# Diagnosis of Seasonal Rainfall Variability over East Africa: A Case Study of 2010-2011 Drought over Kenya

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***Abstract***

*The primary objective of this study was to investigate the recent climate variability over the East African region; with focus on the 2010-2011 rainfall failure over Kenya. The seasonal rainfall over the region is bimodal, mainly influenced by the Inter-Tropical Convergence Zone (ITCZ) and El-Nino Southern Oscillation (ENSO).The observed rainfall in October – December (OND) 2010 and March-May (MAM) 2011 was below normal with respect to the respective long term means (LTMs). The low level divergence was observed during 2010 OND, especially in the eastern and western parts of the country. Although the western parts of the country experienced low level convergence during MAM, the south easterlies that partly transport moisture from the Indian Ocean were generally observed to be very strong as compared to the seasonal climatology. The condition reduces the chances of low level convergence, leading to a reduction in rainfall. Relative humidity was noted to be below normal in the northeastern sector of the study area, as opposed to the western sector where it was above normal. This is associated with the observed positive anomaly of rainfall in the western sector. The combination of the observed phenomena led to the observed drought in 2010 - 2011 over most parts of the country. Similar phenomena should be keenly monitored in future especially during seasonal weather forecasting to detect the possible occurrence of drought for planning purposes.*

**Key Words:** Climate Variability, Rainfall, Drought, ITCZ, ENSO

## Introduction

Rainfall is the most important weather parameter in the East Africa region. This is so because the economies of the countries in the region are mainly dependent on rain fed agriculture (Funk et al., 2008; Ngetich et al., 2014; Fox and Rockström, 2005; Ongoma, 2013). Failure in rainfall in the region results into drought that causes serious socio-economic losses and deaths (Eguru, 2012; Shisanya et al., 2011).

The rainfall in the region is highly variable both in space and time, this is attributed to the orography and the presence of big and numerous water bodies such as Lake Victoria (Nyakwada, 2009; Indeje et al., 2001; Oettli and Camberlin, 2005). There have been cases of climate variability ranging from recent droughts (1999 - 2001, 2005 - 2006 and 2010 - 2011) that affected many parts of the east Africa. Floods however occur on smaller spatial scale at the onset of rains in some locations but have adverse effects. This thus calls for continuous monitoring of the rainfall and the main weather systems influencing it for better rainfall forecast and consequently stable economies.

The East Africa lies with the tropics (Figure 1), the rainfall regime experienced in the region is mainly bimodal with 'long rains' in March-May (MAM) and the 'short rains' in October - December (OND) (Nicholson, 2014; Hastenrath el al., 2010; Camberlin and Okoola, 2003; Owiti, 2012; Ogwang et al., 2012). The main synoptic feature influencing the rainfall occurrence in the region is the Inter-Tropical Convergence Zone (ITCZ) (Asnani, 1993; Mukabana and Pielke, 1996; Okoola, 1999; Okoola, 1996). The most dominant mode of inter-annual rainfall variability over eastern Africa corresponds to El-Nino Southern Oscillation (ENSO) climate variability (Ogallo, 1988; Indeje et al., 2000; Mutemi, 2003). Mutemi (2003) for instance found a strong relationship between rainfall over east Africa and evolutionary phases of ENSO. The results showed that ENSO plays a significant role in determining the monthly and seasonal rainfall patterns in the East African region. According to studies (e.g. Rasmusson and Carpenter, 1982; Nicholson and Kim, 1997; Ogallo, 1989), during the warm ENSO

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events most of the east Africa region receives abundant rainfall tending to above normal especially during the short rains. In addition to ENSO, a study by Schreck and Semazzi (2004) isolated a separate eastern Africa mode, in rainfall, with a time evolution that is consistent with increasing warming of the global climate.

The region has in the recent past faced extreme drought events leading to devastating impacts on socio-economy (Funk et al., 2005; Huho et al., 2011; Hillbruner and Moloney, 2012; Verdin et al., 2005). The October 2010 - April 2011 drought especially over Kenya caused severe humanitarian disaster (Lautze et al., 2012; Lott et al., 2013; Mosley, 2012). The drought was characterized by failure of two consecutive rainy seasons: the 2010 'short rains' and the 2011 'long rains'. The two seasons exhibited rainfall with a standard deviation less than -1, which is considered a threshold for drought as used previous studies (e.g. Okoola, 1999; Koumare, 2014)

A few studies with varying output have been done to diagnose the October 2010 - April 2011 drought. Differently from Williams and Funk (2011) who suggested the 'long rains' in 2011 were in a multi-decadal decline, another study (Lyon and DeWitt, 2012) presented a different view. Williams and Funk (2011) associated the drying trend with an anthropogenically forced relatively rapid warming of Indian Ocean sea surface temperatures (SSTs), which they contend extends the warm pool and Walker circulation westward, resulting in a subsidence anomaly and drying over east Africa. However, Lyon and DeWitt (2012) linked the decline in the East African 'long rains' with a shift to warmer SSTs over the western tropical Pacific and cooler SSTs over the central and eastern tropical Pacific. This has prompted this research to diagnose this extreme climatic anomaly in the context of the causative circulation mechanisms and its severity.

A similar occurrence was witnessed in 2005 (Hastenrath et al., 2006). According to the study, the 'short rains' of East Africa were hampered by an enhanced subsidence at the western extremity of the intensified equatorial zonal circulation cell, favored by the anomalously fast surface equatorial westerlies. The study further found out that the acceleration of the westerlies was due to a steepened eastward pressure gradient along the equator, resulting from anomalously high pressure in the west. The study however, recommended further study into the occurrence and causes for enhanced pressure in the west.

The aim of this study is thus to diagnose the rainfall failure that led to the severe drought over Kenya in 2010 - 2011. This analysis information can help improve long term forecasts to identify the potential drought years that produce downward precipitation trends; this will greatly help in the development of famine early warning system to avert loss of life and property. The accurate and timely understanding of the occurrence of extreme weather can improve the effectiveness of humanitarian responses (Ververs, 2012) in this region. This is possible by enabling aid agencies to avail food supplies, organize funding, and set in place the appropriate contingency plans.

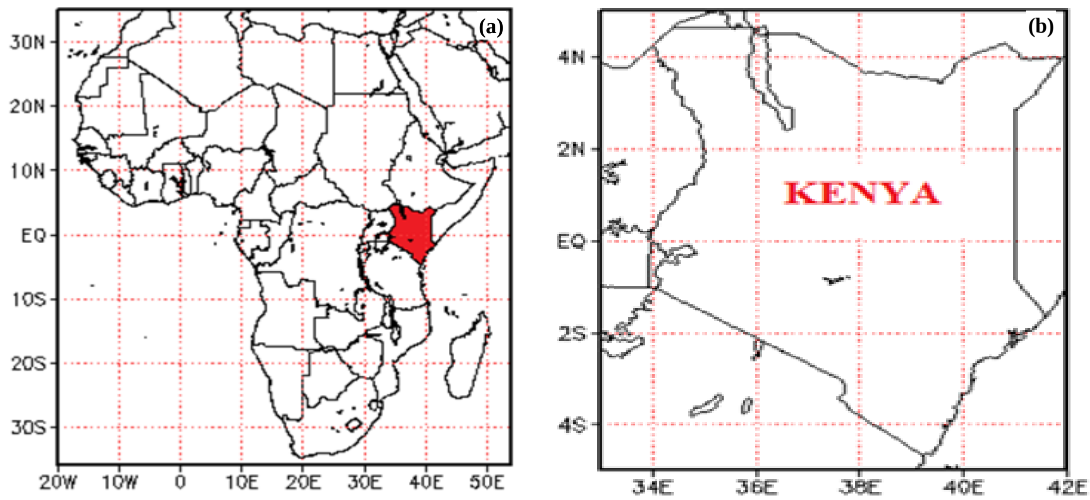


**Figure 1: (a)** Map of Africa showing the Kenya (study area, shaded red), **(b)** Map of Kenya [longitude 34°E - 42°E and latidue 5°S - 5°N]

## Data and Methodology

The precipitation dataset used in this study is the Climate Research Unit (CRU) dataset, described by Harris et al. (2013). The CRU data is a monthly gridded climatology of station data for the period 1901–2011 at a resolution of 0.5 degree. This is because the African rain-gauge data observed during the post-independence era of 1970's through to recent years have many spatial and temporal discontinuities over large sections of east Africa (Schreck and Semaazi, 2004; Ogwang et al., 2014). The wind, relative humidity and temperature used to determine the moisture transport are those of ERA-interim, gridded at 0.75 degree resolution (Dee et al., 2011).

In order to understand the possible causes of this drought event, this study investigated the prevailing wind pattern and strength, moisture flux and pressure vertical velocity (omega) during the case study.

## Results and Discussion

The OND (MAM) rainfall amount recorded in Kenya in the year 2010 (2011) was examined with respect to the rainfall climatology of the respective seasons over Kenya.

The long term mean (LTM) (Figure 2) indicates that the country receives bimodal rainfall with MAM reporting more rainfall as compared to OND (Figure 3). This is in agreement with the previous studies (e.g., Camberlin and Okoola, 2003; Owiti, 2012). The analysis further shows that in year 2010, OND rainfall was below normal, whereas during 2011, MAM rainfall was noted to be below normal (Figures 2 and 4). The rainfall failure in the two consecutive seasons led to the severe drought observed in the early 2011.

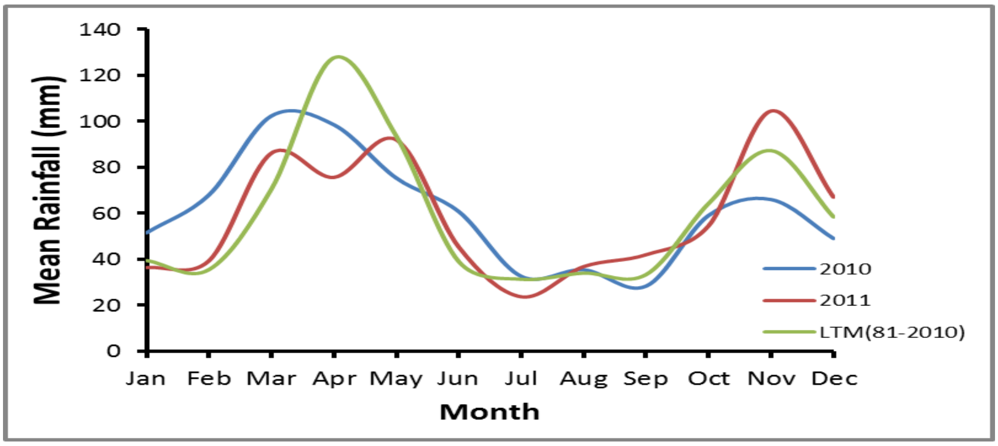


**Figure 2:** The annual cycle of rainfall over Kenya, (averaged between longitudes 33°E – 42°E and latitudes 5 °S – 5°N), showing the climatology of the annual cycle (LTM) based on the period 1981 - 2010, the annual cycle of year 2010 (exhibiting OND drought) and the annual cycle of year 2011 (depicting MAM drought).

Figure 3 presents the long term rainfall over Kenya for the two seasons: OND and MAM, against OND (2010) and MAM (2011) respectively.

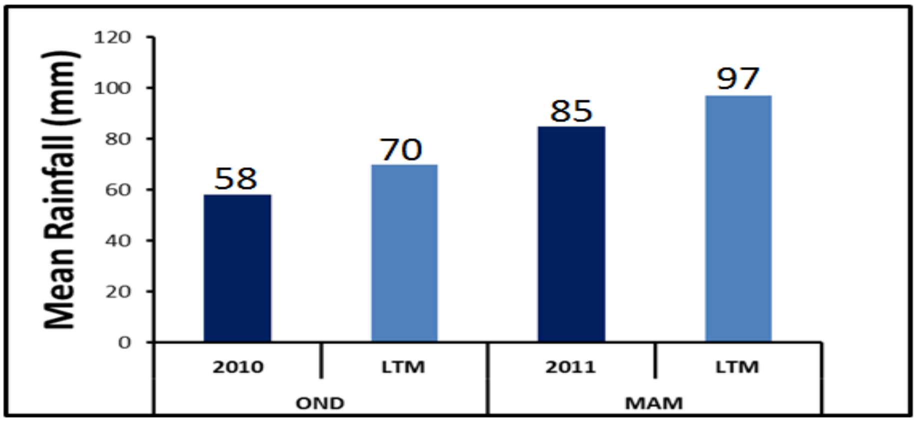


**Figure 3:** Mean rainfall over Kenya (averaged between longitudes 33°E - 42°E and latitudes 5°S - 5°N) for both OND (2010) and MAM (2011). The LTM denotes the long term mean.

Figure 4 displays the spatial distribution of OND and MAM rainfall, with the respective biases during 2010 and 2011. Results indicate the most of the regions in Kenya experienced drought conditions (widely spread), especially during 2010 OND season (Figure 4c), with exception of the northwestern region of the study area. During 2011 MAM season (Figure 4d); drought was mainly experienced in the southern sector of Kenya, with a higher anomaly magnitude.

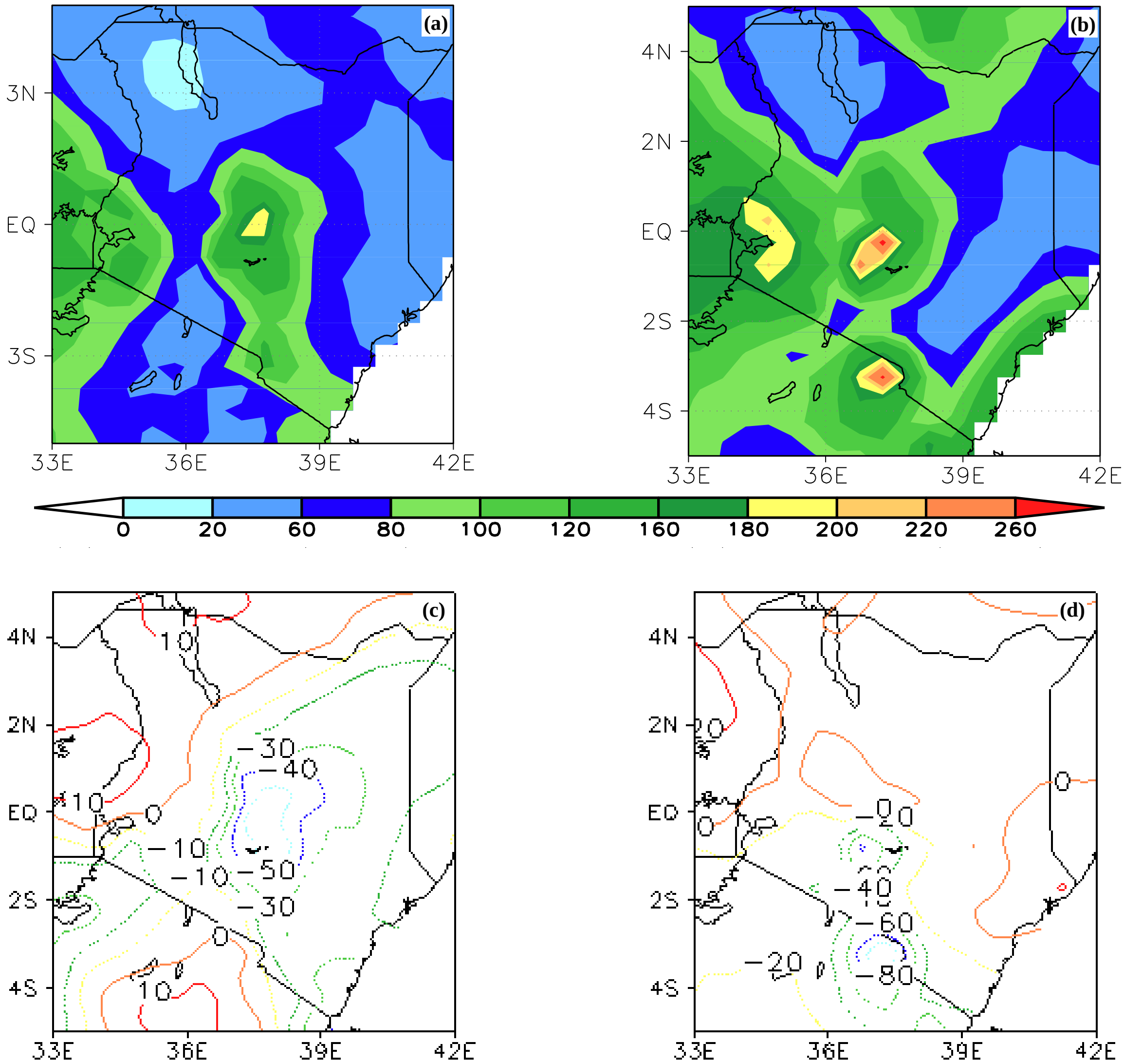


**Figure 4: (a)** Climatology of OND rainfall based on the period 1981-2010 **(b)** Climatology of MAM rainfall **(c)** OND rainfall bias (2010 OND rainfall minus OND rainfall climatology) during year 2010, and **(d)** MAM rainfall bias (2011 MAM rainfall minus MAM rainfall climatology) during year 2011

Further investigation of the moisture transport and convergence/divergence reveals that generally, the western Kenya region is a region of low level moisture convergence during the two rainfall seasons. This could be attributed to the presence of Lake Victoria in the region as well as the hilly orography. The observation in the western region leads to high rainfall in comparison with other localities in the country, which is in agreement with Indeje et al. (2001).

In the year 2010, a divergence was mainly observed in the low levels especially in the eastern and western parts of the country (Figure 5c). Although the western parts of the country experienced a low level convergence during MAM, the south easterlies that partly transport moisture from the Indian Ocean were generally observed to be very strong as compared to the seasonal climatology. The condition reduced the chances of low level convergence leading to a reduced rainfall. The combination of the two phenomena led to the observed drought in 2010 – 2011 over most parts of the country.

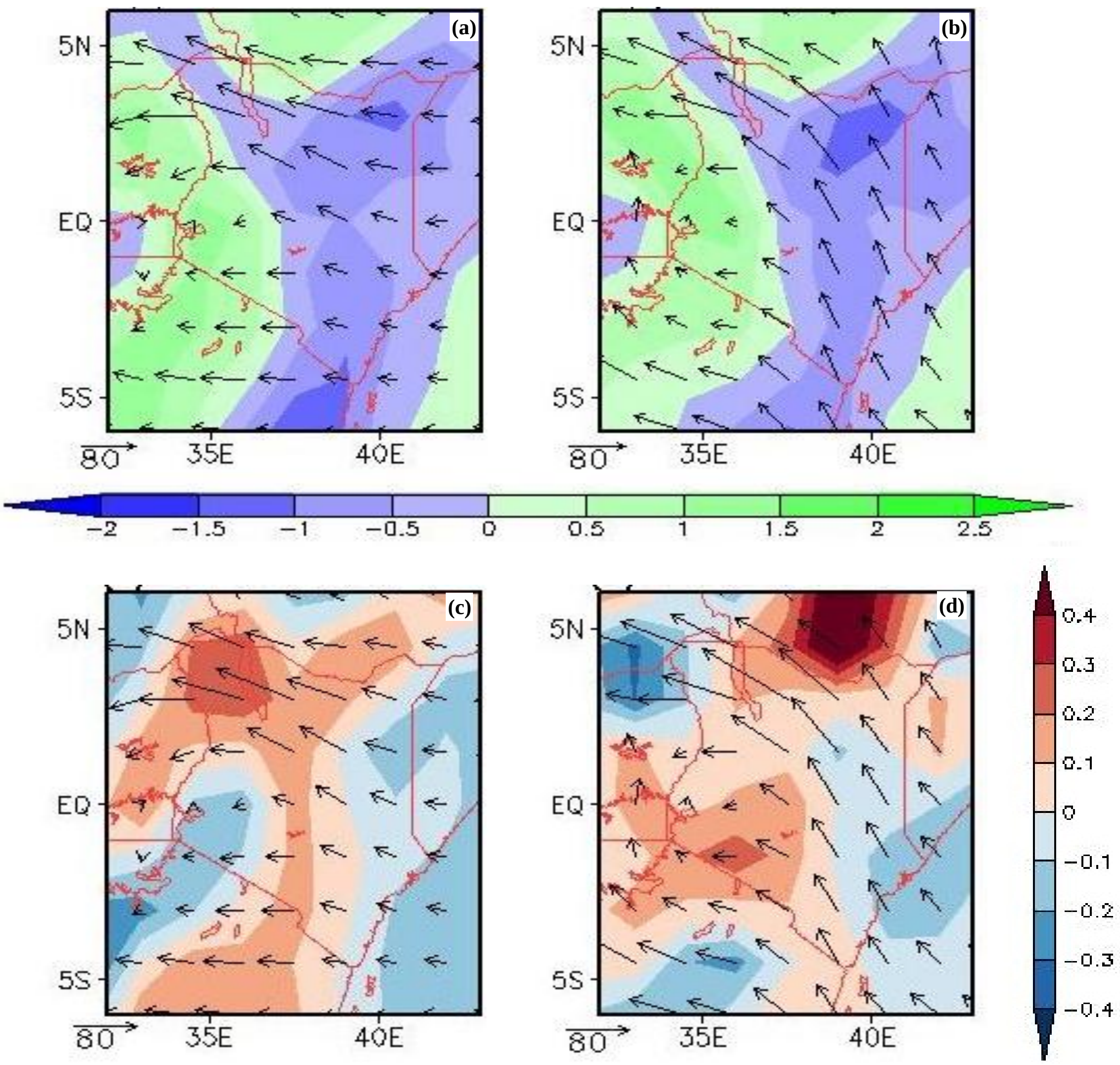


**Figure 5:** Climatology of water vapor/moisture transport (MTR) at 850hpa in g kg-1ms-1 over the period 1981-2010 **(a)** for OND **(b)** for MAM. The shaded regions indicate moisture convergence (Positive), moisture divergence (negative), and the vectors show water vapor transport. **(c)** OND MTR anomaly for year 2010 season and **(d)** MAM MTR anomaly for year 2011season. Vectors indicate water vapor transport, whereas moisture convergence (divergence) is shaded with positive (negative) anomaly.

According to Lu and Takle (2010), there is a high positive correlation between precipitation and relative humidity at interannual timescale. The analysis of the relative humidity (Figure 6) during OND season (2010) and MAM season (2011) revealed that the relative humidity had negative normaly in the northeastern sector of the study area, as opposed to the western sector which exhibited above normal relative humidity (Figures 6c and d). This was consistent with the observed positive anomaly of rainfall in the western sector (Figures 4c and d). The northeastern region; a semi-arid area as reported by Ogwang et al. (2015), Davies et al. (1985), Mutai et al. (1998), Ongoma (2013), Owiti and Zhu (2012). The area is inhabited by pastoralists generally receives the lowest rainfall in the country, below normal rainfall thus causes serious economic loss through death of livestock (Ogallo and Oludhe, 2009; Huho et al., 2011).

The seasonal migration of the ITCZ mainly controls the seasonality of the rainfall observed in the region, as displayed in Figure 2; bimodal rainfall regime. On the other hand, the influence of ENSO on rainfall over the study area varies between La Nina and El Nino events. The years 2010/2011 experienced strong La Nina events, which are associated with drought in the entire East African region, hence the observed dry conditions.

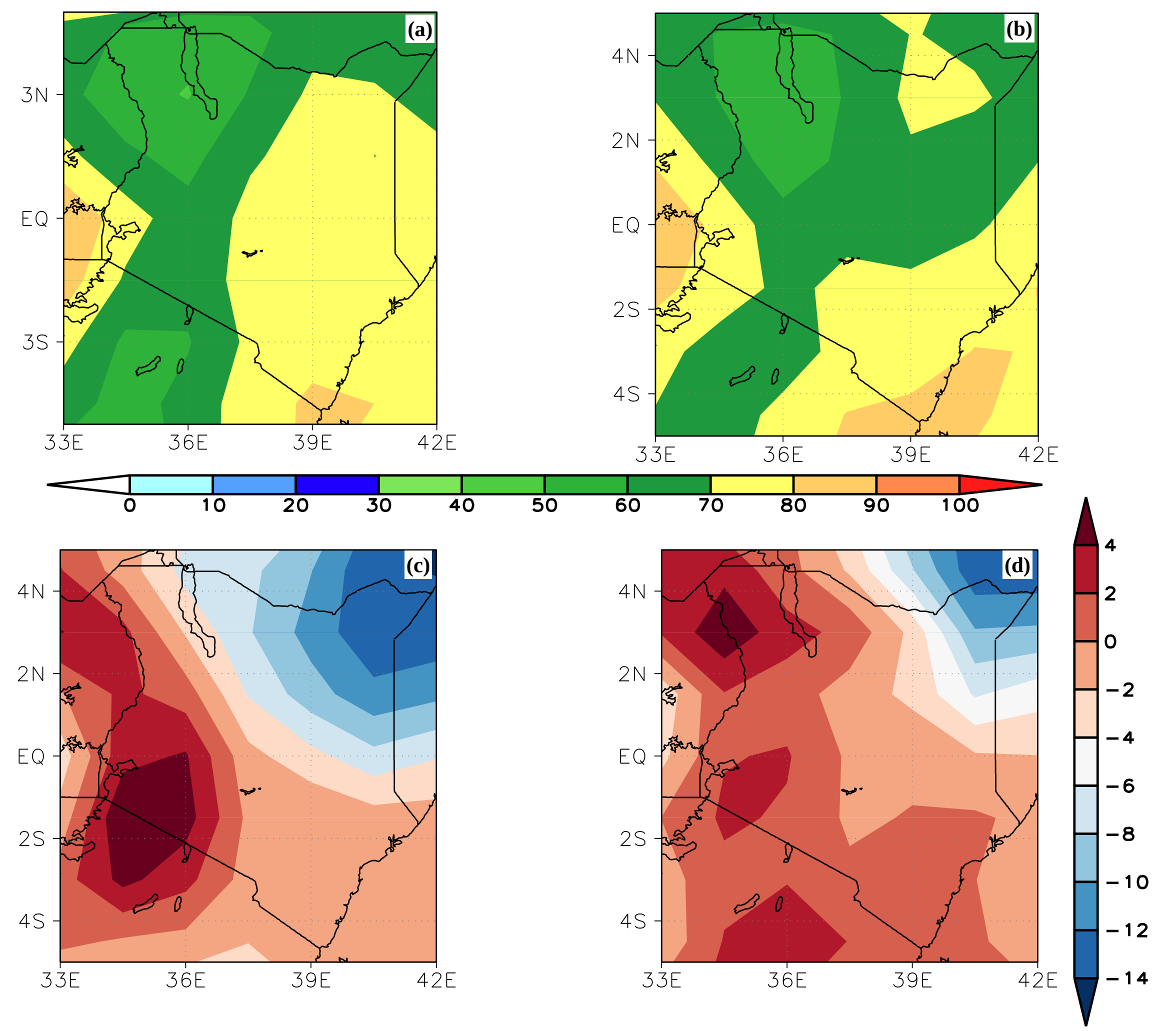


**Figure 6:** Climatology of relative humidity (RH) (shaded in %) at 850 hpa over the period 1981-2010 **(a)** OND season **(b)** MAM season **(c)** The RH anomaly for OND season (2010) , and **(d)** The RH anomaly for MAM season (2011).

## Conclusion and Recommendation

The observed rainfall in OND 2010 and MAM 2011 was below normal with respect to the respective LTMs.

The low level divergence was observed during the 2010 OND especially in the eastern and western parts of the country. Although the western parts of the country experienced a low level convergence during MAM, the south easterlies that partly transport moisture from the Indian Ocean were generally observed to be very strong as compared to the seasonal climatology. The condition reduced the chances of low level convergence leading to reduced rainfall. The combination of the two phenomena led to the observed drought in 2010 – 2011 over most parts of the country. Relative humidity was observed to exhibit negative anomaly in the northeastern sector of the study area, as opposed to the western sector of the country, especially during the OND of 2010 as compared to MAM of 2011.

Monitoring of similar phenomena should be done keenly in future especially during seasonal weather forecasting to detect the possible occurrence of drought for planning purposes.

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