Tanzania Journal of Science 49(5): 1110-1126, 2023
ISSN 0856-1761, e-ISSN 2507-7961

Quantifying the Strength of the El Niño Southern Oscillation and the Indian Ocean Dipole in Influencing the OND Rainfall Season in Tanzania

Benjamin William Ongito[1] and Paul TS Limbu[1,2*]
[1]*Department of Physics, University of Dar es Salaam, P. O. Box 35063, Dar es Salaam, Tanzania*
[2]*Environmental and Atmospheric Sciences Group, University of Dar es Salaam, Tanzania*
** Corresponding Author: E-mail addresses: paul.limbu@ymail.com; Mobil: +255654615275*
Received 23 Jul 2023, Revised 18 Oct 2023, Accepted Dec 2023, Published Jan 2024
https://dx.doi.org/10.4314/tjs.v49i5.14

Abstract

The current paper examines the strength of variability between the El Niño-Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) in influencing October to December (OND) rainfall over the bimodal rainfall regime of Tanzania. The empirical orthogonal function (EOF), correlation analysis, and composite analysis were used during the data analysis. The results show more rainfall distribution over the western part of the Lake Victoria basin and to the peripheral of the northern coast of the country, thus suggesting that, during the OND rainfall season, the onset starts in the western part of the Lake Victoria basin, then spreads to the rest of the areas under investigation as the season progresses. Furthermore, on the spatial scale, the findings revealed that there is a strong correlation between IOD and ENSO indices and OND rains in the northeastern highlands. Furthermore, a robust temporal correlation is revealed between the mean OND rains over the bimodal rainfall areas and IOD (r = 0.70) compared to ENSO (r = 0.62). The anomalous warming over the western Indian Ocean (positive IOD) has a faster response to OND rains over the bimodal rainfall regime of Tanzania compared to the remote influence induced by anomalous warming from the central equatorial Pacific Ocean (warm phase of ENSO). Meanwhile, dry years are associated with negative IOD and the cold phase of ENSO conditions. The findings offer valuable insights on strategies for mitigating the effects associated with extreme weather events and improving resilience in Tanzania.

Keywords: *OND Rainfall, Bimodal Rainfall Region, ENSO, IOD, Tanzania*

Introduction

Tanzania is among the East African countries whose economy and livelihoods of her people mainly dependent on rain-fed agriculture. Rainfall is known to be vital to all socio-economic sectors such as fisheries, water resources, hydroelectric power generation and infrastructures. According to NBS 2022, rain-fed agriculture in Tanzania is the primary source of livelihood for about 65.3%of the population, and agricultural sector account 26.9 % of the National Gross Domestic Product (GDP). Therefore, understanding the inter-annual variability of rainfall and the likely dominant climatic indices during the October to December (OND) rainfall season over the bimodal rainfall areas of Tanzania will have an added advantage towards improving the people's livelihood and the nation's economy as a whole. The nature and extent of rainfall variability have received considerable attention from several researchers in Eastern Africa. For example, Rozanski et al. (2019) and Liu et al. (2020) linked the East African rainfall patterns to the movement of the

Intertropical Convergence Zone (ITCZ), indicating that bimodal rainfall over Tanzania is influenced by the movement of ITCZ between October and May.

Numerous researchers (e.g., Indeje et al. 2000, Hastenrath 2007, Mbigi and Xiao 2021) have revealed that the El Niño Southern Oscillation (ENSO) plays a significant role in determining the monthly and seasonal rainfall patterns in Tanzania and East Africa, with warm events being associated with high rainfall and cold events with low rainfall. It was, however, noted that the robust relationship between the East African rainfall is found to be during the OND rain season and weak from March to May (MAM). ENSO also influences seasonal rainfall's onset, secession, and peaks (Nicholson 2017). The warm ENSO phase is associated with high and low pressure over the western and eastern Indian oceans, respectively, resulting in enhanced westerly cooling over the western parts of the ocean. The negative phase has the opposite effect, leading to enhanced rainfall over the western Indian Ocean and East Africa (Hastenrath 2007). The significant influence of ENSO on climate has motivated studies exploring its use as a predictor of climate in the region and beyond. The approaches that use ENSO as a predictor start by forecasting ENSO and follow it with possible impacts, which depend on the strength of ENSO (Wang et al. 2013).

A study by Behera et al. (2005) showed a coherent association of the Indian Ocean Dipole (IOD) with several flooding events across the East African region. Another study by King'uza and Limbu (2019) associated the wetness and dryness conditions during the OND rainfall season with the Indian Ocean Walker Circulation. King'uza and Limbu (2019) noted that the wetness (dryness) condition is linked with the rising (descending) limb of the Walker circulation over the western Indian Ocean (WIO). During positive Indian Ocean Dipole (IOD) events, the Walker circulation cell over the Indian Ocean is well-defined and more comparable than it is during El Niño years. In El Niño years, the Walker circulation cell becomes weaker than in positive IOD events, where the zonal winds strengthen, resulting in active convective activities over the WIO. IOD and the related Indian Ocean Zonal Mode are sea surface temperature (SST) modes that have been observed to significantly influence rainfall over the region and other areas neighbouring the Indian Ocean (Yamagata et al. 2004, Ajayamohan and Rao 2008, Otieno et al. 2018). The IOD is caused by air-sea interactions in the tropical Indian Ocean, leading to the warming and cooling of the western and eastern tropical Indian Ocean during the positive and negative phases, resulting in the reversal of SST gradients and changes in the zonal wind currents (Clark et al. 2003, Saji and Yamagata 2003, Behera et al. 2005).

The warm (cool) condition in the western (eastern) Indian Ocean is associated with enhanced (deficient) OND seasonal rainfall over East Africa (Saji and Yamagata 2003, Mafuru and Guirong 2018) resulting from the anomalous changes in Walker circulation over the Indian Ocean that lead to anomalous moisture transport and convergence (Behera et al. 2005). However, ENSO events that co-occur with IOD events are more robust than those that occur (Saji and Yamagata 2003, Behera et al. 2005). Similarly, the IOD events that co-occur with ENSO events are more potent than those that occur independently (Behera and Yamagata 2003, Behera et al. 2005). Some studies have indicated that the IOD is not related to ENSO (Annamalai and Liu 2005, Kug et al. 2005, 2006), while others have indicated some relationships (Meyers et al. 2007), and some have indicated that some events are independent of ENSO but some co-occur with ENSO (Kug et al. 2006).

Despite the fact that previous research has indicated the potential impact of both ENSO and IOD on global and regional climate patterns, there is a lack of in-depth analysis focusing on their joint effects on Tanzania's bimodal rainfall regime during the OND season. Although several studies (e.g., Hastenrath 2007, Mbigi and Xiao 2021) have investigated ENSO and IOD's effects on various aspects of climate, there is currently no comprehensive assessment quantifying the relative intensity of these two phenomena and their interactions on the specific target region's rainfall patterns. This paper intends to bridge these voids by providing a comprehensive analysis of the connection between ENSO, IOD, and OND rainfall patterns in Tanzania. This entails evaluating the individual and combined strengths of ENSO and IOD, analysing their potential interaction effects, and quantifying their impact on the bimodal rainfall regime during the OND season. The results of this paper could contribute substantially to the understanding of regional climate dynamics and to the development of climate resilience strategies in Tanzania.

The remaining parts are subdivided into the following sections: Materials and methods are detailed in Section 2. The results and discussion are explained in Section 3. The final remarks of this study are addressed as the conclusion in Section 4.

Materials and Methods

Description of the study area

The study domain comprises the bimodal rainfall regime of Tanzania, encompassing the northern sector extending from latitudes 2° to 6° S and longitudes 32° to 40°E (Figure 1). The area is characterised by the northwest to southeast mountain ranges, including the highest mountain in Africa (i.e., Mount Kilimanjaro), and extends from the western Indian Ocean to Lake Victoria. The region experiences two main rainy seasons, the *Masika* (March, April, and May) and the *Vuli* (October, November, and December) rains, commonly associated with the ITCZ. Generally, the weather and climate over northern Tanzania are mainly influenced by monsoons, the ITCZ, subtropical anticyclones, African jet streams, and easterly and/or westerly wave perturbations (Chang'a 2021). In addition, teleconnections with global-scale systems like ENSO and regional systems play an essential role. At the same time, the climatic conditions in northern Tanzania are notably influenced by the two major anticyclones, the Arabian and Mascarene high-pressure systems in the northern and southern Indian Ocean, respectively (Nkurunziza et al. 2019, Vizy and Cook 2020).

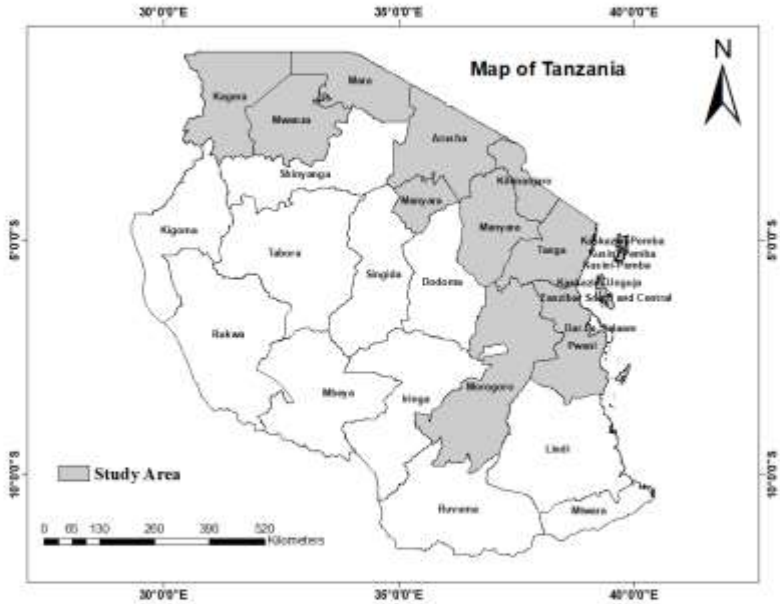

Figure 1: Map of Tanzania showing the location of the meteorological stations used over the study area (the shaded area of the bimodal rainfall regime).

Sources of data

This paper utilised the monthly rainfall data sets from 12 synoptic stations located over the bimodal rainfall regime (Figure 1) sourced from the Tanzania Meteorological Authority (TMA) based on 1981–2010 climatology. The average seasonal rainfall values for the OND season are computed from the monthly observed data sets. The monthly mean sea surface temperature data were obtained from the National Oceanic and Atmospheric Administration (NOAA) with a 2.0˚ latitude-longitude resolution, which is retrieved from https://psl.noaa.gov/data/gridded/data.noaa.ersst.v5.html. Based on the SST anomalies (SSTA), the IOD indices are computed by finding the difference between the West Tropical Indian Ocean (WTIO) and the South East Tropical Indian Ocean (SETIO). The WTIO region is defined by the domain 50°E–70°E, 10°S–10°N, while the SETIO region is 90°E–110°E, 10° S–0°. Meanwhile, ENSO indices are obtained by averaging the SSTA data sets from the Niño3.4 (5°N–5°S, 170°W–120°W) region. To further understand the atmospheric circulation patterns, reanalysis fields from the National Centres for Environmental Prediction/National Centre for Atmospheric Research (NCEP/NCAR) were used similarly to Kalnay et al. (2018).

Data analysis

The empirical orthogonal function (EOF) was used to explore the leading climatic modes from the mean OND observed rainfall over the bimodal rainfall regime of Tanzania based on 1981–2010 climatology. This analysis is frequently applied to derive patterns and indices from identifying climate modes expressed in state variables. The approaches identify patterns in space known as EOF modes in one or multiple variables from the eigenvectors of the covariance matrix for the gridded data sets. Then the original centred data are projected onto the spatial patterns to obtain time series indices (i.e., the principal components). Therefore, the first EOF spatial mode of the mean OND rainfall is then taken as the dominant mode, further explaining areas prone to wetness or dryness over the entire climatology as it was used by Mafuru and Guirong (2018).

Exploring the relationship between ENSO, IOD, and OND seasonal rains for stations over the study domain, correlation analysis was used to assess the strength of the association. To quantify this relationship over the study domain, the first principal component (PC1) was correlated with the respective ENSO and IOD indices. Furthermore, this paper employed composite analysis to assess some circulation anomalies responsible for ENSO's warm/cold phase and the positive and negative IOD phases. The critical conditions for the composite analysis of this research were the warm/cold phase of ENSO and the positive and negative IOD phases. The composite analysis method typically involves sorting data into categories and comparing their means for different groups. Over eastern Africa, the composite analysis method has been widely used for various studies (e.g., Chowdary and Gnanaseelan 2007, Jo et al. 2022) to analyse the ENSO and IOD signals.

Results and Discussion

The climatic characteristic of bimodal rainfall regime

The climatological distribution of rainfall during October (Figure 2a) based on 1981–2010 climatology shows that there are more rains in the western part of the Lake Victoria basin (mainly Bukoba) and the peripheral part of the northern coast of the country. This condition suggests that during the OND rainfall season, the onset starts in the western part of the Lake Victoria basin, then spreads to the rest of the area under study as the season progresses. During November (Figure 2b), most bimodal rainfall areas revealed enhanced rainfall with much weight in the western Lake Victoria basin. However, the coverage and abundance of precipitation recede as it progresses to December over much of the bimodal rainfall regime (Figure 2c). November marks the midpoint of the OND season and characterises enhanced rainfall over most areas, while December (Figure 2c) marks the end of the OND season. Most areas in this season receive a high amount of rainfall except for some parts of the northeastern highlands, and an enhanced amount of rainfall is well observed over the country's Lake Victoria basin and northern coastal belt (Figure 2d). This suggests that, from a climatological perspective, the Lake Victoria basin experiences a greater amount of rainfall during the OND period compared to other regions of the area under investigation, with coastal areas following closely after.

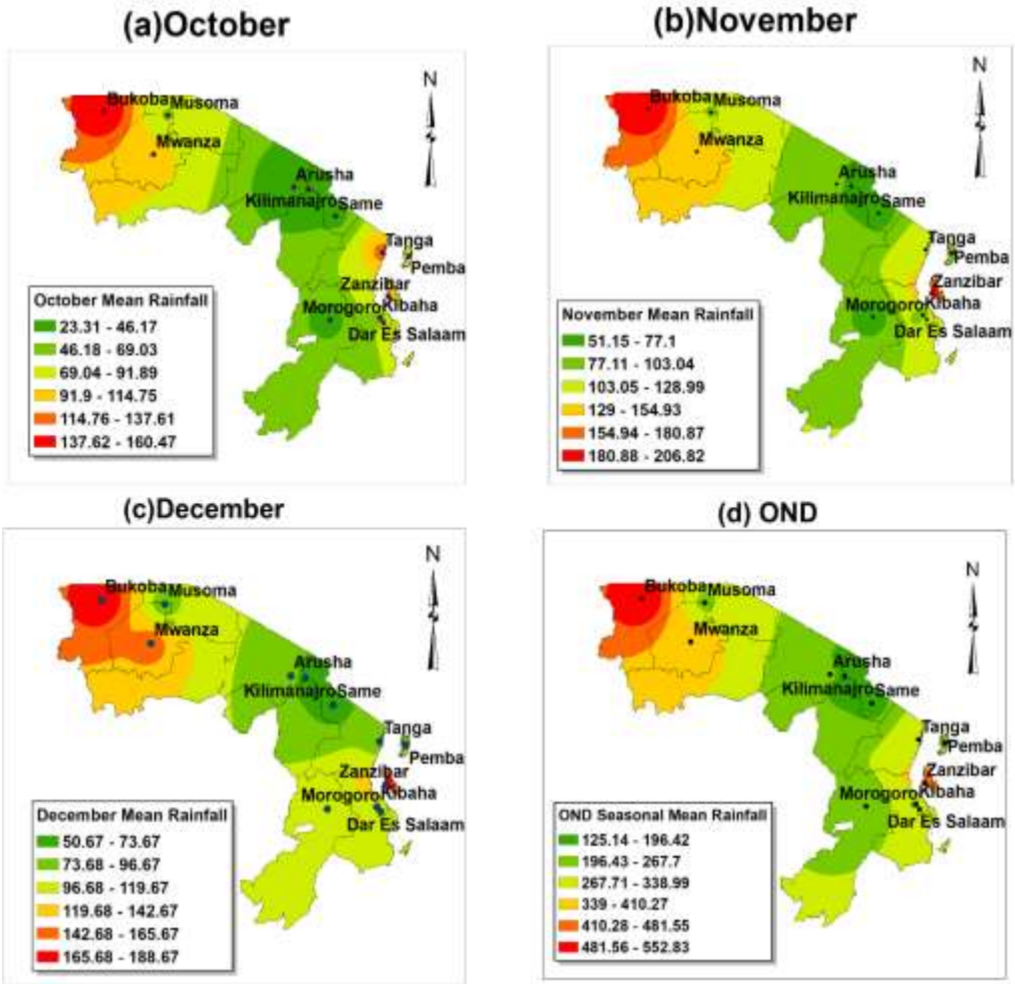

Figure 2: The spatial mean monthly rainfall distribution over the bimodal areas of Tanzania during (a) October (b) November (c) December (d) October to December (OND) based on 1981 to 2010 climatology.

The OND rainfall variability over the bimodal rainfall regime

The EOF analysis method aims to investigate the spatial and temporal variability of OND rainfall in the bimodal rainfall regime of Tanzania. The first three EOF patterns explain more than 85.35% of the total variance and therefore are more representative of the seasonal variability during the OND season. Figure 3a depicts the dominant mode (EOF-1) and its corresponding principal component time series (PC-1, in Figure 3b) for the mean OND rainfall anomalies over the bimodal rainfall areas based on 1981–2010 climatology. The EOF-1 accounts for more than 72.19% of the total variance and exhibits the monopole mode of variability, with positive loadings directed to the majority of areas within the bimodal rainfall regime of Tanzania (Figure 3a). The most substantial positive loadings concentrate on the country's northeastern highlands and the northern coast. On the other hand, reduced loadings are well observed over the southern part of the Lake Victoria basin. The results suggest that rainfall variability over the study area during OND is uniform, with more rainfall over the western Lake Victoria basin, northeastern highlands, and northern coast with suppression to the southern Lake Victoria.

Meanwhile, Figure 4a and Figure 5a show the spatial patterns of the second (EOF-2) and third (EOF-3) modes of EOF with their corresponding principal component time series in Figure 4b and Figure 5b, respectively, during the OND rainfall season. In Figure 4a, the second mode (EOF-2) elucidates 7.51% of the overall variances, displaying a bipolar variability pattern. Positive loadings predominantly occur within the Lake Victoria basin, while negative loadings were observed across the other regions characterized by a bimodal rainfall regime. Furthermore, in Figure 5a, EOF-3 contributes to 5.65% of the total variance, showcasing predominant positive loadings in the northeastern highlands and northern coastal belt, while the rest of the region is characterized by dominant negative loadings. This situation is consistent with a study done by Borhara et al. (2020) and Ame et al. (2021) where they revealed enhanced precipitation over the northeastern sector of Tanzania. It's important to highlight that the time series of principal component scores offers valuable insights into the persistence of an EOF pattern over time. The outcomes derived from EOF-1 indicate that years exhibiting normalized heavy rainfall departures exceeding one standard deviation (>+1) were primarily recorded in 1982, 1991, 1994, 1997, 2002, 2006, and 2009.

On the contrary, years with normalised departures of less than minus one (<-1) were observed in 1984, 1988, 1992, 1996, 1998, 1999, 2007, and 2010. Some of these years (i.e., years with a strong amplitude of greater than +1 or less than −1 of the standard deviation) were then used in the composite analysis as positive/negative IOD and warm/cold phase of ENSO to find the more robust possible circulation pattern among the two indices with regards to the pronounced heavy rainfall during the study period. Generally, the spatial patterns represented in EOF-1 to EOF-3 in Figures 3a, 4a, and 5a are in agreement with the results obtained in Figure 2d, which signifies the reliable areas over the western Lake Victoria basin (mainly Bukoba), northeastern highlands, and northern coastal belt of the country receive an enhanced amount of rainfall during the season.

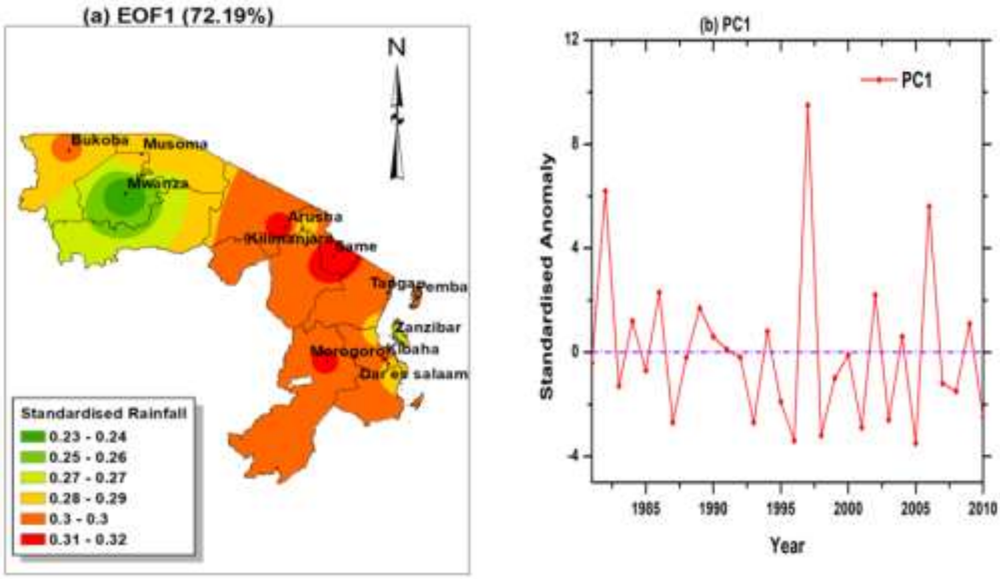

Figure 3: (a) The spatial pattern of the first EOF mode (EOF-1) and (b) its corresponding PC time series of the mean OND rainfall over the bimodal rainfall regime of Tanzania based on 1981–2010 climatology.

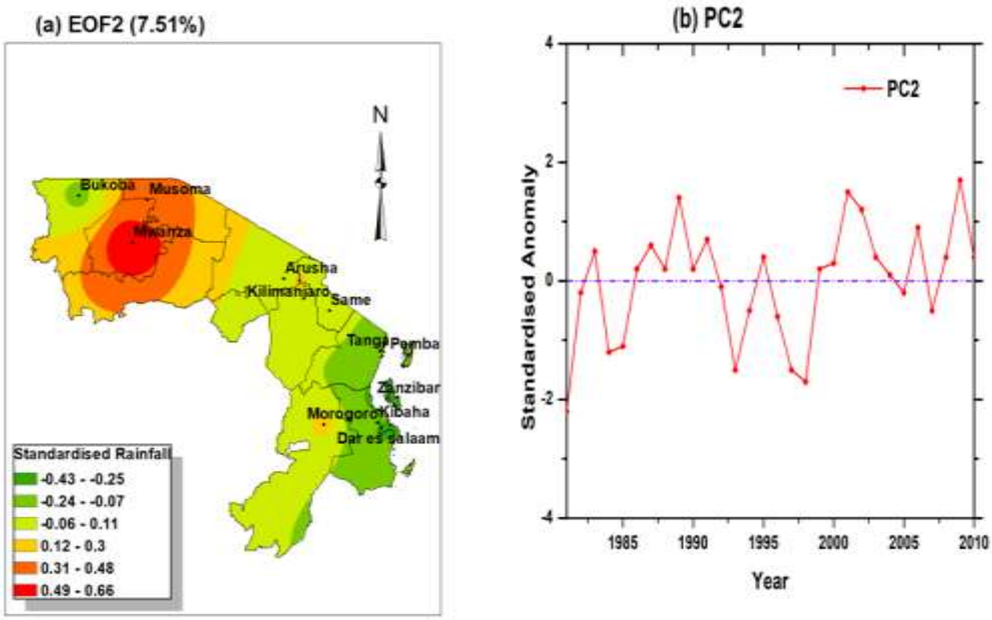

Figure 4: (a) The spatial pattern of the second EOF mode (EOF2) and (b) its corresponding PC time series of the mean OND rainfall over the bimodal rainfall regime of Tanzania based on 1981–2010 climatology.

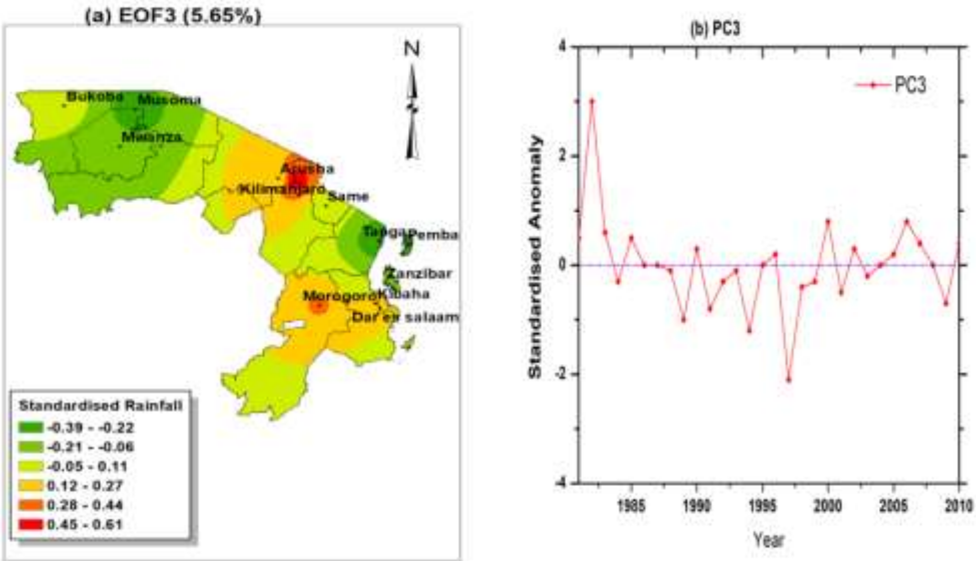

Figure 5: The spatial pattern of the third EOF mode (EOF-3) and (b) its corresponding PC time series of the mean OND rainfall over the bimodal rainfall regime of Tanzania based on 1981–2010 climatology.

The influence of ENSO and IOD on OND rainfall over the bimodal rainfall regime

This research paper carried out an in-phase correlation analysis between the IOD, ENSO, and OND rains over the bimodal rainfall regime of Tanzania. Spatially, both the mean IOD and ENSO indices during October to December are found to be well correlated with OND rains over the bimodal areas (Lake Victoria basin, NEH, and northern coast), with the strongest correlation being over the northeastern highlands (Figures 6a and 7a). Furthermore, the time series correlation coefficient between the IOD, ENSO, and OND rains shows that a strong significant correlation exists at the 95% confidence level with the IOD (r = 0.72) compared to ENSO (r = 0.62) as indicated in Figures 6b and 7b, respectively. This scenario shows that the anomalous warming over the western Indian Ocean (i.e., IOD influence) has a faster response to OND rains over the bimodal rainfall regime of Tanzania than the remote influence induced by anomalous warming from the central Pacific Ocean (i.e., ENSO influence) does.

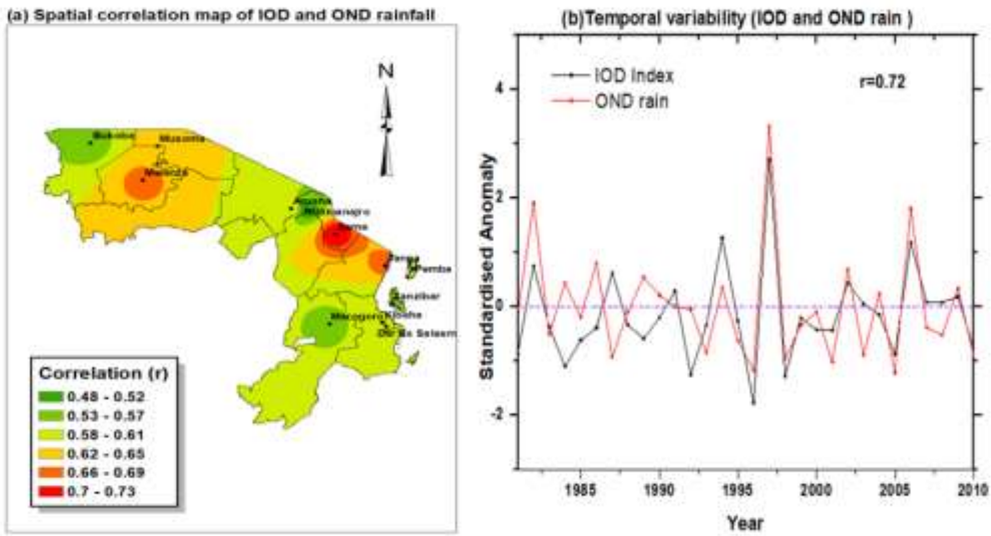

Figure6: (a) The spatial pattern of the correlation coefficient (b) temporal variability of the mean IOD indices during October to December and the OND rains over the bimodal rainfall regime of Tanzania based on 1981 to 2010 climatology.

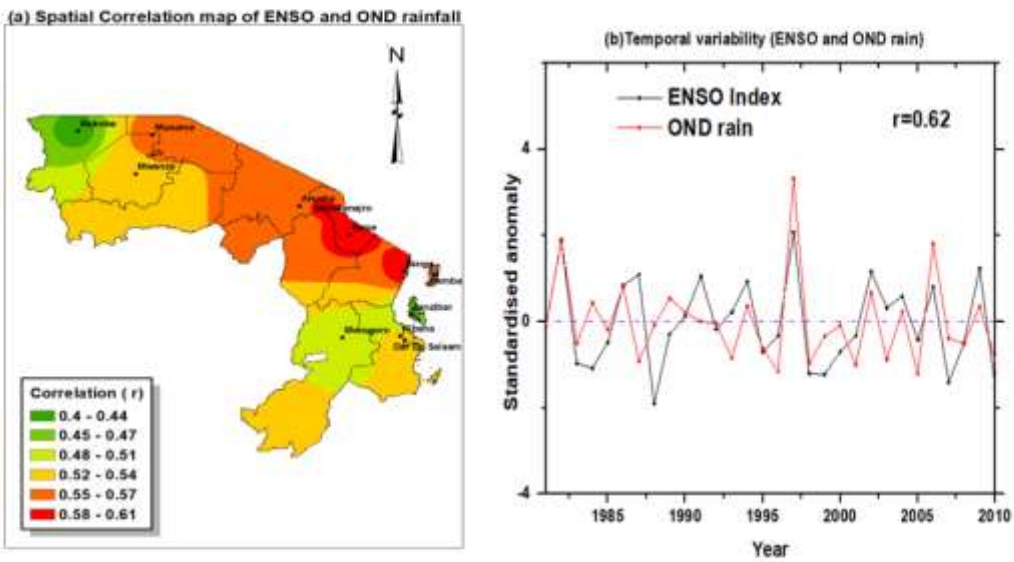

Figure7: (a) The spatial pattern of the correlation coefficient (b) temporal variability of the mean ENSO indices during October to December and the OND rains over the bimodal rainfall regime of Tanzania based on 1981 to 2010 climatology.

Circulation anomalies associated with wetness or dryness condition during OND rainfall

In order to enumerate the association between years with enhanced or suppressed rainfall and the circulation of weather anomalies over the bimodal areas of the country, a composite analysis with some of the weather parameters was performed. The basis for the composite relies on the principal component time series (PC-1, in Figure 3b) for the OND rainfall expansion. Figures 8a and 8b show the composite analysis of wind anomalies during wet and dry years at low levels (i.e., 850hPa). The results show that during wet years (Figure 8a), there is a dominance of westerly wind anomalies carrying moist air from the Congo basin converging with the moist southeasterly wind anomalies sourced from the southwest Indian Ocean (SWIO). This condition impacts ascending the air at a lower level for convective activities. The winds are, however, converging with the maritime north-easterly wind from the Indian Ocean, mainly to the northeastern highlands and northern coast of the study area, and probably being the source of enhanced precipitation during the season. This finding aligns well with the studies done by Hastenrath (2007) and Mafuru and Guirong (2018), in which they confirmed that westerly wind anomaly flow sourced from the Congo basin is associated with enhanced East African precipitation. Remarkably, significant changes are observed during dry years (Figure 8b), where the low-level south-easterly wind anomalies dominate and diverge over many parts of the country. This situation is consistent with a study by Ame et al. (2021), which revealed that convergence at a low level gives rise to vertical stretching, whereas divergence results in vertical shrinking, suppressing convection due to subsidence.

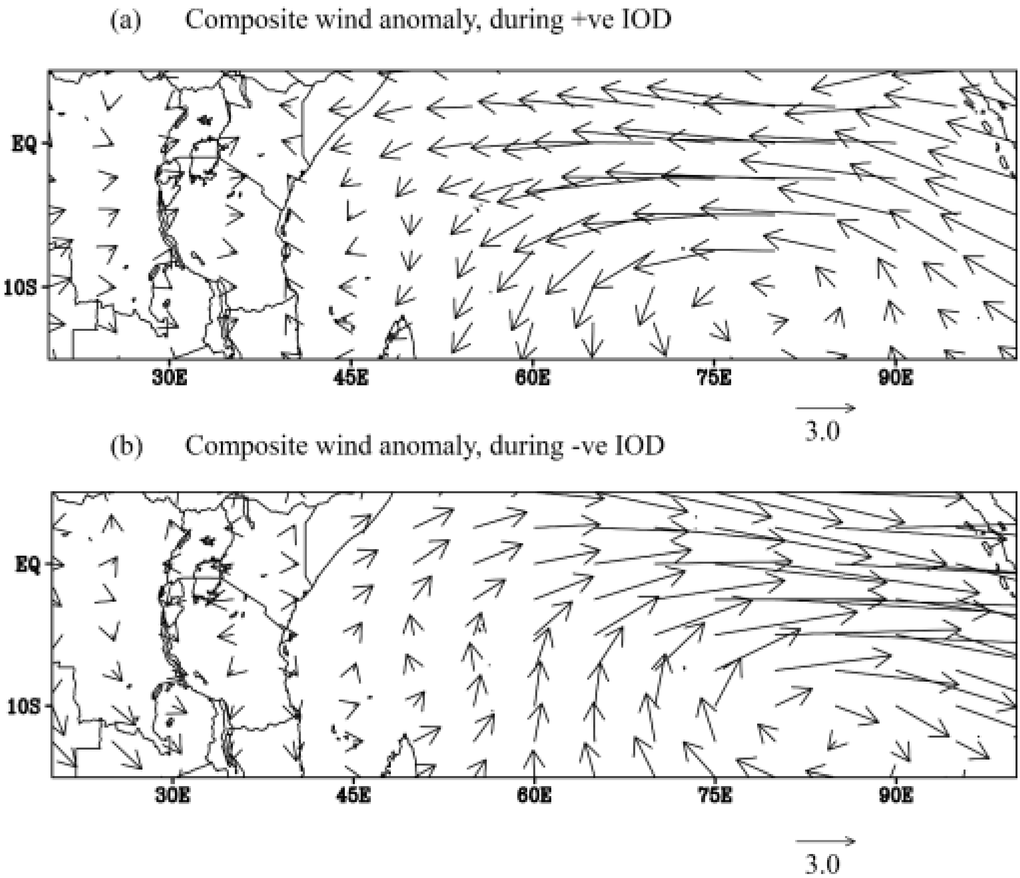

Figure8: (a) The composite wind flow pattern at 850 hPa during (a) positive IOD (b) negative IOD of 1981 to 2010 climatology.

Sea surface temperature anomaly

Figure 9a represents the composite sea surface temperature anomaly during wet years and Figure 9b during dry years. There are enhanced warm SST anomalies over the western Indian Ocean with cool SST anomalies compared to their counterparts in the eastern Indian Ocean (Figure 9a) during wet years. Also, it reveals enhanced warm SST anomalies over the central Pacific (*i.e.*, over the Niño 3.4 region; figures are not included in this research paper). This condition generally recaptures the positive IOD and warm phase of ENSO (i.e., the El Nino condition). Meanwhile, cool (warm) SST anomalies are depicted over the western (eastern) Indian Ocean during dry years, with cool SST anomalies over the central Pacific Ocean (Figures 10a and 10b). This scenario recaptures both the adverse IOD condition and the cold phase of ENSO (i.e., the La Nina condition). The pattern of the SST anomalies for the difference between wet and dry years indicated in Figure 11 also agrees that the enhanced wet condition during the OND season is influenced by both the positive phase of the IOD and ENSO conditions.

Meanwhile, the time series correlation coefficient between the mean ENSO, IOD, and the first principal component (PC1) reveals a strong correlation (r = 0.7) with IOD (Figure 11b) compared to ENSO (r = 0.62). Therefore, IOD has more strength in modulating bimodal rainfall regimes in Tanzania during the OND season than ENSO. In this case, it can be noted that anomalous warming over the western Indian Ocean has a faster response to OND rains in Tanzania compared to the remote influence induced by anomalous warming from the central Pacific Ocean.

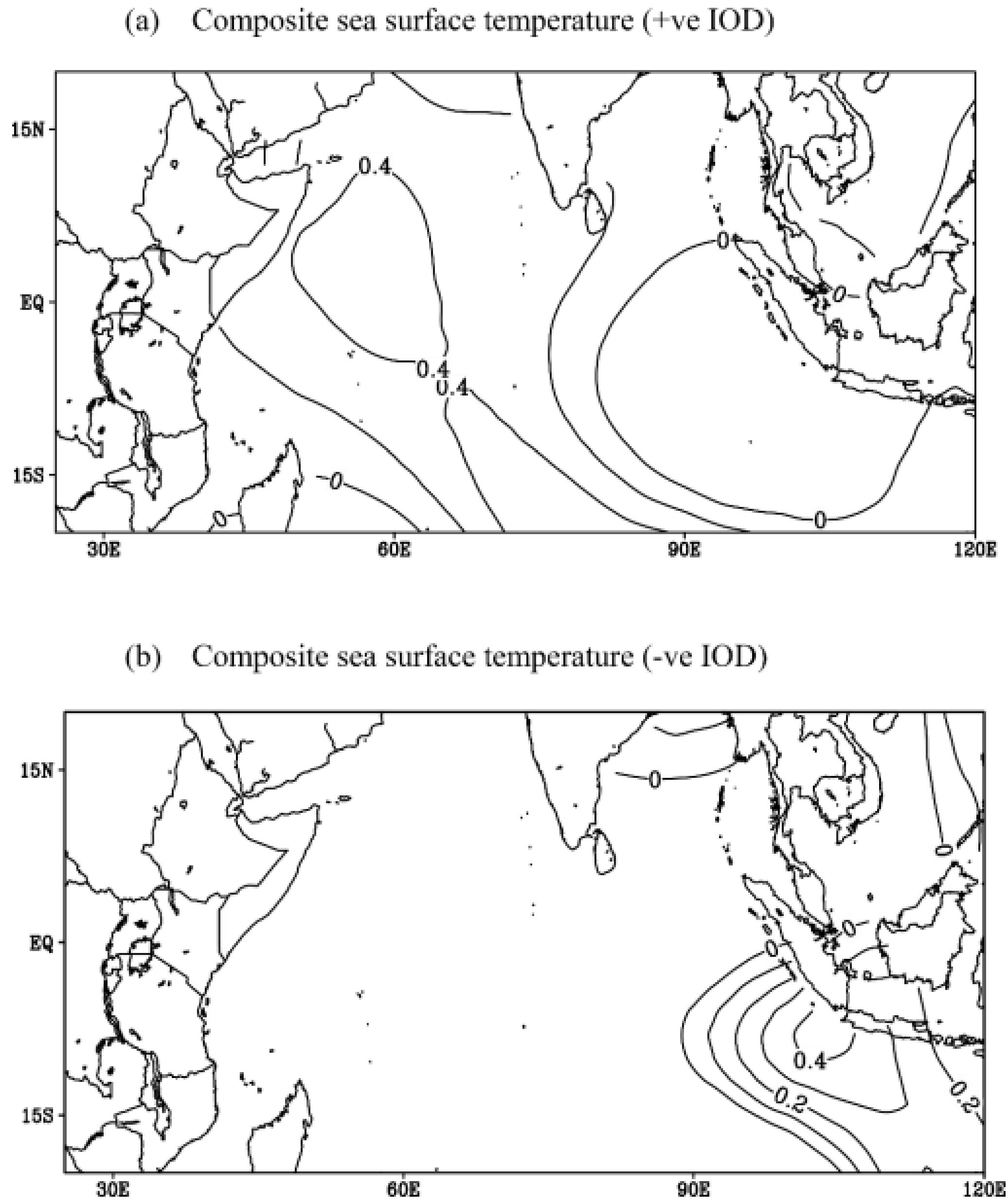

Figure9: The composite sea surface temperature during (a) positive IOD (b) negative IOD of 1981 to 2010 climatology.

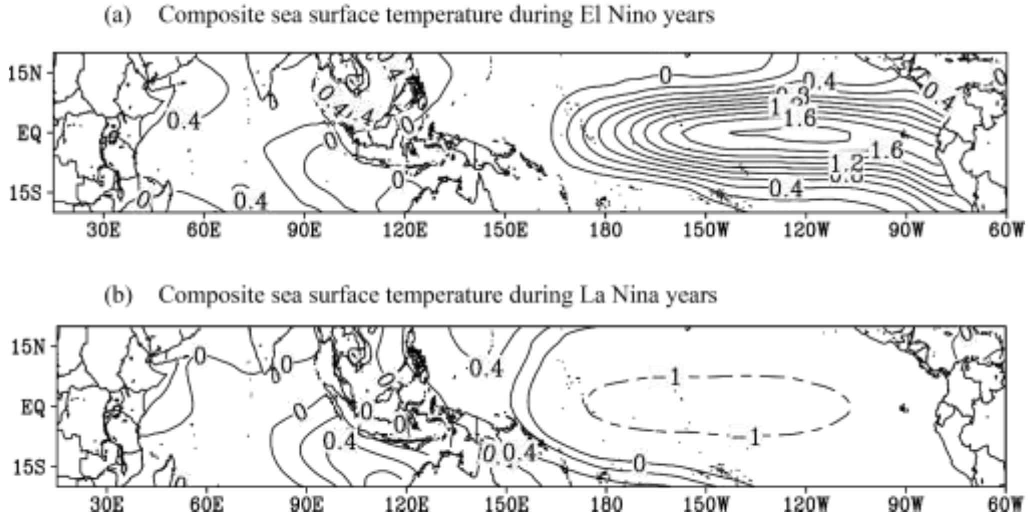

Figure10: The composite sea surface temperature during (a) El Nino (b) La Nina based on 1981 to 2010.

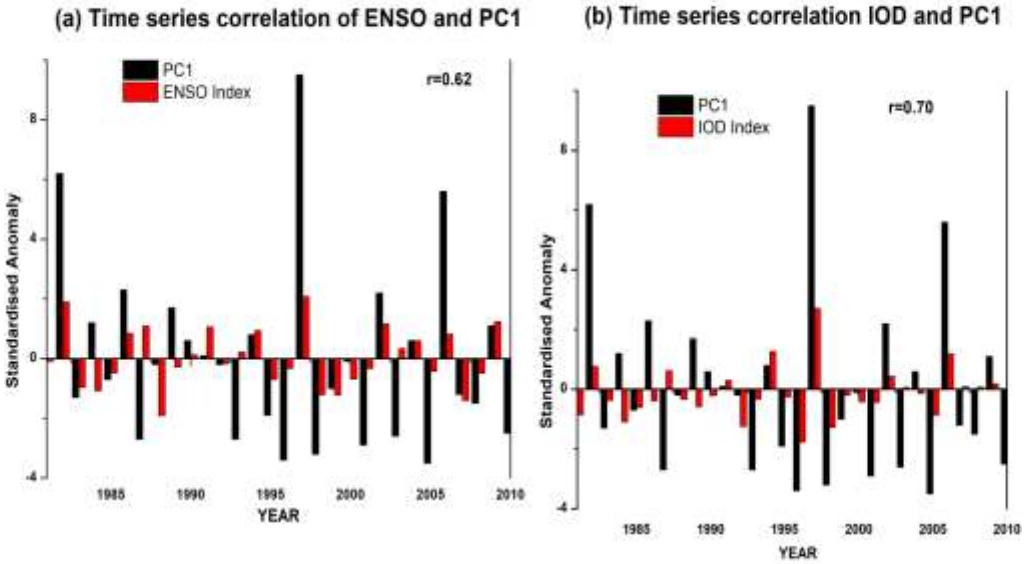

Figure11: (a) Time series correlation of ENSO with corresponding PC1 Time series and (b) Time series correlation of IOD with PC1 Time series.

Conclusion and Recommendations

This research paper investigates the influence of ENSO and IOD fluctuations on Tanzania's bimodal rainfall pattern during OND rains and the possible circulation anomalies based on 1981–2010 climatology. The results show that the distribution of rainfall during October indicates more rains over the extreme western Lake Victoria basin (i.e., mainly Bukoba) and to the peripheral of the northern coast of the country, which could be contributed by the early onset of rainfall over the western and Lake Victoria basin then spreading to the rest of the areas as the season progresses. In this case, understanding the dynamics of the onset and cessation of OND rainfall is of paramount importance and worth input for enhanced forecasting accuracy of rainfall onset and cessation, which has yet to be very elusive over the years. During November, most bimodal areas reveal an enhanced amount of rainfall with much weight to the western Lake Victoria basin. However, the coverage and abundance of precipitation recede as it progresses to December over much of the bimodal rainfall regime.

Subsequently, the study examined the circulation patterns associated with the wet and dry years during the OND season from 1981 to 2010. The observed circulation patterns indicate that wet years are coupled with the low-level moist and unstable wind from the Congo basin, which organises and forms a confluent zone (ITCZ) extending from the Congo to the northern sector of the country. These winds converge with the maritime north-easterly wind from the Indian Ocean, mainly to the study area's northeastern highlands and northern coast, and are among the potential causes of enhanced rainfall during the season.

The study also noted that wet years are generally associated with the positive IOD condition and the warm phase of the ENSO condition. On the spatial scale, it was revealed that the IOD and ENSO indices are well correlated with OND rains over the bimodal rainfall areas (Lake Victoria basin, NEH, and northern coast), with a strong correlation being over the northeastern highlands. A robust temporal correlation was revealed between the mean OND rains over the bimodal rainfall areas and IOD ($r = 0.70$) compared to ENSO ($r = 0.62$). This scenario shows that the anomalous warming over the western Indian Ocean has a faster response to OND rains in Tanzania than the remote influence induced by anomalous warming from the central Pacific Ocean does. The patterns associated with dry years are found to be linked with the diverging low-level south-easterly wind anomalies over many parts of the country. On the other hand, dry years were associated with negative IOD and the cold phase of ENSO conditions. It is crucial to comprehend the extent of variability in ENSO and IOD in order to assess their impact on the bimodal rainfall pattern in Tanzania. This understanding holds significant implications for policymaking, infrastructure planning, and the general monitoring of climate change effects on drought conditions. This research paper offers valuable insights into comprehending the features of drought in Tanzania and forecasting potential future situations.

Acknowledgements

The authors are grateful to the University of Dar es Salaam for providing a conducive learning environment and to the Tanzania Meteorology Authority (TMA) for providing a high-resolution rainfall dataset. The authors would like to thank Dr. Kantamla Biseke Mafuru for reviewing the manuscript and providing helpful suggestions for this paper.

Declaration of Interest

The authors declare that they have no competing interests.

Reference

Ajayamohan RS and Rao SA 2008 Indian Ocean dipole modulates the number of extreme rainfall events over India in a warming environment.*J. Meteorol. Soc. Japan. Ser. II.*86(1): 245-252.

Ame HK, KijaziA, Changa L, Mafuru K, Ngwali M, Faki M, HmadA and Miraji M 2021 Rainfall Variability over Tanzania during October to December and Its Association with Sea Surface Temperature (SST). *Atmosph. Clim. Sci.*11***:***324-341. https://doi.org/10.4236/acs.2021.112019.

Annamalai H and Liu P 2005 Response of the Asian summer monsoon to changes in El Niño properties. *J.Atmosph.Sci,Appl.Meteorol. Phys.Oceanogr.*.131(607): 805-831. https://doi.org/10.1256/qj.04.08.

Behera SK, LuoJJ, Masson S, Delecluse P, Gualdi S, Navarra A and Yamagata T 2005 Paramount impact of the Indian Ocean dipole on the East African short rains: A CGCM study.*J. Clim.* 18(21): 4514-4530.

Behera S and Yamagata T 2003Influence of the Indian Ocean Dipole on the Southern Oscillation. *J. Meteorol. Soc. Japan*. 81(1): 169–177.https://

doi.org/10.2151/jmsj.81.169.

Borhara K, Pokharel B, Bean B, Deng L and Wang SY 2020 On Tanzania's precipitation climatology, variability, and future projection. *Climate*. 8(2):34.

Chang'a L 2021 Climate Variability and Its Impacts in Tanzania: Climatology of Tanzania. Xlibris Corporation,

Chowdary JS and Gnanaseelan C 2007 Basin-wide warming of the Indian Ocean during El Niño and Indian Ocean dipole years. International Journal of Climatology: *J. R. Meteorol. Soc*. 27(11):1421-38.

Clark CO, Webster PJ and Cole JE 2003 Interdecadal variability of the relationship between the Indian Ocean zonal mode and East African coastal rainfall anomalies. J. *Climate*. 16(3):548-54.

Hastenrath S 2007 Circulation mechanisms of climate anomalies in East Africa and the equatorial Indian Ocean.*Dynam. Atmosph. Ocean*.43: 25-35.

Indeje M, Semazzi FH and Ogallo LJ 2000 ENSO signals in East African rainfall seasons. *J. R. Meteorol. Soc.*.20(1): 19-46.

Jo HS, Ham YG, Kug JS, Li T, Kim JH, Kim JG and Kim H 2022 Southern Indian Ocean Dipole as a trigger for Central Pacific El Niño since the 2000s. *Nat. Communicat*. 13(1):6965.

Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Iredell M, Saha S, White G, Woollen J and Zhu Y 2018 The NCEP/NCAR 40-year reanalysis project. *Renew.Energy*. 1: 146-194.

King'uza PH and Limbu PTS 2019 Inter-annual Variability of March to May Rainfall over Tanzania and Its association with Atmospheric circulation anomalies.*Geogr. Pannonica*. 23(3).

Kug JS, An SI, Jin FF and Kang IS 2005 Preconditions for El Niño and La Niña onsets and their relation to the Indian Ocean.*Geophys. Res. Lett.* 32(5). https://doi.org/10.1029/2004GL021674.

Kug JS, Li T, An SI, Kang IS, Lu JJ, Masson S and Yamagata T 2006 Role of the ENSO–Indian Ocean coupling on ENSO variability in a coupled GCM.*Geophys. Res. Lett.* 33(9): L09710. https://doi.org/10.1029/2005GL024916.

Liu C, Liao X, Qiu J, Yang Y, Feng X, Allan RP, Cao N, Long J and Xu J 2020 Observed variability of intertropical convergence zone over 1998—2018. *Environ. Res. Lett*. 15(10):104011.

Mafuru KB and GuirongT 2018Assessing Prone Areas to Heavy Rainfall and the Impaction of the Upper Warm Temperature Anomaly during March–May Rainfall Season in Tanzania. *Adv. Meteorol.*. 2018: 1–17.https://doi.org/10.1155/2018/8353296.

Mbigi D and Xiao Z 2021 Analysis of rainfall variability for the October to December over Tanzania on different timescales during 1951–2015. *Int. J. Climatol.*. 41(14):6183-204.

Meyers G, McIntosh P, Pigot L and Pook M2007The Years of El Niño, La Niña, and Interactions with the Tropical Indian Ocean. *J. Climate*. 20(13): 2872–2880.https://doi.org/10.1175/JCLI4152.1.

Nicholson SE 2017 Climate and climatic variability of rainfall over eastern Africa.*R. Geophys.*.55(3): 590-635. https://doi.org/10.1002/2016RG000544.

Nkurunziza IF, Guirong T, Ngarukiyimana JP and Sindikubwabo C 2019 Influence of the Mascarene High on October-December rainfall and their associated atmospheric circulation anomalies over Rwanda. *J. Environ.Agric.* 20:1-20.

Otieno G, Mutemi J, Opijah F, Ogallo L and Omondi H 2018 The impact of cumulus parameterization on rainfall simulations over East Africa.*Atmosph. Clim. Sci.* 8(3): 355-371.

Rozanski K, Araguas-Aragua L, Gonfiantini R 2019 Isotope patterns of precipitation in the East African region. *InLimnology, climatology and paleoclimatology of the East African lakes*.13:79-94.

Saji NH and Yamagata T 2003 Possible impacts of Indian Ocean Dipole mode events on global climate.*Clim. Res*. 25: 151–169. https://doi.org/10.3354/cr025151.

Vizy EK and Cook KH 2020 Interannual variability of East African rainfall: role of seasonal transitions of the low-level cross-equatorial flow. *Clim. Dynam.* 54:4563-87.

Wang C, Li C, Mu Mand Duan W 2013 Seasonal modulations of different impacts of two types of ENSO events on tropical cyclone activity in the western North Pacific. *Clim. Dynam*. 40:2887-902.

YamagataT, Behera SK, Luo JJ, MassonS, Jury MR and Rao SA 2004 Coupled ocean-atmosphere variability in the tropical Indian Ocean.Earth's Climate: *The Ocean–Atmosph. Interact., Geophys. Monogr*.147: 189-212.