Determination of October to December Seasonal Rainfall Variability, its Seasonal Onset and Cessation Dates in Zanzibar, Tanzania

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Abstract: This study aimed in determining the October to December (OND) rainfall variability, seasonal onset and cessation dates in Zanzibar, Tanzania. The study used 10 years daily rainfall (2012–2021) and 30 years monthly rainfall datasets obtained from six meteorological stations. Other climate parameters of Sea Surface Temperature (SST), Winds, Relative Humidity and Vertical Velocity having temporal resolution of 30 years (1992-2021) were also used. Rainfall seasonal variability was analyzed using Climatological mean and Empirical Orthogonal Function (EOF) analysis, onset and cessation dates was calculated using Cumulative percentage anomalies. The composite analysis was taken to examine the atmospheric circulation anomalies associated with OND seasonal rainfall. The study revealed that; OND season is characterized by normal to moderate rainfall variations from region to region with its peak marked at November (mid-season). Despite the slight differences over both Islands, average onset dates occur on third dekade of October (22^{nd} – 25^{th}) and cessation dates on the second dekade of December (i.e.10^{th} -12^{th}), indicating a maximum duration of 55- 60 days and makes a cycle of the short rains. The atmospheric circulation anomalies of SST, Winds, Relative Humidity and Vertical Velocity during wet years are linked with low level unstable moist winds originated from Congo basin. These anomalies are organized and converges with maritime north easterly winds from the Indian Ocean (mostly over the northern coast of Tanzania, including Zanzibar) and becoming a potential cause for rainfall during the season, while during dry years, the winds diverge as a result of dryness over the region. Therefore the results indicates that convergence (divergence) of the northwesterly to westerly, easterly and southeasterly flow contributed to the early(late) wetness (dryness) over Zanzibar and its surroundings. The study results will help to enhance the improvement of short rains seasonal onsets and cessations forecasts and improve the socio - economic activities over Zanzibar and Tanzanian at large.

Keywords: *Onset, Cessation, Rainfall, Sea Surface Temperature, Zanzibar*

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1. Introduction

Number of published studies have realized the rainfall to be major and important meteorological weather and climate parameter. It is a significant source to improve both qualities and quantities of daily and long-term socio-economics of the rain-fed countries including Kenya, Uganda, Tanzania, and Zanzibar in particular. Most socio economic sectors including Industry, Domestic, Agriculture, food security energy, and water supply as well as hydropower generation highly depends on the availability of enough amount of water, and conducive environment for their sustainability. This was particularly linked to inter-annual rainfall variability, as documented by (Jury, (2002) and Yonah et al., (2023). The study of Banchiamlak and Mekonnen, (2010) defined rainfall variability as the degree of the rainfall variation in terms of amount, space and time. The properties which makes it to be an important climate characteristic of an area. For instance, March to May (MAM) rains is characterized by abundance, good coverage and longtime rains as compared to October to December (OND) seasonal rains which are less abundant, short and poorly distributed rain in the

Islands (Camberlin & Okoola, 2003; Kai et al., 2020). Also it is well reported by Kai et al., (2020) and Nicholson, (2016) that Zanzibar agricultural activities are rain- fed and by 85% acts as determinant of their most economics. Other important mentioned rainfall indices for farmers in agricultural activities are rain onsets and cessation (Oguntunde et al., 2012). Basically, the seasonal rainfall onset and cessation may provide an estimates of success or failure of agricultural crops production as noted by Yonah et al., (2023). Therefore, Climate is being mostly important factor in determining the agricultural potential based on rainfall characteristics, such as onset, cessation and the length of the rainy seasons in Tanzania and Zanzibar being particular.

Indeed, in East Africa; some publicized studies including (Camberlin & Okoola, 2003) reported the difficulties on identification of onset and cessation of the rain seasons. However, a number of methods have been developed (and continues to be developed) to reduce or remove these difficulties in Africa as well as East Africa including Tanzania, Zanzibar. Currently about 18 methods have become useful in West Africa (Fitzpatrick et al., 2015). For instance, the studies of Atiah et al., (2021); Boyard-Micheau et al., 2013; Camberlin et al., 2009; Camberlin & Okoola, 2003; Dunning et al., 2016; Kamara, 2016; Kijazi & Reason, 2005; Marengo et al., 2001; Mugalavai et al., 2008; Tumaini, 2009) used the percentage cumulative mean rainfall model and in regional bases. These models were linked with local, atmospheric and oceanic circulations in its variations (Recha et al., 2012). Ferijal et al., (2022) on identifying dry spells, on their seasonal onset/cessation analysis, related their impact of dry spells on planting dates and crop productions. In this regard, due to limited documentation of scientific studies in rainfall variability, onset and cessation, particularly Zanzibar, there is a needs for clearly understanding the climate knowledge of the seasonal rainfall patterns by examining the variability, onset and cessations dates. These phenomenon are vital in determining the economics and contribute to the development ideas that would guarantee in increasing agricultural production, poverty eradication, food security and uninterrupted power supply through drought/flood mitigation strategies. Specifically the study aimed to (i) determine the spatial and temporal OND rainfall variability, (ii) examine the climatological status of the atmospheric circulation patterns (climate anomalies) of Sea Surface Temperature (SST), vertical velocity, winds, and relative humidity (RH) at upper and lower level (850hPa &200hPa) and its influence in rainfall over an area, and (iii) determine the onset and cessation dates of the OND rainy season over Zanzibar.

2. Materials and methods

2.1. Study area

Zanzibar (Unguja and Pemba) (Fig. 1) is located in the South Western Indian Ocean (SWIO) basin, east coast of Africa. These Islands are composed of number of small islets which includes Tumbatu, Kojani, Fundo, Kisiwa panza among others. The Island of Unguja is situated in grid points between 5.75˚S - 6.5˚S, and 39˚.27˚E - 39.53˚E and for Pemba in 4.93˚S - 5.28˚S and 39.67˚'E - 39.73˚E respectively. The climate of Zanzibar as reported by (Francis & Mahongo, 2012; Kai et al., 2020; Kai, et al., 2021) falls under the tropical climate with two rainfall regimes; long rainfall regime observed between mid-March to May (MAM), and short rainfall regimes observed between mid-October to early December (OND) (Mugalavai et al., 2008). The rainfall regimes as described by Camberlin & Okoola, (2003) are greatly concurred with the northward or southward movement of Inter-Tropical Convergence Zone, ITCZ which also influence early/ late onset and cessation of the seasonal rains.

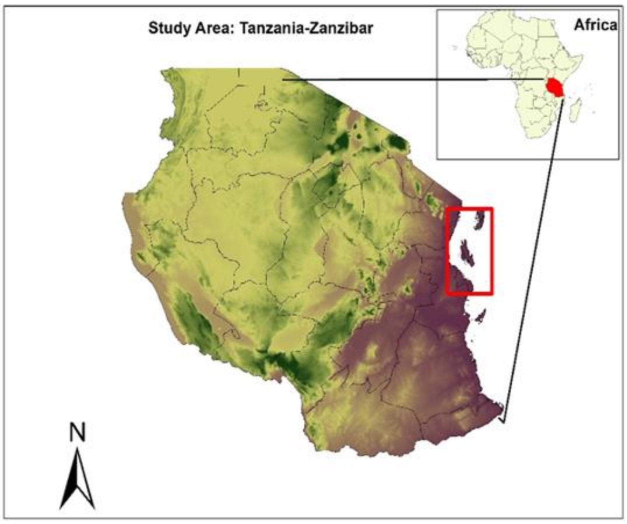

Figure 1: Geographical location of Zanzibar, a case study within Tanzania (red rectangular box).

Several factors have been documented to influence rainfall characteristics of an area ranging from mesoscale to global scale including; the meso-scale circulation induced by Oceans, Inter-Tropical Convergence Zone, and the moist Congo Air masses (Hamisi, 2013; Ininda, 1994; Mugalavai et al., 2008), positive polarity of the Indian Ocean Dipole, IOD (Mahongo et al., (2011); Zorita & Tilya, (2002)) defined by (Kai, 2019) as sea surface temperature (SST) gradient anomalies between the western (50˚- 70˚) E and (10˚S - 10˚N) and southeastern (90˚- 110˚) E and (10˚S - 0˚N) of equatorial Indian Ocean, ENSO; El Nino (warm ENSO) and La Nina (cold ENSO) events as recognized by Kai et al., (2020); Kijazi & Reason, (2005); Nicholson, (2017) and Ogallo, (1988) which impacts OND rainfall variations in Zanzibar and act as interaction between the atmosphere, land and sea. Monsoonal flow is also stated to impacts the short rains which accompanying with the northeast monsoon flow while the long rains are accounted by southerly to southwesterly and southeasterly monsoon winds (Kai, 2019).

2.2. Data sets

To achieve the stated objectives, the study used observed daily data with 10 years (2012 - 2021) and monthly total rainfall of 30 years (1992-2021) life span, collected from six meteorological stations of the Tanzania Meteorological Authority (TMA). The daily and monthly observed data were used to calculate the October to December (OND) seasonal onset and cessation dates and its average rainfall values to understand the climatological status in monthly and seasonal rainfall distribution in Zanzibar, Tanzania. Reanalyzed data of Global Extended Reconstructed Sea Surface Temperature version v5 (ERSST v5) (Borhara et al., 2020a; Huang et al., 2017) obtained from National Oceanic and Atmospheric Administration, National Climate Data Centre (NOAA, NCDC). Additionally, monthly Meridional and Zonal wind (v &u), Relative humidity at higher and lower levels (850hPa & 200hPa), and vertical velocity were acquired from ERA 5, the fifth generation of the ECMWF. These datasets have high spatial and temporal resolution of 0.25o x 0.25o from 1992 to 2021 in horizontal grid spacing and the vertical layers of 137 in 1-h interval with more than 240 physical parameters available (Tang et al., 2023). The stations used for the observed datasets for Unguja Island include Kisauni (Zanzibar airport), Kizimbani agro-met, and Kilombero, while for Pemba Island the stations include Mkoani, Wete and Matangatuani.

2.3. Methods

The study use the empirical orthogonal function, EOF analysis (Ame et al., 2021a; Makula & Zhou, 2022; Yosef et al., 2017) to examine the OND spatial patterns of rainfall distribution over Zanzibar (Unguja & Pemba) Island state using EOFs and the temporal variations of the climate modes of precipitation patterns presented by principle components, PCs (Addo et al., 2017; Philippon et al., 2010) from 1992 to 2021. EOF analysis, uses covariance matrix, R (equation 1) to decompose the time-spaced data into spatial patterns and associated time indices derived from matrix, M in (equation 2) respectively, and the eigenvalues of the covariance matrix was then founded by (equation 3). Then time series for principal component also been derived by projecting original data series into eigenvectors by (equation 4) (Lorenz, 1956). Therefore, it helped to find a first strength variation leading mode (spatial and temporal) and the latitudinal circulations related to wet and dry years (Vigaud et al., 2009).

$$R = \frac{1}{n-1} M'^{T} M' \quad (1)$$
$$M = [Mt_x] n \times p \quad (2)$$
$$RE_i = E_i \lambda_{tx} \quad (3)$$
$$A = M'E \quad (4)$$

Whereby; R represent the covariance matrix of rainfall values, M^' the rainfall anomaly, M^('^T) the p*n transpose matrix of M^', 〖Mt〗_x rainfall amount collected at the time (t =1, 2… n) in station (x =1, 2… p), Ei the ith eigenvectors, λ_tx the eigenvalues and A is the principal components matrix with an element called principal components, PCs representing the coefficients time series of each EOF mode in its anomalies. The composite years with threshold of standardized anomaly of greater than +1 and less than -1 (1997, 2006, 2011, 2017, 2019) and (1996, 2001, 2005, 2008, 2010, 2020) of the time series, PC1 in the EOF 1 mode of OND rainfall were clearly selected as wet and dry years respectively. Composite analysis of sea surface temperature SST, winds, Relative humidity, velocity potential and geopotential anomalies were done during wet and dry composite years to study atmospheric circulation patterns (anomalies) that influence rainfall during OND season and the composite variables were then tested by statistical significance of the student t-test (equation 5).

$$t = \frac{\bar{X}_1-\bar{X}_2}{S\bar{X}_1-\bar{X}_2} \quad (5)$$
$$S\bar{X}_1 - \bar{X}_2 = \sqrt{\frac{(n_1-1)S^2{}_1+(n_2-1)S^2{}_2}{n_1-n_2-2}}\left(\frac{1}{n_1}+\frac{1}{n_2}\right) \quad (6)$$

Where by $n_1 + n_2 - 2$= degree of freedom, $\bar{X}$= Mean, S $\bar{X}$ = standardized error of the mean, S^2 = standard deviation. The results of the composite anomaly values are presented from 1992 to 2021 of the climatology and its basis was determined by the principal component time series (PC1 of EOF1 in Figure 4a) of the OND rainfall representation. The OND seasonal rainfall onset and cessation dates was determined using modified Liebmann (2012) method as used by (Dunning et al., 2016) for annual and biannual rainfall regimes. In using this approach, the climatological mean rainfall, Qi of each day of the year calendar and climatological daily mean rainfall, Q¯ were calculated, where i represents month series arrangements from 1 January to 31 December and noted as day (d) in calculations, then the climatological cumulative anomaly daily rainfall data on day d, C (d) was calculated by (equation 7). Also time series from climatological daily mean rainfall, climatological mean rainfall anomaly, and climatological cumulative anomaly of daily rainfall data were plotted (Figure 2) and used for determining the onset and cessation dates of OND rainy season for a period of 2012 to 2021.

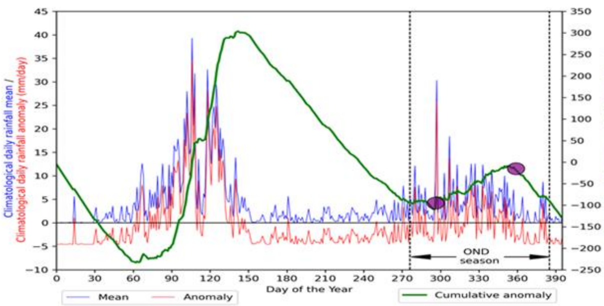

Figure 1: Zanzibar climatological cumulative rainfall anomaly curve (green) averaged over 2012–2021, Climatological daily mean rainfall for each day of the year (blue), and climatological daily mean rainfall anomaly (red). The purple dots mark the coverage of the climatological OND season.

The minimum and maximum point values obtained from $C(d)$ are used to define onset and cessation dates, in which the day of the minimum pointed value marked as the start time of the climatological water season, d_s and the maximum marked as the termination, d_t (Dunning et al., 2016). Lastly, the individual onset dates for each year are then calculated by using daily cumulative rainfall anomaly on day D, $A(D)$ by (8).

$$C(d) = \sum_{i=1Jan}^{d}(Q_i - \bar{Q}) \quad (7)$$

$$A(D) = \sum_{j=d_s-x}^{D}(R_i - \bar{Q}) \quad (8)$$

R_i represents the rainfall on day j, where j ranges from $d_s - x$ to $d_s + x$ for each year, considered as day (D) and x is the horizontal graphical point's interval (30 days interval in figure 2). Thus, the day after $A(D)$ minimum (maximum) is considered as the onset (cessation) of the rainfall duration, and the rainfall intensity persists (going to fall) after this, shown by purple dots in Figure 2. The criterion of 2 days was selected to provide enough minimum (maximum) day's points as $d_{01}, d_{c1}, d_{02}, d_{c2}$ followed by rain (dry) days to identify the onset (cessation) dates of rainy season.

3. Results and discussion

3.1. Climatology

The spatial climatological monthly rainfall distribution, Figure 3 (a, b & c) of OND shows that during OND rainy season, most areas in Pemba Island received rainfall amount more than 90 mm, whereas the higher amount was increased in November at the northern and southwestern areas, whereas in December southwestern parts of the island were mapped with peak rainfall exceeding 190 mm. As for Unguja Island Figure 3 shows more than 90 mm of rainfall was received during OND, with November having higher rainfalls of more than 190 mm mapped over the northern extending to central and western, while in December higher rainfall were mapped in the western parts of the Island. Also low average rainfall of below 80 mm was recorded during October in southern parts of the Unguja Island. These results implies that, during OND rainy season the onset (cessation) occurred earlier from northern of Pemba Island, spreading to Unguja Island as the season continued.

Figure 3(d), seasonal climatology of spatial rainfall distribution shows that the OND rainy season of both Islands (Unguja & Pemba) is characterized by normal average rainfall ranging between 90-190 mm. Moreover, higher average rainfall amounts of more than 180 mm were observed over small parts of southwestern Pemba and western Unguja, respectively. In contrast to Unguja Island, Figure 3d shows that the Pemba Island received more rainfall especially northern and southern part of the Island and this could be associated with the fact that ITCZ reached the Pemba Island earlier than Unguja as moved southward of the country as noted by (Chang'a et al., 2017; Kai et al., 2021; Okoola & Ambenje, 2003). Other studies which were in agreement to this study that Zanzibar is having more heavier precipitation records due to moisture convergence in sea breezes (Hamisi, 2013; Mahongo & Francis, 2012), while (Chang'a et al., 2010; Darmawan et al., 2021; Kijazi & Reason, 2005; Nicholson, 2019; Nicholson, 2017) noted the higher rainfall was due to the interaction the moist easterly trade winds, orographic and monsoonal circulation local circulation patterns around coastal areas, and (Kai, et al., 2021) noted that the higher rainfall was due to the occurrence of positive phases of the Madden Julian Oscillation (MJO) and Indian Ocean Dipole (IOD) respectively. In East Africa, the studies of different rainfall analysis have been done which shows the insignificant downward rainfall trends along the coastal of Tanzania as well as Zanzibar (Borhara et al., 2020a; Francis & Mahongo, 2012) that indicates the sign of having normal or below normal rainfall and were consistent with the finding observed in this study.

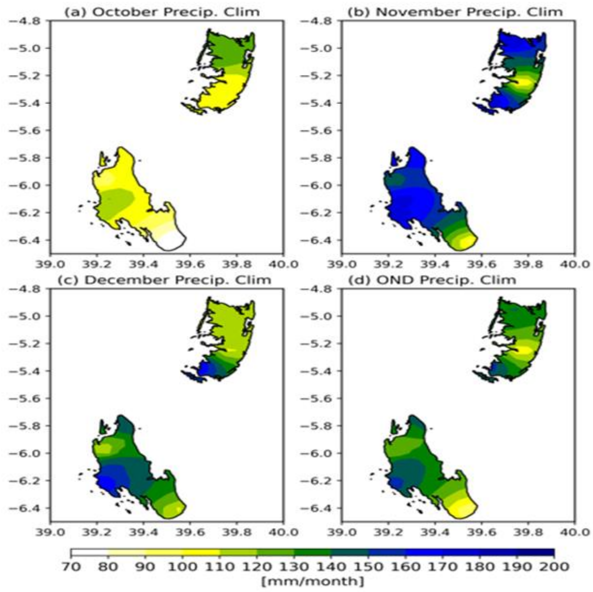

Figure 3: (a, b & c) Mean monthly, October, November and December, and (d) Seasonal Climatology of Spatial rainfall distributions from 1992-2021 (in mm) over Zanzibar.

3.2. The OND rainfall variability

The results of the spatial and temporal patterns of OND seasonal rainfalls for 1992 to 2021 using the EOF analysis presented in Figure 4(a, b& c) shows that about 87.3% of the total variance accounted by the first three EOF modes. The analysis of EOF1 mode as the most dominant, corresponds to the principal component time series (PC1) during 1992-2021 of the monthly standardized rainfall anomalies. The mode accounts for 74.6% of the total variance (Figure 4a) describes a positive loading (presence of rainfall) over the study area. The strongest and homogeneous loading was seen over entire area except for some parts of Northern and Western of Unguja island which shows the rainfall increasing, where as weak (lack of rainfall) loading observed over a tailed Northern part of the Island. As for Pemba Island, the strongest loading seen over central, and stronger ones over central and northern part. The weak loading was detected in southern part, and between the central and north of the island.

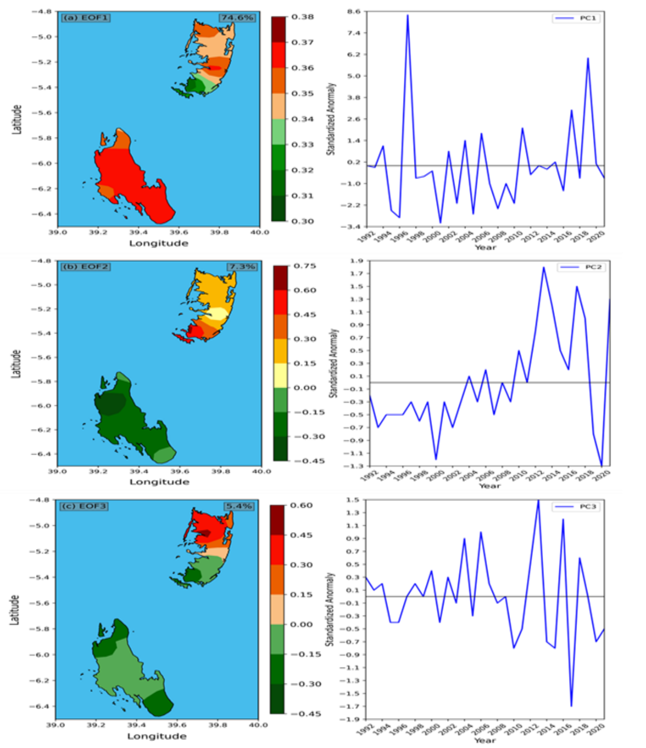

Figure 4: a) The first spatial mode, EOF1 which explains 74.6% of the total variance corresponding to time series, PC1, b) The Second spatial mode, EOF2 which explains 7.3% of the total variance corresponding to time series, PC2, and c) The Third spatial mode, EOF3 with 5.4% of the total variance corresponding to time series, PC3.

Thus, the results imply to have uniform OND rainfall variability over study area with more rainfall over the central, northern and entire area except for tailed northern parts for Pemba and Unguja, respectively. Moreover, the spatial patterns of EOF 2 (Figure 4b) and its PC2, depicts the positive and negative loading over the Islands with 7.3% of the total variance. The positive loading were seen over the entire Pemba Island. More positive strength in southern part and weak loading in central of the island, while negative loading was seen to cover the whole Unguja Island with the highest negative in north western and weak negative in northern and southern parts of the island. In EOF3 (Figure 4c), and the PC3 with 5.4% of the total variance also explains the positive loading as dominated over the northern parts including central parts of Pemba and negative loading were observed southern part, most negative and positive strength noted at small parts in southern and western, while for Unguja island was dominated by negative loading observed over the entire island though, large parts (central part) of the island seen to have light negative loading and some parts of northern and southern have strong negative loading.

3.3. Climate anomalies influencing OND rainfall over the study area

In this section, the analysis based on the seasonal climate anomalies for sea surface temperature (SST), winds, relative humidity (RH) and vertical velocity fields during OND rainy season of the selected composites wet and dry years obtained from PC1 in EOF1 as explained in section 3.2.

Sea surface temperature (SST) anomaly

Generally, the anomalous circulations in wet and dry years were connected with warmer and cooler SST that explains the presence of positive and negative precipitation anomalies in regions over the equatorial belt (Darmawan et al., 2021). It is also known as chief controller of tropical convective activities (Johnson & Xie, 2010). The composite of seasonal SST anomaly pattern for wet and dry years Figure (5 a and b) shows, SST warming anomalies over western of Indian Ocean with anomalous SST cooling over eastern India ocean during wet years (Figure 5a), while the situation reversed during dry years (Figure 5b).

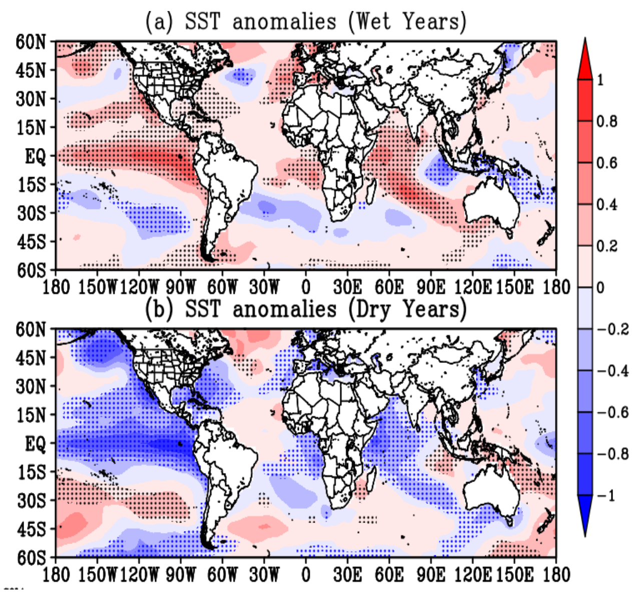

Figure 5: Composite SST anomaly (ºC) for (a) wet years (b) dry years. The shaded regions are significant at 95% confidence levels.

This result implies that, presence of warming (cooling) induced the strong cyclonic (anticyclonic) circulation anomalies. These anomalies encourages lower (upper) level convergence (divergence) as well as the ascending (descending) motions which act as a major factor representing positive (negative) precipitation anomalies over Zanzibar. Therefore, SST warming anomalies in wet years provide more moisture content transported through easterly winds anomalies to the study area. Similar findings were reported by (Ame et al., 2021a; Japheth et al., 2021) in which the warming (cooling) of SSTs in western of Indian Ocean and the central Pacific Ocean (i.e., over Niño 3.4 region) enhanced wet condition during OND season and further influenced by positive phases of IOD and ENSO condition, its extremes causes severe weather in many regions. Therefore, increasing of SST leads to heavy rainfall over east Africa coastal area as remarked by (Francis & Mahongo, 2012). Also Liebmann & Marengo, (2001) have noted the relationship between anomalies of SST and rainfall season and seems to have association with onset and cessation instead of rain scale of wet season. That is; longer (shorter) with less (more) intensity of rain season are associated with warm (cooler) SSTs (Moron et al., 2009). Thus, being late (anticipate) of SST alarm of either warming (cooling) will also results to the late (anticipate) of onset (cessation) of the rain season.

Wind anomaly

At 850 hPa low level, during the wet years (Figure 6a), Tanzania including Zanzibar are mainly controlled and influenced by warm and moist westerly winds anomalies from Congo Basin which converges much with north easterly winds anomalies from Indian Ocean. Furthermore, the observed cyclonic circulation in southern part of the country extract and strengthen the moisture transport of wind anomalies from the Indian Ocean as a result of convection which influence the rainfall to the study area. On the other hand, during dry years (Figure 6b), the north easterly winds anomalies dominated and diverge, turned to southerly and south-westerly as approached to the coast of Tanzania, and Zanzibar in particular. Though, the cyclonic circulation over central-western of Tanzania were developed from diverging winds with less moist and brings little rainfall over the study area. Again, anticyclone circulation of wind anomalies developed in east coast of Indian Ocean reduces convection as well as moisture transport from the Indian Ocean and results to little or no rainfall favored over study regions. This study results is consistent with many study findings including Ame et al., (2021a) which indicates the Indian Ocean as a significant moisture source for the OND rainfall season of Tanzania, including Zanzibar. This moisture is transported to the study regions through easterly winds. The 200 hPa upper-level composite wind vectors recognize that, during wet years (Figure 6c), south easterly winds anomaly diverges and turns to easterly and further north easterly to westerly. This situation developing an anticyclonic movement as a result of the divergence at the upper level. In contrary to wet years, during dry years (Figure 6d), the south westerly and westerly winds anomalies converges and turns to north easterly results into cyclonic circulation that tends to defeat the ascending motion as well as precipitation over Zanzibar. This finding is in agreement with Mafuru & Guirong (2018) who noted that wind convergence is due to the persistence of low pressure at low-level which goes with divergence of the wind due to the presence of high-pressure system in upper level. Ferijal et al., (2022) indicates that, the climate conditions to be mainly illustrated by wet and dry seasons which based on the sunshine period over the year. Consistent with the results (Figure 6d), Okoola (1999) showed the easterly wind anomalies in the upper levels associated with dry conditions over East Africa (Oo, 2022).

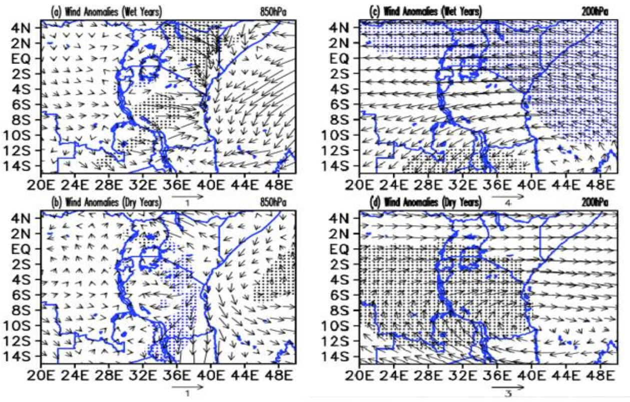

Figure 6: Composite wind anomaly vectors (ms-1) (a &b) for 850 hPa and (c &d) for 200 hPa wet and dry years. The region is significant at 95% confidence level

Relative humidity, RH anomaly

The results in Figure 7(a, b, c & d) illustrates relative humidity composite anomaly fields for the OND 1992 to 2021 climatology. At the low level, 850 hPa in Figure 7 (a & b) indicating that, during wet years (Figure 7a), high moisture distribution anomalies is seen along the coast of Tanzania including Zanzibar islands, and in most part of the country. Higher and significant moisture was seen over northeast to central of Indian Ocean indicating good onshore moist air advection as well as precipitation to the islands. Additionally, this situation can influence easterly and northeasterly flow from the ocean to the study areas as agreed by Figure 6a. In dry years (Figure 7b) the condition were reversed, the moisture content anomaly decreasing over Indian Ocean and along the south coast of Tanzania as well as central part of the country including northern and southern parts. A very little moisture anomaly observed in northern coast of the country including Zanzibar islands had very little influence of convective activities as a result of little or no rainfall over study area. For the 200 hPa higher level, during wet years (Figure 7c) show an increase moisture content anomaly along the coast of Tanzania, Zanzibar included. Also the stronger moisture contents was observed over the ocean than the coast. During dry years (Figure 7d) noted the decreased moisture anomaly over the southern coastal of Tanzania and the ocean, whereas over the northern coast, the moisture content was slightly increased. The extension of moisture distribution anomaly at (850 to 200) hPa in wet years, define a well vertical moisture distribution over coastal of Tanzania, Zanzibar in particular and provide a good sign for convective clouds formation as well as convective precipitation. During dry years, little or no precipitation depicted due to the presence of less moisture anomaly over the coast of the country as agreed by (Kai et al., 2021). The existence of large water bodies including the Indian Ocean are major and significant factor in the distribution of moisture pattern in Tanzania as well as island states. The study result is in agreement with Chang'a et al., (2010) who revealed that, South East (SE) and North East (NE) monsoons (prevailing during June to September, JJAS and October to March, ONDJFM respectively), Congo air masses and Topographic nature of the areas are other important factors modifying the moisture distribution in Tanzania, Zanzibar being particular. These factors indicating the positive influence from the ocean due to the presence of higher RH in coastal areas around the Indian Ocean. Also Chang'a et al., (2010) noted that the rainfall of more than 80 mm which was received around the coast of Indian Ocean in Tanzania including Zanzibar was due to the moisture influx from the Ocean enhanced by SE monsoonal winds which is the typical dry and cold.

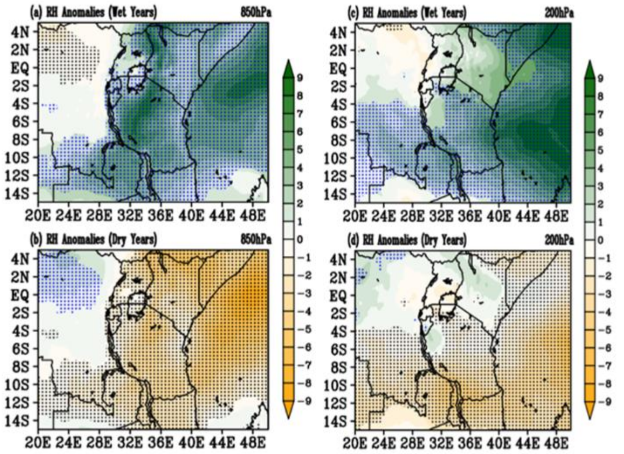

Figure 7: Relative humidity anomalies (a & b) at 850hPa and (c & d) at 200 hPa for wet years and dry years. The shaded areas indicate the 95% significant confidence level.

Vertical velocity anomaly

Vertical Velocity is documented as the rising and sinking of air (Wang, 2002). Figure 8 (a, b, c & d) presents the composite anomalies in cross- section of vertical velocity for wet and dry years of OND 1992 to 2021 period at a fixed latitude and longitude. The result revealed that, at fixed latitude and longitude for wet years Figure 8(a &c), the regions are characterized by strong upward motions (negative values) extends from lower to higher level and provide a favorable condition for cloud formation that leads the precipitation during OND season. On the other hand, during dry years Figure 8(b & d) experienced downward motions (positive values) extending from lower to higher level that obstruct the formation of the rain cloud as well as precipitation. The negative (positive) values imply relative ascent (descent) of air that enhanced inflow (outflow) motion. Our study finding is in line with Japheth et al., (2021) who realized the relative ascent pointed as location of the ascending arm of the Walker Circulation over Indian Ocean in East African region which enhances convection of easterly winds and warm moist Congo air masses, leading to the rainfall events within the study area. Also Nicholson, (2018) revealed that, the areas of ascent are associated with the surface positions of the ITCZ and are also evident in association with topographic peaks and the areas of low-level subsidence (descent) are largely linked with the areas of low-level divergence or at mostly very weak convergence. Thus, the above low level (850 hPa), the strong ascent (descent) over wet (dry) years reached into the upper level lengthened (shortened) the latitudinal rain belt over the Islands.

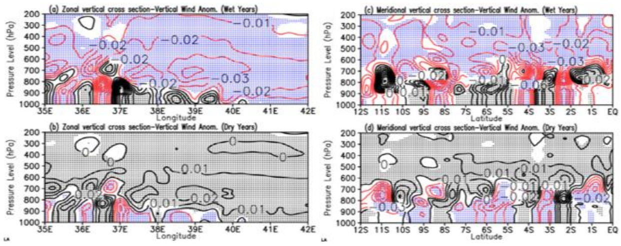

Figure 8: Vertical Velocity anomaly (Pas -1) (a & b) at fixed longitude (39o E) and (c& d) at fixed Latitude (6oS) for wet years and dry years. The area is significant at 95% confidence level.

3.4. Onset and cessation dates of October to December, OND rainfall season analysis

The onset and cessation dates for October to December, OND 1992 to 2021 can be seen in Figure 9 (a to f) with slight differences in some stations over both Islands. Over Unguja Island, Figure 9 (a, b & c) indicates the rainfall onset dates in the first half of the time period 2012 - 2016 falls within the third dekades of October and first dekades of November for all stations while the second half years period 2017 -2021 earlier rainfall onset dates started within the first dekade of October to the first dekade of November was observed at Zanzibar Airport and Kizimbani stations with earliest year 2019. At Kilombero station, the onset date was observed in second dekade of October to the first dekade of November and 2019 the late onset was noted within the first dekade of November. On the other hand; much earlier cessation dates counted in Kilombero rainfall station compared to the other rainfall stations which observed between the second dekade of November and the first dekade of December. In Zanzibar Airport and Kizimbani meteorological stations, the cessation dates were determined within the third dekades of November and the first dekades of the January. Moreover, the length of the rainfall season was seen to be increasing over Zanzibar Airport station throughout the years and the longest observed at 2019 similar to Kizimbani station in which the rainfall length was observed to expand over recent years and near consistently over early year's period. At Kilombero station at year 2021 the false (undefined) cessation date was noted which result unclear information of the station.

As for Pemba Island, Figure 9 (d, e &f) shows the earlier rainfall onset dates in northern of the island stations; Matangatuani and Wete which coincide with Zanzibar Airport and Kizimbani stations occurred within the first dekades of the October and November and much earlier in 2019. The onset dates of the Mkoani station starting from second dekade of October to second dekade of November and the late onset in 2019 also observed started in second dekade of November which shorten the length of the rain season of the station. On the other hand, the cessation dates of the stations were observed around second dekade of November at Matangatuani to the first dekade of January as observed in Mkoani rainfall station. The length of the rainfall season of Wete station seen to be longer over a period of the years compared to the other stations and the longest observed over 2019 similar to Matangatuani station and the shortest observed at Mkoani at 2018 with the rainfall start within the late of the first dekade of November and lasts within the early first dekade of the December. Kai et al., (2021) who revealed 2019 OND rainfall seasons, the Island states (Unguja and Pemba) characterized with earlier than normal onset with higher chance of wetter conditions and also downscaled forecast for 2019 OND of TMA noted that the onset and cessation dates take place on second week of October and fourth week of December which fully agrees with study findings.

Generally, over both islands the mean rain onset dates ranges between first dekade of October and the late second dekade of November with an average onset date falls within the early third dekade of October (22^{nd} – 25^{th}). Similarly, mean cessation dates were observed between the second dekade of November and the first dekade of January with an average cessation date within second dekade of December (10^{th} -12^{th}) for a period 2012- 2021. That is, early onset and delayed cessation results lengthened of the rainy season and the opposite leads to shortened the rainy season, as documented by Sivakumar, (1987) and also can leads to years with higher than normal rainfall, El-Niño (Francis & Mahongo, 2012). This result reveals a good depiction and agreement of the onset and cessation dates as derived from the method explained above. Moreover, the studies done by Okoola, (1998b); Camberlin & Okoola, (2003); Recha et al., (2012); Borhara et al., (2020) reported that, the patterns of rainfall onset dates as well as cessation dates were attributed by local factors including hills, convective activities, Hadley circulation and seasonal immigration of the Intertropical Convergence Zone (ITCZ) on both sides of the equator which is mostly control the fluctuation between wet and dry years. The climate change is also being reported by Feng et al., (2013), IPCC, (2014); Kebacho, (2021) and USAID, (2014) to modify the rainfall magnitude, seasonal distribution and interannual variability in tropics, causes seasonal deviation and result to an increase of uncertain timing of the rainy seasons. Chang'a et al., (2017) have reported an annual timescale percentage increase of mean temperature anomaly, in warm days (nights), and a decrease in cold days (nights) in most regions in Tanzania including Dar-es-Salaam, Zanzibar, Mtwara, Mbeya and Kilimanjaro by 0.69˚C, 9.37%, 12.05%, 10.00%, and 7.64% respectively. This affect the onset and cessation of the rainy season which are unequal over years (Salack et al., 2011) whereby, greatly, farmers can face the difficulty to adjust the period for planting seeds as well as the length of the growing season (Olaniran, 1983; Mugalavai et al., 2008; Ndomba & Wambura, 2010).

Also Mugalavai et al., (2008) recognized that, during the month of November to December, the North Easterly winds become predominate, originated from Arabian high-pressure Centre over the subcontinent of Arabian and Indian as a dry wind which also seen to diverge over East Africa, Zanzibar in particular as in (Figure 6b). It is then providing clear understanding on why cessation take place during this period. As documented by Kai et al., (2021), the seasonal variability and shifting of the onset and cessation significantly impacts the economics of the key sectors like water supply in dams, lakes, rivers and ponds and further affect the agricultural activities including land preparation, crops choice to grow, seeding, weeding, spraying, irrigation etc.. These impacts weakens the food security situation in Tanzania including Zanzibar (TMA climate Outlook For OND, 2022 Rainy season) and also early warning of onset and cessation (Owusu et al., 2017). Other impacts was recognized at energy sector, mineral extraction, and livestock keeping due to the decline of seasonal rainfall. Apart from the impacts, rainfall act as potential source of recharge of the underground water as well as aquifers.

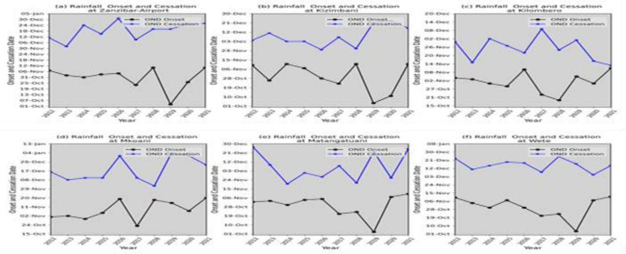

Figure 9: Time series of rainfall onset and cessation dates of short rain, OND (black and blue solid lines, respectively) for Unguja & Pemba islands meteorological stations in Zanzibar from 2012- 2021.

4. Conclusion

This study was conducted to examine OND seasonal rainfall variability as well as onset and cessation dates in Zanzibar, based on 1992 to 2021 rainfall climatology. The rainfall variability was examined using EOF analysis, mean onset and cessation dates were determined using the modified Liebmann (2012) analysis. Mean monthly and seasonal climatology of spatial rainfall distributions (in mm) are also calculated. The study reveals that:

The spatial climatological rainfall distribution of the 30 past years (1992 -2021) shows normal rainfall OND season over both Islands (Unguja & Pemba) with amount ranging between 90 mm and 190 mm in average, the highest rainfall amounts exceeding 180 mm and the lowest amount less than 110 mm were also recorded. The significant increasing of rainfall was mapped in November and decrease in October. Empirical Orthogonal Function, EOF comes with the maximum and minimum mode accounted 74.6% and 5.4% respectively of their total variances. The maximum mode noted with positive loading (presence of rainfall) over Unguja Island. The strongest and homogeneous seen over the entire area, stronger in some part and weak loading (lack of rainfall) over a tailed northern part of the island. For Pemba Island, the strongest loading was observed in central and northern part while weak loading observed between central and northern part and also southern part of the Island.

The composite analysis of the atmospheric circulation anomalies of Sea Surface Temperature, meridional and zonal wind, relative humidity, vertical velocity investigated in wet and dry years shows the wet years are linked with low level unstable and moist winds originated from Congo basin, organized and converges with maritime north easterly wind from the Indian Ocean mostly to the northern coast of Tanzania, Zanzibar included and become a potential cause for rainfall during the season.

During OND, Zanzibar Islands (Unguja & Pemba) shows a slight difference of the rain seasonal onset and cessation dates. Both Islands have average onset dates within early third dekade of October (22nd – 25th) and average cessation dates within the second dekade of December (10th -12th) for a period of 2012- 2021. This indicates a figure of maximum duration of 55- 60 days which makes the cycle of OND, short rains. Usually, it is known; the OND seasonal rain onset and cessation date's starts in October and ends up in December where by the rain- depended activities are mostly done including rain-fed agricultural systems and other socio- economic sectors. These findings have greatly implications in socio-economic activities including rain-fed agricultural practices as a main economic depended of the country, food security as well as water resource management. Also, study come up with better and improved forecasts dates of rain onset and cessation in Zanzibar. Accurate forecasts guiding the people's development including social – economic sectors and impacts associated with. Further; the study on variability of onset and cessation and it forecast for both seasonal rainfall, Long rain; March, April, May and Short rain; October, November, December is under considerations to reduce dates uncertain for water related economic development purposes.

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