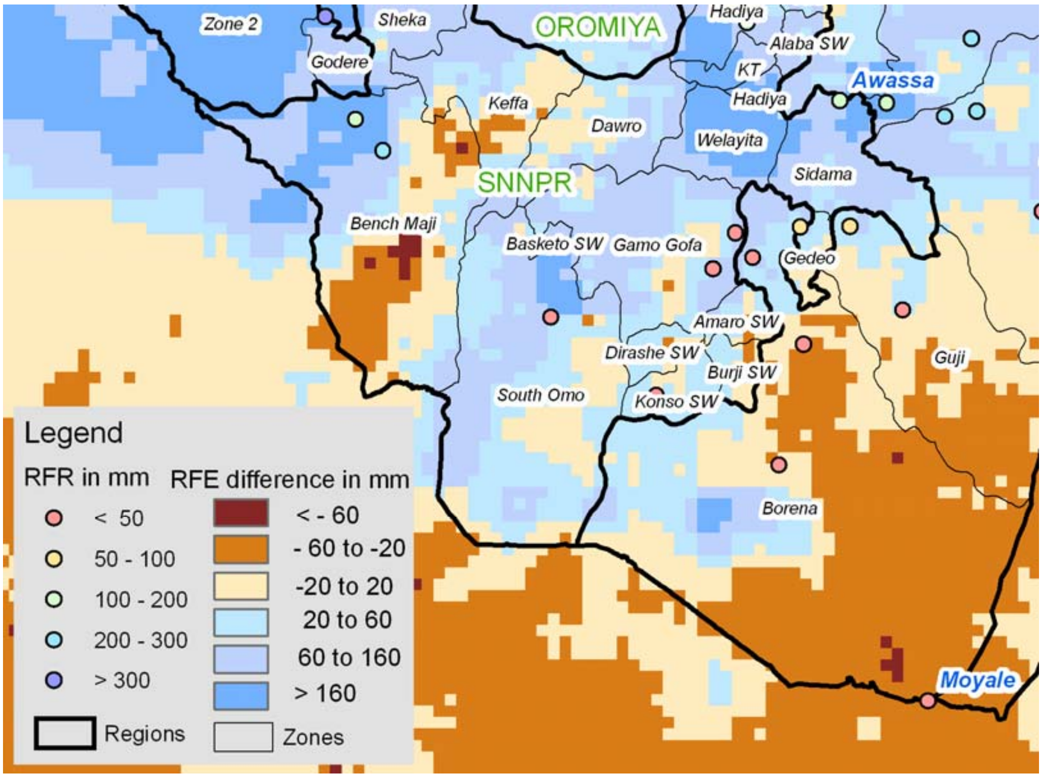


Fig. 4.7 Difference between 2006 RFE and Long term with overlay of 2006 winter weather stations' rainfall records

It is clearly visible on Fig 4.8 that the rainfall amount collected from the weather stations and RFE data recorded different values. For example, weather stations found in Gamo Gofa zone of SNNPR the stations recorded below 50 mm of rainfall and the RFE shows that rainfall amount reaches up to 200 mm. In Fig 4.9, the 2006 winter rainfall data are compared with long term average and this showed that most of the records gathered from the stations showed that the rainfall in 2006 winter is below normal. This means the two datasets showed to opposing results. The RFE record shows that the rainfall condition in winter 2006 is above normal and stations' records showed below normal rainfall.

In order to know what has happened during the winter 2006, to study vegetation condition during the period is found to be important. To do so NDVI data are considered to see how the vegetation responded to the rainfall condition happened during winter 2006. Fig 4.10 depicts the vegetation condition is bellow normal as compared to the long-term average shown in Fig 4.11.

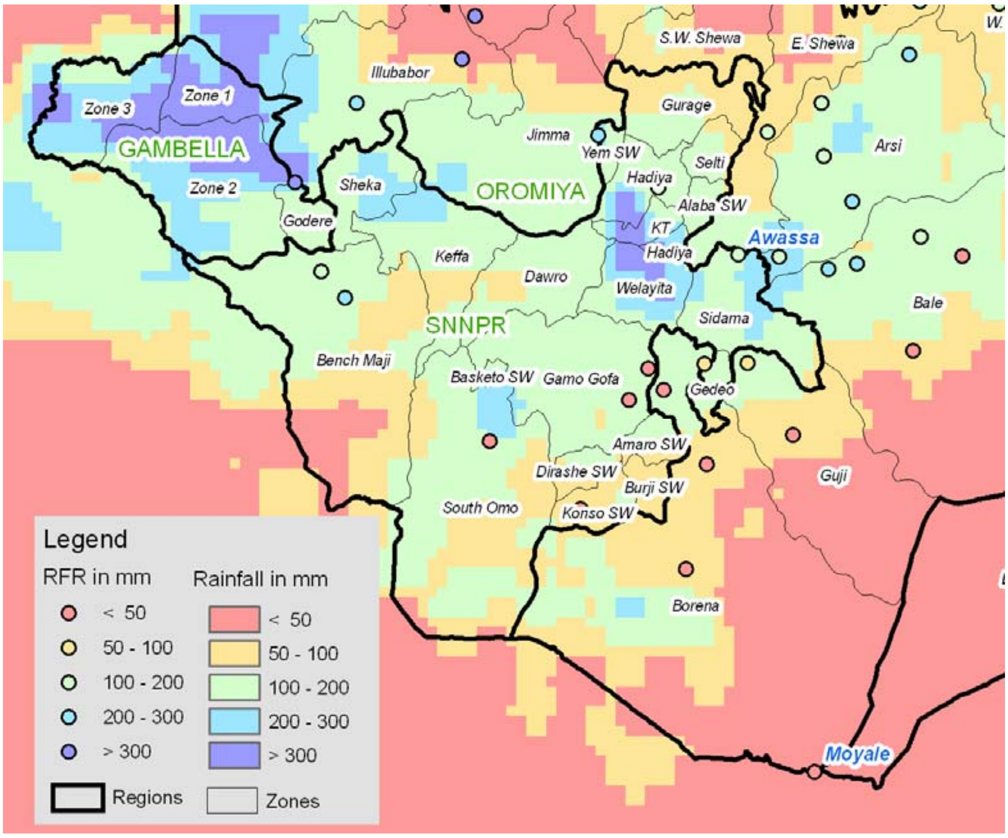


Fig 4.8 Winter 2006 weather stations' rainfall records overlaid with 2006 winter RFE (Map by EGB)

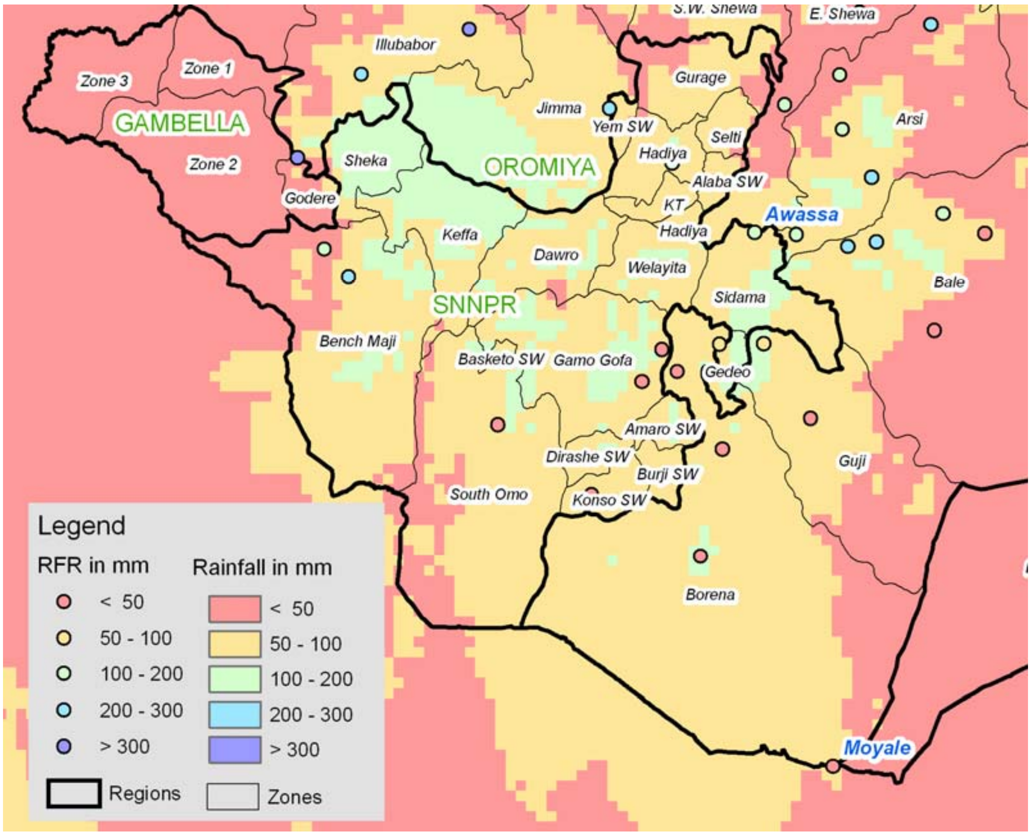


Fig 4.9 Winter 2006 weather stations' rainfall records overlaid with Long term RFE (Map by EGB)

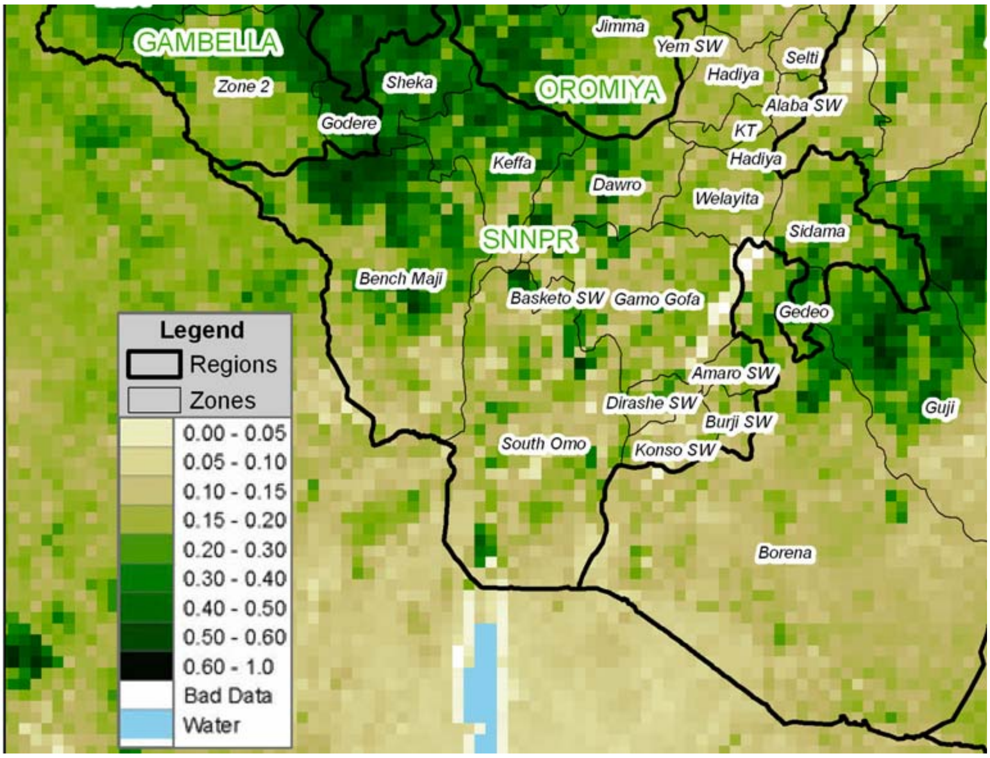


Fig. 4.10 Mean NDVI of 2006 winter (Map by EGB)

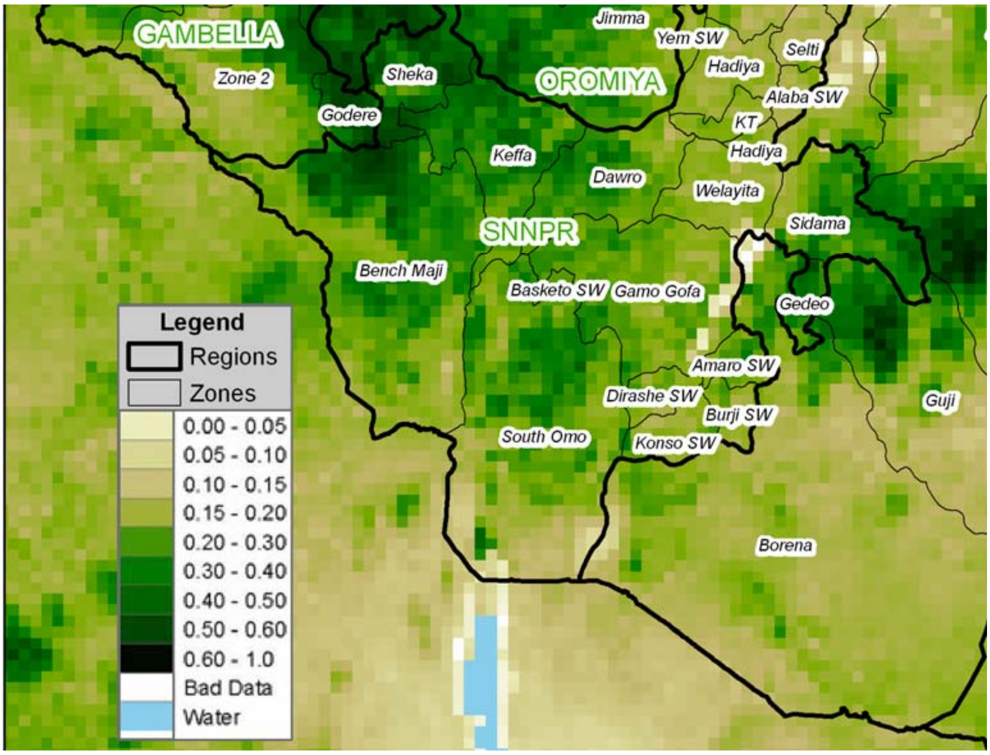


Fig. 4.11 Mean NDVI of Long-term (1982 – 2008) Average of winter (Map by EGB)

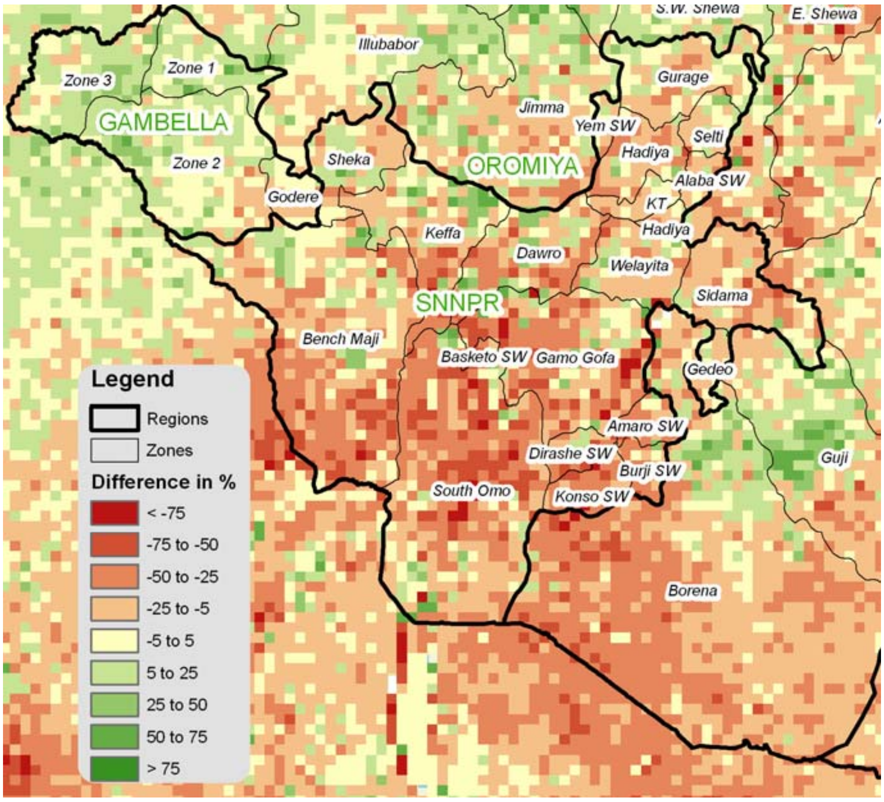


Fig. 4.12 Percental Difference between mean NDVI of Winter 2006 and long-term Average (Map by EGB)

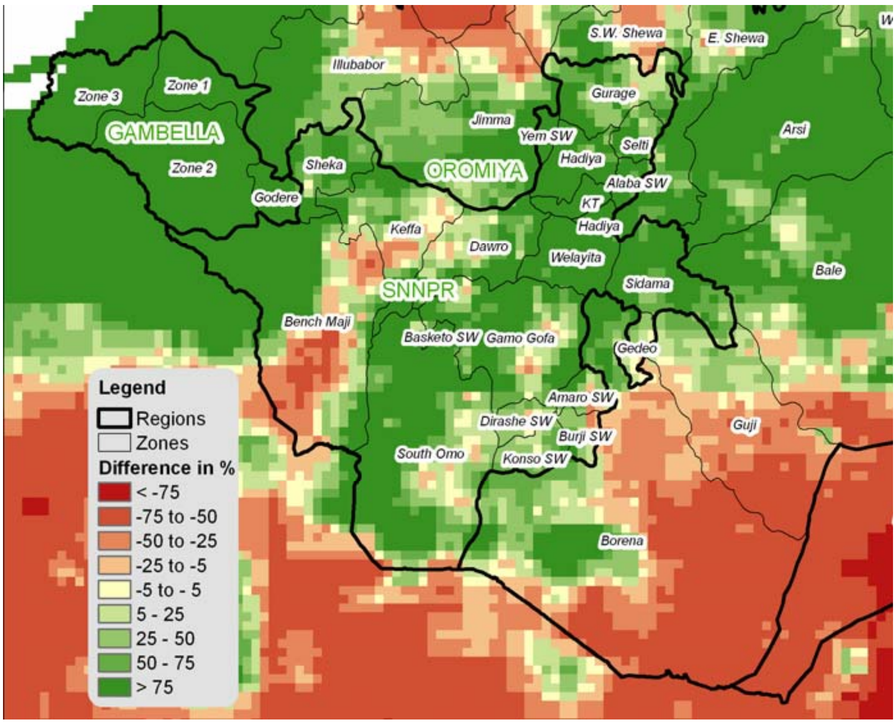


Fig. 4.13 Percental Difference between 2006 Winter RFE and Long term Average of Winter rainfall (Map by EGB)

Fig 4.12 and Fig 4.13 shows the difference between long term (1982 – 2008) and winter 2006 NDVI and RFE in percent respectively. The vegetation condition for most parts of SNNPR found too much below normal which above 50% decreases in many parts as depicted ion Fig 12. However, the RFE comparison on Fig 4.13 showed that the rainfall amount received much above normal for most part of SNNPR which does not reflect on the vegetation condition. The data from the rainfall weather stations are proofed to be better.

In order to analyse the spatial correlation, pairs of values acquired from RFE and Stations' data of the entire period were calculated for each station individually. After calculating correlation for all stations, it was found that the Synoptic weather station located at Addis Ababa showed the highest correlation with a value of 0.9. The correlation value of Mekele, Dire Dawa, Nekemte and Moyale are 0.71, 0.65, 0.48, and 0.71 respectively. The overall level of significance is 0.01.

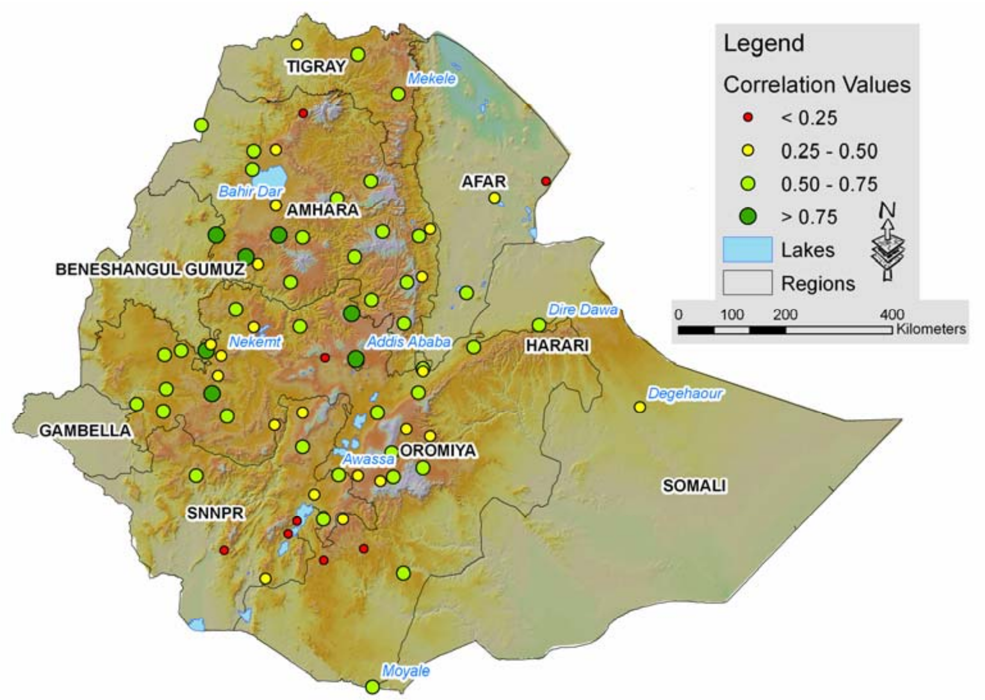


Fig 4.14 Correlation of RFE and weather stations' rainfall records for the period (1996 to 2006) (Map by EGB)

Generally the two datasets are well correlated during the important rainy seasons, summer and spring. As depicted in Fig 4.14, many weather stations have correlation values above 0.5 and 0.75. As a result, RFE images are reliable enough to be used for timely spatio-temporal analyses of disasters in times characterised by late inception, dry spells and early cessation of rainfall. The analysis of RFE images is a key tool for an advanced early warning system in the country. The RFE images are very useful to show rainfall stress timely in the lowlands where there are few meteorological stations. Despite the different methods used to create RFE1.0 and 2.0 and the fact that RFE 2.0 images underestimate the rainfall amount, the results of correlation are very similar.

4.3 Rainfall Onset, Cessation, and Dry-Spell Mapping

While rainfall is only one factor in a complex tableau of factors that influence global climate, it plays an important role in regulating the climate of Eastern and Southern Africa. Satellites help us monitor the climate by tracking atmospheric conditions (Funk, 2009).

Fundamental to determining dates of rainy season onset, cessation, and dry-spells is the rainfall total needed for a day to be classified as a ‘‘rain day’’. The amount used typically has been in the 01–1.0mm range, depending on the application context (e.g., agriculture, water resources) and whether individual stations or area-averages are considered (e.g., Stern et al, 1982; Shaw, 1987; Peppler). However, (Sivakumar 1992) noted that a ‘‘minimum rainfall threshold of 1mm is an insignificant amount for crop use, but it does signify the ending of a dry-spell’’, and Cook and Heerdegen (2001) used a 5mm threshold because daily potential evapo-transpiration generally exceeds that amount in northern Australia. Days not classified as rain-days are considered ‘‘dry days’’, sequences of which are important for defining rainy season cessation and dry-spells.

Segele in 2005 stated for the delimitation of dry-spells, rain-days were defined. It found informative to use three different rain-day thresholds – 0.1, 5, and 10mm per day. Due to the complex topography and large spatial rainfall variability, a single ‘Kiremt’ onset criterion could not be established for all of Ethiopia. This situation stemmed, first, from onset criteria requiring an initial wet-spell length of more than one day giving unreasonable onset dates for dry regions where wet ‘‘spells’’ often are limited to a single day (low lying regions of eastern Ethiopia, northern Rift Valley, south-western lowlands in Gambela region. Conversely, applying onset criteria that performed well in the dry areas to other Ethiopian regions gave extremely early and unreasonable onset dates. Therefore, two separate sets of onset criteria were developed, one for the wetter regions that average more than 30 rain-days in July–August, and the other for dry regions with less July–August rain-days.

Determination of ‘Kiremt’ onset for stations in the dry regions of the northern Rift Valley and eastern and south-western lowlands where the average number of July–August rain-days was less than 30 – involved one major difference from the above procedures for the wetter areas. This difference concerned the length (1 day) and amount (10mm) of the year’s first wet-spell that provided the basic onset date. Once the basic onset date was established for a dry station using these criteria, the possible subsequent procedures applied to that station were the same as described above for the wetter stations (Segele, 2005).

In the works of Segele, 2005, three alternative criteria were used to identify and characterize dry-spells that occurred each year between the above determined ‘Kiremt’ onset and cessation. To be considered a dry-spell required either at least

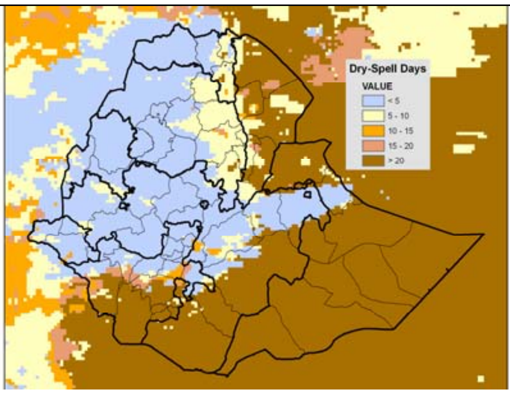
(i) Three contiguous dry days (<0.1mm),
(ii) Five contiguous days with no more than 5mm of rain on any day, or
(iii) Five contiguous days during which rain did not exceed 10mm.

The third definition of dry spell was used for the analysis of the research. In order to calculate the dry spell in ArcGIS a formula is used in the raster calculate tool of Spatial Analyst. This conditional formula produces a raster file with a number of dry-spell days since the beging of July. The RFE file names are coded to represent the year and date. For example, the raster file input rain_2001182 represent daily rainfall in the year 2001 on the 182^{nd} day which is July 1^{st} which means the first 4 digits represent always the year and the last 3 digits represent the date. The formula below calculates up to 9 days with dry-spell and the rest of the area which does not qualify for the conditional statement are areas with no dry-spell for that period.

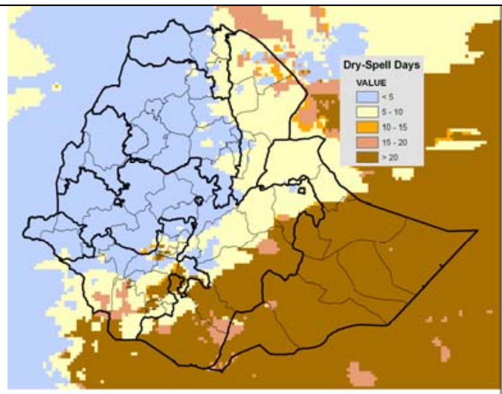
An Example of dry spell conditional formula used for the analyses:
con((([rain_2001182] + [rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186]) < 10 & ([rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186] + [rain_2001187]) < 10 & ([rain_2001184] + [rain_2001185] + [rain_2001186] + [rain_2001187] + [rain_2001188]) < 10 & ([rain_2001185] + [rain_2001186] + [rain_2001187] + [rain_2001188] + [rain_2001189]) < 10 & ([rain_2001186] + [rain_2001187] + [rain_2001188] + [rain_2001189] + [rain_2001190]) < 10), 9, (([rain_2001182] + [rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186]) < 10 & ([rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186] + [rain_2001187]) < 10 & ([rain_2001184] + [rain_2001185] + [rain_2001186] + [rain_2001187] + [rain_2001188]) < 10 & ([rain_2001185] + [rain_2001186] + [rain_2001187] + [rain_2001188] + [rain_2001189]) < 10), 8, (([rain_2001182] + [rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186]) < 10 & ([rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186] + [rain_2001187]) < 10 & ([rain_2001184] + [rain_2001185] + [rain_2001186] + [rain_2001187] + [rain_2001188]) < 10), 7, (([rain_2001182] + [rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186]) < 10 & ([rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186] + [rain_2001187]) < 10), 6, (([rain_2001182] + [rain_2001183] + [rain_2001184] + [rain_2001185] + [rain_2001186]) < 10), 5, 0)

The month of July and August are very important rainy months in terms of rainfall amount for most parts in the Ethiopian highlands as it has been discussed the previous chapters. Occurrence of dry-spells has huge negative effect on the plant growth and success of agricultural production. As a result the spatial-temporal distributions of dry-spell during two months are depicted on the following series of map in Fig 4.15. Generally the occurrence of dry-spells is higher during the month of July as compared to August both in terms of its duration and spatial coverage. As it is depicted in Fig 3.7 in Chapter 3, the months of July and August rains are very important for the northern half of the country. So the occurrence of dry spells during this period affects plant growth in this part of the country as well.

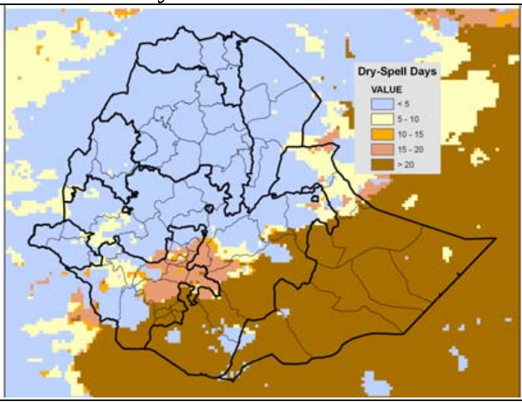
As it is the case of other countries characterised with seasonal rains, Ethiopia is also severely affected by the late-onset of the major and minor rain season. In addition to this the occurrence of dry spells in the middle rain season is also wide spread. The other characteristic of seasonal rains is early cessation or termination of the rain before the normal time. These important characteristics negatively affect crop production or pasture land development very significantly. These characteristics vary significantly from one place to the other. Therefore it is important to map out these occurrences and understand the pattern carefully.



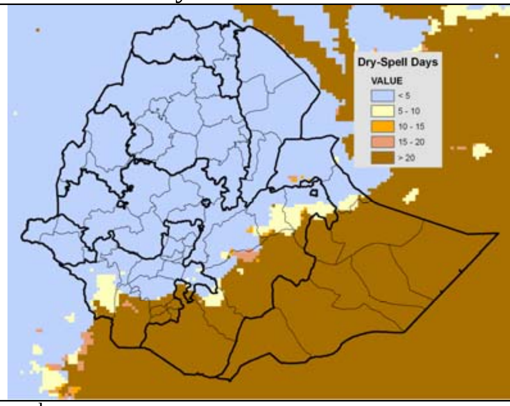
1st half of July 2001



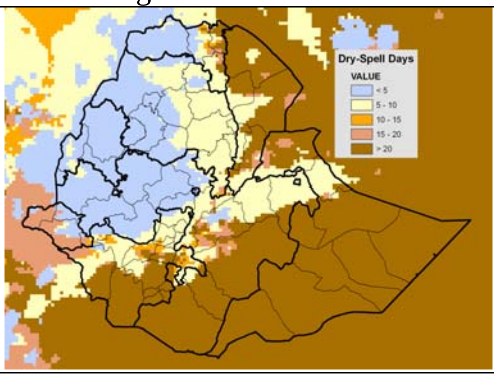
2nd half of July 2001



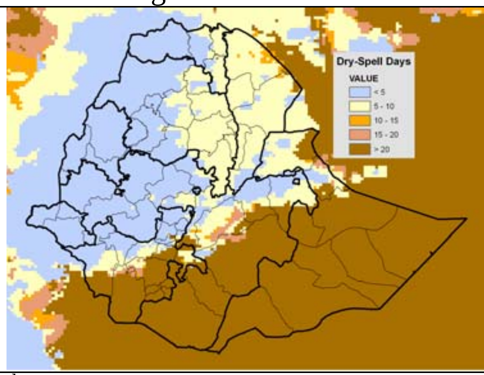
1st half of August 2001



2nd half of August 2001



1st half of July 2002



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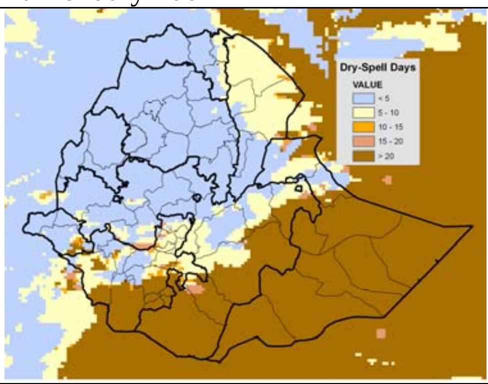
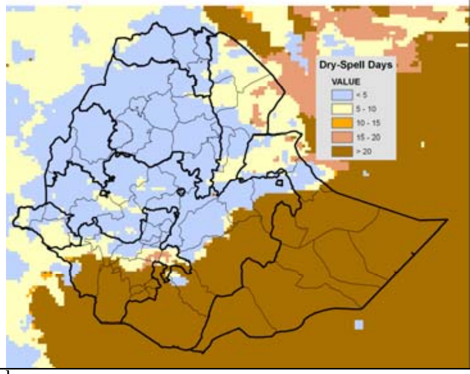


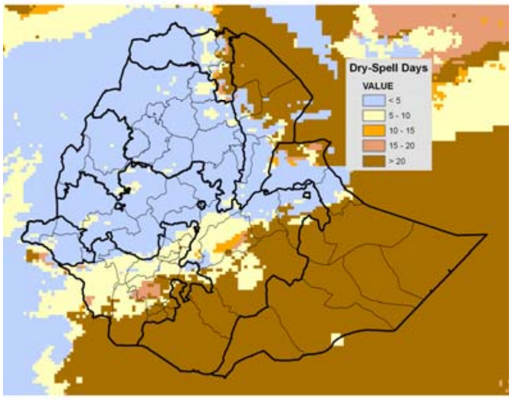
1st half of August 2002



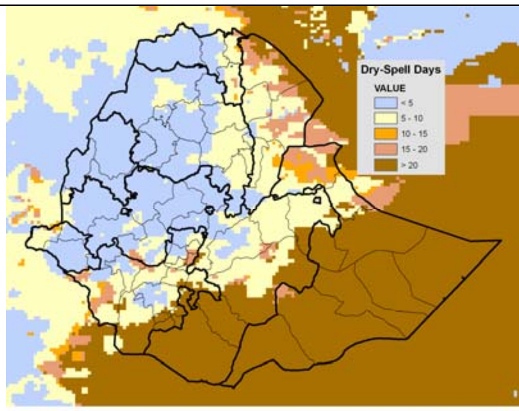
2nd half of August 2002

Fig 4.15 Occurrence of dry spell during first and second halves of July and August(Maps by EGB)

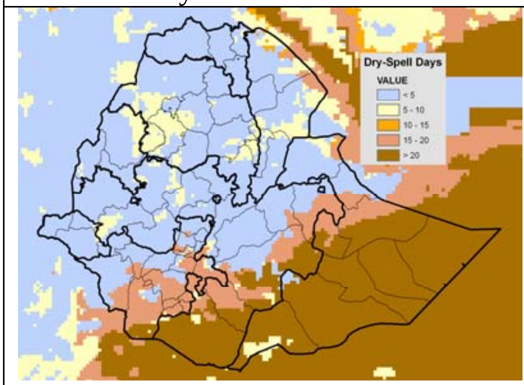
Continued from Fig 4.15



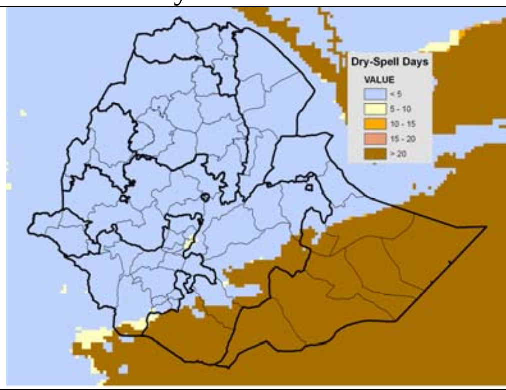
1st half of July 2003



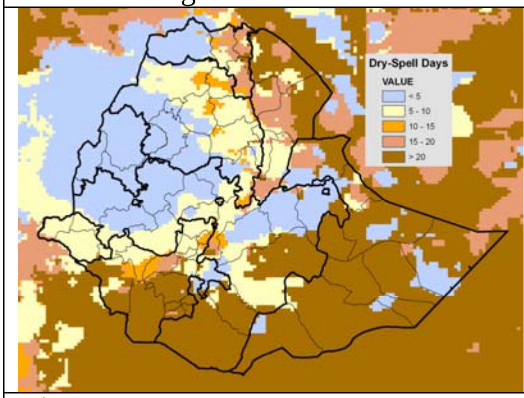
2nd half of July 2003



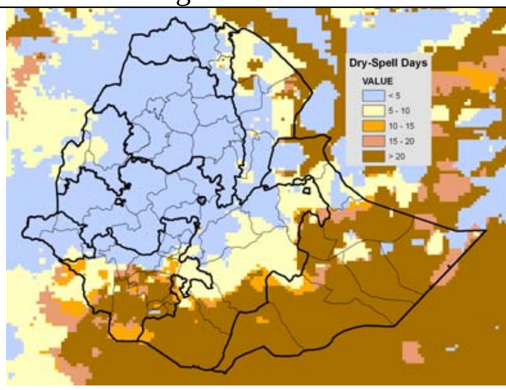
1st half of August 2003



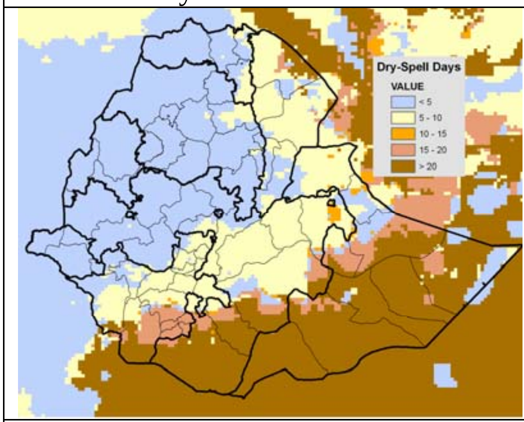
2nd half of August 2003



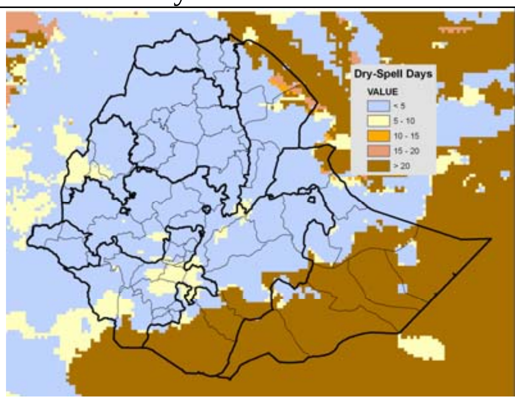
1st half of July 2004



2nd half of July 2004

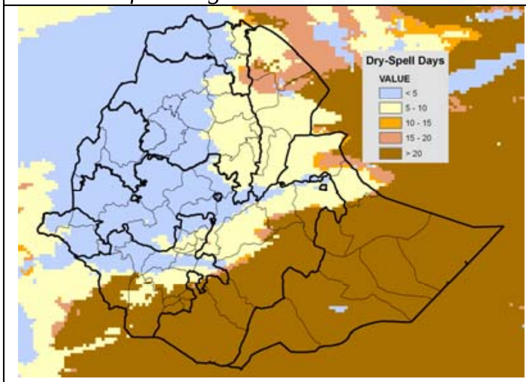


1st half of August 2004

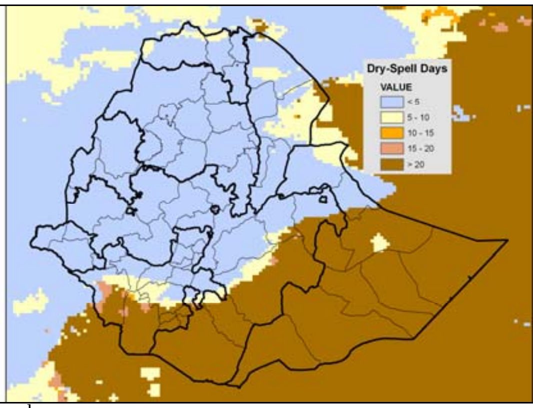


2nd half of August 2004

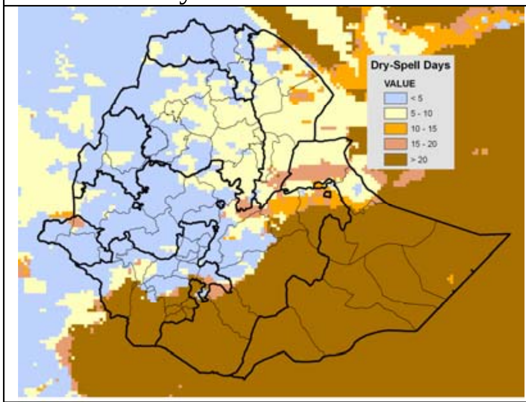
Continued from Fig 4.15



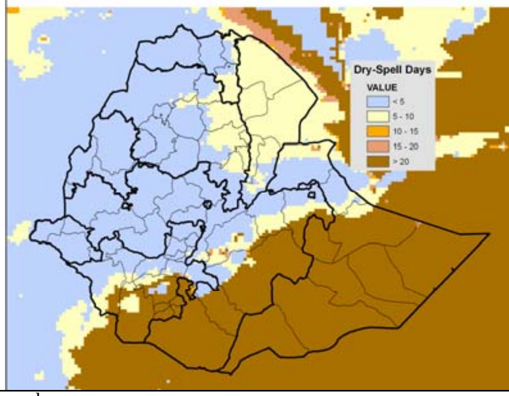
1st half of July 2005



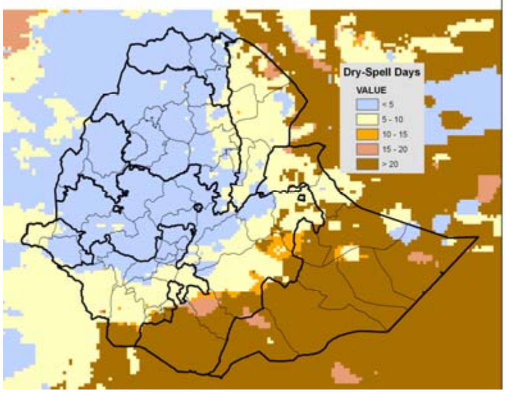
2nd half of July 2005



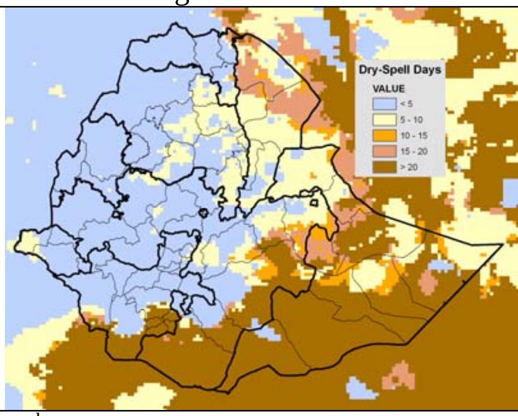
1st half of August 2005



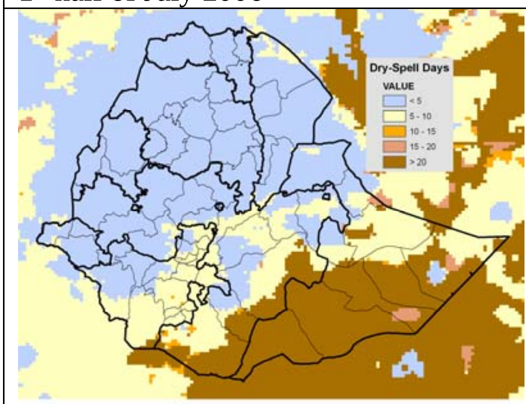
2nd half of August 2005



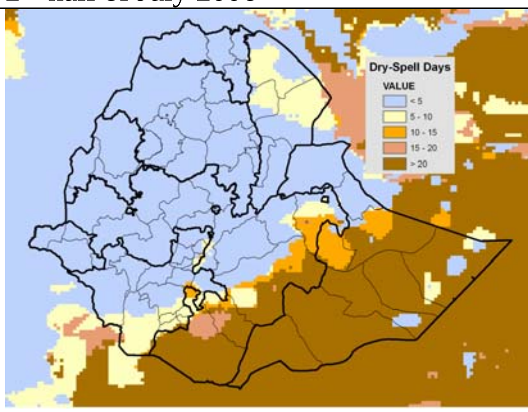
1st half of July 2006



2nd half of July 2006

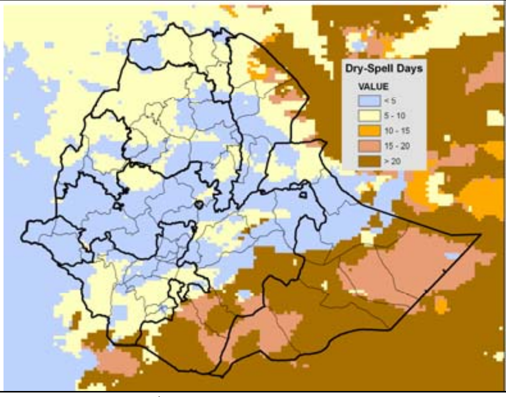


1st half of August 2006

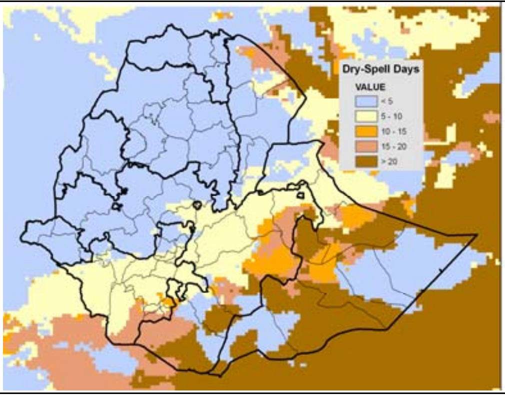


2nd half of August 2006

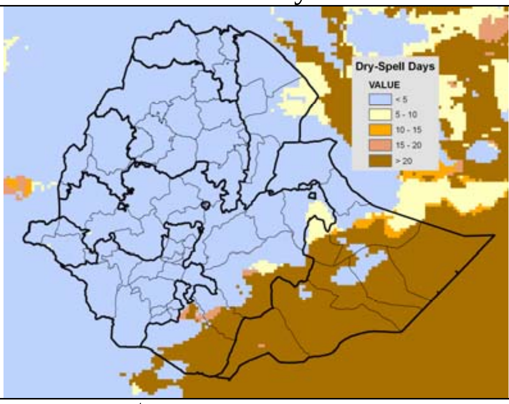
Continued from Fig 4.15



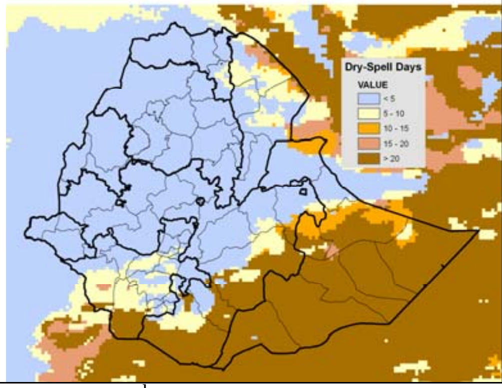
1st half of July 2007



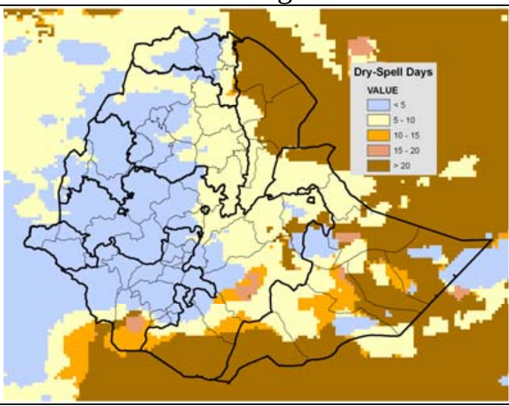
2nd half of July 2007



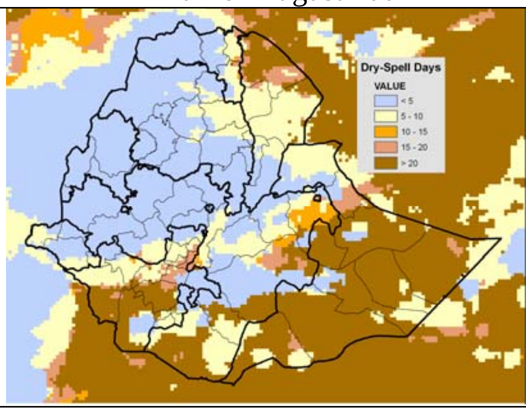
1st half of August 2007



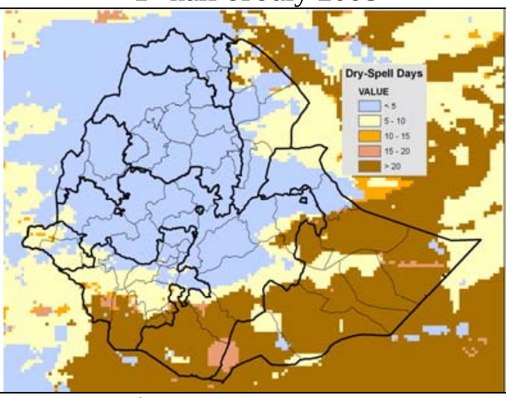
2nd half of August 2007



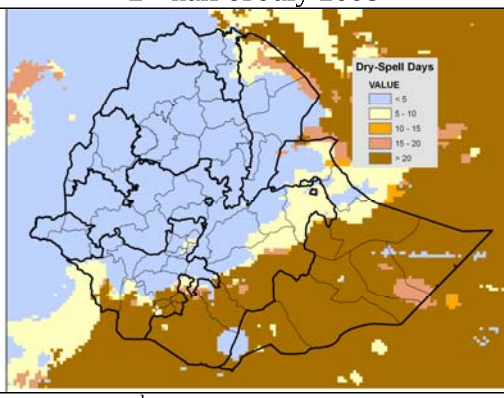
1st half of July 2008



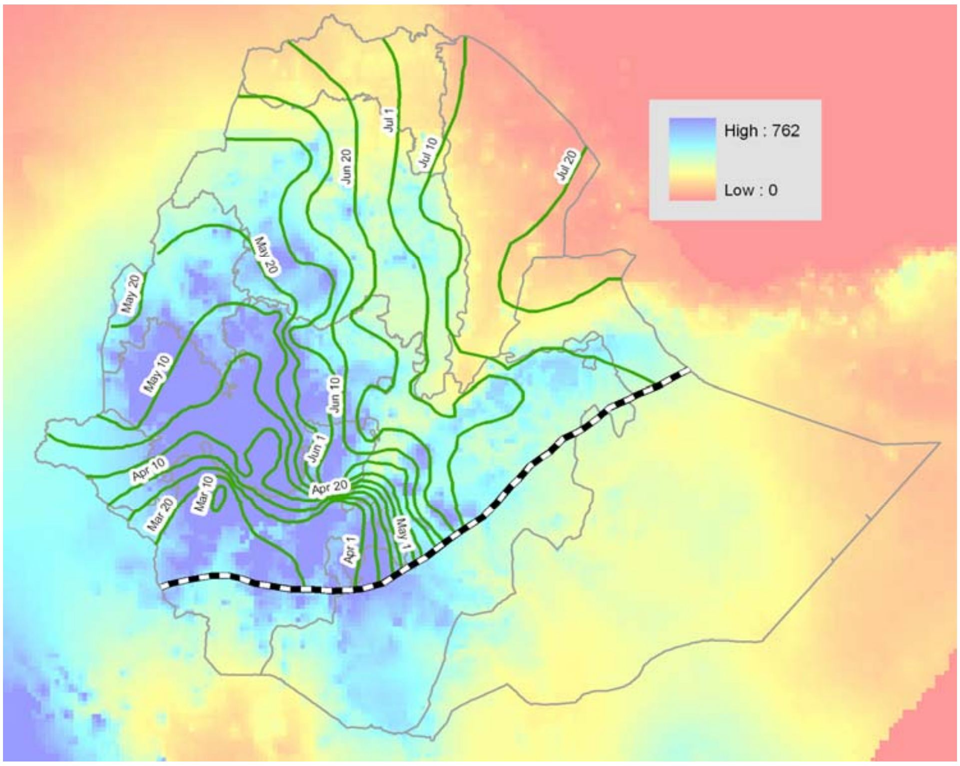
2nd half of July 2008



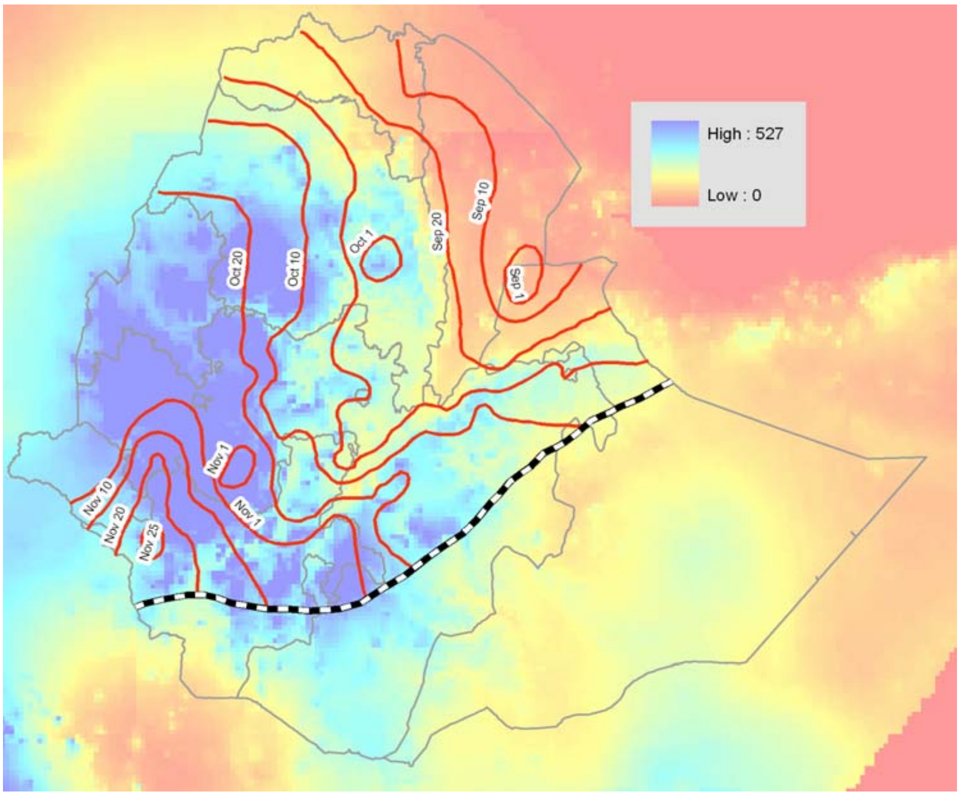
1st half of August 2008



2nd half of August 2008



(a)



(b)

Fig 4.16 Pattern of Long-term Kiremt Mean Onset date and total rainfall of March to July (a) and Mean Cessation date and total rainfall of September to November (b) and Kiremt boundary is represented by zebra line (Basic source: segele, 2005 and NOAA). (Maps modified by EGB)

It is stated in several yearly Humanitarian Appeals for Ethiopia (DPPC 2002 – 2007) that time to time in different part of the country the seasonal rains starts late or discontinues for certain periods or even stops before the normal rainy season ends. This has been observed during the past decades. It is important to analyse the spatial and temporal extent of the existing problems such as late inception, dry spell and early cessations applying geospatial techniques. The good correlation that is analysed in the previous sessions between the two data sets during the main rainy seasons shows that the RFE data can be used to analyse the spatial and temporal extent of climatic variability occurring in large parts of the county during recent decades.

For most parts of the southwestern highland there is no break between spring and autumn rain. As result it is considered as a long rain period starting in March. On Fig 4.16 (a) the 'Kiremt' onset map shows that the onset date ranges from early march in the south east to late July in the north east. In the west-Gojam zone of Amhara region, *'Kiremt'* starts toward the end of may and in the northeast part of the Amhara region the onset is in July. In most parts of Tigray 'Kiremt' starts late June to early July. Consequently, as result the total amount of rainfall in this area is also very low.

The withdrawal of some monsoon systems is often more abrupt, and hence better defined and organized, than their onset (e.g., Ayoade, 1974; Adefolalu, 1983; Odekunle, 2004). The only parameter needed to determine cessation was dry-spell length. However, because of the complex topography and large spatial rainfall variability), Segele in 2005 had to use two dry-spell length thresholds. The *Kiremt* cessation map shows that the cessation date ranges, from September in the northern part of the country to October in the south-western part (See Fig 4.16 b).

In order to calculate variability, cell statistics tools available in spatial analyst tool of ArcGIS are used to generate raster dataset of standard deviation and mean. By dividing them each other the coefficient of variation are calculated.

4.4 Vegetation Cover Trend and Variability

Land degradation is commonly perceived to be severe in many parts of Ethiopia. The transition towards market economy since the 1991 reforms, have set marginal dry lands under added pressure in the form of increased livestock numbers and expanding cultivation on erosive soils. Over utilization of meager resources, such as overgrazing, gathering of wood for fuel and medical herbs, reclaiming steppe land for rain-fed cultivation in combination with erratic rainfall, is often recognized as a cause of land degradation. Time series of digital satellite images are useful in the studying of biomass change, vegetation phenology, temporal trends and spatial variations.

NDVI express a time series of a vegetation index that can be linked to biological production of vegetation. The task is to analyze if the trends of biological production using NDVI during the 27 year period 1982-2008 are indicating severe degradation of land resources in the east African environments.

However, conclusions drawn regarding environmental degradation cannot be based on the image-time series alone but in relation to how rainfall properties have developed over the same period of time. For natural vegetation (e.g. grassland, or rain-fed agriculture, the correlation between NDVI and rainfall is therefore interesting to explore. For irrigated cultivated areas, the biological production will not be very rain dependent.

NDVI is valuable for studying annual phenology and trends of vegetation. However, the regression between the yield-NDVI, for example, is site and crop specific. The NOAA pixel is 8*8 km, therefore a spectral mixture of the pixel is unavoidable. Studying the trend through the same pixel, an increase in NDVI through time could either be caused by a land use change, change in vegetation cover for the pixel or an actual change in biological production of natural vegetation. When studying trends over a period of time, it is essential to first explore the behaviour of the annual vegetation cycle. Integrating NDVI around peak seasons would approximate the biological production or yield each year, providing a time series to analyze.

Hence, time series of satellite images can be used to study environmental change, land use change for an area. A change in NDVI driven by rainfall change is likely a natural change. Calculating the gain coefficient for each pixel through the time series would provide a map of the spatial change and its gain (size). The linear trend line equation is called the simple linear regression and can be calculated by most statistical programs. However there is no function in ArcGIS yet, to calculate the trend of pixels for time series of sequential satellite images (Runnström 2000).

The simple linear regression formula is given as:

$$y = \alpha + \beta x$$

where:

α is the offset, where the regression lines cut the y-axis at x = 0

β is the gain coefficient, showing how much the y value is changing for each x step.

To explore biomass change expressed as NDVI for the study area, you will only focus on calculating the gain coefficient. According to statistical references (Draper, 1998), the following is a formula to calculate trend.

$$\beta = \frac{S_{xy}}{S_{xx}}$$

$$S_{xy} = \sum_{i=1}^{n} (x_i - \overline{x}) * (y_i - \overline{y})$$

$$S_{xx} = \sum_{i=1}^{n} (x_i - \overline{x})^2$$

This can be expressed for each pixel as the value is compared to the mean value for the complete time series on dekadal (10-days) bases. To calculate the gain coefficient in ArcGIS, first, an average image (summarize all images and divide by 14) is produced. This forms values of $\overline{y}$. $\overline{x}$ is a constant and the time series will instead of specific years (e.g. 1982) instead be substituted by 1,2,3,4, etc. Raster calculator tool found in ArcGIS's spatial Analyst extension, is used calculate to produce $\overline{y}$ and $\overline{x}$

calculated with table calculator. Then S_{xy} in ArcMap is produced. S_{xx} is calculated in excel as it only uses the 1 to 15 constants, and finally, β calculated in the raster calculator. β is then visualized to explore where high positive / negative changes of NDVI has occurred. In order to see the trends of rainfall amount, a similar technique is used based on RFE 2 images for the period 2001 to 2009.

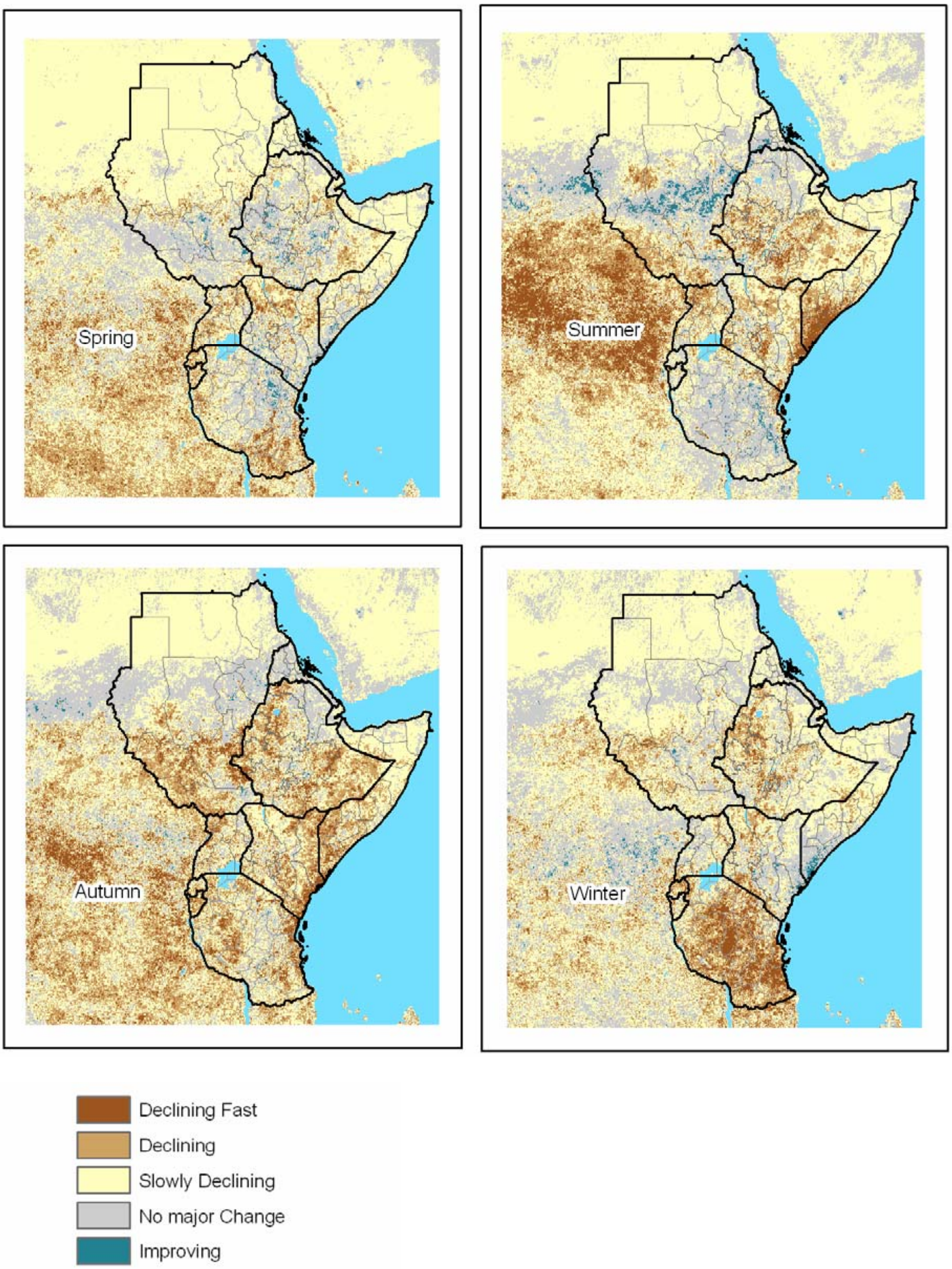


Fig 4.17.Trend of vegetation cover based on NDVI (1982 – 1995) *(Map by EGB)*

To compare the past and recent trends, the analyses were done by dividing the period in to two parts, the first 14 years between 1982 and 1995 and the last 14 years from 1995 to 2008 (see Fig 4.17 and Fig 4.18). The trend values are calculated based on 10-days NDVI data. The monthly, seasonal and annual aggregations are prepared by taking the mean values of trends. The trend is further used to forecast the future vegetation pattern. The vegetation cover is in a continuous dynamics because of climatic and other social factors.

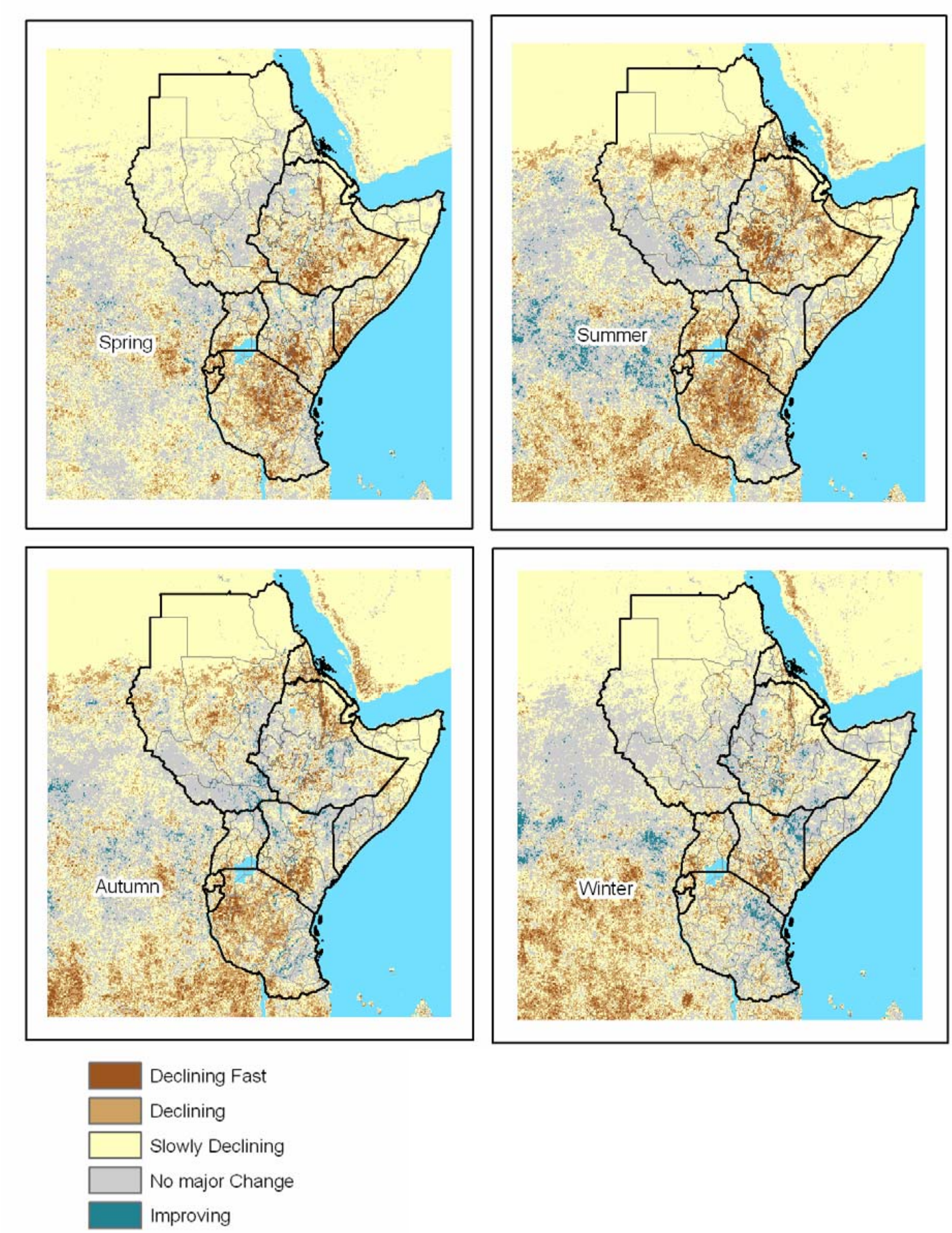


Fig 4.18 Trend of vegetation cover based on NDVI (1995 – 2008) *(Map by EGB)*

During the first half the study period the overall vegetation cover was in constant decline in most parts of the east African nations, with the exception of Sudan where relative stability was observed. In the central parts of Sudan, vegetation cover in summer showed a positive trend and the opposite was true for most parts of southern Ethiopia and Somalia. Vegetation condition was improving during spring of this first half and in autumn it was mostly declining. There was a fast decline in most parts of Tanzania during winter time.

During the 2nd half of the study period, the overall vegetation cover trend is better than the 1st part. However, there are areas of fast decline in the western escarpment of Ethiopian rift valley, southern Kenya and western Uganda (See Fig. 18). The trend showed higher decline during summer and spring seasons. The trend depicted the deterioration of vegetation cover near and around the Victoria region, most parts of central and northern Tanzania, a significant portion of southern Ethiopia and northern parts of the rift-valley escarpment. In fact, there is also improvement of vegetation cover in some of the arid areas of east Africa like the north-eastern Kenya and Tanzania during winter seasons.

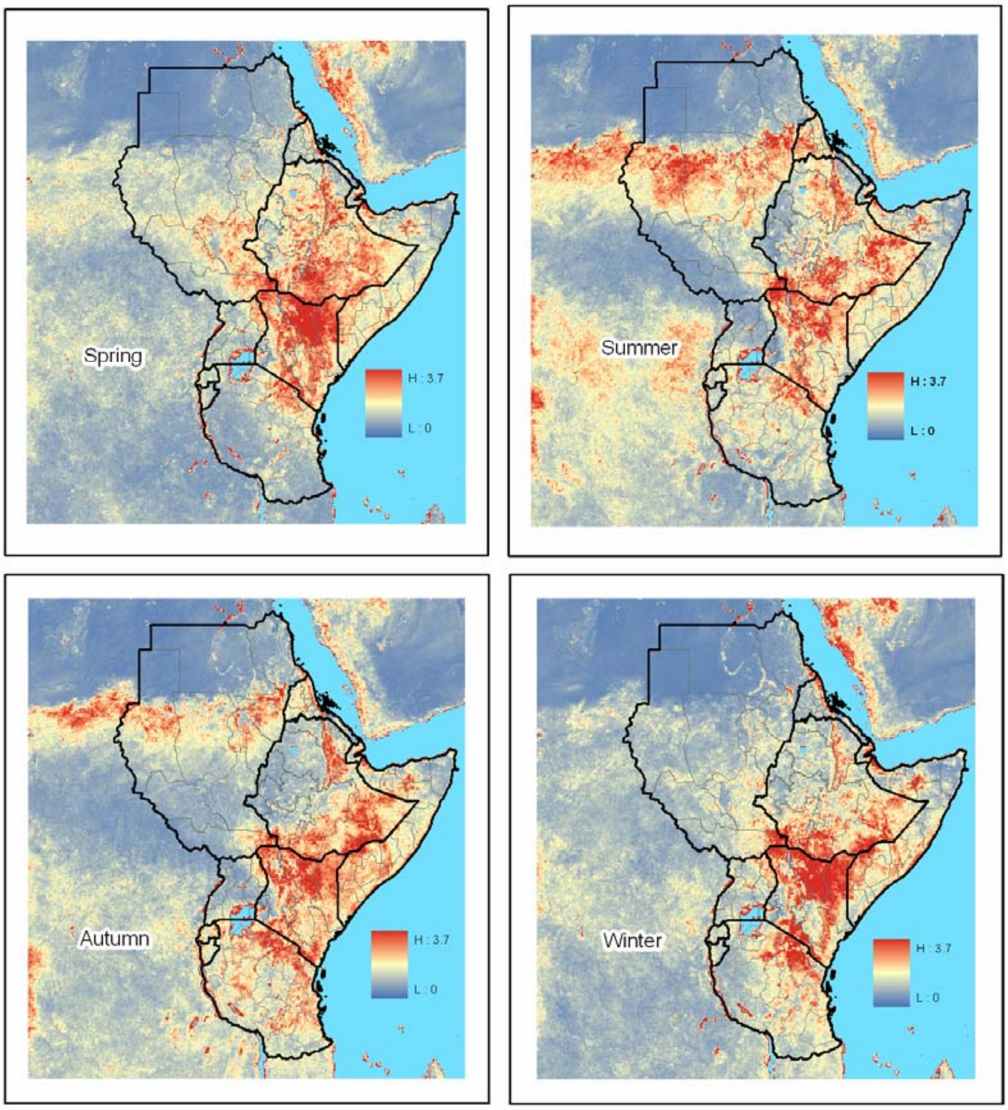


Fig 4.19 Variability of vegetation cover based on Coefficient of Variation NDVI (1982 – 1995) *(Map by EGB)*

The overall biomass production during main growing-season have decreased in food-insecure countries located in the Great horn of Africa Ethiopia, Sudan, Somali, Kenya and Tanzania (Funk 2009). Most parts of south Sudan showed a positive trend during the 2nd half. On the other hand, in Kenya and Uganda, with exceptions in the north east corners, in Tanzania excluding the area near the cost, in Ethiopia with the exception of some pocket areas as well in Rwanda and Burundi the trend is negative. The negative trend values are very high in the northern part of Ethiopia as well as in areas near Lake Victoria and further south. The improvement and deterioration of vegetation cover observed during the 2nd half are larger in their value as compared to the differences in first part.

The NDVI variability analysis showed that the lowland plains of southern Ethiopia, the extended lowlands of northern Kenya and northern Tanzania experience high variability of vegetation cover. This implies the area is in the process environmental change since the vegetation density showed that the normal vegetation pattern is disturbed and dominated by greater variation from one year to the other significantly. Fig 4.19 and Fig 4.20 depict that the variability during summer is higher than in the 1st half and for spring the variability is higher in the 2nd half.

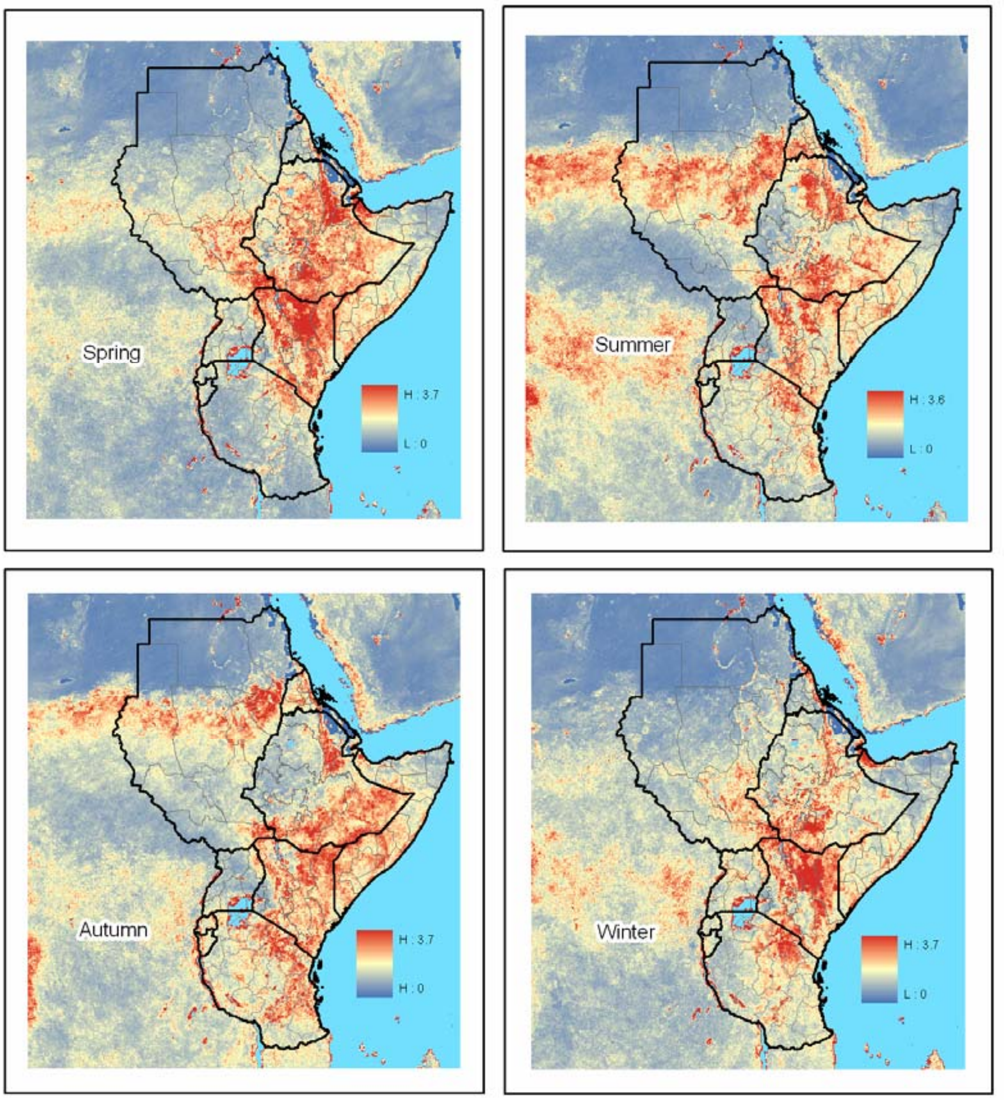


Fig 4.20 Variability of vegetation cover based on Coefficient of Variation NDVI (1995 – 2008) (Map by EGB)

4.5 Environmental Change and Climatic variability Impacts on Food Security

Food security is defined by the Food and Agriculture Organization (FAO) as a situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. On the other hand food insecurity incorporates low food intake, variable access to food, and vulnerability – a livelihood strategy that generates adequate food in good times but is not resilient against shocks. These outcomes correspond broadly to chronic, cyclical and transitory food insecurity, and all are endemic in Ethiopia.

Ethiopia has been structurally food deficit since at least 1980. The food gap rose from 0.75 million tons in 1979/80 to 5 million tons in 1993/94, falling to 2.6 million tons in 1995/96 despite a record harvest (Degfe, 2000). Even in that year, 240,000 tons of food aids were delivered, suggesting that chronic food insecurity afflicts millions of Ethiopians in the absence of transitory production shocks. The poor performance of Ethiopian agriculture is certainly a large part of the explanation. Fig. 4.1 illustrates the extreme variability of agricultural performance during the 1980s and 1990s, ranging from -20% to +20% growth, with no discernible average or 'normal' year. Fig. 4.21 also reveals the close correlation between agriculture and GDP (Devereux, 2000).

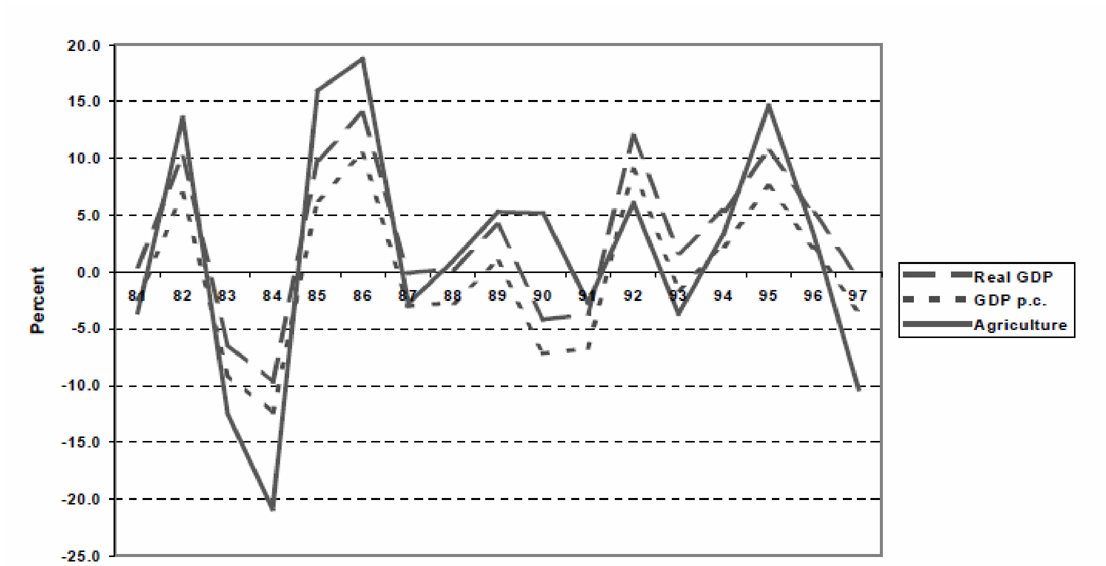


Fig 4.21 GDP and Agriculture Growth Rates in Ethiopia. Source: (Stefen Devereux, 2000) (Map by EGB)

The main triggers of transitory food insecurity in Ethiopia are drought and war. Structural factors contributing to chronic food insecurity include poverty (as both cause and consequence), the fragile natural resource base, weak institutions (notably markets and land tenure) and unhelpful or inconsistent government policies (Devereux, 2000).

In Ethiopia, a predominantly rural society, the life of peasants is rooted in the land, from which they eke out a meagre existence. Through the ages, they have faced frequent natural disasters, armed conflict, and political repression, and in the process they have suffered hunger, societal disruption, and death.

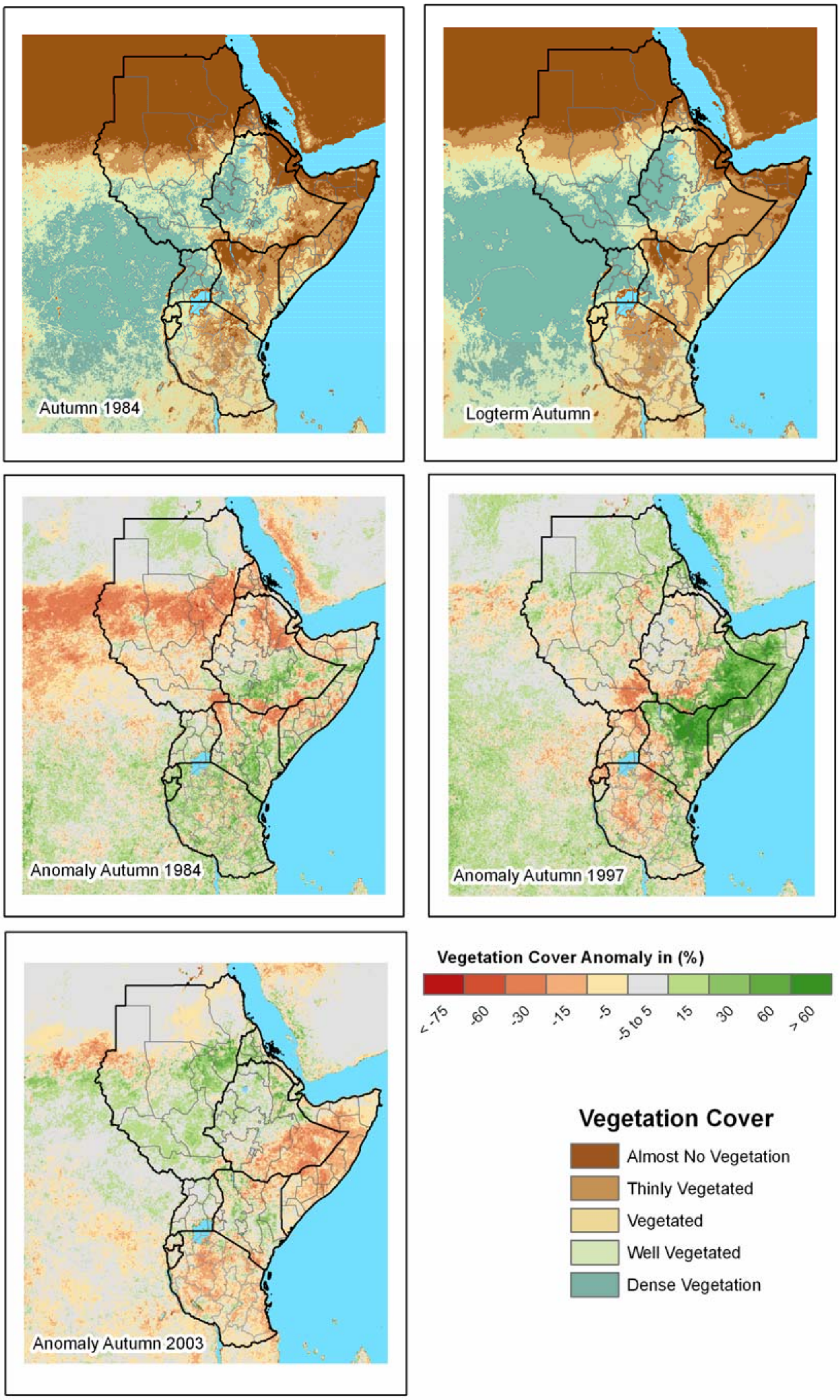


Fig 4.22 Vegetation cover Anomaly map of East Africa. Source: (Basic Data Source: NOAA) (Map by EGB)

Periodic crop failures and losses of livestock often occur when seasonal rains fail or when unusually heavy storms cause widespread flooding. Pastoral nomads, who move seasonally in search of water and grazing, often are trapped when drought inhibits rejuvenation of the denuded grasslands, which their overgrazing produces. During such times, a family's emergency food supplies diminish rapidly, and hunger and starvation become commonplace until weather conditions improve and livestock herds are subsequently rejuvenated.

By 1973 the attendant famine had threatened the lives of hundreds of thousands of Ethiopian nomads, who had to leave their home grounds and struggle into Somalia, Djibouti, Kenya, and Sudan, seeking relief from starvation. By the end of 1973, famine had claimed the lives of about 300,000 peasants of Tigray and Welo, and thousands more had sought relief in Ethiopian towns and villages.

By mid-1984 it was evident that another drought and resulting famine of major proportions had begun to affect large parts of northern Ethiopia. Just as evident was the government's inability to provide relief. The almost total failure of crops in the northern part of Ethiopia which is reflected on overall vegetation cover (See Fig 4.22) was compounded by fighting in and around Eritrea, which hindered the passage of relief supplies. Although international relief organizations made a major effort to provide food to the affected areas, the persistence of drought and poor security conditions in the north resulted in continuing need as well as hazards for famine relief workers. In late 1985, another year of drought was forecast, and by early 1986 the famine had spread to parts of the southern highlands, with an estimated 5.8 million people dependent on relief food. Exacerbating the problem in 1986 were locust plagues.

Close to 8 million people became famine victims during the drought of 1984, and over 1 million died. The Ethiopian government's inability or unwillingness to deal with the 1984-85 famine provoked universal condemnation by the international community. Even many supporters of the Ethiopian regime opposed its policy of withholding food shipments to rebel areas. The combined effects of famine and internal war had by then put the nation's economy into a state of collapse.

According to BBC report on March 3 2010 at the time of 1984-85 famine, the Ethiopian government was fighting rebellions in the northern provinces of Eritrea and Tigray. Much of the countryside was outside of government control, so relief agencies brought aid in from neighbouring Sudan. Some was in the form of food, some as cash, to buy grain from Ethiopian farmers in areas that were still in surplus. The CIA, in a 1985 assessment entitled Ethiopia: Political and Security Impact of the Drought, alleged aid money was being misused. Its report concluded: "Some funds that insurgent organisations are raising for relief operations, as a result of increased world publicity, are almost certainly being diverted for military purposes." Many mistakes were made in the 1980s, both by the West and by the Ethiopian Government. The West was criticised for not reacting to the crisis in time; the Ethiopian Government for its spending on civil war.

In 1997 there was occurrence El Niño which brought excusive rainfall and flood in eastern of the horn of Africa. Fig 4.20 depict the vegetation cover was much above average. On the other hand in 2003 most of south eastern Ethiopia, north eastern

Kenya were there was a vegetation cover stress which claimed live of many livestock and the pastoral community depended on it.

In order to associate the vegetation cover trend with the rainfall trends, based on the recent 10 years satellite RFE data the rainfall trend is calculated which helped to forecast the total rainfall amount of the four seasons. By comparing the forecasted rainfall with the current rainfall the changes are calculated. In general there will a decrease in the rainfall amount in most parts of east Africa particularly during winter and spring. For example in more than 90% of the total area of the rainfall amount in spring is expected to decrease by 7 %. On the other hand in southern Sudan Autumn and Spring rainfall amount is in increasing trend so there will increase that reach up to 10% around central part of southern Sudan.

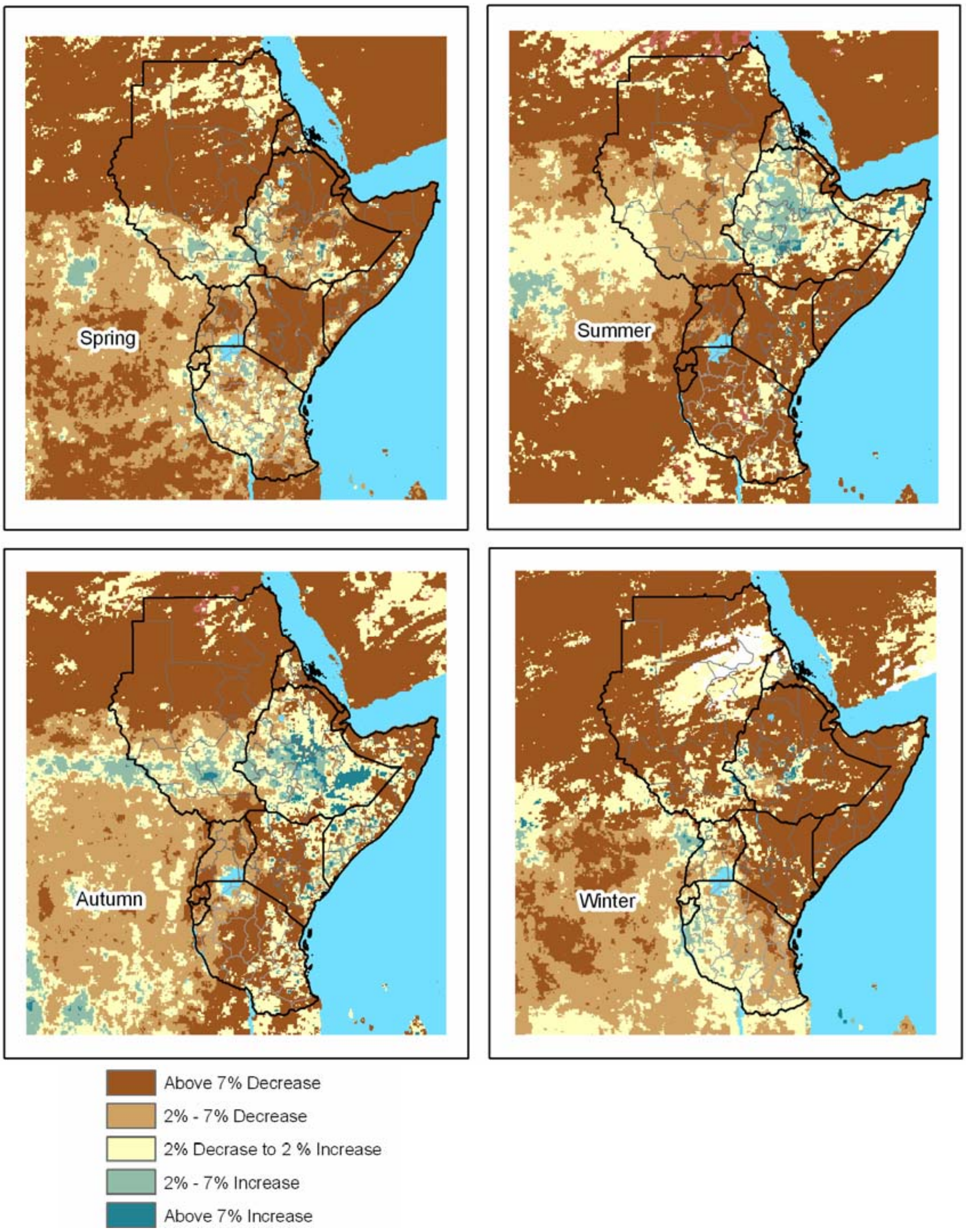


Fig 4.23 Forecast of Rainfall in 10 years compared with the current rainfall (Map by EGB)

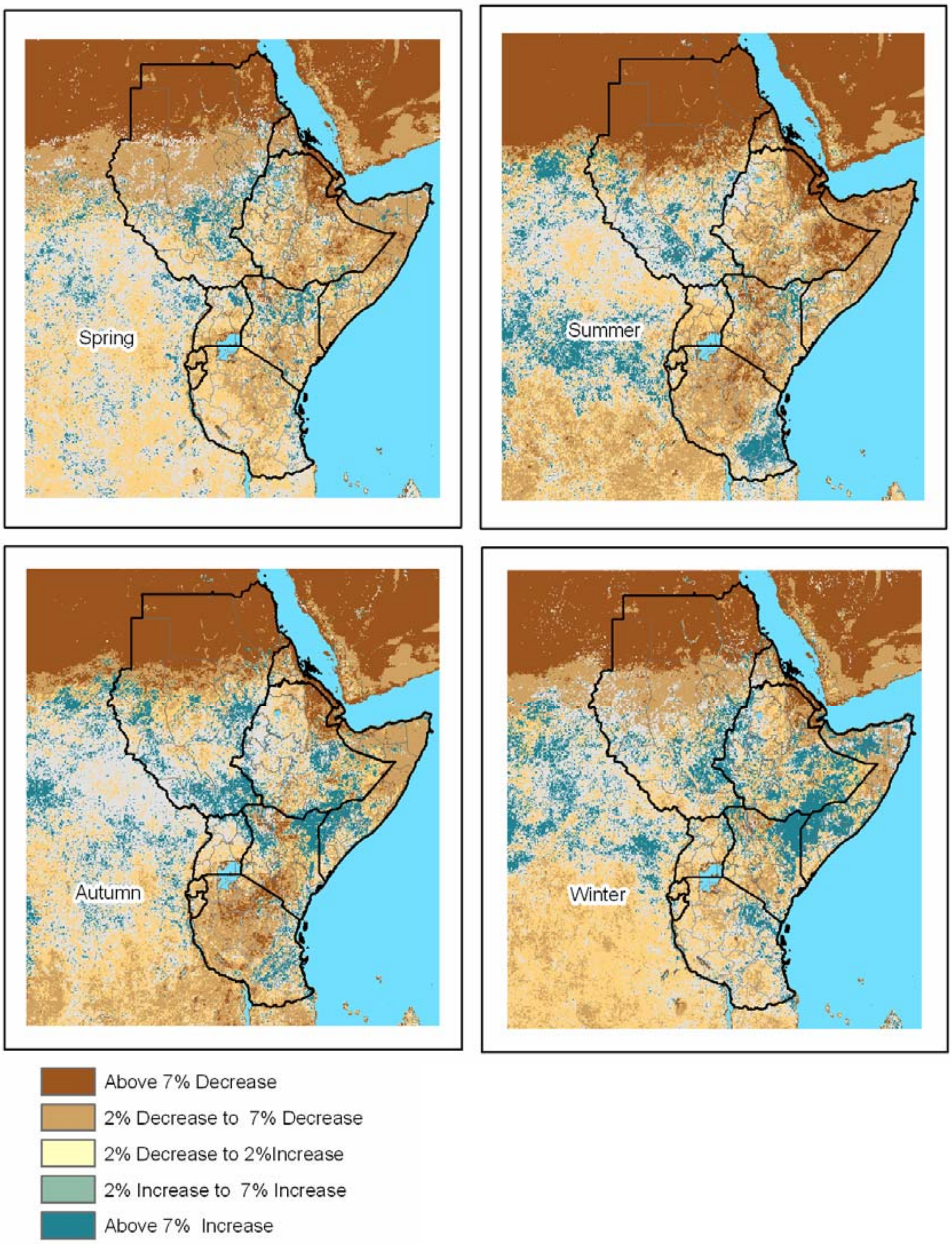


Fig 4.24 Comparison of Forecasted Vegetation cover after 10 years with the current Vegetation Cover (Map by EGB)

The increasing trend of autumn rain is expected to affect positively the vegetation situation of most part of south eastern Ethiopia, southern Somalia and eastern Kenya during autumn and winter seasons. More than 7% increase is forecasted by comparing the vegetation cover with the current average status winter season (See Fig 4.24). However the increase of autumn rains in the highland of Ethiopia will have distractive effect since during this period most of the crops are at the final stage of their growth. Due to the declining trend of spring rainfall there will be vegetation cover decrease south eastern Ethiopia, northern Tanzania and southern Kenya. This will affect the livestock population and people depend on it in pastoral community of south eastern

Ethiopia. The vegetation performance during the forecasted average autumn seasons there will be a decrease above 7% for most parts of southern Kenya and Tanzania which will have impact on pastoral community as well as the wildlife in some national parks.

For most parts Ethiopian highland the spring rainfall expected to decline up to 10% based on the linear trend analyses and rainfall date of the past ten years rainfall (See Fig 2. 23). On the other hand summer rainfall is expected to rise in most part of Ethiopian highlands. However the vegetation cover forecast showed there will be not be better vegetation cover situation (See Fig 2. 24). The deteriorating soil condition, increasing temperature condition and population pressure shape the vegetation condition regardless of the rainfall increase.

5. Summary

The study analysed monthly satellite RFE (rainfall estimates) from NOAA (National Atmospheric and Oceanic Administration) and monthly rainfall records (January 1996–December 2006) collected from selected weather stations in Ethiopia by NMA (National Meteorological Agency of Ethiopia). The study further analysed seasonal trend of vegetation cover in east Africa using the Normalized Difference vegetation Index (NDVI) from Advanced Very High Resolution Radiometer (AVHRR) between January 1982 and December 2008.

The main research questions are: Can the RFE data be used reliably to analyse seasonal rainfall variability? How well are NOAA satellite rainfall estimates (RFE) and NMA rainfall records correlated? How do the seasonal rainfall and vegetation cover trends and variability look like?

Since 1996, RFE are available without for free and limitation on download size from a website implemented through FEWSNET (Famine and Early Warning Network) for users to enrich early warning systems with remotely sensed products for east Africa as well as different parts of the earth. RFE images have a spatial resolution of 8 km and cover the entire country; on the other hand, NMA stations have a lower spatial representation and are concentrated in built-up areas leading to a lack of information within agricultural areas. Moreover, RFE data is very timely compared to stations data.

NMA's rainfall records have a higher temporal coverage than RFE since the meteorology station data has been collected for more than half a century in Ethiopia. The other advantage that we have with station data has, unlike RFE, is that it records the actual rainfall amount on the ground. Out of over 650 weather stations in Ethiopia about 150 stations are provided with better equipment and are surveyed by well trained workers. These are referred to as synoptic and principal weather stations. Data from these stations were considered for the analysis of this research. The gauge data has undergone routine quality checks by the NMA.

After doing spatio-temporal analysis of the satellite RFE and monthly weather stations rainfall records, it is found that the two datasets are well correlated during the important rainy seasons, summer and spring. RFE data and weather stations' rainfall data register significantly similar values during summer seasons. In most parts of the highlands where agriculture is important for livelihood, summer rains followed by spring rains are the main source of water for agriculture. The correlation values are higher for the months with higher rainfall and lower during the period of little rain. It is possible to associate better estimations with higher rainfall and vice versa. However an in-depth study on the algorithm of RFE is required in order to establish exactly why it shows such kind of seasonal variation of correlation values.

The analysis showed that there is higher correlation (r) during summer and spring seasons and weak correlation during winter. The summer average value of ‘r’ for RFE 1.0 is 0.75 and the max and min values are 0.87 and 0.64 respectively, while the winter value is 0.38 on average with a minimum of -0.19. For RFE 2.0 images, the summer average ‘r’ value, max and min of summer are 0.75, 0.86 and 0.60 respectively. The datasets also showed satisfactory correlation in autumn which is around 0.57 for RFE 1.0 and 0.64 for RFE 2.0 images.

Rainfall amount is better estimated on RFE 1.0 images. It is found that RFE 1.0 images recorded the rainfall amount 7% lower than NMA records of summer rains in average. However, RFE 2.0 images estimate 36% lower rainfall than NMA’s records in average.

In order to see how the vegetation cover responded during the months that showed significant differences in the rainfall, the research compared NDVI values with long term monthly NDVI averages. This helped to determine the rainfall during that time was above or below normal condition. The result showed that NMA records were closer to the actual data.

In order to analyse the spatial correlation, pairs of values were acquired from RFE and Stations’ data of the entire period were calculated for each station individually. After calculating correlation for all stations, it was found that the Synoptic weather station located at Addis Ababa showed the highest correlation with a value of 0.9. The correlation value of Mekele, Dire Dawa, Nekemte and Moyale are 0.71, 0.65, 0.48, and 0.71 respectively.

The overall analysis showed that RFE are reliable enough to be used for timely spatio-temporal analysis of disasters in times characterized by late inception, dry spells and early cessation of rainfall. The analysis of RFE images is a key tool for an advanced early warning system in the country. The RFE images are very useful to show rainfall disruption timely. This is very useful particularly in the lowlands where there are few meteorological stations. Despite the different methods used to create RFE1.0 and 2.0 and the fact that RFE 2.0 images underestimate the rainfall amount the results of correlation are very similar. Therefore, the RFE can be used reliably for early warning systems in the country and to empower decision makers on the consequences caused by the changes in the magnitude, timing, duration, and frequency of rainfall deficits on different spatial and temporal scales.

As it is the case of other countries characterised by seasonal rains, Ethiopia is also severely affected by late-onset of the major and minor rain seasons. In addition to this, the occurrence of dry spells in the middle rain season is also widespread. The other characteristic of seasonal rains is early cessation or termination of the rain before the normal time. These important characteristics affect negatively crop production or pasture land development significantly. These characteristics vary significantly from one place to the other. Therefore, it is important to map out these occurrences and establish the pattern carefully.

To study the vegetation cover trend the study period that rages from 1982 to 2010 was categorised in two parts in order to compare past and recent trends. The first part is between 1982 and 1995 and the 2nd part which is from 1995 to 2008. During the first half, the overall vegetation cover was in constant decline in most parts of east Africa with the exception of Sudan where relative stability was observed. During the second half, the overall vegetation trend was better than the first half. Though relatively stable, there are areas with fast decline particularly in western escarpment of the Ethiopian rift valley, southern Kenya and western Uganda. The trend also shows higher decline during summer and spring seasons.

The trend showed higher decline during summer and spring seasons. There is an increasing deterioration of vegetation cover near and around Victoria region, most part of central and northern Tanzania, significant portion of southern Ethiopia and northern part of the rift-valley escarpment. The changes in the current rainfall with a rainfall amount forecasted using trend analyses were compared and it showed a decrease in the rainfall amount in most parts of east Africa particularly during winter and spring. This was reflected in the poor relative poor performance of summer vegetation. For example, in more than 90% of the total area of Kenya, the rainfall amount in spring after 10 years of time is expected to decrease by 7 % or more. On the other hand, in southern Sudan autumn and spring rainfall amount shows an increasing trend that will increase its reach by up to 10% particularly around the central part of southern Sudan.

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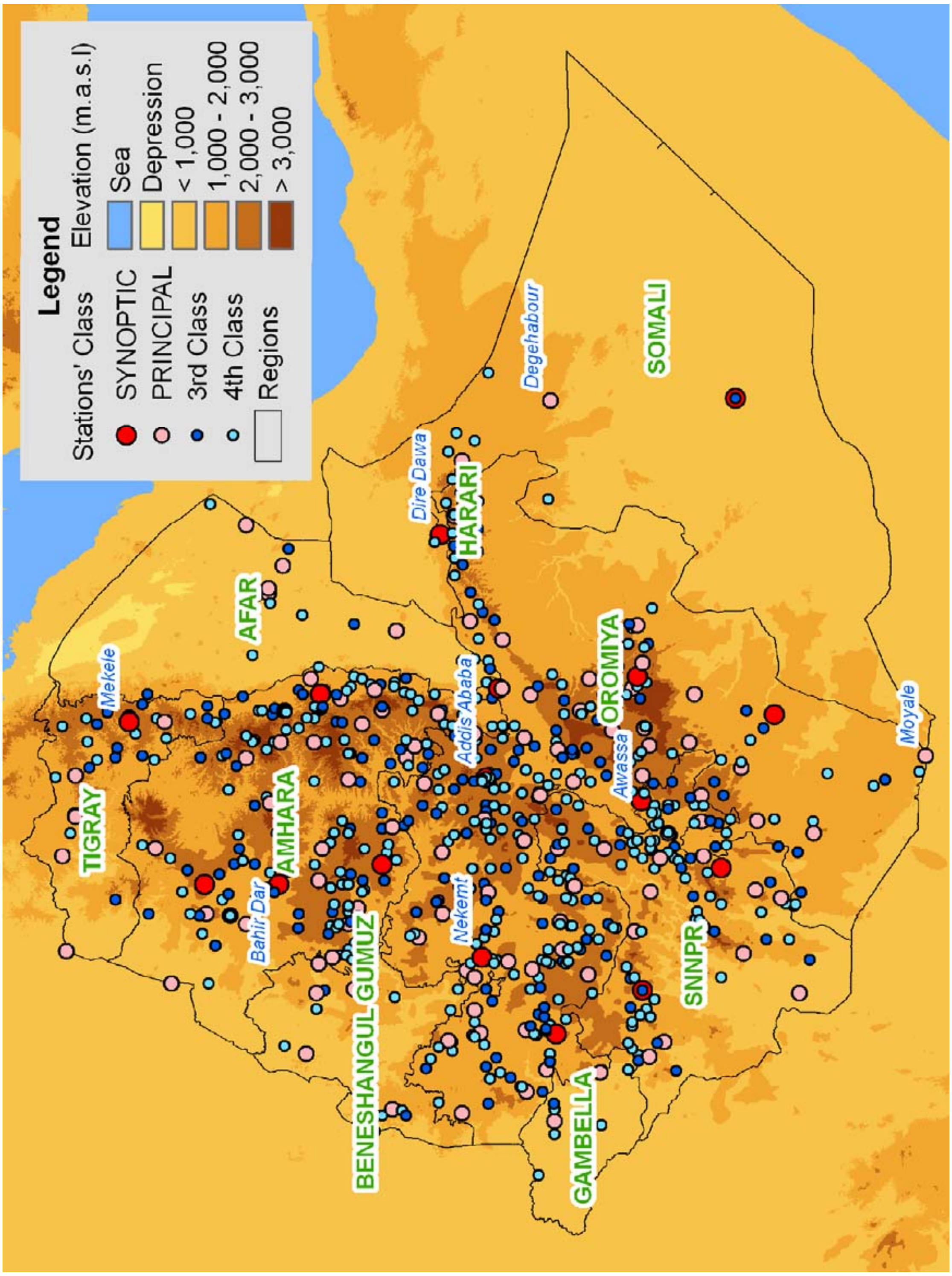
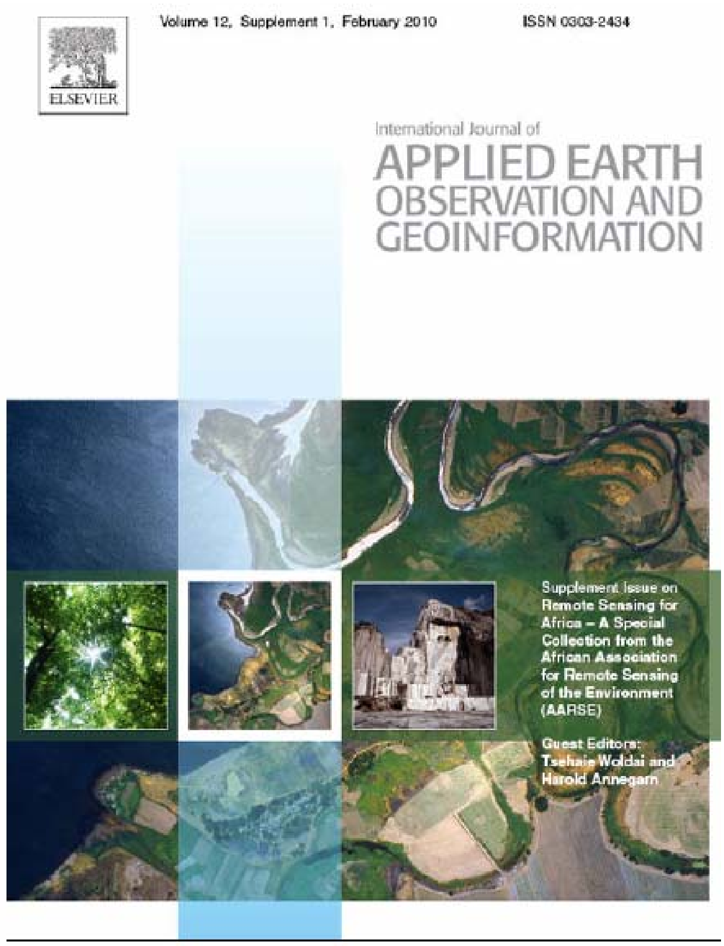
Annex 1

Distribution of Meteorological stations in Ethiopia. *(Map by EGB)*



Annex 2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Spatio-temporal analyses of correlation between NOAA satellite RFE and weather stations' rainfall record in Ethiopia

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The study analysed monthly satellite RFE (rainfall estimates) from NOAA (National Atmospheric and Oceanic Administration) and monthly rainfall records (January 1996–December 2006) collected from weather stations by NMA (National Meteorological Agency of Ethiopia). Can the RFE data be used reliably to analyse seasonal rainfall variability? After doing spatio-temporal analyses of the two datasets, a significant correlation during the important rainy seasons, summer and spring and a low correlation during winter was shown. In conclusion the RFE images can be used reliably for early warning systems in the country and to empower decision makers on the consequences caused by the changes in the magnitude, timing, duration, and frequency of rainfall deficits on different spatial and temporal scales.

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Acronyms

AVHRR – Advanced Very High Resolution Radiometer

BBC – British Broadcasting Service

CIA – Central Intelligence Agency

CSA – Central Statistics Office

CV – Coefficient of variation

DPPA – Disaster Prevention and Preparedness Agency

DPPC – Disaster Prevention and Preparedness Commission

EMA – Ethiopian Mapping Agency

EGB – Ephrem Gebremariam Beyene, Maps prepared by

FAO – Food and Agriculture Organisation

FEWS-NET – Famine and Early Warning System Network

GDP – Gross Domestic Product

GTS – Global Telecommunication Satellite

IFPRI – International Food Policy Research Institute

IOZM – Indian Ocean dipole or zonal mode

ITCZ – Inter Tropical Convergence Zone

LEAP – Livelihood, Ethiopia, Assessment, and Protection

LEWS – Livestock Early Warning System

MEDaC – Ministry of economic Development and Cooperation

MOA – Ministry of Agriculture

MoARD – Ministry of Agriculture and Rural Development

MoFED – Ministry of Finance and Economic Development

MOH – Ministry of Health

MWR – Ministry Water Resources

NASA – National Atmospheric and Space Administration

NDVI – Normalised Difference Vegetation Index

NGOs – Non Governmental Organisation

NMA – National Meteorological Agency

NMSA – National Meteorological Services Agency

NOAA – National Oceanic and Atmospheric Agency

RFE – Rainfall Estimates

RFR – Rainfall Records

SC-UK – Save the Children United Kingdom

SC-US – Save the Children United States

SD – Standard Deviation

SNNP – Southern Nations and Nationality People Regional State

SST – Sea Surface Temperature

UNEP – United Nations Environmental Program

UNICEF – United Nations Children Fund

UNPD – United Nations Population Division

USGS – United Stated Geological Survey

WFP – World Food Program

WFP/VAM – Vulnerability Assessment and Mapping