East Africa

1.1 Introduction

Climate change is real and happening now. The average global surface temperature has warmed 0.8°C in the past century and 0.6°C in the past three decades (Hansen *et al*., 2006), in large part because of human activities (IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC) has projected that if greenhouse gas emissions, the leading cause of climate change, continue to rise, the mean global temperatures will increase 1.4 – 5.8°C by the end of the 21st century (IPCC, 2007).

Climate change impacts have the potential to undermine and even, undo progress made in improving the socio-economic well-being of many of the African countries. The negative impacts associated with climate change are also compounded by many factors, including widespread poverty, human diseases, and high population density, which is estimated to double the demand for food, water, and livestock forage within the next 30 years.

The countries of Eastern Africa are prone to extreme climatic events such as droughts and floods. In the past, these events have had severe negative impacts on key socioeconomic sectors of the economies of most countries in the sub region. In the late seventies and eighties, droughts caused widespread famine and economic hardships in many countries of the sub region. There is evidence that future climate change may lead to a change in the frequency or severity of such extreme weather events, potentially worsening these impacts. In addition, future climate change will lead to increases in average mean temperature and sea level rise, and changes in annual and seasonal rainfall. These will have potentially important effects across all economic and social sectors in the region, possibly affecting agricultural production, health status, water availability, energy use, biodiversity and ecosystem services (including tourism). Any resulting impacts are likely to have a strong distributional pattern and amplify inequities in health status and access to resources, as vulnerability is exacerbated by existing developmental challenges, and because many groups (e.g. rural livelihoods) will have low adaptive capacity.

East Africa is characterised by widely diverse climates ranging from desert to forest over relatively small areas. Rainfall seasonality is complex, changing within tens of kilometres. Altitude is also an important contributing factor. The annual cycle of East African rainfall is bimodal, with wet seasons from March to May and October to December. The Long Rains (March to May) contribute more than 70% to the annual rainfall and the Short Rains less than 20%. Much of the interannual variability comes from Short Rains (coefficient of variability = 74% compared with 35% for the Long Rains) (WWF, 2006).

1.2 Regional historic climate trends

Results from recent work from stations in Kenya and Tanzania, indicate that since 1905, and even recently, the trend of daily maximum temperature is not significantly different from zero. However, daily minimum temperature results suggest an accelerating temperature rise (Christy *et al*., 2009).

A further study looking at day and night temperatures concluded that the northern part of East Africa region generally indicated nighttime warming and daytime cooling in recent years. The trend patterns were, however, reversed at coastal and lake areas. There were thus large geographical and temporal variations in the observed trends, with some neighbouring locations at times indicating opposite trends. A significant feature in the temperature variability patterns was the recurrence of extreme values. Such recurrences were significantly correlated with the patterns of convective activities, especially El Niño-Southern Oscillation (ENSO), cloudiness, and above/below normal rainfall.

During recent decades, eastern Africa has been experiencing an intensifying dipole rainfall pattern on the decadal time-scale. The dipole is characterised by increasing rainfall over the northern sector and declining amounts over the southern sector (Schreck and Semazzi, 2004).

East Africa has suffered both excessive and deficient rainfall in recent years (Webster et al., 1999, Hastenrath et al., 2007). In particular, the frequency of anomalously strong rainfall causing floods has increased. Shongwe, van Oldenborgh and Aalst (2009) report that their analysis of data from the International Disaster Database (EM-DAT) shows that there has been an increase in the number of reported hydrometeorological disasters in the region, from an average of less than 3 events per year in the 1980s to over 7 events per year in the 1990s and 10 events per year from 2000 to 2006, with a particular increase in floods. In the period 2000-2006 these disasters affected on average almost two million people per year.

Historic context of climate extremes in East Africa:

- Large variability in rainfall with occurrence of extreme events in terms of droughts and floods.
- Droughts in the last 20 years -1983/84, 1991/92, 1995/96, 1999/2001, 2004/2005 (led to famine).
- El-Niño related floods of 1997/98 – very severe event enhanced by unusual pattern of SST in the Indian Ocean (IPCC, 2007).
- The La Niña related drought of 1999/2001.

The most recent El Niño (1997/98) and La Niña (1999/2000) were the most severe in 50 years.

1.3 Regional climate variability

Recent research suggests that warming sea surface temperatures, especially in the southwest Indian Ocean, in addition to inter-annual climate variability (i.e., El Niño/Southern Oscillation (ENSO)) may play a key role in East African rainfall and may be linked to the change in rainfall across some parts of equatorial-subtropical East Africa (Cane *et al*., 1986; Plisnier *et al*., 2000; Rowe, 2001). Warm sea surface temperatures are thought to be responsible for the recent droughts in equatorial and subtropical Eastern Africa during the 1980s to the 2000s (Funk *et al*., 2005). According to the

U.N. Food and Agriculture Organization (FAO, 2004), the number of African food crises per year has tripled from the 1980s to 2000s. Drought diminished water supplies reduce crop productivity and have resulted in widespread famine in East Africa.

El Niño is the most important factor in interannual variability of precipitation in East Africa. The Indian and Atlantic Oceans also play a role. Local geographic factors may complicate the impact of large-scale factors. There have been relatively few recent studies of rainfall variability in East Africa, compared with areas such as the Sahel. Even fewer studies exist of Indian Ocean variability and its impact on the climate.

Interannual variability of rainfall is remarkably coherent within a region. The Short Rains, in particular, are characterised by greater spatial coherence and are linked more to large scale than regional factors. The Long Rains (March to May) contribute more than 70% to the annual rainfall and the Short Rains less than 20%. Much of the interannual variability comes from Short Rains (coefficient of variability = 74% compared with 35% for the Long Rains). As a result, the Short Rains are more predictable at seasonal time scales than the Long Rains.

Work on East African climate is focused on rainfall variability but is thinly spread amongst mechanisms of mean climate control, circulation relationships to rainfall variability, the role of ocean patterns (including ENSO and Indian Ocean Dipole (IOD)) in rainfall variability, and the representation of rainfall in regional and global models and the predictability of rainfall. There has also been research on East African lake variability; for example the 1961-1962 rains caused rapid rises in the levels of east African lakes. Lake Victoria rose 2 m in little more than a year (Flohn and Nicholson, 1980). This was not an ENSO year, but exceedingly high sea-surface temperatures (SSTs) occurred in the nearby Indian Ocean as well as the Atlantic.

ENSO comprises two opposite extremes, El Niño and La Niña. El Niño is associated with anomalously wet conditions during the Short Rains and some El Niño events, such as 1997, with extreme flooding. The IOD is regarded as a separate pattern of ocean-based variability although IOD events have occurred together with ENSO leading to extreme conditions over East Africa (e.g. 1982, 1997, 1994, see Figure 2). La Niña conditions are associated with unusually dry conditions over East Africa (Figure 3) during the Short Rains, although the relationship is less reliable than that for El Niño (taken from Downing et al., Final Report – Appendices, Kenya: Climate Screening and Information Exchange. AEA Technology plc. UK).

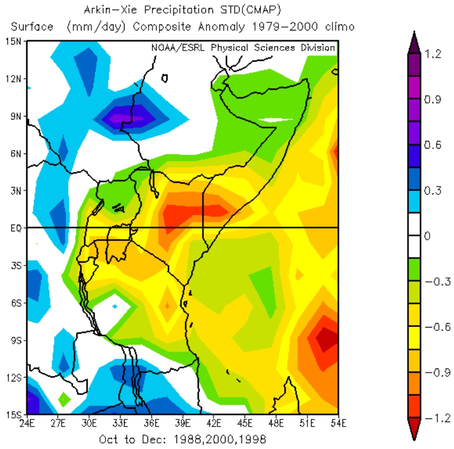

Figure 1 Satellite derived Short rain anomalies in mm/day (i.e. differences from the long term mean) for October-December 1982, 1994, 1997 (La Niña) (taken from Downing et al., Final Report – Appendices, Kenya: Climate Screening and Information Exchange. AEA Technology plc. UK)..

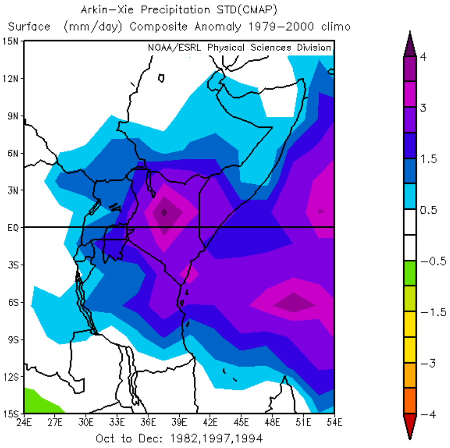

Figure 2 Satellite derived Short rain anomalies in mm/day (i.e. differences from the long term mean) for October-December 1988, 1998, 2000 (El Nino) (taken from Downing et al., Final Report – Appendices, Kenya: Climate Screening and Information Exchange. AEA Technology plc. UK)..

1.4 Regional scenario projections

Although there have been studies of Global Climate Models (GCM)-simulated climate change for several regions in Africa, the downscaling of GCM outputs to finer spatial and temporal scales has received relatively little attention in Africa. The result of on attempt at the use of a regional model for East Africa is present below following the results of the AR4 climate change scenarios. This work was done as part of the DFID funded work on Climate Screening for Kenya (Downing et al., 2007).

For the application of the Special Report on Emissions Scenarios (SRES) scenarios using the AR4 GCMs there are limitations which apply more to uncertainties in rainfall than temperature projections. The models have not been closely evaluated over the Kenya region, so each of the 8 GCMs used is given equal weight. Model resolution is coarse (c.200km) and the data cannot be applied to the sub-regional scale (e.g. Mount Kenya). It is best to applied over broad regions.

1.4.1 Results from AR4 climate change scenarios

Regardless of the SRES scenario, decade, season or model, all the data points to a warmer future. No simulation shows temperatures cooler than present. The A2 scenario produces warming of around 4 degrees by the end of the century in both seasons. Warming of one degree or less is more typical by 2020.

Almost all the simulations show wetter conditions in October to December, even by 2020. Wetter conditions in Kenya, especially in the Short Rains and especially in northern Kenya (where rainfall increases by 40% by the end of the century) are likely. Analysis of the northern Kenya region show that the increase in seasonal total rainfall in the Short Rains occurs by means of a trend of increasing rainfall extremes which, in models like MPI, are evident from the outset of the 21st Century. At the same time the droughts remain as extreme as present, even increasing in intensity through the 21st Century.

There is little change in the timing of the seasonal variations for either rainfall or temperature over future decades.

In brief, climate model experiments using AR4 climate scenarios (IPCC, 2007) based on the gridded model data show that:

- East African climate is likely to become wetter, particularly in the Short Rains (October to December) and particularly in northern Kenya, in the forthcoming decades.
- East Africa will almost certainly become warmer than present in all seasons in the forthcoming decades.
- Changes in rainfall seasonality over forthcoming decades are unlikely.
- A trend towards more extremely wet seasons is likely for the Short Rains, particularly in northern Kenya, in the forthcoming decades.
- Droughts are likely to continue (notwithstanding the generally wetter conditions), particularly in northern Kenya, in the forthcoming decades. In many model simulations, the drought events every 7 years or so become more extreme than present.
- The wetting component evident in observed Kenyan rainfall may well be a forerunner of the longer term climate change.

1.4.2 Regional climate change modelling (RegCM3)

Regional climate simulation for the East Africa region has so far been confined to one model and one emission scenario (A2) so the results are very uncertain (Downing et al., 2006). To improve the certainty it would need multiple regional models and emission scenarios - a modelling effort which amounts to years more work. Ideally, future regional downscaling of the global climate projections for Kenya should be extended to other IPCC GCMs, to gain a better sense of the uncertainty associated with the regional climate model projections.

The regional climate projections indicate that the role of sharp mountain range slopes, such as the Great Rift Valley in Kenya, can greatly affect local climate. The IPCC GCMs are based on a large grid resolution (200 x 200km ^{2}) and do not include modifications for altitude. GCM projections are valuable for projections on the large scale, as long as they are interpreted with caution, particularly when large contrasts in altitude exist over short distances like in Kenya.

Results from the North Carolina State University enhanced version of the RegCM3 regional model (Anyah et al, 2006) which were run for both a control and one climate change (A2 scenario) simulation, have been analysed for Kenya. A domain resolution of 20 km forms the basis of these experiments. These class of models offer much higher resolution than the GCMs and, as a result, are of relevance to complex terrain which characterizes Kenya. The regional model was forced by global fields from the FvGCM model.

- Climate analysis using the Regional GCM model indicates that Kenya is likely to experience the following climate changes between the late 2020s and 2100:
- Average annual temperature will rise by between 1°C and 5°C, typically 1°C by 2020s and 4°C by 2100.
- Climate is likely to become wetter in both rainy seasons, but particularly in the Short Rains (October to December). Global Climate Models predict increases in northern Kenya (rainfall increases by 40% by the end of the century), whilst a regional model suggests that there may be greater rainfall in the West.
- The rainfall seasonality i.e. Short and Long Rains are likely to remain the same.
- Rainfall events during the wet seasons will become more extreme by 2100. Consequently flood events are likely to increase in frequency and severity.
- Droughts are likely to occur with similar frequency as at present, but to increase in severity.
- This is linked to the increase in temperature.
- The Intergovernmental Panel on Climate Change (IPCC) predict an 18 to 59 cm rise in sea-level globally by 2100. One study suggests that 17% of Mombasa's area could be submerged by a sea-level rise of 30 cm (Orindi and Adwera, 2008).

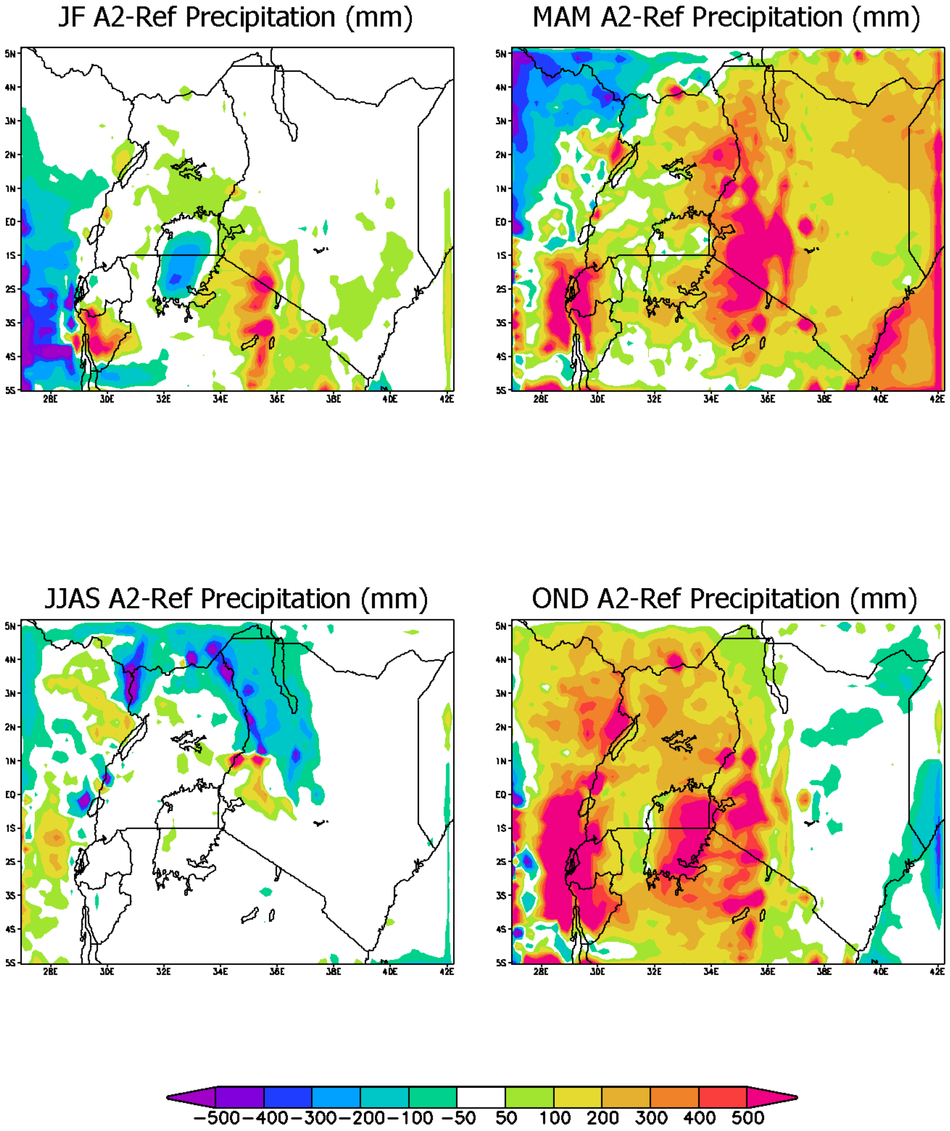

Figure 3 REGCM3 projection results for 2071 – 2100 (A2 RF, 20km resolution) for four seasons - rainfall

1.4.3 Extreme events projections

The IPCC 4th Assessment reports that GCMs project that increasing atmospheric concentrations of greenhouse gases will result in changes in daily, seasonal, inter-annual, and decadal variability. There is projected to be a decrease in diurnal temperature range in many areas, with nighttime lows increasing more than daytime highs. Current projections show little change or a small increase in amplitude for El Niño events over the next 100 years. Many models show a more El Niño-like mean response in the tropical Pacific, with the central and eastern equatorial Pacific sea surface temperatures projected to warm more than the western equatorial Pacific and with a corresponding mean eastward shift of precipitation. Even with little or no change in El Niño strength, global warming is likely to lead to greater extremes of drying and heavy rainfall and increase the risk of droughts and floods that occur with El Niño events in many different regions. There is no clear agreement between models concerning the changes in frequency or structure of other naturally occurring atmosphere-ocean circulation pattern such as the North Atlantic Oscillation (NAO). Philip and van Oldenborgh (2006) have used climate model simulations from the fourth IPCC Assessment Report (4AR) to investigate changes in ENSO events. The models that simulate El Niño most realistically on average do not show changes in the mean state that resemble the ENSO pattern. The projected changes in amplitude are similar to the observed variability over the last 150 years.

Kenya

Kenya lies between latitudes 5° North and 5° South and between longitudes 34° and 42° East on the eastern side of the African continent. Rain-fed agriculture is one of the main sectors of the economy. Additionally, livestock production is central to livelihoods and food security in the arid and semi-arid lands (ASALs). Weather-related hazards therefore present a serious threat to the socio-economic development of the country.

Kenya has a dipole rainy season in which the long rains are generally from March to May as the ITCZ moves northwards, and the short rains are typically from October to December as the ITCZ retreats southwards. There is significant inter-annual and spatial variation in the strength and timing of these rains. Rainfall varies from over 2000mm/year in some areas to less than 300mm/year in the arid northern areas. Drought and floods are the major climatic hazards in Kenya, with an estimated 23 million people affected by widespread drought in 1999. El Niño also has a large effect on climate in Kenya, intensifying rainfall and causing flooding.

Traditionally, the ASALS have been more prone to drought. These have been exacerbated by refugees resulting from armed conflicts in neighbouring countries, and localized conflicts over limited resources by communities living in these areas. Increased population, sedentary lifestyles and introduction of some rain dependent crop farming have sometimes restricted the migration of the pastoralists making the society more vulnerable to climate variability and change.

In recent years some droughts have persisted for long periods, as can be seen in Figure 1. Some of the long droughts have been followed or preceded by floods, especially those associated with El Niño / La Niña (Ogallo, 1988, 1989, 1993). It has been noted that, when weighted by GDP impact, droughts pose a substantially higher risk than floods throughout the country.

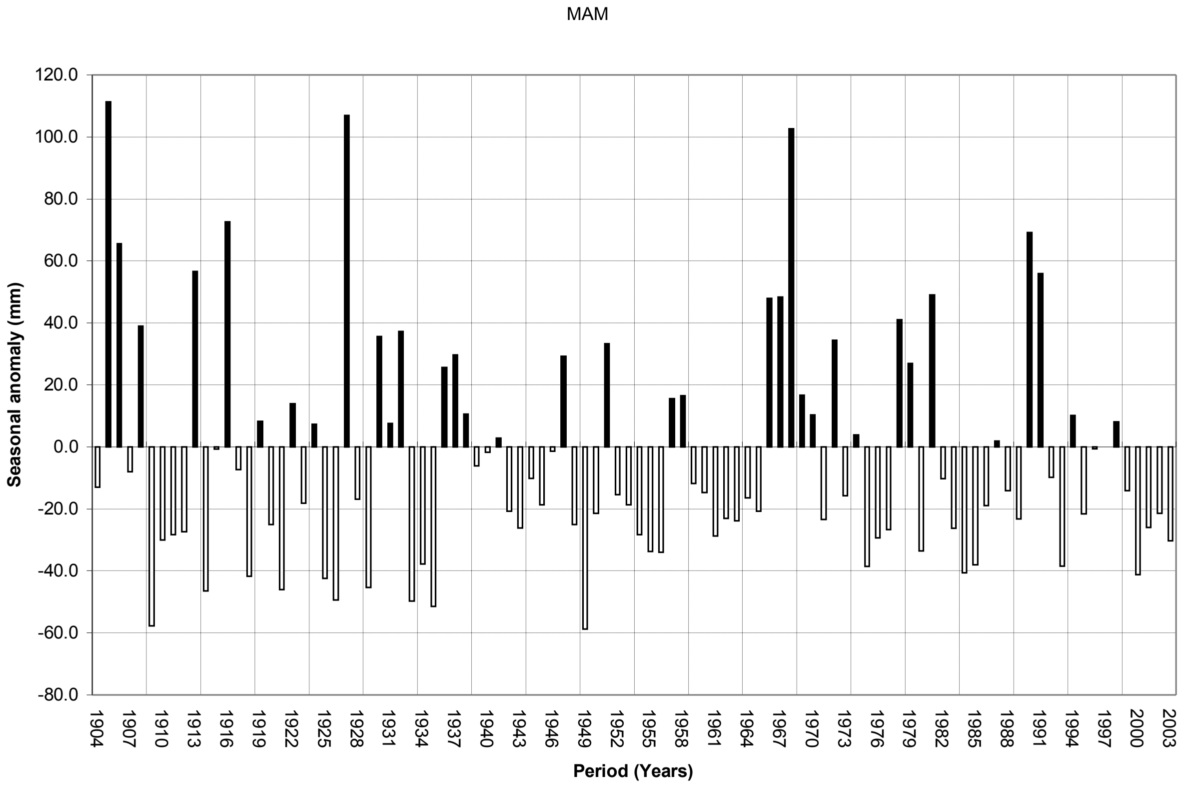

Figure 4 Temporal variations of the March-May rainfall season in Voi (S.E Kenya)

Over two-thirds of Kenya receives less than 500 mm of rainfall per year and 79% has less than 700 mm per year (Figure 5a). The degree of variability is highest in the Arid and semi arid areas (Figure 5b). Most of the country experiences a bimodal rainfall seasonal pattern, with two rainy periods, namely the short rainfall season concentrated within October to December and long rainfall season in March to May. The hot dry season is concentrated within mid-December to mid-March; while June to August is generally a cool and dry season with parts of western Kenya having a third rainfall season during this period. Substantial rainfall is received near some large water bodies, especially Lake Victoria, throughout the year.

Both instrumental and proxy records have shown significant variations in the space-time patterns of climate in Kenya. Such records include indices derived from temperature (Figure 5c) and rainfall (Figure 5d). Details of these can be obtained from Birkett et al., (1999) and Ogallo (2002). Increase in extreme rainfall events in the recent years is evident in Figure 5d.

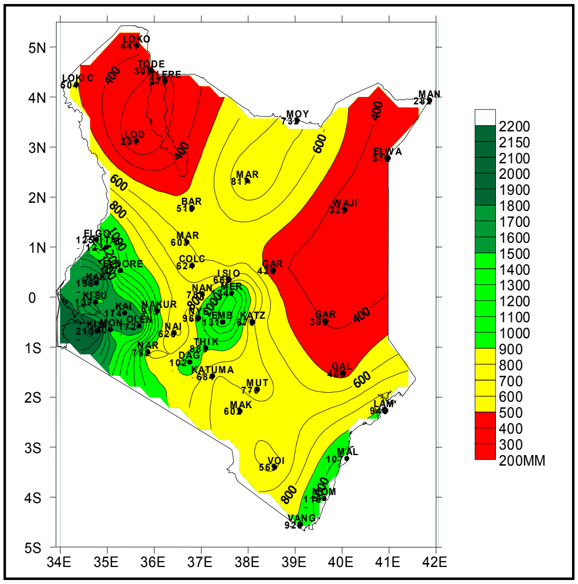

Figure 5a: Distribution of mean annual rainfall (showing wetter areas bordering Lake Victoria and central highlands of the Rift Valley)

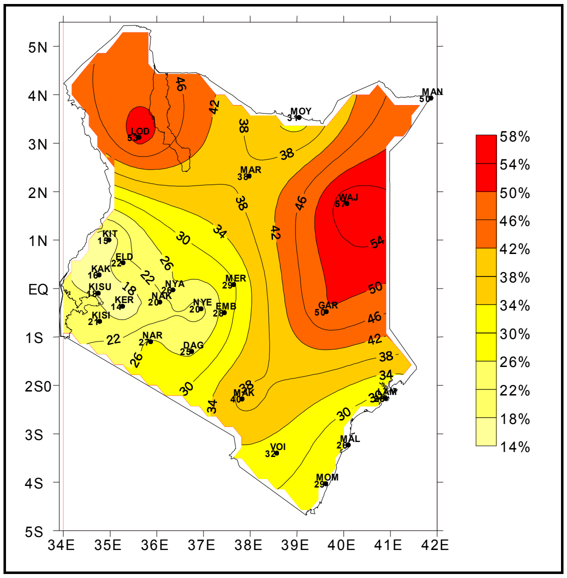

Figure 5b: The coefficient of variation of annual rainfall in Kenya (higher values in areas with large intra-annual variability)

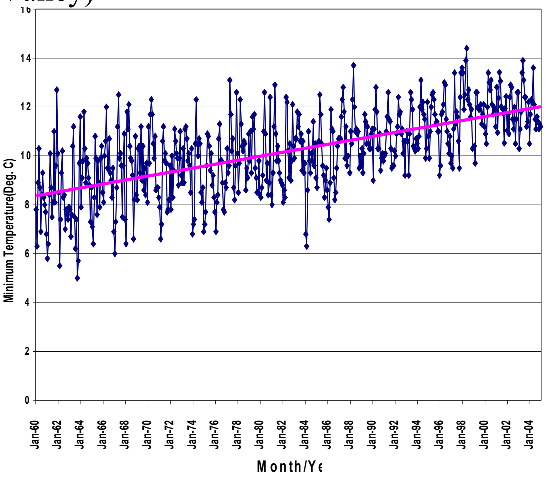

Figure 5c: Minimum temperature for Kericho

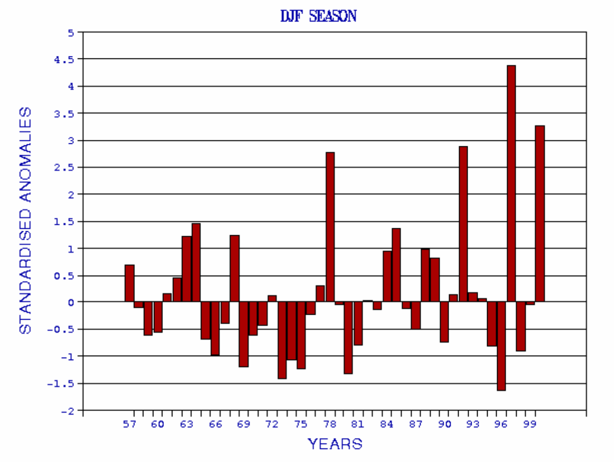

Figure 5d Seasonal rainfall trends in Kenya

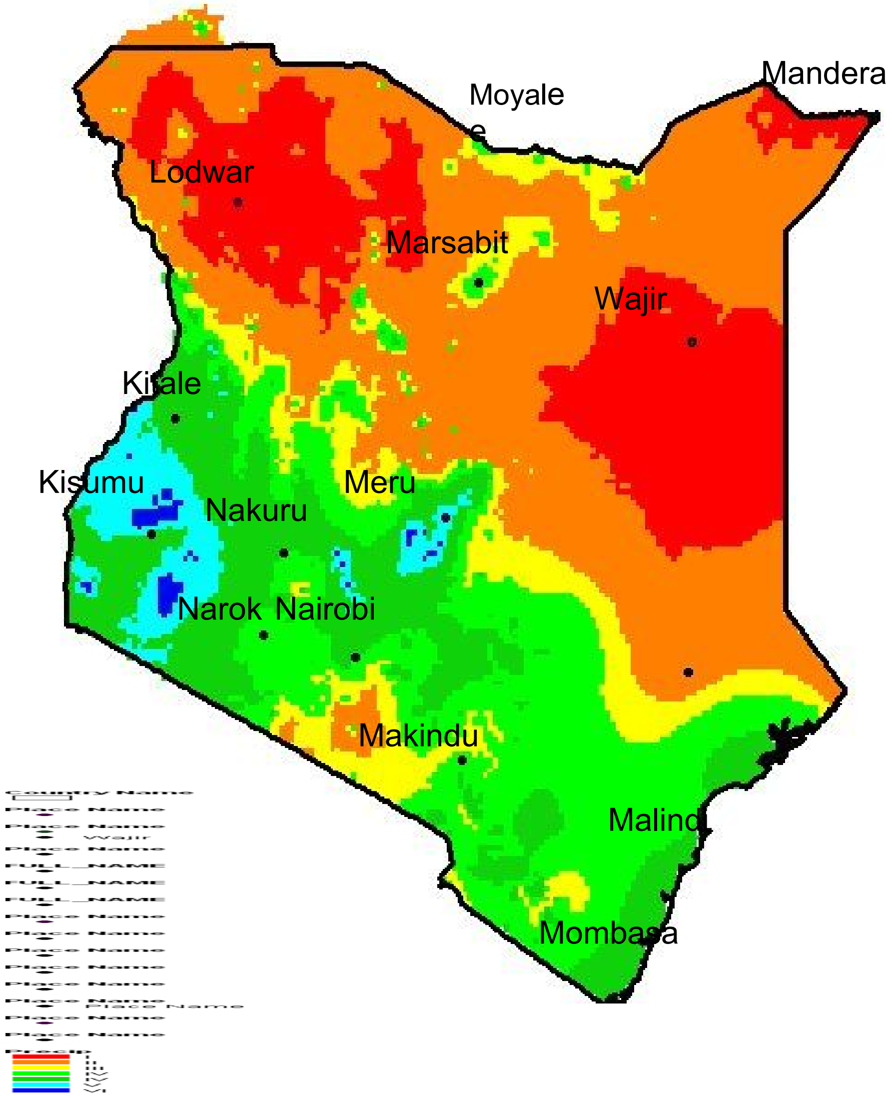

Figure 6 Major agroclimatic zones based on annual precipitation I Very arid, II Arid, III Semi-arid, IV Semi-arid to Semi-humid, V Humid, VI Sub-humid, VII Semi-humid. Based on Sombroek *et al.* (1982)

1.5 Observed Rainfall Variability and Trends in Kenya

Figure 6 shows the spatial distribution of annual precipitation for Kenya distinguishing some of the climatic zones. Figure 7a to 7s gives the trends as well as the seasonal variations of the rainfall over some selected stations in Kenya. It can be seen that most stations depict decreasing trends in rainfall both for annual and seasonal totals (particularly Long season) except for the coastal stations in Kenya - Mombasa, Mtwata and also Mandera. However further analysis could indicate drying earlier in the time period which is thought to have started in the early 1970s (Conway *et al*., 2008) followed by recovery in later decades at some sites which is more in agreement with regional studies of rainfall changes (see Figure 5b).

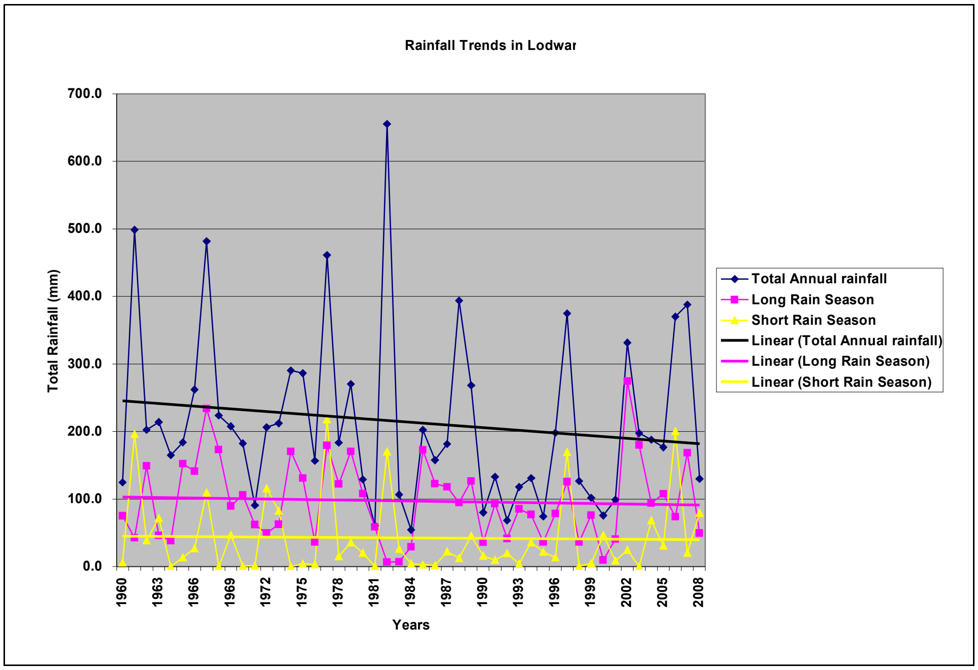

Figure 7a: Trends of the Total Seasonal and Annual variation rainfall over Lodwar (NW Kenya)

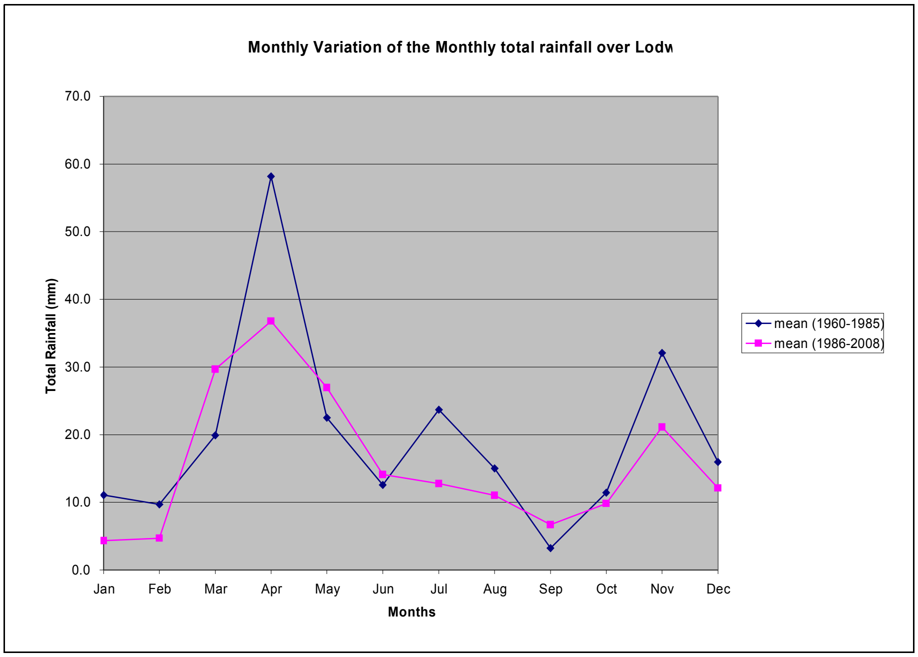

Figure 7b: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Lodwar (NW Kenya)

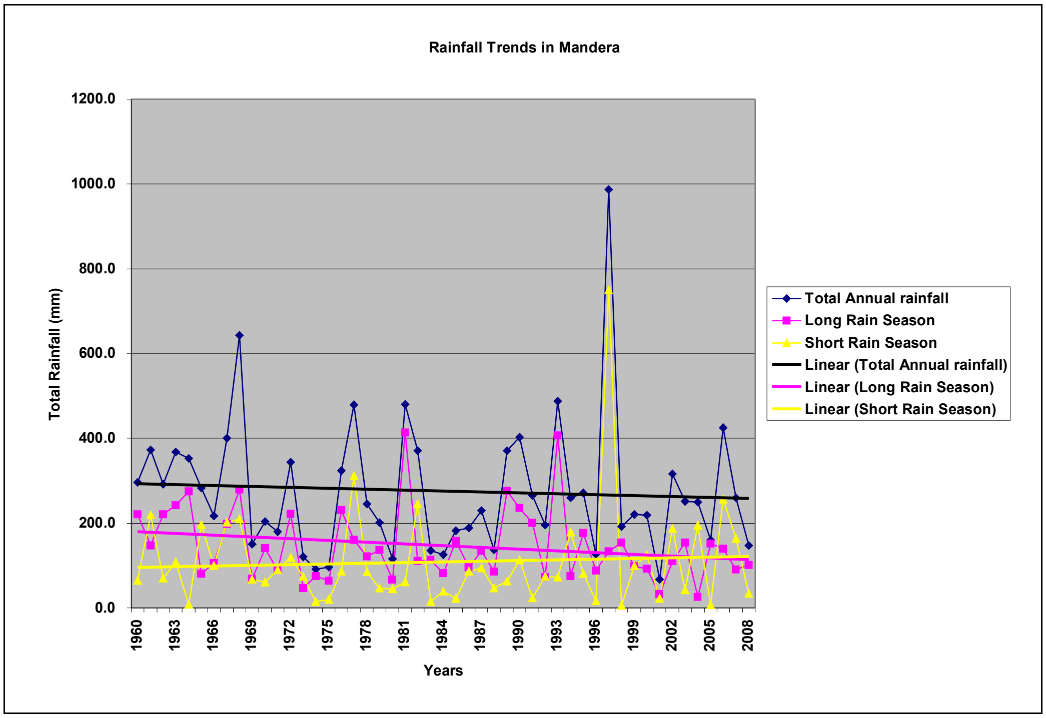

Figure 7c: Trends of the Total Seasonal and Annual variation rainfall over Mandera (NE Kenya)

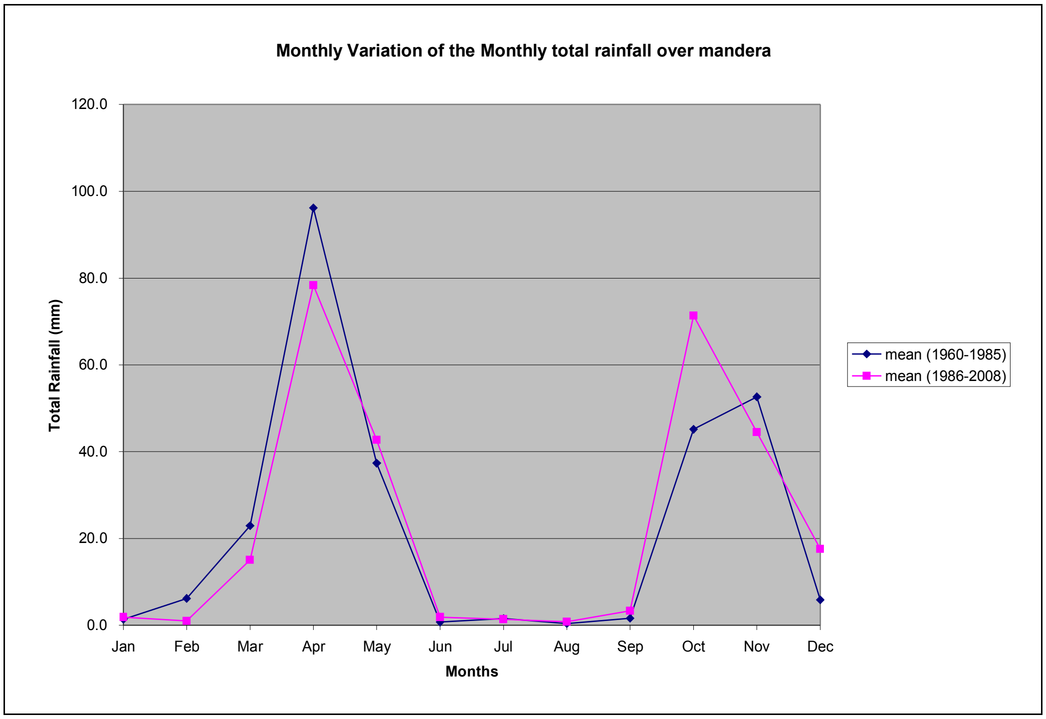

Figure 7d: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Mandera (NE Kenya)

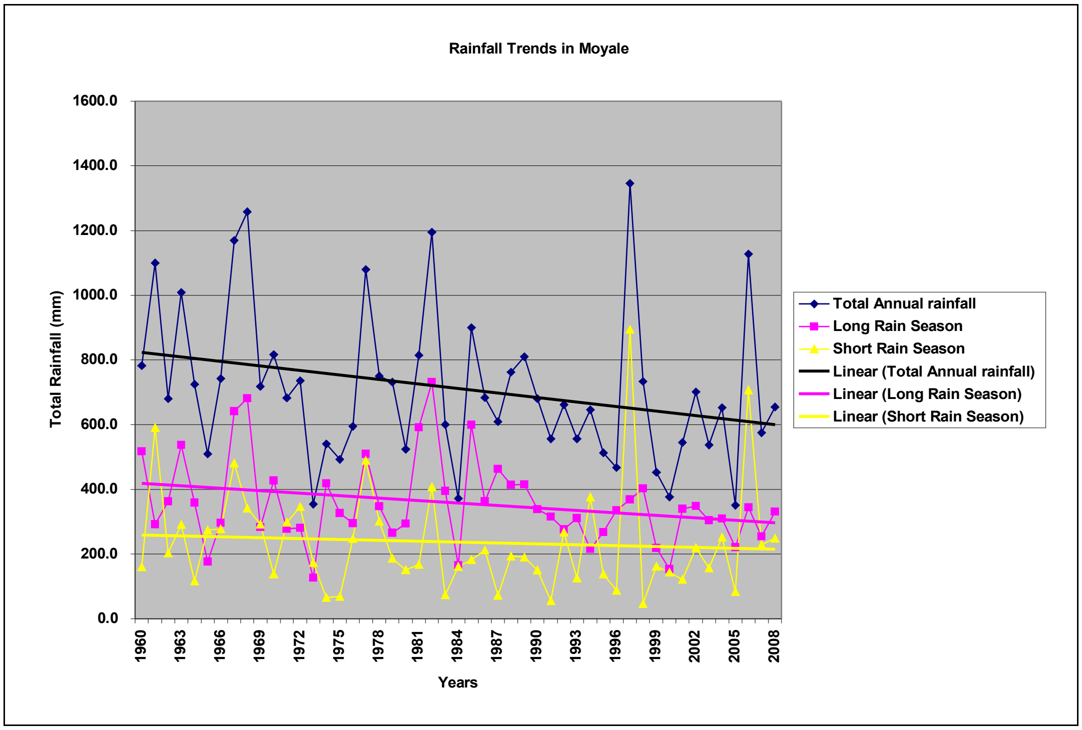

Figure 7e: Trends of the Total Seasonal and Annual variation rainfall over Moyale (NE Kenya)

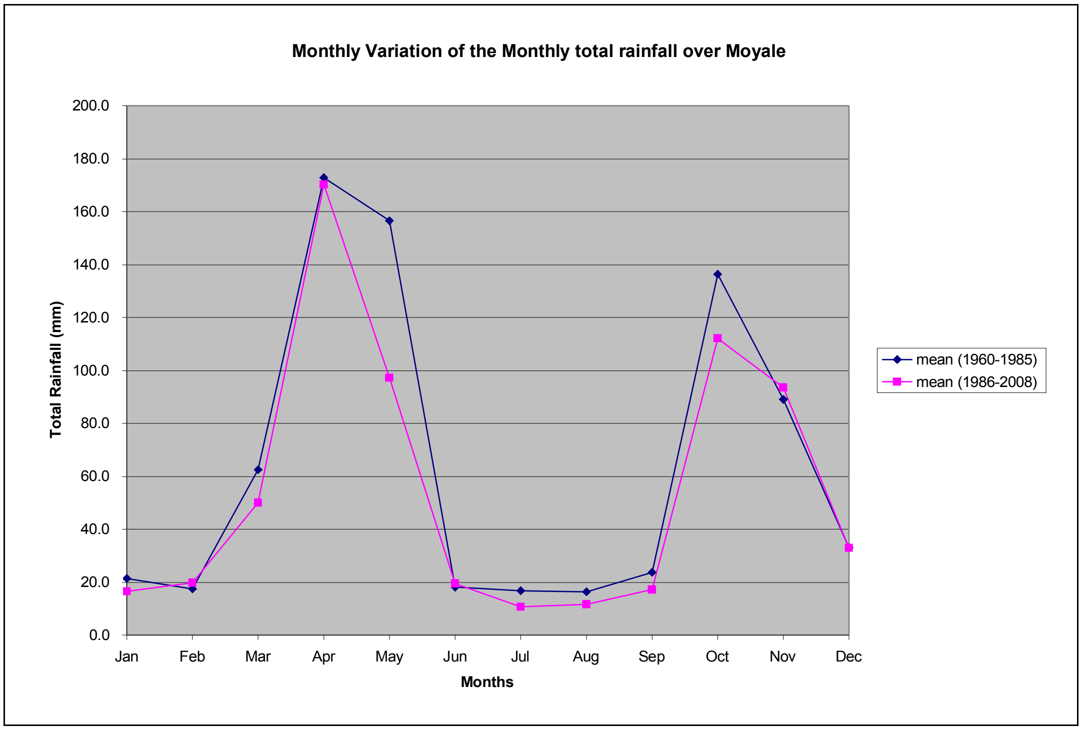

Figure 7f: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Moyale (E Kenya)

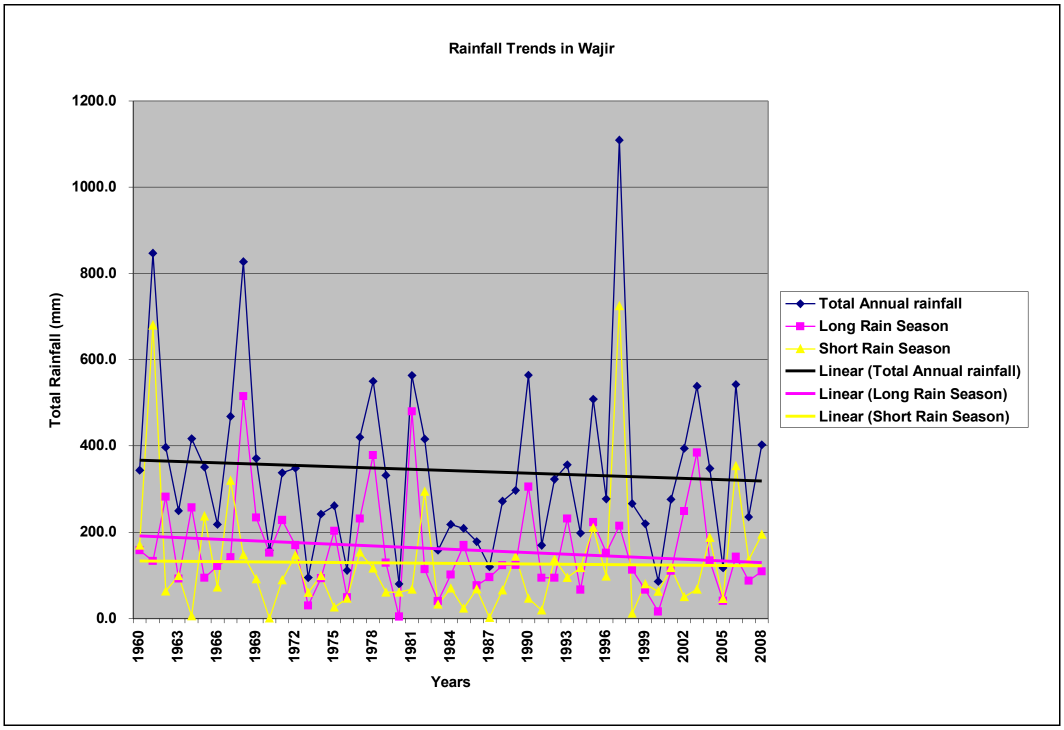

Figure 7g: Trends of the Total Seasonal and Annual variation rainfall over Wajir (E Kenya)

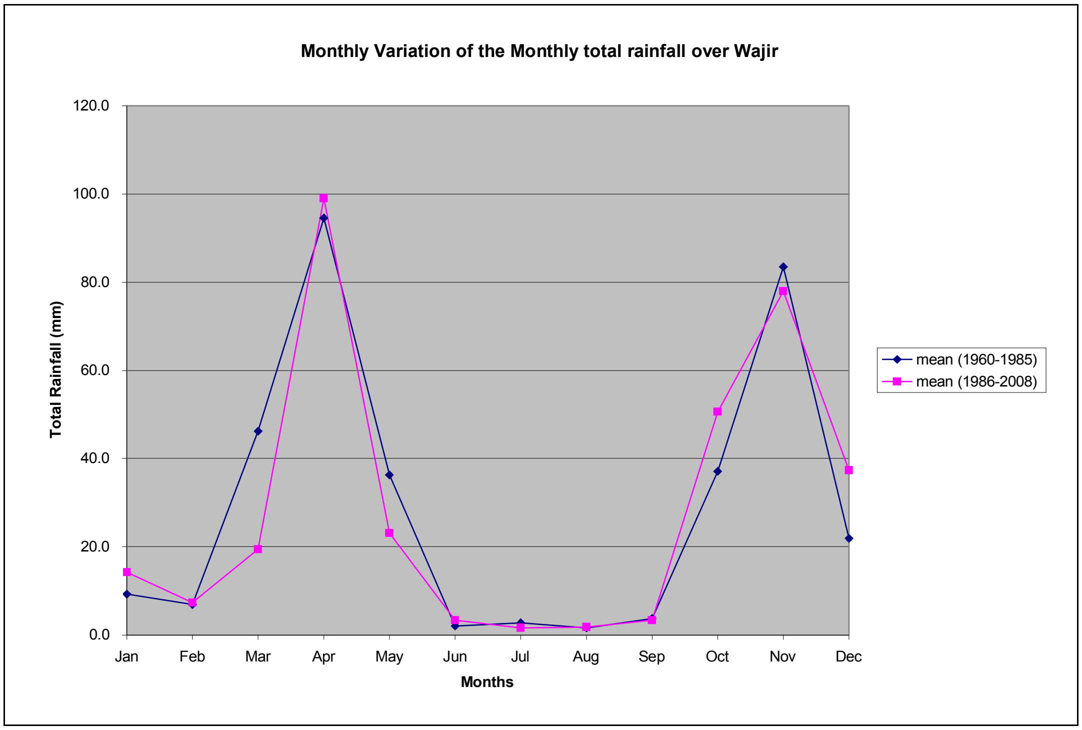

Figure 7h: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Wajir (E Kenya)

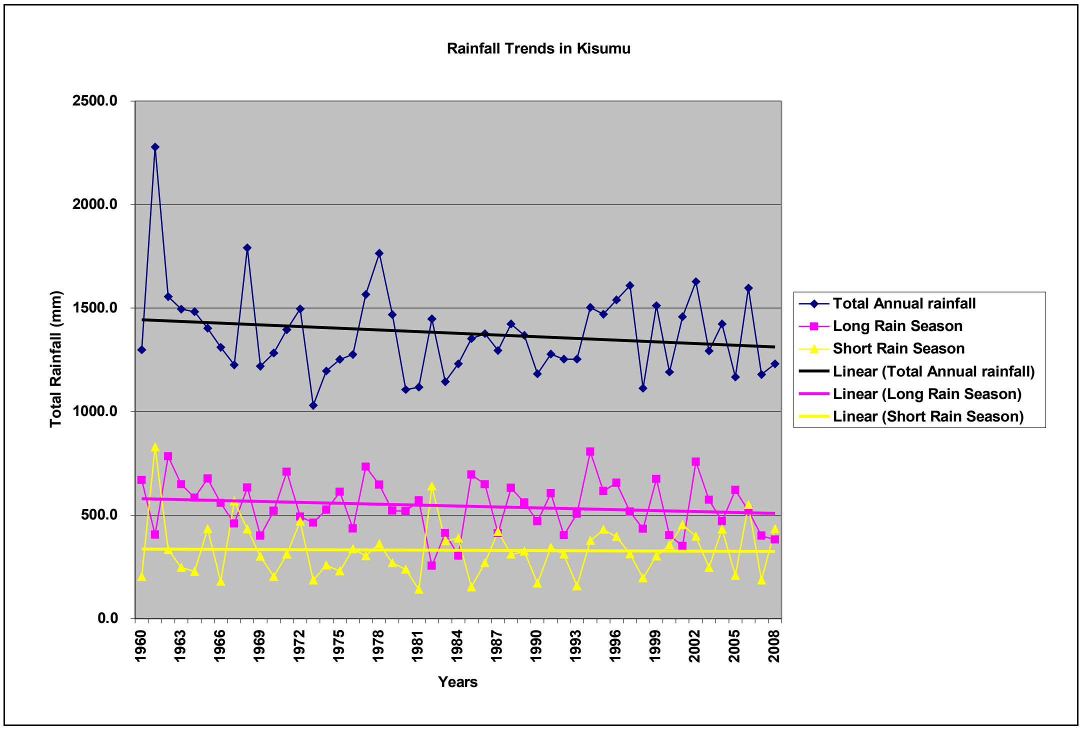

Figure 7h: Trends of the Total Seasonal and Annual variation rainfall over Kisumu (W Kenya)

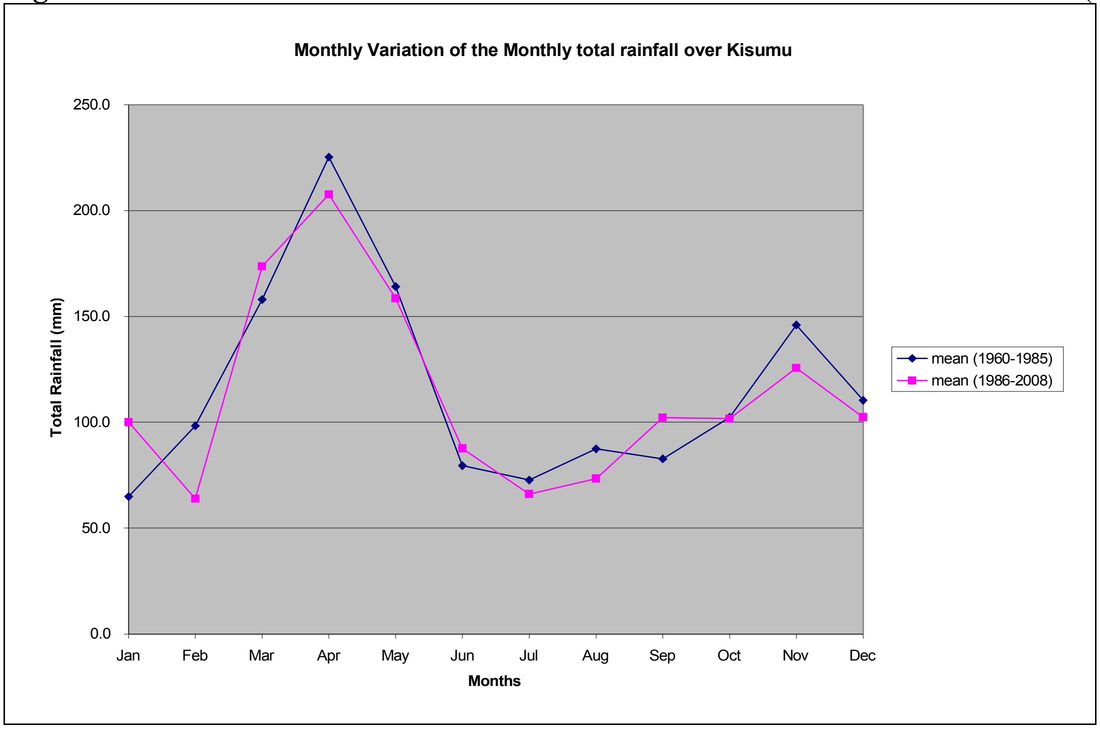

Figure 7i: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Kisumu (W Kenya)

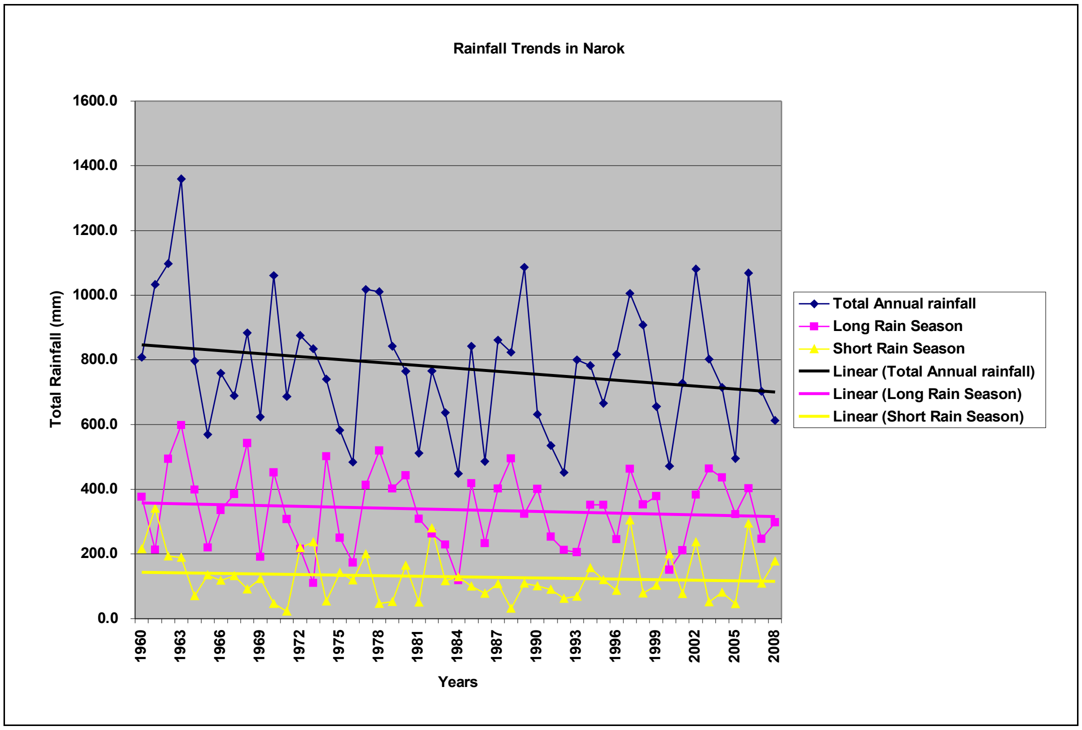

Figure 7j: Trends of the Total Seasonal and Annual variation rainfall over Narok (S Kenya)

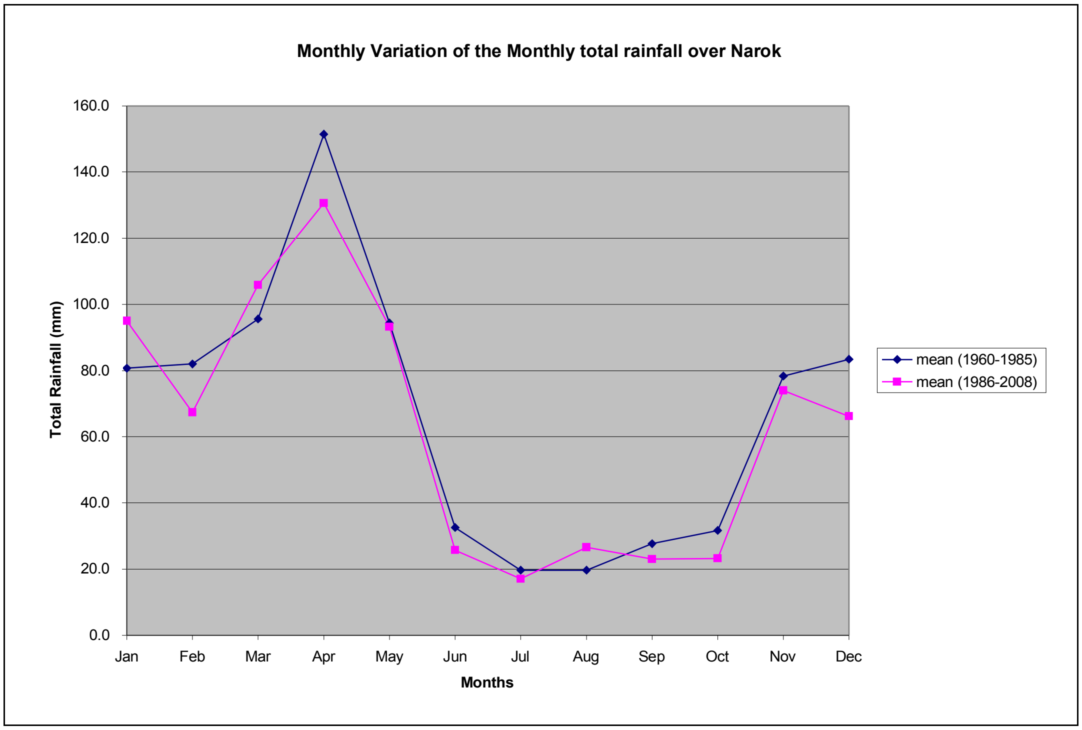

Figure 7k: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Narok (S Kenya)

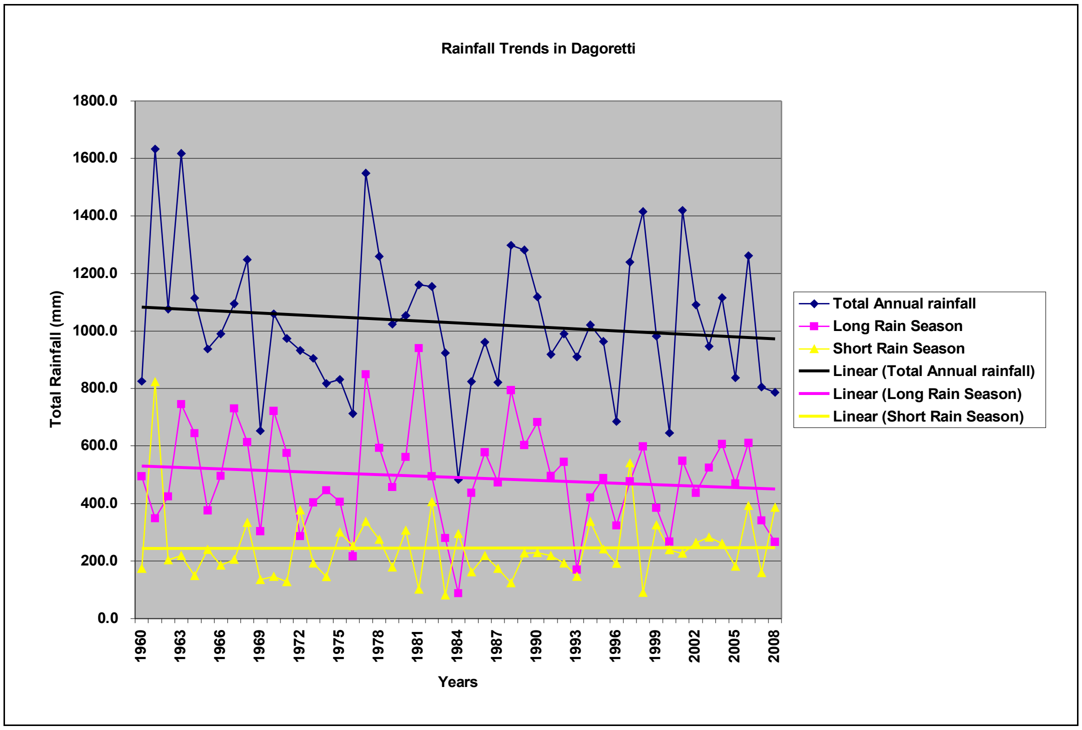

Figure 7l: Trends of the Total Seasonal and Annual variation rainfall over Dagoretti (C Kenya)

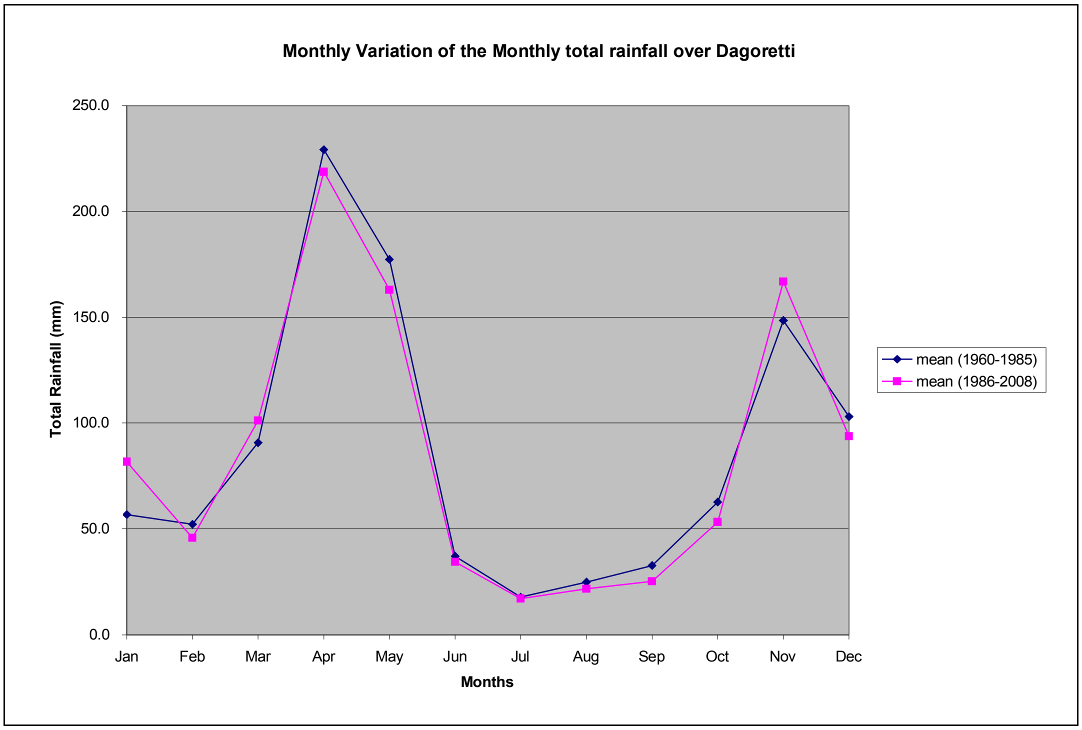

Figure 7m: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Dagoretti (C Kenya)

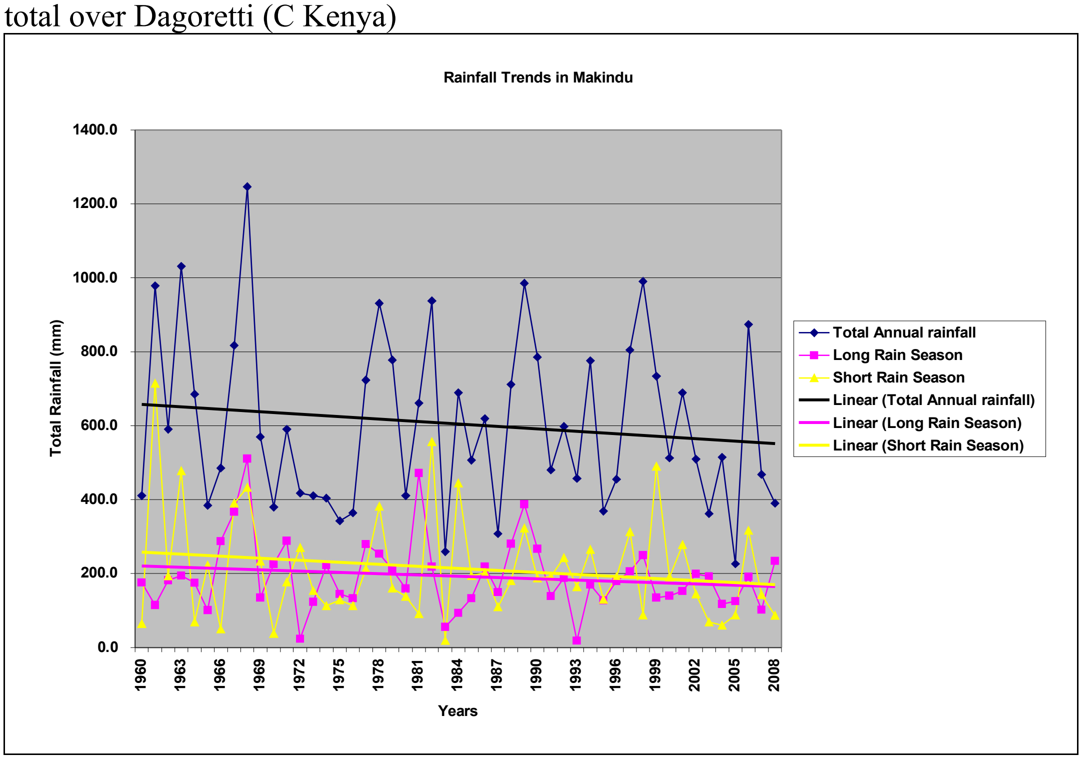

Figure 7n: Trends of the Total Seasonal and Annual variation rainfall over Makindu (SE Kenya)

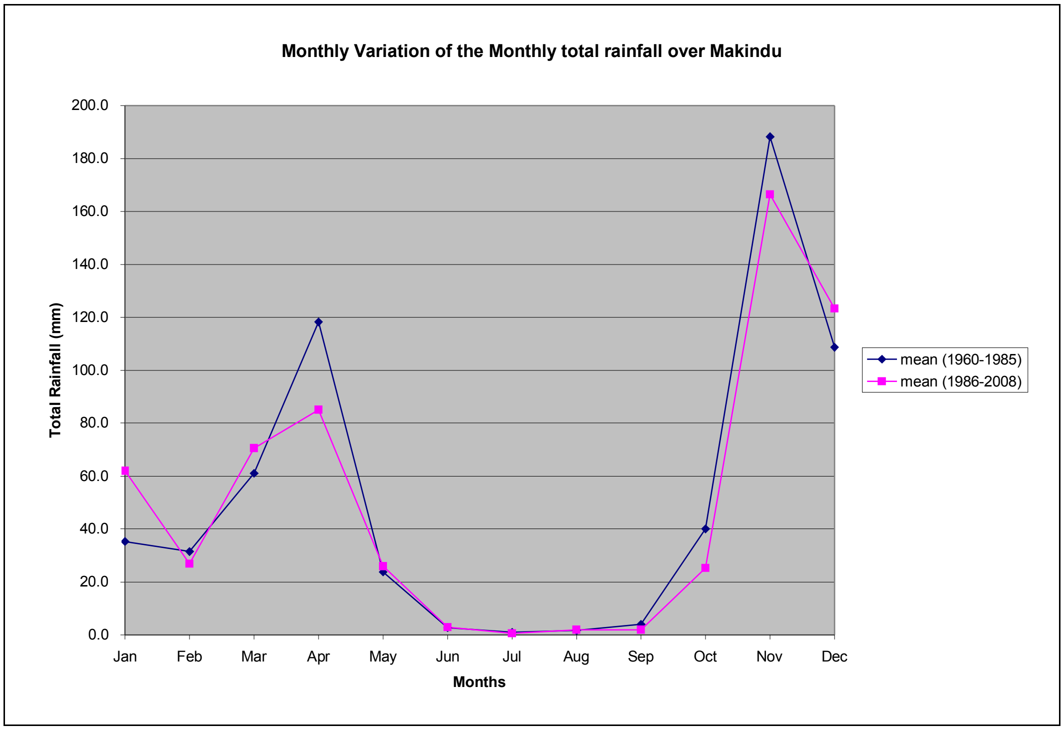

Figure 7o: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Makindu (SE Kenya)

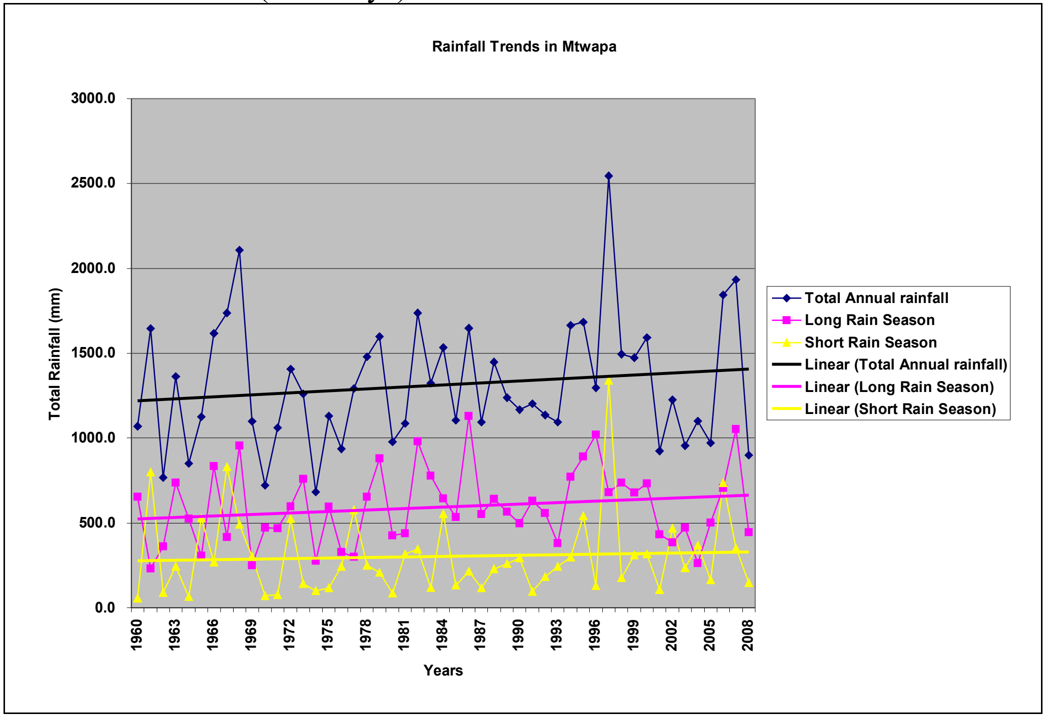

Figure 7p: Trends of the Total Seasonal and Annual variation rainfall over Mtwapa (Kenyan Coast)

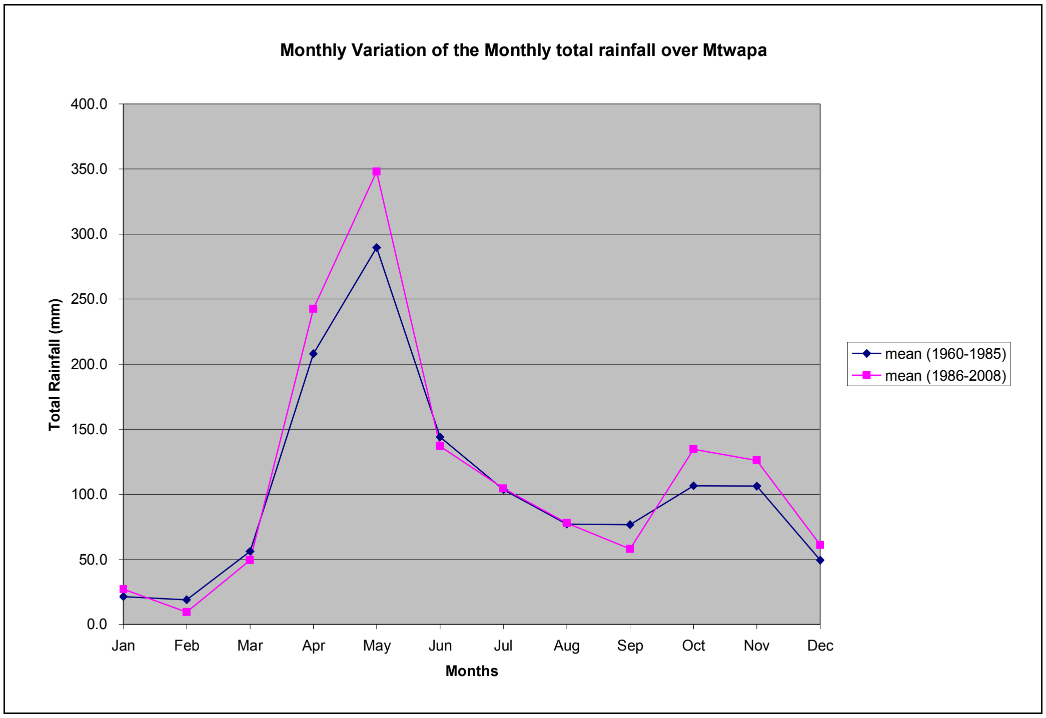

Figure 7q: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Mtwapa (Kenyan Coast)

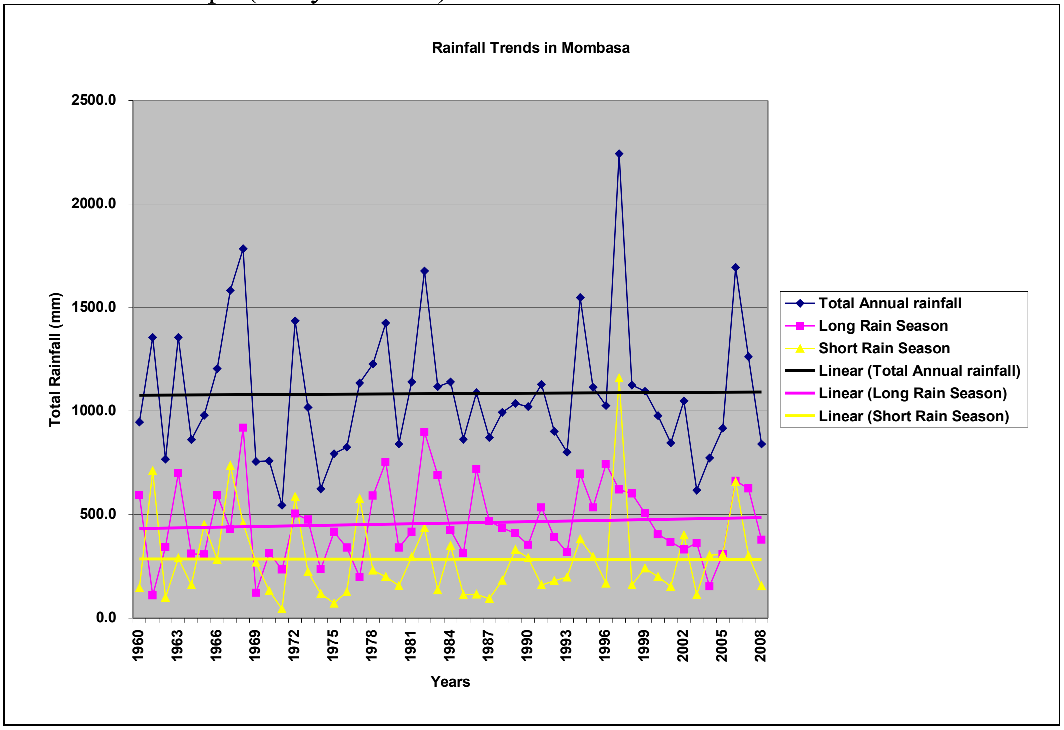

Figure 7r: Trends of the Total Seasonal and Annual variation rainfall over Mombasa (Kenyan Coast)

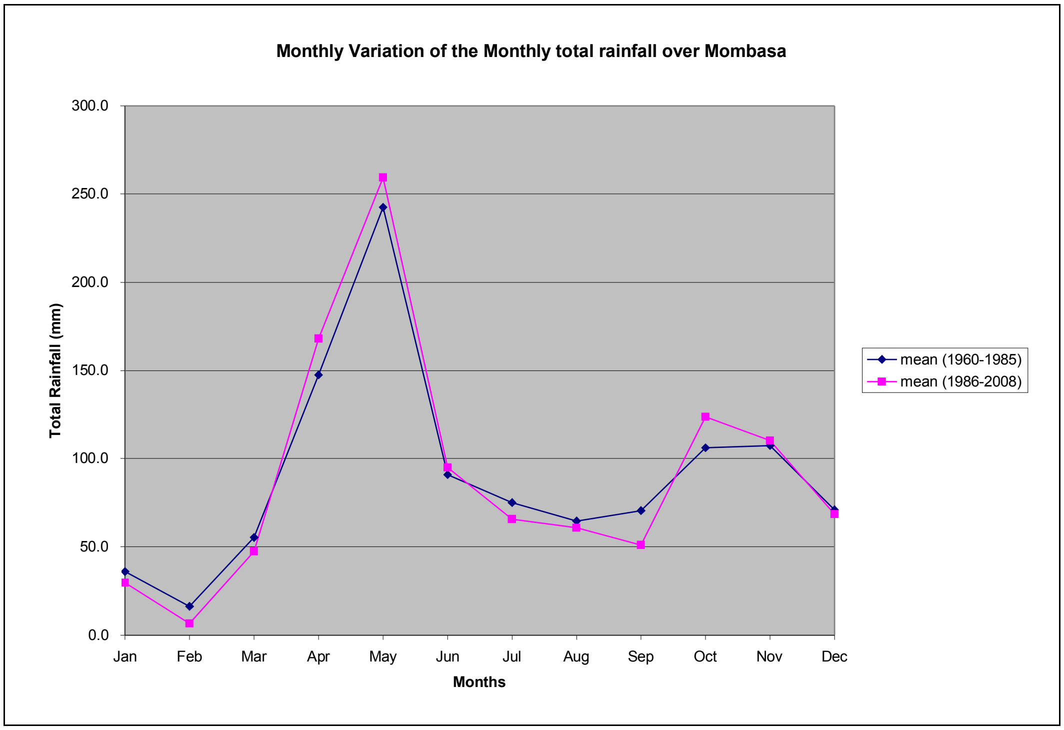

Figure 7s: Current (1986 – 2008) and past (1960 – 1985) Monthly Variation of the Seasonal rainfall total over Mombasa (Kenyan Coast)

1.6 Historic temperature trends

Some temperature data is available for sites in Kenya although like the precipitation data there are gaps in the series and missing data throughout the time period.

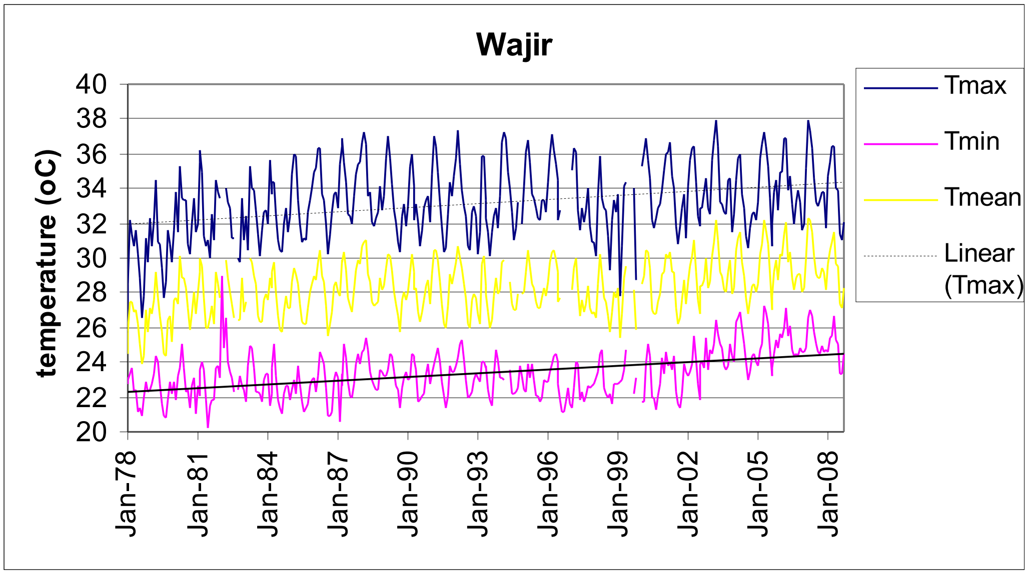

Figure 8 Wajir, monthly temperature and precipitation time series

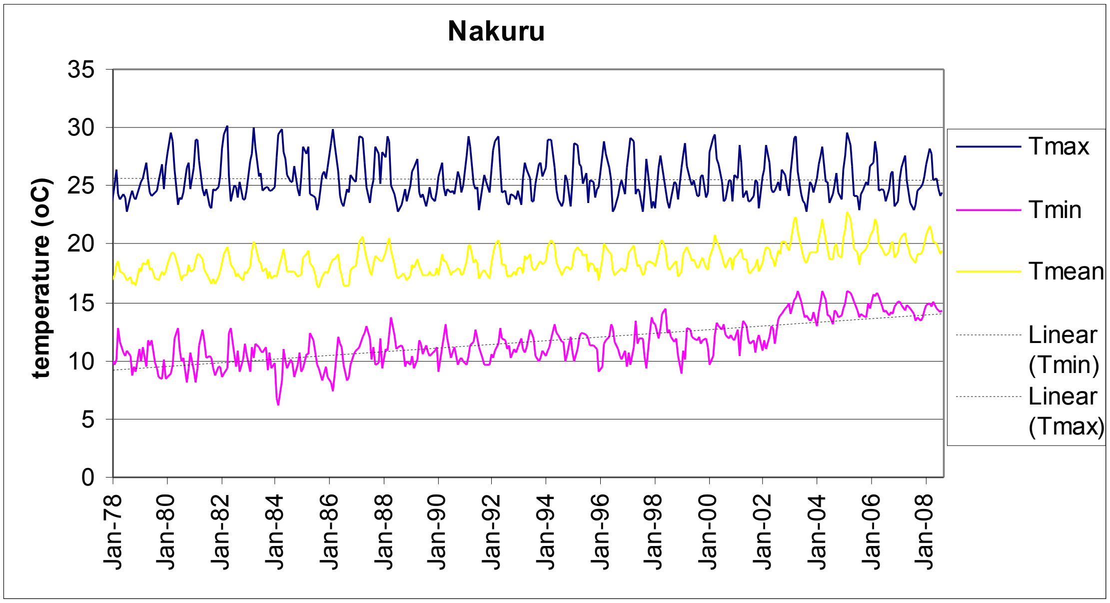

Figure 9 Nakuru temperature and precipitation monthly time series

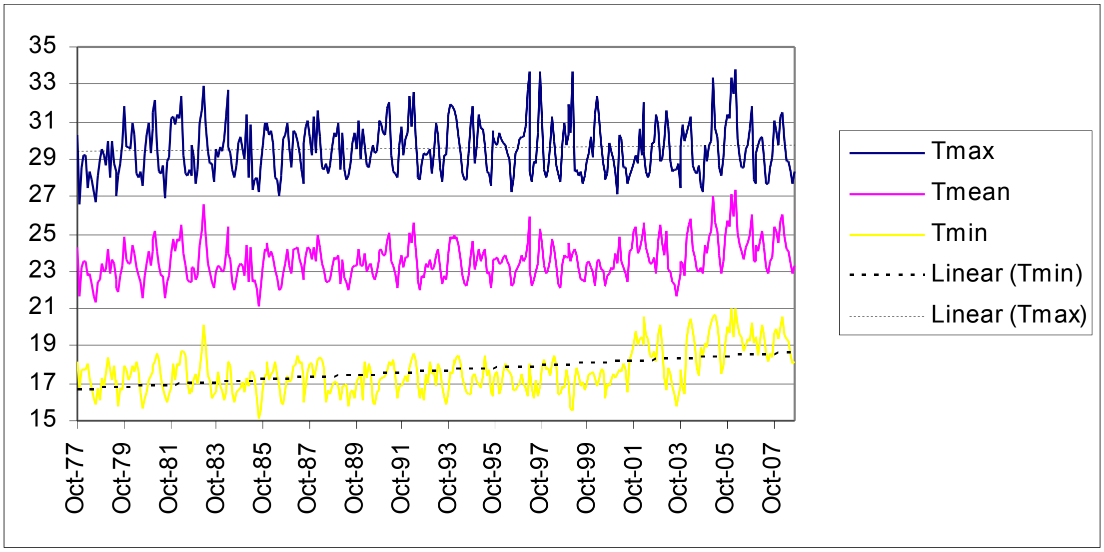

Figure 10 Kisumu temperature and precipitation monthly time series

The station sites shown above (Figure 8, 9 and 10) indicate the general increase in temperature since 1977, particularly for minimum temperatures and it is particularly marked during the last decade.

1.6.1 Extreme events

Prolonged droughts have become common in the recent years, particularly since 2000 (Table 1). This has affected larger areas and extended the arid and semi-arid conditions, increasing the number of the arid and semi-arid districts in the country to 36 covering over 80% of the total territorial surface area of the country (SOE 2006/7).

Table 1 Number of people in Kenya requiring relief in flood and drought disasters between 1965 and 2006**.**

Year	Number of People Needing Relief	% Fraction of the Total Population	Type of Disaster	Year	Number of People Needing Relief	% Fraction of the Total Population	Type of Disaster
1965	260,000	0.008	Drought	2000	125,000	0.004	Floods
1971	130,000	0.004	Drought	2000	2,740,000	0.079	Drought
1979	40,000	0.001	Drought	2001	3,400,000	0.098	Drought
1984	600,000	0.017	Drought	2002	60,000	0.002	Floods
1992	2,700,000	0.078	Drought	2003	45,000	0.001	Floods
1993	1,200,000	0.035	Drought	2005	3,500,000	0.101	Drought
1997	212,000	0.006	Floods	2006	Records not yet available		Drought January-August 2006
1998	539,000	0.016	Floods	2006	Records not yet available		Floods September-December 2006

(Sources: UN-ISDR, UN socio-economic database, Government of Kenya. 2007 Population values of 34.5M was used based on projections from 1999 Census)

Table 2 Summary analysis of climate trends for Kenya

Threat	Example	Location	Observed trends			
			Trend in likelihood	Trend in magnitude	Trend in location	Other trends/ descriptions/ Identified thresholds
Drought	Periodic drought	Arid and semi-arid lands (<500mm annual rainfall) (plus Muranga, Embu Kajiado, Makueni, Laikipia, Kitui and Machakos districts).	Frequency of droughts expected to increase. Observations show that southern Kenya becoming dryer – see Malindi.	severity expected to increase	Shifting border of semi-arid and arid lands	ASAL population is increasing due to natural growth and immigration- so more people are at risk. Increasing deforestation is also affecting rainfall

Floods	Flash floods 2006	Arid and semi-arid lands, Coast and lakeshore	Increased frequency of floods	severity expected to increase		
Temperatures			Increasing, particularly minimum temperatures			Reduce the number of species in parks and reducing wildlife population

1.7 Climate Change Scenario projections

There are a number of approaches for developing future climate change scenarios (Cubasch *et al*. 2001; Chaponniere and Smakhtin, 2006; UK MET OFFICE, 2004) including incremental (arbitrary) scenarios, and General Circulation Models (GMCs). The GCMs use the expected future state of emissions as inputs to develop scenarios for the future periods. IPCC (2001) have developed a set of six global emission scenarios that can be used in climate change studies. These are known as SRES scenarios A1FI, A1T, A1B, A2, B1 and B2.

Realistic regional and local scale climate change scenarios are critical for an assessment of the impacts, and vulnerability for the specific socio-economic sectors and hence the development of appropriate adaptation strategies. In order to generate regional climate change scenarios, high resolution Regional Climate Models (RCMs) are usually “nested” within GCMs to be able to represent the unique effects of smaller scale factors such as mountains, lakes, and land use among others (IPCC, 2001).

Several computer application software packages are now available for down scaling regional climate change scenarios based on these IPCC SRES scenarios. These include Providing Regional Climates for Impacts Studies (PRECIS), COSMIC and MAGICC/SCENGEN among many others (Raper *et al*. 1996, Harvey *et al*. 1997). The Model for the Assessment of Greenhouse-gas Induced Climate Change (MAGICC) module consists of a suite of coupled gas-cycle, climate and ice-melt models integrated into a single software package that determines changes in greenhouse-gas concentrations, global-mean surface air temperature and sea-level resulting from anthropogenic emissions of greenhouse gases and aerosols. The SCENario GENerator (SCENGEN) uses the output from MAGICC to produce maps showing the regional details of future climate. MAGICC/SCENGEN has been used in this report due to its simplicity, and its availability for free download and use. An overview of MAGICC/SCENGEN is given in Raper *et al*. (1996).

Although about 17 models are available for use in MAGICC/SCENGEN, an ensemble of only six GCMs were used in this study based on some previous studies carried out over the region. These included CSM_98, ECH395, ECH498, GFDL90, HAD295, and HAD300. The advantage of using such ensemble averages is that they provide better results by reducing the uncertainty associated with individual models (Raper *et al*. 1996, Harvey et al. 1997, IPCC 2007).

1.7.1 SCENGEN Scenario Projections of Kenya for 2030 and 2050

Results for Kenya show that, compared to the 1961-1990 average, the mean annual temperature will increase by between 0.8 - 0.9 °C across the country by the year 2030 and from 1.5 to 1.6 °C by the year 2050 for the IPCC mid-range emission scenario (A1B), while annual precipitation will change from 7.0 - 9.7 % and 13.3 - 18.8 % for 2030 and 2050 respectively. The order of magnitude projected in mean seasonal temperature changes among the four seasons (DJF, MAM, JJA and SON) is more or less similar to the annual changes. It should be noted that the observed increase in temperature will enhance evapotranspiration, resulting in significant reduction in water resources availability. Areas that are projected to have increased rainfall (most parts of Kenya) may not necessarily have surplus water, as evapotranspiration rates and water conservation practices will be significant factors in the water balance of those areas and hence determine water availability. While the temperature variation was not significant among the seasons, it was noted that for rainfall, the December-February season showed significant increase compared to the baseline rainfall (1961-1990).

1.7.2 Floods and Drought Projections

It should be noted that although the physical reality of most of the projections have not been vigorously tested in this study due to various limitations, the results of the projections indicate increases of mean annual rainfall of up to 10% in northern parts of Kenya for 2030 scenario, with corresponding values of 18% in northern Kenya for 2050. However, these regions are generally arid and semi-arid, such that the percentage projected increase in rainfall may not result in significant amounts but may result in episodic flooding. These projections may have far reaching implications on the frequency or severity of floods and droughts.

In general, the rainfall projections indicate an increase in precipitation across the equatorial and the northern parts of Kenya (Table 3).

Table 3 Rainfall MAGICC/SCENGEN projections over Kenya

			Projections	
Country	Region	Seasons	2030	2050
KENYA	Whole of Kenya	MAM	2 – 12 % increase	4 – 22% increase
	North/Western	JJA	5% increase	9% increase
	Eastern/Southern		4 – 11% decrease	8 – 21% decrease
	Whole of Kenya	SON	1 – 6% increase	0.5 – 11% increase
	Whole of Kenya	DJF	6 – 21% increase	11 – 40% increase
	Whole of Kenya	Annual	7.0-9.7 % increase	13.3-18.8 % increase

1.8 Downscaled station projections in temperature and rainfall

The Climate Change Explorer tool (produced by CSAG, University of Cape Town, see Box 1) provides downscaled, station-level response to GCM output. Average monthly and daily values, monthly time series for precipitation, minimum and maximum temperatures as well some derivative statistics for model periods listed below: control: 1961-2000; future (a) (early 21st century) 2045-2065; future (b) (late 21st century) 2081-2100. All the results shown here are for the future (a) time period centred around 2050.

Average temperatures in Kenya are likely to increase in the range of 1-3.5ºC by the 2050s according to downscaled results from 9 climate models using the climate change explorer tool, and maximum temperatures show similar changes. The greatest warming generally occurs from July to September.

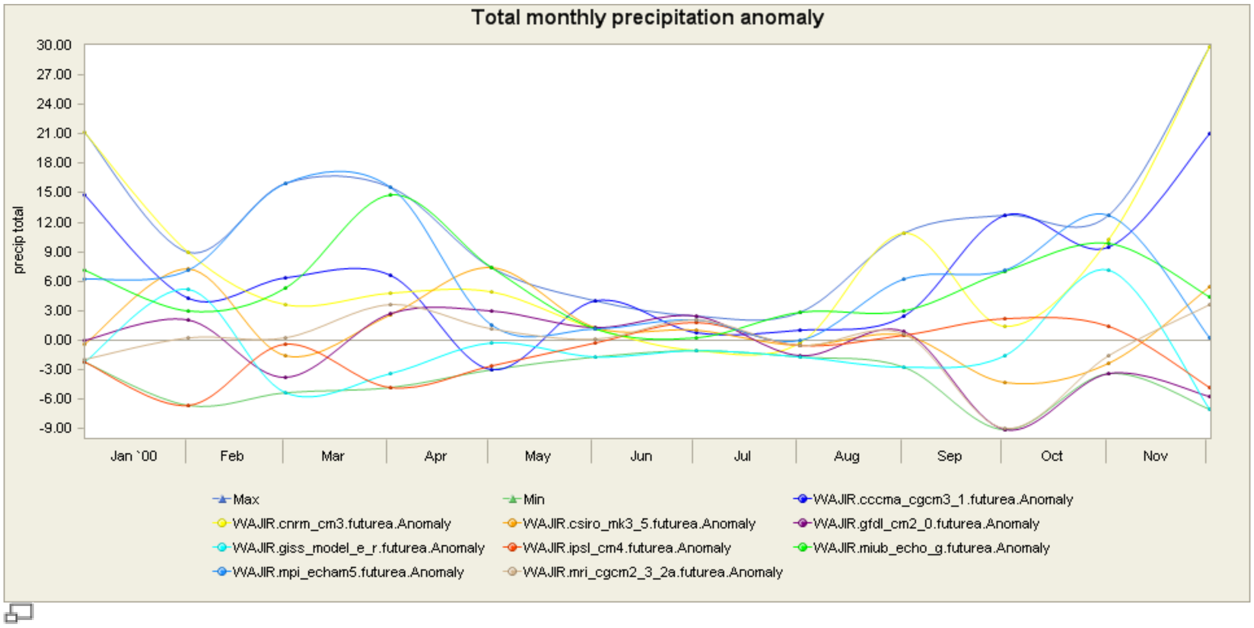

Figure 11 Monthly rainfall anomaly for the period 2046-2065 at Wajir (northern Kenya)

In Wajir the models indicate that temperatures are likely to increase by +1.3-3.3ºC above the 1960-1990 baseline by 2046-2065. The greatest average maximum increases occur in May and June, and the greatest highest maximum temperatures from Jun-Sep. The smallest increases are projected to occur in December and January.

The intensity of precipitation is likely to increase. There is good model agreement that there will be an increase in total rainfall during the Long rainy season, less agreement but higher increases in the Short Rains, but what is less clear is the magnitude of the changes. There is less agreement over changes to the late rains with some GCMS showing less rainfall (**Figure** 11).

The scenario predictions show no change to the broad yearly pattern of rains (i.e. the dry months will still be dry).

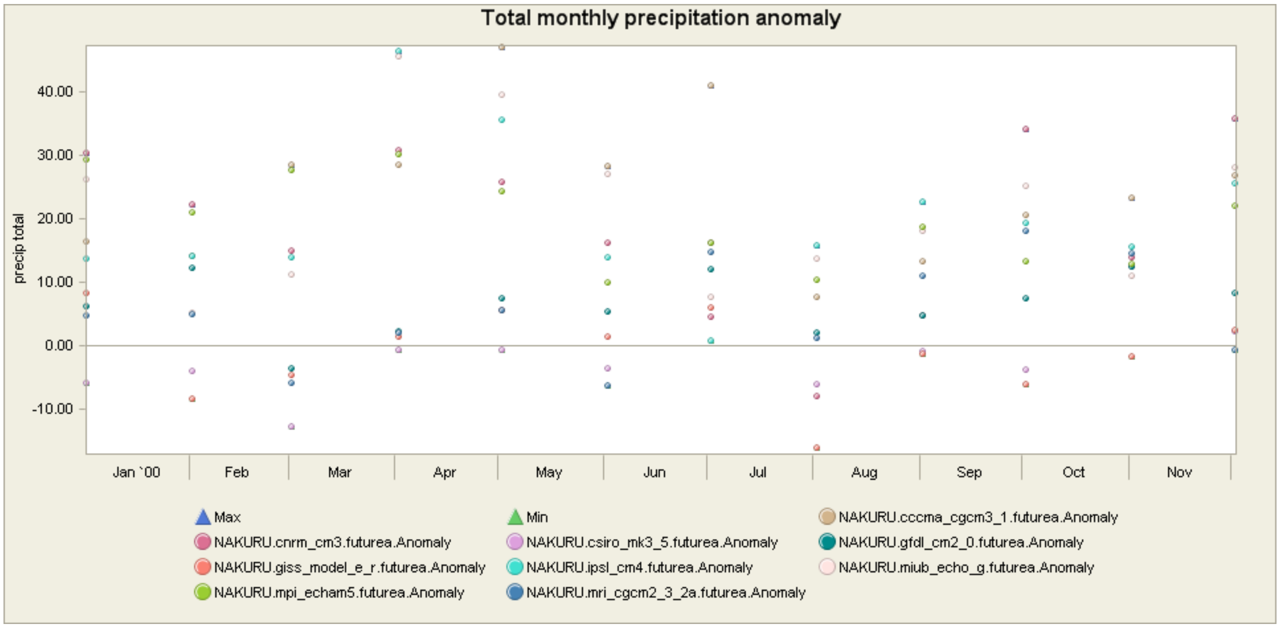

Figure 12 Monthly rainfall anomaly for the period 2046-2065 at Nakuru

At Nakuru in the Central uplands, average maximum monthly temperatures are projected to increase by 1.4-3ºC, most warming from July to September. There is a wide spread in monthly precipitation from minus 10 to plus 40mm increase per month with the largest range across the models in the Long rains (Figure 12). As Nakuru has some rainfall in all months with the least in January and February, the yearly pattern will continue but with the strongest possibility of being wetter in all months.

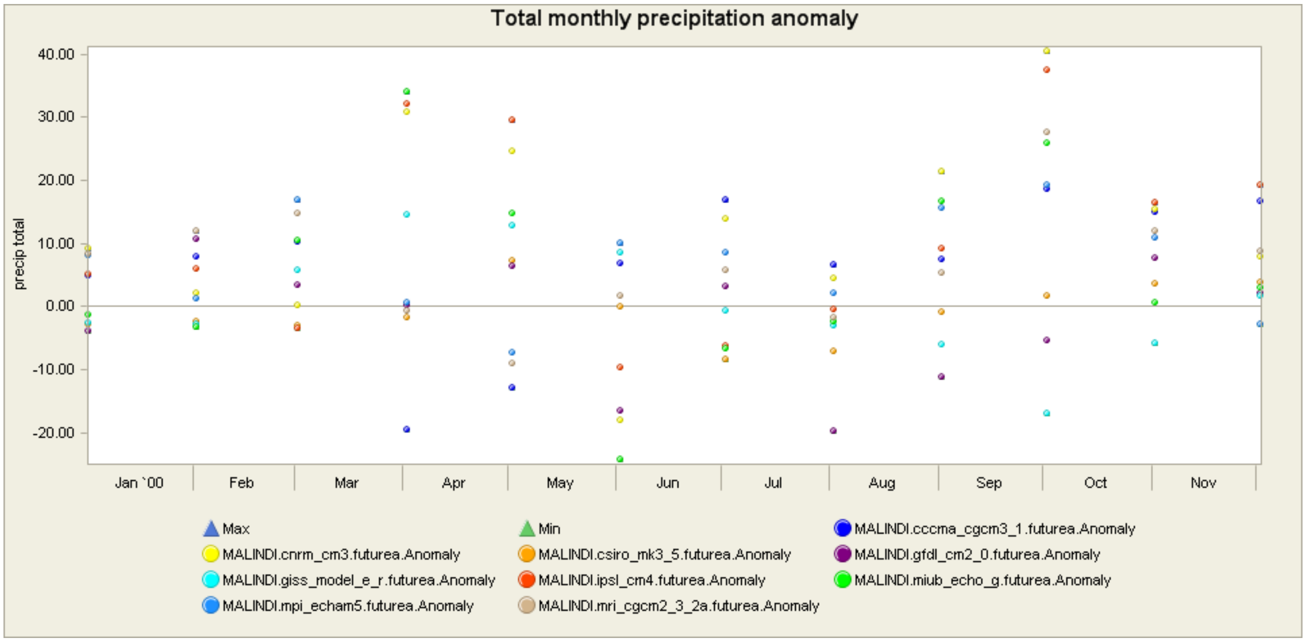

Figure 13 Monthly rainfall anomaly for the period 2046-2065 at Malindi

Average maximum temperatures are expected to increase in the range of 1.3-2.4ºC, with greatest warming in July at Malindi. The highest maximum temperatures will increase in the range of 1.2-3.3C, with greatest warming again in July and August.

There is more uncertainty regarding precipitation (Figure 13). The only month where all models agree on the direction of change is November. There is model disagreement in the direction of the change for the months April-August, which covers the majority of the rainy season. From November to March at least 8/9 models show an increase in precipitation, indicating that there may be more rainfall during the dry season. Some of the changes are very small, however, so it may be that there is little real change.

1.9 Future climate variability

Investigating changes in extremes by looking at high rainfall events at the station level is possible using the Climate Change Explorer by plotting change (from baseline) in monthly precipitation against changes in number of rainy days, with precipitation above the 90th percentile (Figure 15). There are months at all the sites presented where monthly precipitation increases but the numbers of days with high precipitation decreases, but for the Wajir it can be seen in several months and for several scenarios that there will be an increase in days with extreme rainfall corresponding to an increase in monthly total rainfall.

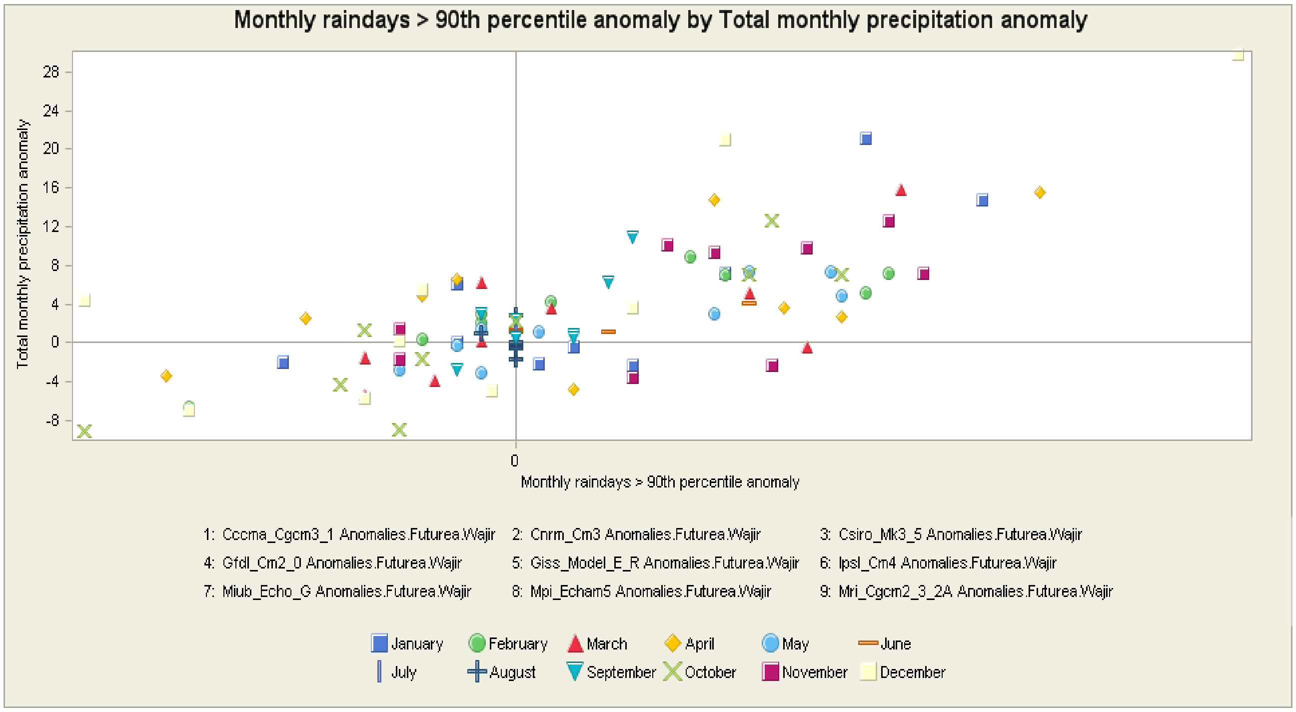

Figure 14 Total monthly precipitation anomaly for 2045 to 2064 timeslice against number of rainy days with precipitation greater than 90th percentile for Wajir

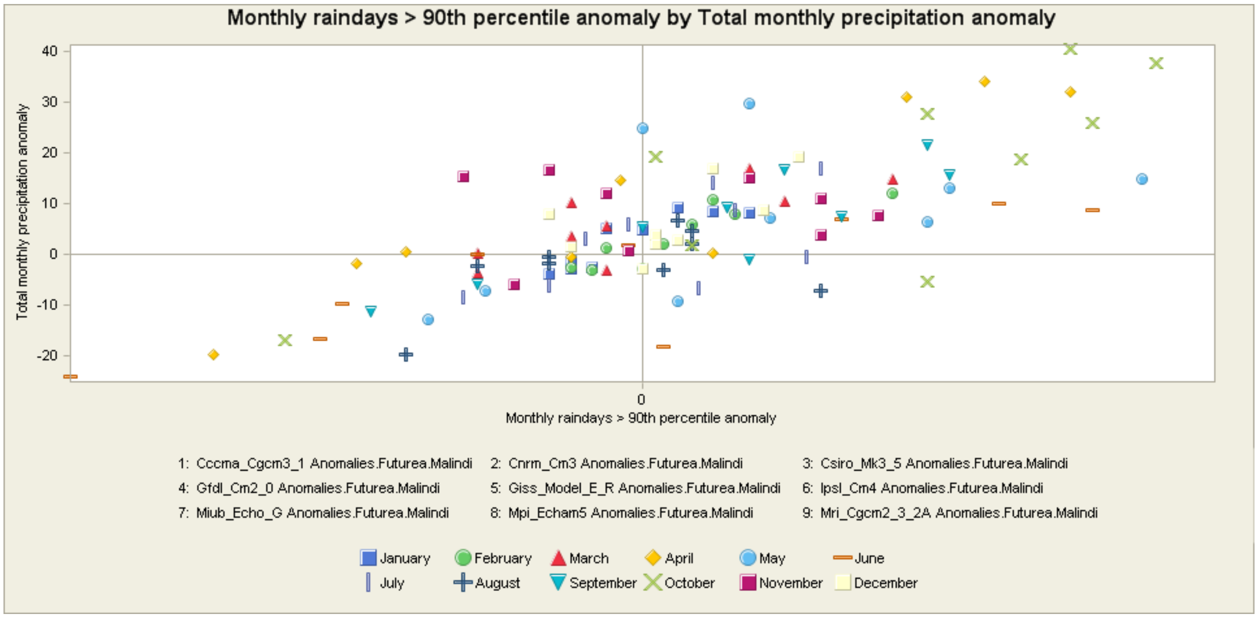

Figure 15 Total monthly precipitation anomaly for 2045 to 2064 timeslice against number of rainy days with precipitation greater than 90th percentile for Malindi

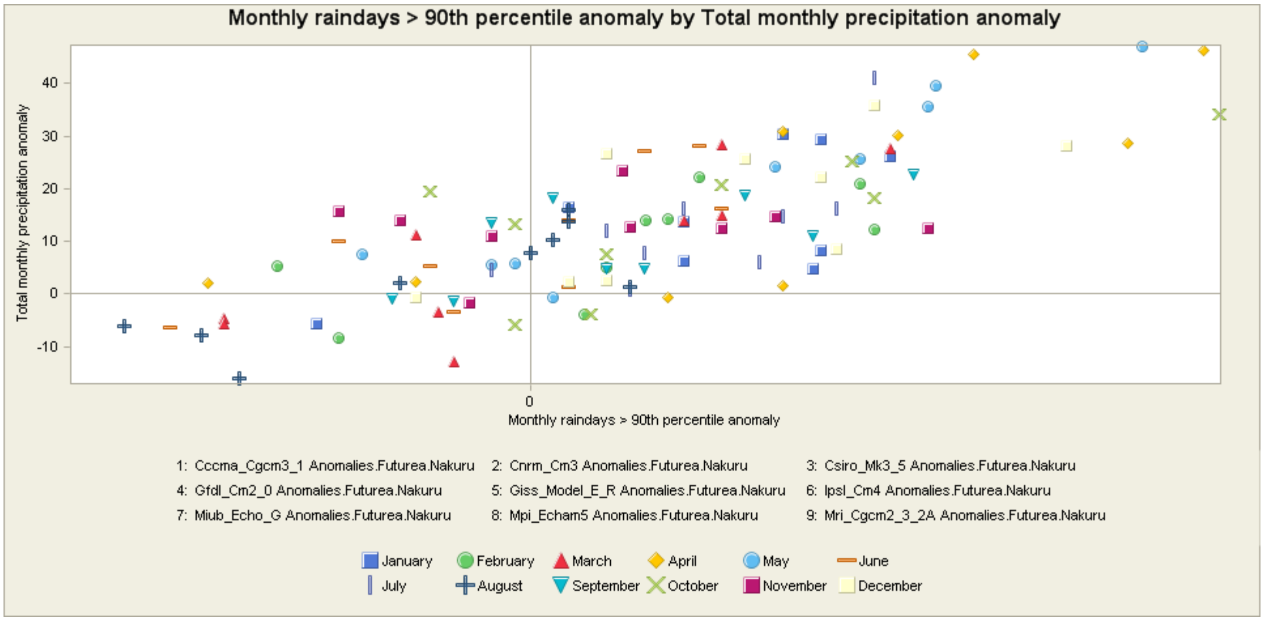

Figure 16 Total monthly precipitation anomaly for 2045 to 2064 timeslice against number of rainy days with precipitation greater than 90th percentile for Nakuru

For temperatures plots there is a corresponding increase in extreme maximum temperatures with an increase in minimum temperature but not in all scenarios and months, which indicates that although average maximum and minimum temperatures will increase, there may not be a big increase in the number of days with extreme high temperatures.

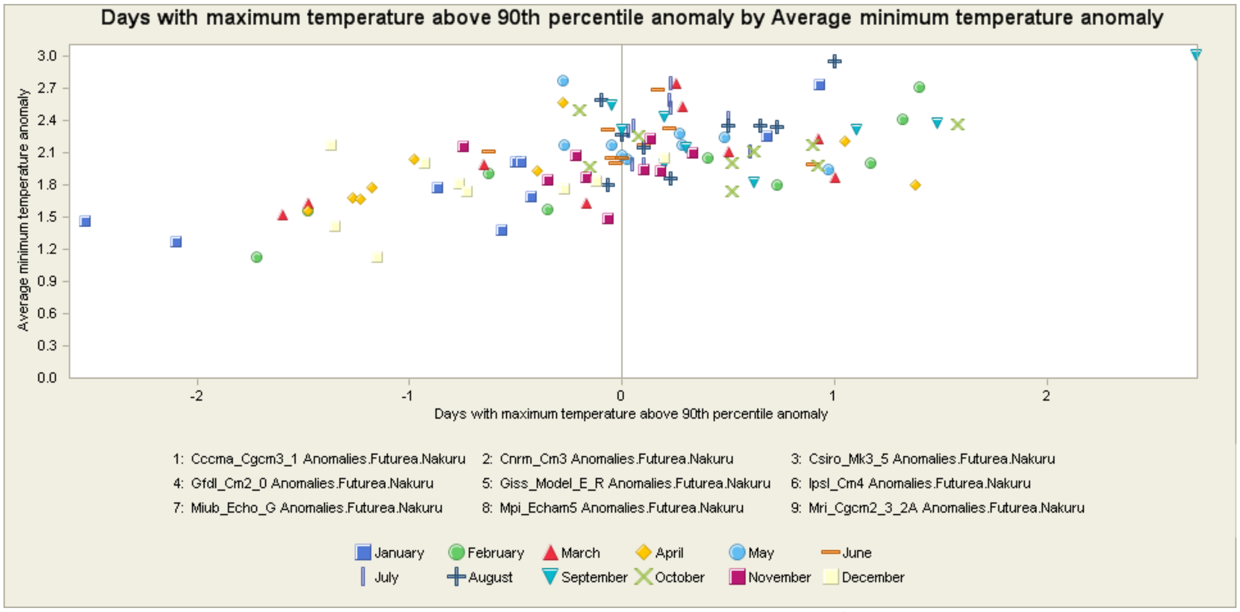

Figure 17 Number of days with maximum temperature above 90th percentile anomaly by average minimum temperature anomaly for Nakuru.

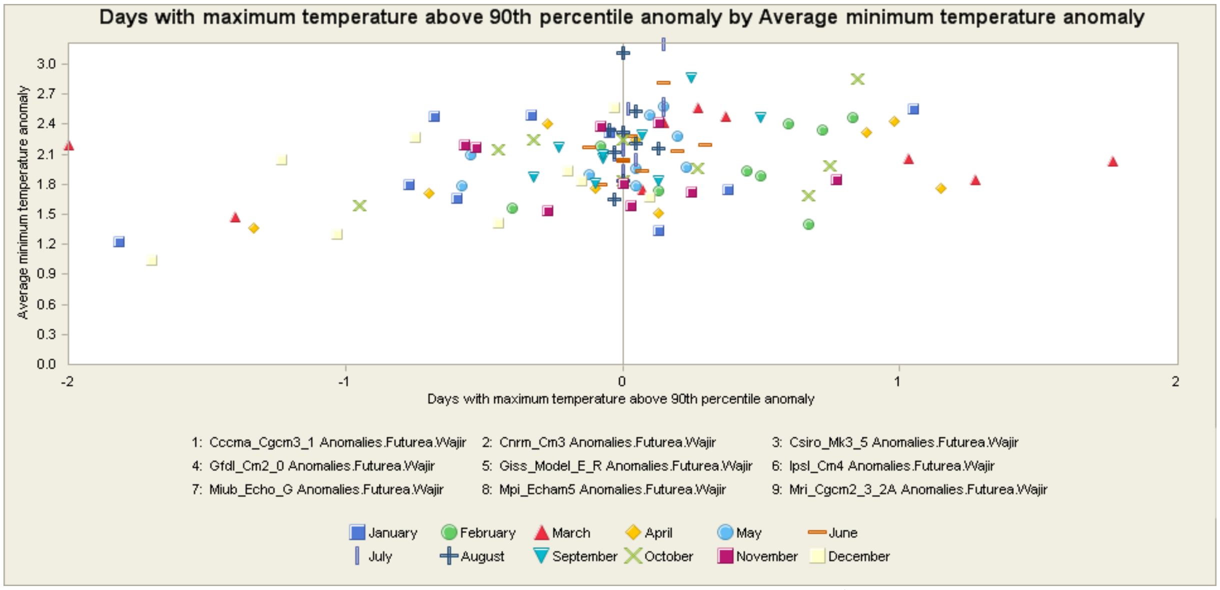

Figure 18 Number of days with maximum temperature above 90th percentile anomaly by average minimum temperature anomaly for Wajir

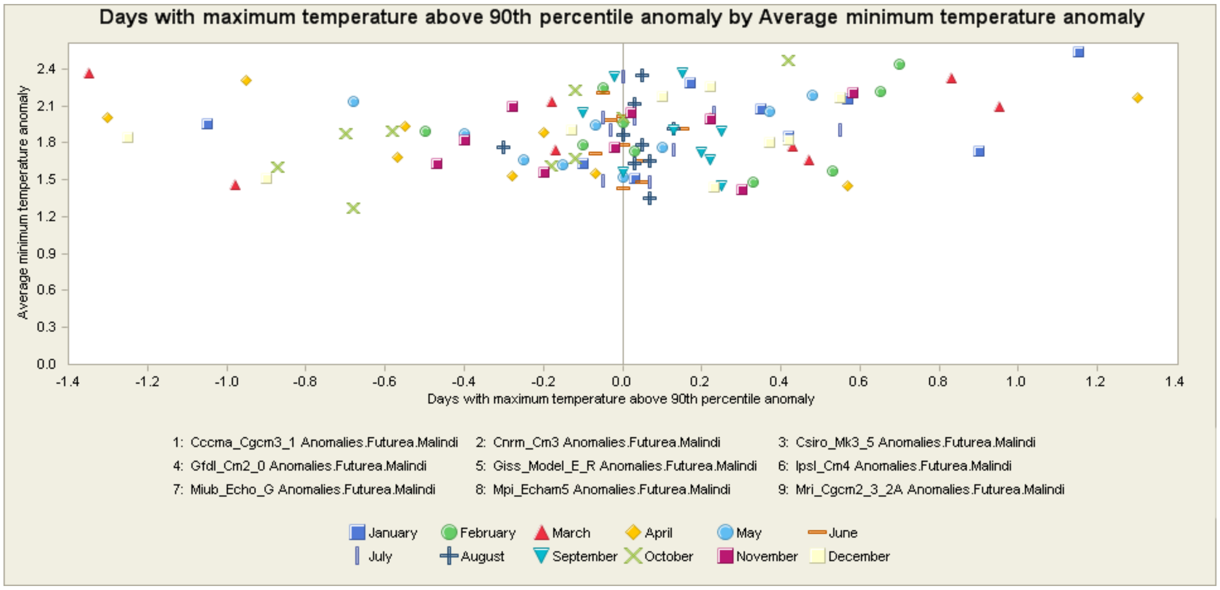

Figure 19 Number of days with maximum temperature above 90th percentile anomaly by average minimum temperature anomaly for Malindi

1.10 Summary of climate changes on Kenya

The wide range of results presented here using different approaches to downscaling, highlights the uncertainties in the projections in climate for Kenya for the middle of this century. Temperature changes are consistently higher, which is in agreement with the observed current trend. Days with extreme high temperatures will increase with the average increase in temperature, although the number of days with temperature higher than the 90th percentile does not give a convincing increase when all GCMs are included. However precipitation is much more difficult to summarise. The predicted increase in precipitation during the short rains is held out in all the results and the model agreement on this is higher than for the long rains. Increase in intensity of rains is expected and that can be seen in the scatter plots for the three stations showing the number of days with rainfall above the 90th percentile. How dry spells will change is hard to predict, however although a general increase in precipitation is expected, the intensity of droughts is not expected to be relieved and dry spells may linger.

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Box 1: Climate Systems Analysis Group's Climate Change Explorer

The Climate Systems Analysis Group (CSAG) (www.csag.uct.ac.za), based at the University of Cape Town, South Africa, operates the preeminent empirical downscaled model for Africa and provides meteorological station level responses to global climate forcings for a growing number of stations across the African continent. The data requirements (10 years of quality controlled daily climate measurements) and technical skills intensity required for empirical downscaling has resulted in no other institutions in Africa producing such data. A growing number of adaptation and climate impact studies benefiting from the downscaled information provided by this and other downscaling approaches (Wilby and Wigley, 1997; Prudhomme et al., 2003; Wilby and Harris, 2006). The figure below shows the downscaled climate data produced by CSAG, as presented in the IPCC (Christensen et al., 2007). One of the key points is that the six different downscaled projections are showing agreement in the direction of change for rainfall in many parts of Africa.

Figure Box 1 - Anomaly of mean monthly precipitation (mm) using daily data empirically downscaled from six GCMs (ECHAM4.5, Hadley Centre Atmospheric Model (HadAM3), CSIRO Mk2, GFDL 2.1, MRI, MIROC) to 858 station locations. The GCMs were forced by the SRES A2 scenario. Anomalies are for the future period (2070 to 2099 for the first three models, and 2080 to 2099 for the latter three models) minus a control 30-year period (from Hewitson and Crane, 2006)