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Assessment of the Off-season Rainfall of January to February 2020 and Its Socio Economic Implications in Tanzania: A Case Study of the Northern Coast of Tanzania

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ABSTRACT

This article examines the off season rainfall in northern coast Tanzania (NCT) including Zanzibar which occurred in January and February 2020 (JF). Like the JF rainfalls of 2001, 2004, 2010, 2016 and 2018, the JF (2020) rainfall was more unique in damages including loss of lives, properties and infrastructures. The study used the NCEP/NCAR reanalysis data to examine the cause of uniqueness of JF rainfall in 2001, 2004, 2010, 2016, 2018 and 2020 over NCT and Zanzibar. These datasets include monthly mean u, v wind at 850, 700, 500, and 200 mb; SSTs, mean sea level pressure (MSLP) anomalies, Dipole Mode Index (DMI), and monthly rainfall from NCT and Zanzibar stations. Datasets were processed and calculated into long term, seasonal, and monthly averages, indeed, Precipitation Index (PI) was calculated. Correlation analysis between the rainfall (December to January), SST, DMI and 850 mb wind vectors; and long-term percentage contribution of investigated parameters was calculated. Results revealed significant positive and negative correlations between JF rainfall, SSTs and DMI. Moreover, JFs of 2004 and 2016 had higher rainfalls of 443 mm with percentage contribution of up to 406%, while January and February, 2020 had the highest of 269.1 and 101.1mm in Zanzibar and 295 and 146.1 mm over and NCT areas, with highest January long-term rainfall contribution of 356% in Zanzibar and 526% over NCT. The DJF (2019/20) had the highest rainfall record of 649.5 mm in Zanzibar contributing up to 286%, while JF 2000 rainfall had a good spatial and temporal distribution over most NCT areas. JF, 2020 rainfall had impacts of more than 20 people died in Lindi and several infrastructures including Kiyegeya Bridge in Morogoro were damaged. Conclusively, more research works on understanding the dynamics of wet and dry JF seasons should be conducted.

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1. Introduction

Rainfall seasons during the last decade seem to have shifted or shown strange behavior over the world^[1-4] and routine observation shows that the shift also takes places in NCT e.g. during January, (2000 -2020) rainfall in Morogoro, Dar es Salaam and Handeni has been observed with an increasing trends. Also^[2] noted that between 1954 - 2007 in most parts of the world seasons occur earlier over land and water than over the oceans with a terrestrial phase shift of 1.7 days. Moreover, the south-north oscillation of the ITCZ in combination with atmospheric circulation features (Hadley cell) control the rainfall regime in East Africa^[5-8]. It is well-known that the agricultural activities over Zanzibar and NCT are rain fed^[9,10] and about 85% of most of the economic activities depends on the climate-driven agricultural sector^[11]. The seasonal shifting of rainfall (i.e. the early onset of the forecasted rainfall (e.g. MAM, 2020; OND, 2020^[10] in Tanzania) results in either enhanced or decline precipitation, which in turn affects the socio economical set up of the society. For instance,^[12] has reported an increase in annual timescale of mean temperature anomaly, percentage of warm days, percentage of warm nights, and a decrease in percentage of cold days and nights by 0.69°C, 9.37%, 12.05%, 7.64% and 10.00%, in most regions of Tanzania including Dar-es-Salaam, Zanzibar, Mtwara, Kilimanjaro and Mbeya, respectively. The seasonal variability and shifting of onset and cessation may affect water supply in dams, rivers, lakes and ponds and hence affect the agricultural activities, energy sector (e.g. the ongoing Mwalimu Nyerere hydropower plant at Rufiji highlands), mineral extraction, and livestock keeping among others due to declined seasonal rainfall. Also rainfall is the main source of recharge of the underground water, aquifers among others.

Climatologically, NCT lies between two distinct rainfall regimes (bimodal) of long rains which takes place on March to May (MAM) and short rains from October to December (OND)^[7,13,14,15,10]. The rainfall regime in Tanzania was previously assessed by previous studies using long term rainfall data of high resolution regional climate models and historical observations to analyse the rainfall cycles, however, the seasonal patterns still seem to have maintained the same pattern^[14,10]. In NCT region most cases of short rain seasons are dominated by poor temporal and spatial coverage except few years e.g. OND 2019^[12,10]. Also the onset and cessations of short rains in East African (EA) and NCT in particular is very poor with low predictability especially on exceptionally dry years^[16]. Moreover, the variability and shifting in timing of these rains has a significant impact on agriculture and early

warning of onset and cessation^[17]. In most times over the NCT region the period covered by December, January and February (JF) is dominated by long sunny and dry conditions as noted by^[18]. Unlike the normal behavior of December to February rainfall in NCT the current or ongoing climate variability and change has resulted in strong October to December (OND) off season rainfall. Other dynamic which may influence the JF off-season rainfall over this region are the existence of tropical cyclones which increases its frequency during December to March^[15,19]. Moreover,^[15,20] and^[10] have noted that TCs either enhances or declines the rainfall in coastal region including the NCT, while^[21] had shown that westerly flows from Congo air mass enhances the rainfall when it coincides with Phase 3 and 4 of the MJO, and during TCs. Indeed,^[22] has noted that during December to March, the north-east monsoon brings dry continental air into East Africa, which declined rainfall during these months. In contrast to^[22] the cessation of the 2019 OND rainfall season in NCT and Zanzibar in particular was followed by heavy rainfall in January to February, 2020, and this rainfall was characterized by high IOD index TMA Book (2019-2020). Also the JF off season rainfall was reported to proceed and coincided with MAM 2020 seasonal rainfall over most NCT areas including Zanzibar and Tanzania at large^[23].

The reported catastrophic heavy rainfall events of late December, 2019 proceeding to JF, 2020 coincided with MAM, 2020 have raised number of questions to researchers and climate scientists over the region. Besides, it is yet unknown whether these reported uncommon JF (2020) rainfall were the extension of 2019 OND rainfall or extraordinary onset of the MAM season or what else. Thus, this study among other things aimed at understanding the scientific plausible explanation of the heavy JF rainfall over NCT and Tanzania at large. Specifically, the study will try to understand the status of the factors pertaining to the late extraordinary December, 2019 rainfall, which extended to JF (2020) rainfall and then coincided to early onset of the MAM rainfall season over most stations in NCT including Zanzibar. Also, the study will examine the climatological status of the wind flow at upper and lower levels (850, 700, 500, 700 and 200 mb) and its influence to rainfall over the region. Lastly the study will examine the differences in climatological and current JF rainfall in NCT and Zanzibar. This study will help to reveal an extensive understanding of the characteristics of the uncommon wet and dry DJF rainfalls in the region, and their variability. Moreover, the study will help operational forecasting units to have more variables for forecasting the status of the JF rainfall over the region.

2. Data and Methods

2.1 Study Site

The study area covers the NCT region including the two sister Islands of Zanzibar i.e. Unguja and Pemba which are well discussed in ^[10] and Mainland northern coastal areas. During the months of December to mid March, the climatology of NCT (northern Morogoro, Zanzibar, Dar es Salaam, Handeni and Tanga) is normally dominated with higher than average temperatures and drier conditions except during the occurrence of abnormal ocean atmosphere coupled events including El Nino, Southern Oscillation (ENSO) extended positive IOD and its reversal conditions ^[15] as well as tropical cyclones. Note that, ENSO is the well-known multiyear mode which controls the climate ^[5,24,25,26,15]. The long term average maximum temperature during January for Zanzibar ranged from 32.4°C for Unguja and 31.6°C for Pemba, while for February is 33.0°C for Unguja and 32.0°C for Pemba. As for the minimum temperature the values ranges from 24.3°C to 23.7°C during January and 23.9°C to 23.4°C for February in Unguja and Pemba, respectively.

2.2 Datasets

The study used the National Center for Environmental Prediction (NCEP) reanalysis 1 datasets including upper level zonal (u) and meridional (v) winds, sea level pressure (SLP) and relative humidity (Rhum) ^[27]. The zonal winds and Rhum had a horizontal resolution of 2.5° x 2.5° and a temporal resolution of 20 yrs, while the extended reconstructed SST anomalies had horizontal and temporal resolutions of 2° x 2° and 20 yrs (1989 - 2019), respectively. SST anomalies were used to show the long term and short term (DJF) monthly positional variation, of SSTs over the SWIO. The gridded datasets of u and v winds, SSTs, SLP and Rhum were customized to cover the SWIO region defined by 40°S - 20°N and 28 - 100°E. On the other hand, the monthly Dipole Mode Index (DMI) or Indian Ocean Zonal Mode (IOZM) data for 2000 - 2018 as define by ^[28,29] was used to feature the SST gradients in the SWIO region. DMI indices datasets were for two periods (i) long term (2000 - 2018) and (ii) short term (December, 2019 to February, 2020). Before analysing the 2020 JF and DJF, the study used six previous JF (2001, 2004, 2010, 2016, and 2018) cases of the first two decades of the 21st century (2000 - 2020) which has shown to have high rainfall impacts in NCT as that of 2020 for developing the conceptual mode. The analysis of these six cases comprises of sea level pressure (SLP) during JF, wind anomalies, the state of the SSTs along the SWIO region,

as well as the state of the moisture content at 850 and 700 mb. Indeed, the JF rainfall for these selected cases at NCT stations was analysed. As for understanding the reasons behind the JF 2020 rainfall the long term monthly gridded datasets and station rainfall observation data for 1989 - 2019 and specific months of December, 2019 and JF (2020) were used to feature the long term rainfall variability over the selected stations in the NCT region and its situation for the December, 2019 and JF (2020). The station observation data were acquired from Tanzania Meteorological Authority (TMA) in Dar es salaam and Zanzibar (Unguja and Pemba) offices. These observation datasets were for stations including Kisauni (Abeid Amani Karume International Airport), Karume airport, Matangatuani, Kizimbani (agro meteorological station), Mahonda, Donge, and Victoria for Zanzibar, and Dar es Salaam, Morogoro, Tanga and Handeni for the NCT.

2.3 Methods

The long term gridded re-analysis data sets for SLP, SSTs, Rhum, u and v winds (850, 500, 700 and 200 mb) were downloaded and calculated into long term monthly and seasonal averages, while that of single December, 2019 and JF, either daily mean or monthly mean were calculated into seasonal DJF and monthly (January to February) averages for main case and only JF averages for specific cases, then these processed data were plotted and analyzed. The differences and the percentage contribution of single month (December, 2019 to February, 2020) and seasonal (DJF) rainfall for each investigated station were calculated, plotted and analyzed. As for the SLP, wind vectors and Rhum, the long term and the current (December, 2019 and JF (2020)) monthly variables was also calculated and analyzed. The comparison of the variables on long term (seasonal) and the current December, 2019 and JF (2020) were made to identify the difference in patterns and strength of each variable over the specified domain and period. Standardized rainfall anomaly or Precipitation Index (PI) was calculated to mark the wet and dry months (December, January and February) for the past 30 years (1989-2019). PI was calculated using ^[30] and ^[31] relation as noted in Equation 1.

$$PI = (X - \bar{X})/\sigma \quad (1)$$

Where X is the monthly rainfall total; \bar{X} is the long term mean rainfall and σ is the standard deviation.

If $PI \geq 1$, it was defined as a wet month, when $PI \leq -1$ was defined as dry month otherwise normal wet/dry month (i.e. $-0.9 \leq PI \leq 0.9$ ^[32,33]). As for the wetness thresholds, reference ^[32] noted that when PI ranges from $1 \leq PI \leq 1.49$ defines moderate wet; while $1.5 \leq PI \leq 1.99$

defines very wet; and $PI \geq 2$ is defined to be extremely wet. Similar negative PI ranges hold for the dryness conditions. The rainfall indices in dry and wet months were then correlated with SST over defined locations as well as DMI index. DMI is an indicator of the east-west temperature gradient across the tropical Indian Ocean (50°E - 70°E and 10°S - 10°N i.e. Western Tropical Indian Ocean WTIO) and south eastern equatorial Indian Ocean (90°E - 110°E and 10°S - 0°N i.e. South eastern Tropical Indian Ocean (SETIO). DMI is calculated as the difference of the defined WTIO and SETIO indices.

The used monthly DMI indices were downloaded from the working group on surface pressure (WGSP) sited by https://psl.noaa.gov/gcos_wgsp/Timeseries/Data/dmi.long.data. The data were then calculated into December and JF means, plotted, analyzed and then correlated with rainfall over the selected stations in Zanzibar and NCT. As for the previous 2019 OND and December, 2019 and JF 2020 the plotted DMI information was obtained from the NOAA Ocean Observation Panel for Climate (OOPC) sited by <https://stateoftheocean.osmc.noaa.gov/sur/ind/dmi.php>. Furthermore, lead and lag correlation between the area averaged SST anomalies for January and February, extracted at three blocks defined by “0 - 15°S and 45 - 65°E ” (hereafter RA); “10 - 25°S and 55 - 80°E ” (hereafter RB); “10 - 25°S and 70 - 95°E ” (hereafter RC) and “0 - 20°S and 40 - 70°E ” (hereafter RD) and station rainfall during January and February were conducted. Besides, 850 mb area averaged wind vectors (magnitude) during December, 2019 to JF2020, these winds at three regions define by R_1 (0 - 20°S and 40 - 70°E); R_2 (0 - 20°S and 70 - 90°E), and R_3 (0 - 20°S and 10 - 40°E) was correlated with the JF 2020 rainfall for about 10 stations in NCT and Zanzibar. These correlations (i.e. SST, DMI and winds) were conducted to see the extent to which warming of the ocean and wind flow stress at the selected blocks affects rainfall in the NCT and Zanzibar. Indeed, one and two months lag correlations between the DMI and JF rainfall of the selected stations in NCT was conducted. These correlations were aimed to understand the influence of December to February east - west SST gradients to rainfall in study area

3. Results

3.1 Results from the Selected Specific Years (2001, 2004, 2010 2016 and 2018)

The results for the mean January to February (JF) SSTs, wind circulation and mean sea level pressure for the selected specific years presented in Figure 1 to Figure 3 revealed that the JF SST anomalies for 2001, 2004 and

2016 (Figure 1) higher values during JF. For instance, the mean SST anomalies for JF of 2001 (Figure 1a) had below normal SST anomalies (-0.3 to -0.4°C) at the coastal waters of Tanzania but at the areas of East African coastal current (EACC) and at the northeastern Madagascar the SST anomalies were higher (0 to 0.6°C) indicating that warm air (moisture) was advection from these areas to the NCT and Zanzibar. Irrespective of the fact that 2000-2001 was characterised by weak La Nina conditions but based on the existence of higher ocean warmth the period had higher rainfall (Table 1) at the entire NCT and Zanzibar in specific. As for the JF of 2004 Figure 1b revealed higher SST anomalies (0.4 to 0.8°C) over the coastal waters of the NCT and over the entire Mozambican channel indicating favorable condition for warm air advection from these areas to the NCT areas. This condition has induced rainfall during the 2004 JF to be higher and the leading one in records of the coastal stations (Table 1). The presented results for the SST anomaly for the JF of 2016 (Figure 1c) revealed ever recorded highest SST anomalies over the entire Southwestern Indian Ocean (SWIO) basin with anomaly values of $0.2 \leq \text{SST anomaly} \leq 1$ equator ward of 22°S and $-0.4 \leq \text{SST anomaly} \leq 1$ southward of 22°S indicating the warm of the whole basin resulting to higher rainfall records over the NCT stations and Zanzibar in particular (Table 1). The JF SST anomalies for the other selected years (e.g. 2010 and 2018) had not presented here but in general the two had relatively higher positive SST anomalies and hence induced higher rainfall over the NCT region (Table 1).

The results of the wind circulation at 850 and 200 mb during JF for 2004 and 2010 presented in Figure 2 (top left and right panels) shows that north easterlies oceanic moist air was advected to the NCT areas (850 mb) while the pure easterly flow (taking the moisture from the ocean to the land) was advected from the ocean. Similar situation holds for JF 2010, 850 and 200mb wind circulation. This could be among the plausible reason for the observed heavy rainfall over NCT areas during 2004 and 2010 as supported by observed rainfall (Table 1).

As for the JF Mean Sea Level Pressure (MSLP) for the selected years the results presented in Figure 3 reveals that during 2001 the entire coastal areas of Tanzania including NCT was under the influence of negative MSLP anomalies of -0.8 mb especially over the NCT areas. These negative low MSLP anomalies indicate these areas were influenced by unstable conditions where vertical ascent (uplifting) became more dominant feature resulting in more convective cloud formation as well as rainfall as supported by Table 1. As for 2004 Figure 3 (top right panel) reveals negative MSLP anomalies (0.4 mb) ridged over

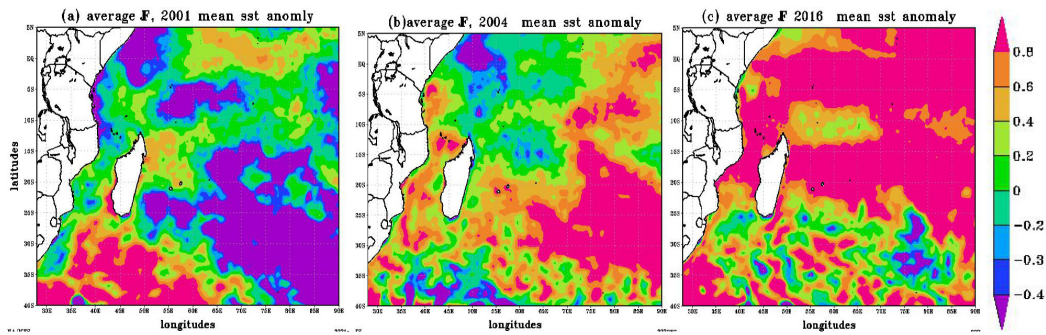


Figure 1. The mean JF SST anomalies for selected cases of 2001, 2004 and 2016, respectively.

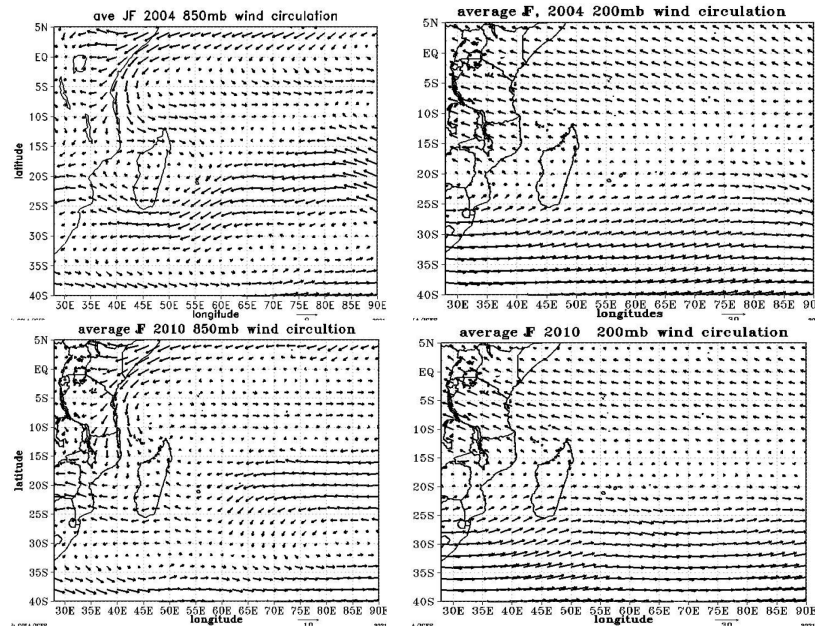


Figure 2. The JF wind circulations at 850 and 200 mb for 2004 and 2010, where top left and right panel are the 850 and 200 mb wind circulation for 2004 and the bottom left and right panels are the 850 and 200mb wind circulation for 2010.

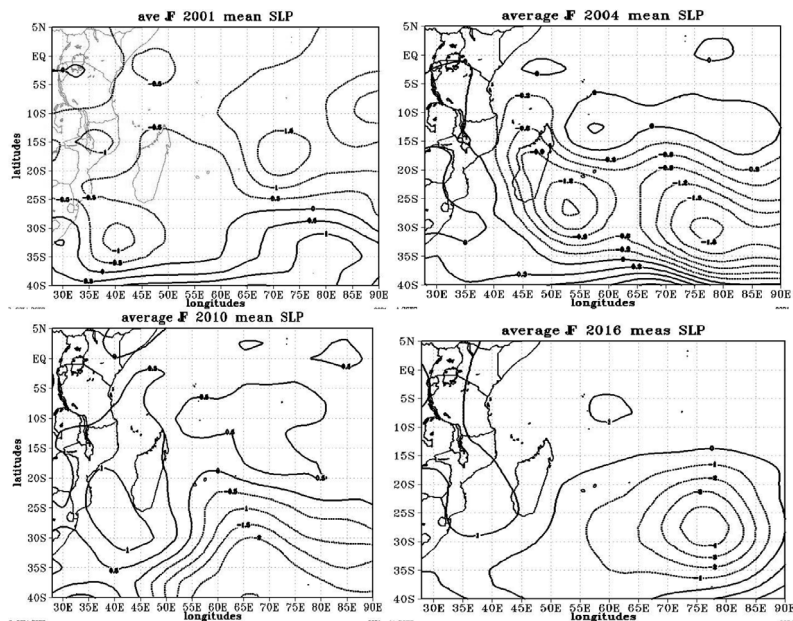


Figure 3. The JF MSLP for 2001 and 2004, 2010 and 2016, respectively; where top left and right panel are the MSLP for 2001 and 2004 and the bottom left and right panels are the MSLP for 2010 and 2016 respectively

northern Mozambican resulting into unstable conditions and moist air advection over the entire coastal Tanzania, inducing vertical uplifting and cloud formation as well as heavy rainfall. Similar conditions but of less strength are revealed by JF MSLP anomalies for 2010 and 2016 (Figure 3 bottom panels). It should be noted that Figure 1 to Figure 3 are supporting each other and Table 1 supports what is happening in these figures. The presented results from Figure 1 to Figure 3 could be the starting point of what is happening in 2020 JF and 2019/2020 DJF rainfall. These years seem to be exceptional in rainfall mechanism as that of JF 2020.

3.2 Long Term and 2019-2020 DJF and JF 2020 Results

The results of the monthly mean SSTs over the SWIO region during the December, 2019 to JF 2020 are shown in Figure 4. During December, 2019 the SSTs anomalies over eastern Madagascar was high ranging between 1 and 1.5 °C, and the mean SSTs along the coastal Tanzania (NCT in particular) and Mozambican channel was also high ranging between 0.5 and 1.5 °C, while that of East African coastal current (EACC) ranged from -0.5 to 0.5 °C, indicating ocean warmth conditions with suitable moisture advection to the coastal and hinterland regions in the country. During January, 2020 (Figure 4b) the mean SSTs anomalies over the coastal Tanzania and Mozambican channel weakened to -0.5 - 1°C, and that of eastern and northeaster Madagascar weakened to -0.5 - 1.5°C. This reduction in mean SST anomaly was caused by northwards propagation of anomalous cool SSTs over the southeastern Madagascar, hence inducing a slight reduction of oceanic moisture advection to the East African (EA) region. In contrary to January, 2020 the mean SSTs anomaly for February, 2020 (Figure 4c) over EA coast, EACC and Mozambican channel was enhanced, while that of eastern Madagascar was further reduced, and on the other hand the SST over the mid latitudes (25° - 40°S) were get-

ting warmer, the phenomenon which could be explained by the influence of Subtropical Indian Ocean Dipole (SIOD) as agreed by [34] and the quasi stationary Mascarene high pressure cell. This fluctuation of the increased mean SST anomaly during December, 2019 to February, 2020 over the SWIO region enhanced the ocean warmth which in turn increases the ocean evaporation resulting in moist air advection to the NCT including Zanzibar. This moist air advection could be among the reason for higher amount of observed rainfall in this period of December, 2019, January and JF, 2020 which in normal years the period seems to be dry in most NCT including Zanzibar and Tanzania at large as agreed by [22]. The correlation analysis between area averaged SSTs over RA, RB, RC and RD with station rainfall for January and February revealed low correlations over most stations, with highly significant ones over few stations. For instance, the JF rainfall at Zanzibar airport (Kisauni), Victoria and Mahonda had a negative correlation ($r = -0.31$ at $p \leq 0.1$) with January and February SSTs at RC, indicating that cold area averaged SSTs declined the January and February over the mentioned stations. Area averaged SST from RA, RB and RD had either weak positive and negative correlations with January or February rainfall over the selected stations in NCT and Zanzibar. This could be explained by the fact that, the weakening of the positive phase of the SST gradients between the west and east (+IOD) could reduce ocean thermal energy and hence affect the rainfall intensity, which was accelerated in December, 2019 due to enhanced SST gradients over SWIO.

The results of long term seasonal wind circulation at 850, 500, 700 and 200 mb presented in Figure 5 revealed that the long term DJF (1989 - 2019) season 850 mb wind circulation (Figure 5a) had a clockwise wind flow pattern at the northeastern tip of Madagascar, and convergence wind flows at the EA coastal strip with linear convergence at the EACC area near the Tanzanian coastal line. Also Figure 5a shows a westerly to northwesterly flow of 850

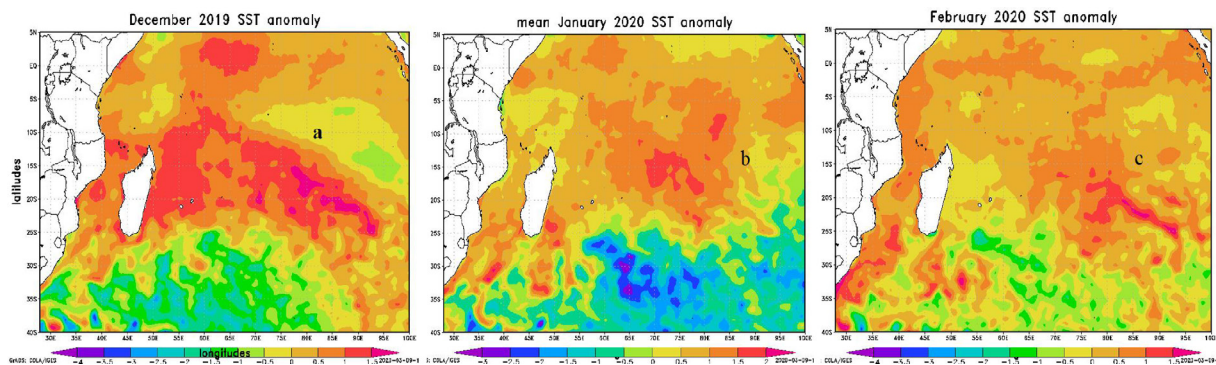


Figure 4. The monthly variability of the SST along the SWIO region during 2019/2020 DJF season.

mb winds from the Congo basin. These winds induced wet conditions over the northwestern Tanzania and over the central areas such as Dodoma. As for long term (1989 - 2019) DJF wind circulation at 500 mb Figure 5b shows pure easterly linearly convergence wind flow over the coastal and hinterlands of Tanzania. This indicate a good high level moisture advection from the deep SWIO region, and similar situation of easterly wind flow for the EA region during the long term DJF period for 200 mb (Figure 5c). The results of the long term (1989-2019) 700 mb wind circulation during DJF presented in Figure 5d reveals coastal strip from Somali to Kenya were dominated by northeasterly flow, while that of Tanzania was under the influence of weak easterlies. Moreover, Figure 5d shows that the region covered by 0 to 15°S was covered by weak north easterlies over northern to central Tanzania and weak easterlies over the coastal strip of Tanzania and Mozambique.

As for the 2019- 2020 DJF season wind circulation at 850, 500,700 and 200 mb the results presented in Figure 5e revealed a strong cyclonic circulation at the north-eastern tip of Madagascar which indicates a dominant low pressure. The winds from this low were linearly converged near the coastal waters of Tanzania; whereas coastal strip was dominated by the northeasterly (i.e. NE mon-

soon winds). Over the western areas of Tanzania (Kigoma, Sumbawanga among others). Figure 5e shows a linearly convergence winds at most areas of Tanzania especial the westerly flow from Congo air mass which is mapped at the western areas of Tanzania. Similar situation of linearly convergent easterly flow is observed at the EA region for the 500 and 200 mb wind circulation (Figure 5f - 5h) with more weak converged easterlies in 500 than in 200 mb. Also it should be noted that at 500 and 200 mb during both long term and short term seasonal DJF period the winds strength and direction varied from lower to higher latitudes. For instance, at 20 - 45°N and 35- 45°S the 500 mb westerly is very strong, while the easterly in other areas is light to weak. Similar situation holds for the 200 mb (Figure 5g). Moreover, the results in Figure 5e - 5g) shows that the DJF (2019-2020) season was influenced by moisture from all areas (i.e. the oceanic e.g. SWIO basin and the continental e.g. Congo air mass). As for the spatial distribution of wind vectors at 700 mb (Figure 5h) reveals an easterly to northeasterly linearly converged onshore winds at the coastal strip of Tanzania indicating an advection to the coastal areas.

As for the correlations between the 850 mb wind vectors and rainfall during January and February at R_1 and R_3 , results revealed that December, 2019 wind vectors

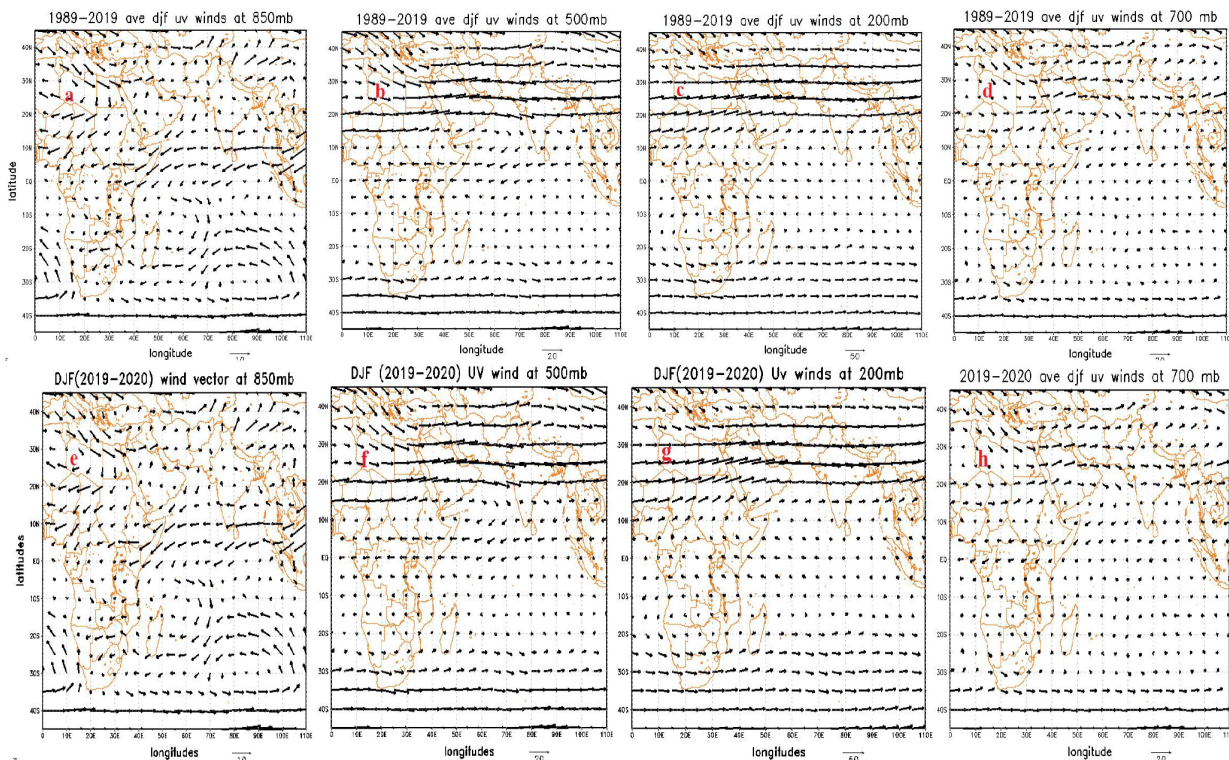


Figure 5. The long and short term seasonal variability of wind circulation at 850, 500 and 200mb. The first row (a - d) are the long term (1989 - 2019) DJF for 850, 500 and 200 and 700 mb wind circulation, while the second row (e - h) are current (2019 - 2020) DJF for 850, 500 and 200 and 700 mb wind circulations

at R_2 had significant negative correlations ranged from -0.4 to 0.6 (at $p \leq 0.05$ to 0.01) at most stations including Kilombero, Mahonda Kizimbani among others, indicating weak winds more dumping and strong wind moisture clearance. On the other hand weak a positive correlation was found at Paje and Matangatuani. R_3 had strong positive and negative correlation of +0.33 and -0.35 at Paje and Kisauni, while R_1 had only weak positive correlation of 0.30 ($p \leq 0.1$) at Paje, otherwise all other stations had negative and very weak correlations (about 0.02). December, 2019 wind vectors at R_3 had correlations of 0.3 ($p \leq 0.1$) with February, 2020 rainfall at southern Unguja area of Makunduchi and Paje, and $r = -0.3$ ($p \leq 0.1$) at Zanzibar airport areas. These correlations indicate that long track December winds at R_3 had an influence to February rainfall at southern Unguja areas. The results of the correlations between February rain with 850 mb wind vectors at R_1 , R_2 and R_3 revealed that the relation was very weak at all three regions except at Karume, Zanzibar airport where negative correlations of -0.4 ($p \leq 0.05$) was found at R_3 while Makunduchi and Paje had a negative and positive r values of -0.3 ($p \leq 0.1$) over R_2 and R_1 , respectively. Indi-

cating weak wind speed was experience resulting to high level of moisture advection over our region.

The results of the analysis of long term and monthly December, 2019 and JF (2020), and monthly mean SLP distribution along 0 - 110°E and 45°S - 45°N are presented in Figure 6. The results revealed that the long term DJF (1989-2019) show that the four oscillatory high pressure cells of Azores, Arabian high Mascarine and St. Helena with that of the northern high pressure cells (Arabian high and Azores) being intensified to 1025 and 1033 mb while that of St. Helena and Mascarine high being relaxed to 1020 mb. This intensification and relaxation of high-pressure cells resulted in northeasterly winds flow through the EA coast via the Somali coast resulting in wet conditions over EA during the northeast monsoon period (i.e. December to February) as agreed by Figure 5a. On the other hand, the relaxation of St Helena and intensification of Azores high-pressure cells results in northwesterly wind flow (refer to Figure 5a) through the Congo basin, hence inducing wet condition over northwestern areas of Tanzania as well as the NCT areas including Zanzibar. As for the oceanic areas of the SWIO region Figure 6a

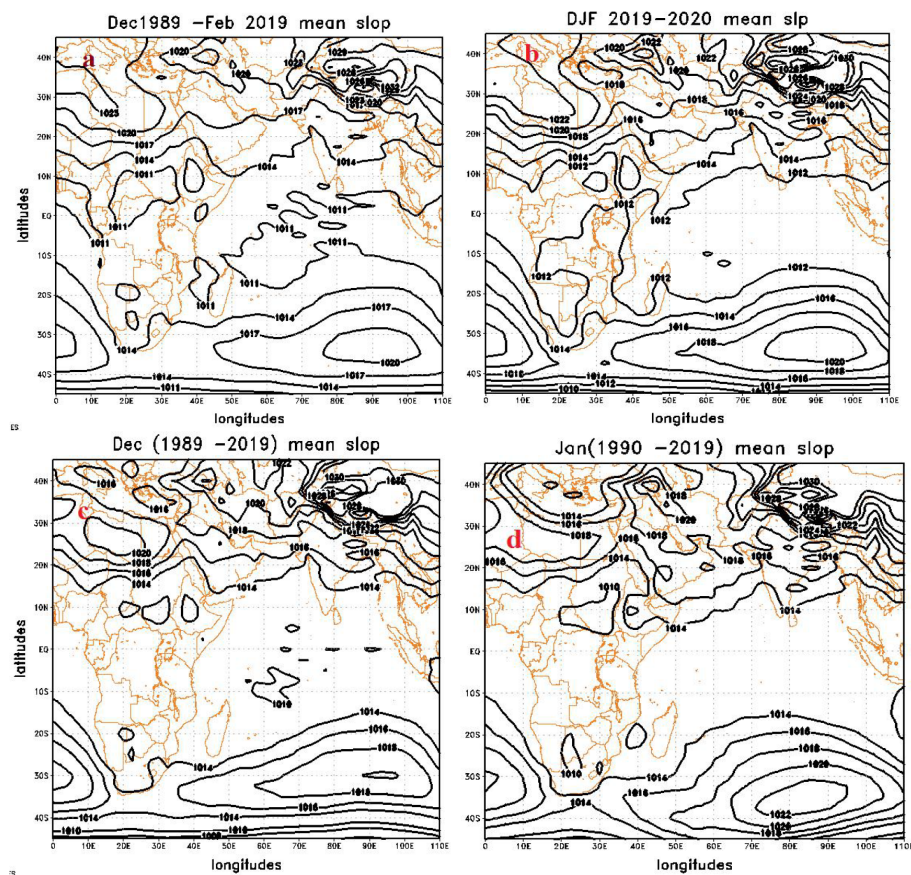


Figure 6. The long term seasonal and monthly variability of SLP for (a) December 1989 - February 2019 (b) December 2019 to February 2020 (c) the long term mean SLP for December and (d) long term mean for January

shows that the region is bounded by 1011 mb with the EA region being under the influence of 1012 Mb indicating a northeasterly to easterly wind flow to the EA coast (this is supported by cyclonic flow over the northern tip of Madagascar Figure 5a). As for the last DJF (2019 - 2020) season, the presented results in Figure 6b show similar cases of intensification of the northern high-pressure cells and relaxation of the southern high-pressure cells, but the SWIO and eastern part of the EA region were under the influence of at most 1012 mb indicating that the wind flow was varying from northeasterly to easterly flow and hence inducing higher moisture content over these areas (Figure 2b shows the wind flow pattern). Similar features are shown by Figure 3c and Figure 6d (i.e. the long term December (1989 - 2019) and January (1989 - 2019)) except that in Figure 6c & 6d the equatorial region (15°S - 15°N) EA region is bounded by a 1014mb. On the other hand in Figure 3b (i.e. the 2019-2020) DJF season), the region was bounded by 1012 mb indicating more activities in this season compared to the last 30 years period.

The results of the distributions of relative humidity during DJF at 850 and 700 mb for the long-term mean (1989-2019) and the last DJF (2019-2020) are presented in Figure 7. The results show that the long-term 850 mb Rhum distribution in Figure 4a had high (70 - 80%)

moisture content distribution in most areas of Tanzania and low (50 - 60%) over the entire coastal strip while over the ocean, long-term average moisture content was higher (70 - 90%) indicating good onshore moist air advection as supported by Figure 5a. As for the 700 mb level, the long-term means moisture distribution Figure 7b (the middle panel) shows an increased moisture content over the central and western areas and decreased moisture over the coastal and hinterlands of Tanzania, whereas over the ocean the long term average moisture content was also reduced as agreed by Figure 5d where the winds near the EA coast is variable, while over the highlands and central Tanzania strong moisture ranged from 70-80% was mapped and this can be the influence of northeasterly flow from lake Victoria to these areas (Figure 5d) as well as the orographic lifting which normally take place in high grounds. Unlike the long term DJF moisture distribution, the previous 2019-2020 DJF season shows that the moisture distribution at 850 mb was high (70 - 100%) in most areas of the country and over the coastal strip (60 - 70%) as well as improved moisture distribution over the ocean Figure 7c. This indicates that the season was dominated by low clouds such as cumulus clouds developing to cumulonimbus clouds as well as medium clouds ^[35,36,37]. As for 700 mb the moisture distribution for the 2019 - 2020

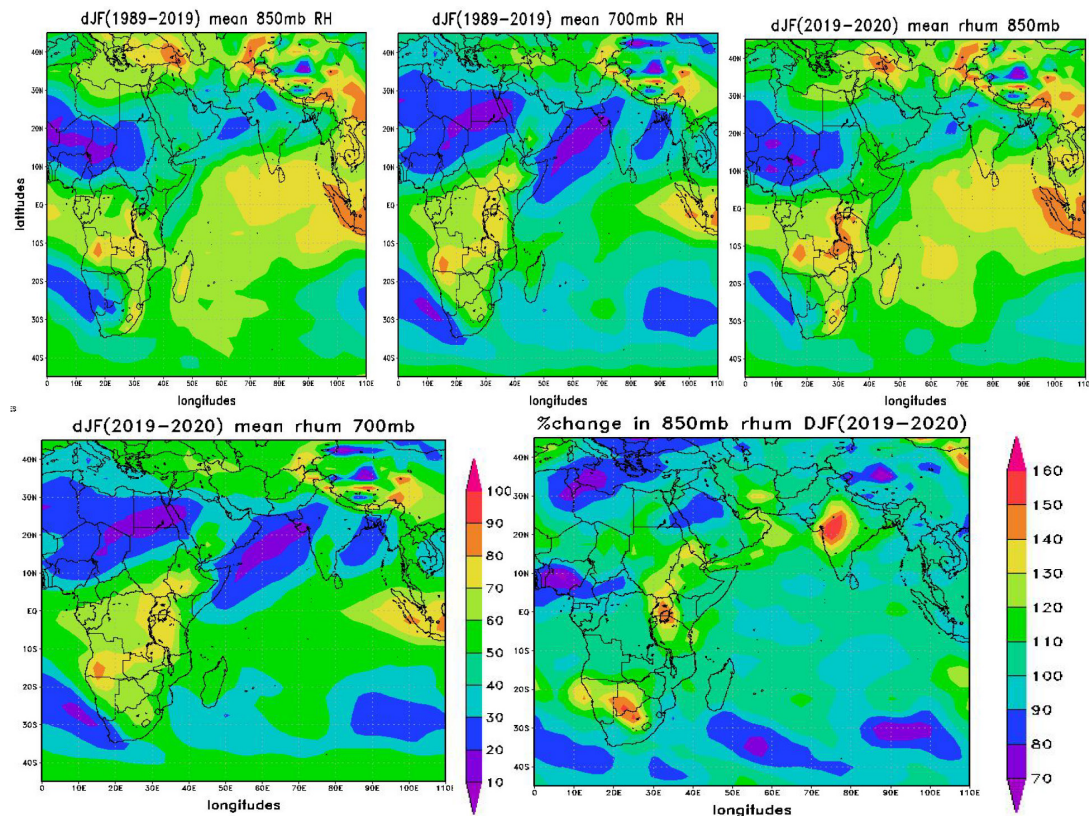


Figure 7. The long and short term variation of relative humidity at 850 and 700 mb during DJF

DJF presented in Figure 7d revealed an increased moisture distribution over the western parts of Tanzania and coastal areas (including Zanzibar) as well as over the ocean. The results in Figure 7c - 7d indicate a well-defined vertical (850 - 700 mb) moisture distribution over Tanzania (both hinterland and coastal areas including NCT) which are good indicators for vertically developed cumulus clouds and convective precipitation. The results are in agreement with [38] who noted that upward motion and convergence of water vapor are two large-scale parameters that are highly correlated with convective precipitation.

As for the percentage change in moisture distribution at 850 mb over NCT (i.e. including Zanzibar) and Tanzania at large and nearby countries, the results presented in Figure 7e shows that the Tanzania coastal areas specifically NCT (Tanga, Zanzibar and Dar es Salaam and northern Morogoro) had higher percentage change ranged from 120 - 140% of Rhum of the long-term mean (1989 - 2019) at 850 mb. Also, the lake zone and the northwestern areas of the Tanzania had higher % change in moisture distribution, while over the ocean the percentage change was not higher. These results could explain as to why the 2019 OND off seasonal rainfall extends to February and then coincided to MAM with higher downpour signs at the coastal and hinterland areas.

3.3 Variability of the Indian Ocean Dipole Mode (DMI)

The results of the analysis of the DMI for the last 18 years (2000 - 2018) and the last two years (2019- 2020) presented in Figure 8 revealed that DMI during OND and DJF has been characterized by an increasing trend $0.012^{\circ}\text{C}/\text{yr}$ and $0.01^{\circ}\text{C}/\text{yr}$, with the highest DMI of $\geq 0.5^{\circ}\text{C}$ during ONDs of 2006, 2011 and 2015, whereas the

DMI during DJFs seems to be less than 0.5°C for most years. Moreover, Figure 8a shows that the effectiveness of the DJF mostly depends on the strength and extension of DMI during OND, though there are some years, the two are in opposite direction (i.e. positive DMI during OND and negative DMI during DJF and vice versa), but in most years the two are in phase and in the same direction. These results indicate that OND seasons with positive IOD may influence the same condition during December to February (i.e. extension of positive SST gradients from OND to DJF, with varying direction in strength, higher during OND than DJF Figure 8a). As for the last three years i.e. 2018 - 2020 the results of the strength of the DMI presented in Figure 5b shows that both the OND and DJF has the DMI values for 2018 and 2019 which was $\geq 0.5^{\circ}\text{C}$, but that of OND 2018 (1.0 peak) was smaller than that of 2019 (2.5 peak). Comparatively, DMI in Figure 8a and 8b show that during OND 2019, the DMI value was highest in the last 20 years of records and similar case holds for the 2019-2020 DJF. Moreover, the results indicates that the extension of rainfall during off season of OND i.e. late December, 2019 and January to February, 2020 could be influenced by SWIO extended high SST gradient i.e. extension of the extreme warming of the ocean over the SWIO region from OND to DJF. Indeed, both Figure 8b and the downloaded data for February show that during February to March the DMI is sharply declining, indicating the reverse or weakening of the SSTs gradient.

3.4 Inter Annual Distribution of Wet and Dry December, 2019 to February, 2020 Rainfall

The results of the inter annual variability of PI over the selected stations in NCT including Zanzibar presented in Figure 9 reveals that most stations in Zanzibar with the

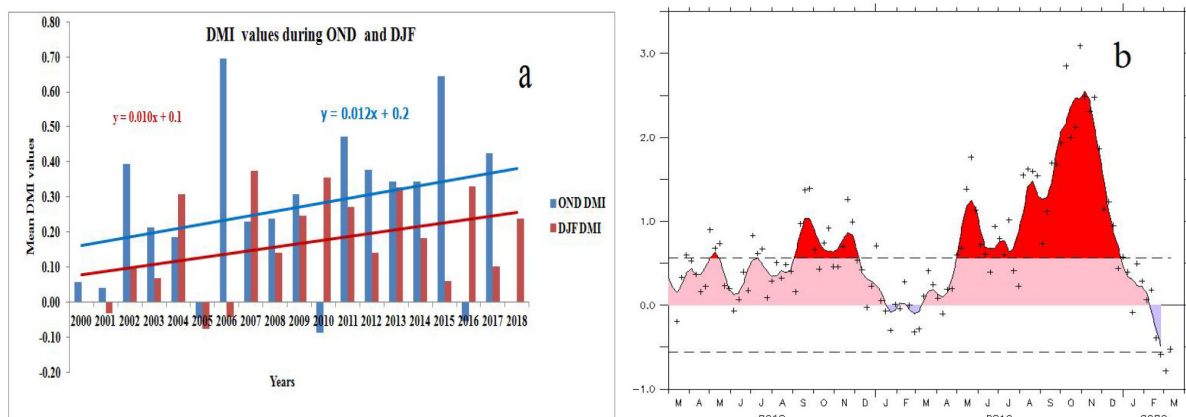


Figure 8. The inter annual and monthly variability of the DMI during OND and DJF where (a) the first from left is inter annual variability from 2000 - 2018 and (b) the second from left is monthly variability for 2018-2020 (source for (b) is OOPC page sited by <https://stateoftheocean.osmc.noaa.gov/sur/ind/dmi.php>)

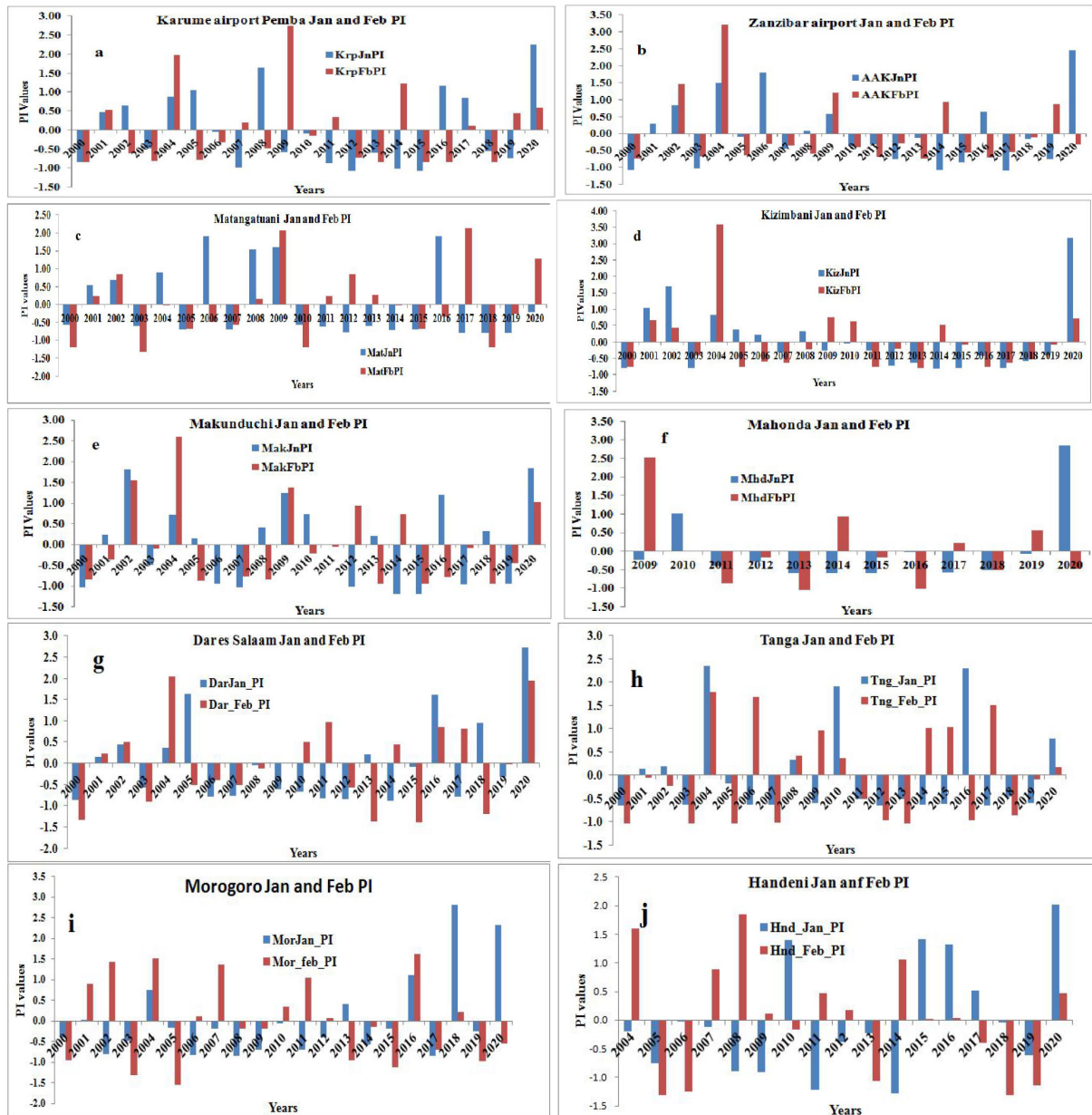


Figure 9. Inter annual variability of wet and dry conditions during January and February across selected stations in NCT and Zanzibar over the last 21 years (i.e. the first two decades of the 21st Century)

exception of Matangatuani (Figure 9e) has wet condition i.e. $PI \geq 1$ during January, 2020, and the strength of this wetness differ among stations. For instance, Kizimbani in Unguja (Figure 9d) had extremely we condition of $PI \geq 3$ followed by Karume airport (Figure 9a), Zanzibar airport and Makunduchi Figure 9b and 9e) which had PI range of $2 \leq PI \leq 3$. These results indicate that the off season OND 2019 rainfall had enhanced the wetness resulted by extra ordinary and unique rainfall during JF 2020^[10]. As for February, 2019 results presented in Figure 9 reveals that the highest PI of $1 \leq PI \leq 1.5$ was observed at Matangatuani and Makunduchi (Figure 9c and 9e), while the lowest

PI of ≤ -0.5 was observed at Zanzibar airport and Mahonda (Figure 9b and 9f) otherwise the remaining stations had normal wet conditions (i.e. $0 \leq PI \leq 0.9$). As for the mainland coastal stations of Dar es Salaam, Morogoro, Tanga and Handeni (Figure 9g-9j) revealed that PI values had increasing trend during January except for Tanga indicating that January rainfall was increasing with time, while during February, Tanga and Dar had positive weak trends while Morogoro and Handeni had negative trends indicating that some areas February rainfall was weakly increases/decreases with time. Moreover, results in Figure 9g shows that Dar es Salaam has been dominated by normal

dry season for January and February with the exception of 2004, 2005, 2016 and 2020 which had extreme seasons, while 2000, 2013 2015 and 2018 were among the extreme dry February. The inter annual variability of wet and dry January and February in Tanga (Figure 9h) revealed that in most years the station was dominated by very normal dry January and February with the exception of 2004, 2006, 2010 and 2016 which had either very wet extent or wet periods. Similar results hold for Figure 9i, while Figure 9j show that Handeni station had been dominated by either wet or very dry Januaries and Februaries indicating that Handeni is more prone to climate change catastrophes of having either wet periods or very dry ones. These results indicate that the strength of the 2019 OND enhanced more off season rainfall in January than in February, 2020. Other years which have high wetness in January over different stations in Zanzibar stations includes 2002, 2006, 2008, 2009 and 2016, while the ones having high wetness in February includes 2004, 2009, and 2017, respectively. Moreover, results in Figure 9 reveal that most station has shown normal dryness conditions i.e. $-0.99 \leq PI \leq 0$, with the exception of few stations including Matangatuani Makunduchi and Handeni which had dryness condition of $-1.49 \leq PI \leq -1$. Moreover, results presented in Figure 9 could explain the cause of the damages reported in some areas NCT and Zanzibar in particular. Indeed, the lack of time lag between heavy rainfall of 2019 OND and the proceeding of January and February, 2020, had resulted in earth/soil to be saturated or near saturated. The condition which leads to flooding could be explained as another reason towards observed damages.

In assessing the reasons behind the wetness presented in Figure 9, the relationship between PI and DMI for January and February was determined through time series and correlations, and the results presented in Figure 10 reveals that though the standardized DMI values during January and February ranged from -0.5 to $+0.5$ (± 0.5 i.e. were lower), but the patterns and the direction of PI and DMI presented in Figure 10 was in most years and stations matching and mismatch over some stations. Indeed, the situations were different for the January and February, 2020. For instance, during January, 2020 both the PI and the DMI were positive in all stations but in opposite trends (i.e. PIs were in increasing trend while DMI were at a decreasing trend) indicating that though DMI were positive but the gradient was in a decreasing mode. As for February PIs and DMI Figure 10 revealed that like in January, 2020, the match and mismatch of the patterns and directions of the two was also observed, but the good thing is that in all Figures 10a - 10f the DMI and PIs was increasing from negative to positive from January and

February 2018 to January and February, 2020.

Due to the existing match and mismatch of the pattern of DMI and PI for different stations leads to have weak correlation between the two, but the correlation between the PIs among stations and among months was high and significant. For instance, the correlation between the February PI at Karume airport and Zanzibar airport was high ($r = 0.69$ at $p \leq 0.01$) similar situation holds for January PI at these two places (i.e. $r = 0.62$ at $p \leq 0.01$), also similar cases holds for January and February PIs among stations. Moreover, the correlation between DMI and PI during January and February for each specific station over NCT and Zanzibar in particular reveals a weak positive correlation except over the few stations. For instance, February PI at Karume airport was significantly correlated with February DMI ($r = 0.37$ at $p \leq 0.1$ i.e. 90% significant level). Also the February PI at Kisauni (Zanzibar airport) was positive and weakly correlated with February DMI ($r = 0.24$, but not significant). Indeed, the correlation between DMI and PI over mainland NCT reveals that January DMI had strong correlation ($r = 0.4$; $p \leq 0.05$ or 95%) with January and February PI at Dar es Salaam and Tanga, while November DMI had strong correlation ($r = 0.5$ at $p \leq 0.01$) with January PI at Dar es Salaam and Morogoro, and similar results holds for December DMI with January PI at Dar es Salaam and Tanga, respectively. These results indicate that the observed rainfall was the output of the large scale synoptic features as noted by ^[39,40]. Indeed, one and two months lagged correlations were performed but the results were positive weak and not significant, indicating that in most cases and stations the period covered by January and February has limited rainfall (dry season) in most stations of Zanzibar except during special events such as tropical cyclone, extremely positive IOD and DMI, extended El Nino event among others. This could also explain the reason why some stations in Zanzibar have more negative PIs than positive ones (Figure 9 and 10)

Additionally, the inter annual variability of DJF PI for four Zanzibar stations of Kisauni, Makunduchi, Kizimbani and Karume airport and that of mainland coastal stations (Dar es Salaam, Tanga, Morogoro and Handeni) presented in Figure 10e - 10f show that almost all investigated stations have a decreasing trend of the DJF rainfall (ranged from -0.05 to -0.07 mm/yr). Besides, Figure 10e and 10f show that most years had DJF rainfall of one σ (standard deviation) either below or above the mean, but the DJF season of 1997-1998 (i.e. December 1997 to February 1998) and 2019 - 2020 had rainfall which ranged from 2 to 5σ above the mean. This indicates that the DJF of 1997/98 and 2019/20 were among the wettest DJF seasons in NCT and Zanzibar since 1993 even if the reasons

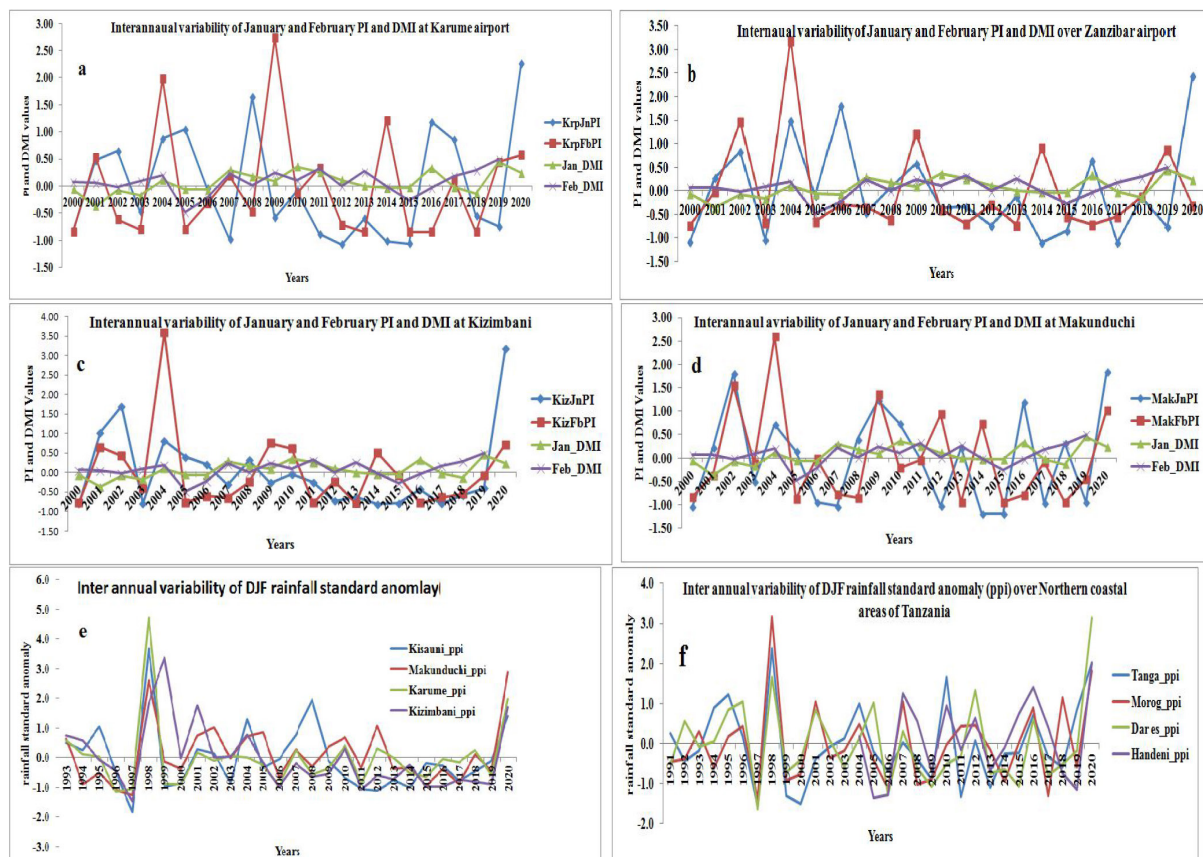


Figure 10. Inter annual variability of PI and DMI during January and February and seasonal DJF for some selected stations in Zanzibar

for this wetness slightly differs. The main reason behind the 1997/98 DJF wetness was the ever recorded 1997/98 El Nino event, while that of 2019/2020 could be explained by the strong warming of the ocean over western SWIO i.e. positive IOD which enhanced the higher DMI values during December to January^[10] and hence results in heavy DJF rainfall (especial on December followed by January).

3.5 Monthly and Seasonal (DJF) Rainfall Variability

The results of the rainfall variability for specific JFs of 2001, 2004, 2010, 2016 and 2018 over Dar es Salaam, Morogoro and Handeni for Mainland NCT rainfall stations and Abeid Amani Karume Airport, Makunduchi, Kizimbani and Karume Airport (Pemba) and Matangatuani in Zanzibar presented in Table 1 revealed that though 2000 -2001 was characterized by weak La Nina conditions, but the JF (or off season rainfall of 2000 OND season) had higher percentage contribution (140 to 223%) from over most stations of NCT (Table 1). The JF rainfall for 2004 was the highest in 20 years record for NCT stations. For instance, rainfall strength ranged from 82 mm at

Matangatuani Pemba to 443 mm at Abeid Amani Karume International Airport (Unguja), contributing to 163 - 406% of the long term JF rainfall. As for 2016 (the strong El Nino period (2015-2016)) rainfall records over the NCT stations reveal higher rainfall amounts but not strong as that of 2004 (Table 1). The 2016 rainfall strengths ranged from 25 to 318 mm with percentage contributions ranged from 27 to 232%.

Note that in Table 1 the abbreviations Dar, Mor, Hnd, Akar, Mak, Kiz , Kar and Mat stands for Dar es Salaam, Morogoro, Handeni, Abeid Amani Karume Airport, Makunduchi, Kizimbani, Karume airport and Matangatuani, respectively.

The results of the analysis of long term (1989 - 2019) and single season DJF (2019 - 2020) rainfall over the selected stations in NCT and Zanzibar (i.e. Karume airport and Matangatuani in Pemba, Kisauni, Victoria, Mahonda, and Makuduchi in Unguja) and that of the mainland coastal stations (Dar es salaam, Tanga, Handeni and northern Morogoro) presented in Figure 11a and 11b revealed that the DJF(2019 - 2020) was among the leading seasonal rainfall records over the DJF history of most analysed stations in the NCT. For instance, in Zanzibar,

Table 1. The total JF rainfall (mm) for specific years for some selected station in NCT. Note that the bolded numbers in brackets are percentage contribution to the long term (2001 - 2019) except for Handeni (2003-2019) JF rainfall over that station

Year	Dar	Mor	Hnd	Akar	Mak	Kiz	Kar	Mat
2001	136(125)	203(122)	-	135(116)	93(94)	2011(223)	89(152)	75(140)
2004	228(209)	284(171)	189(163)	443(363)	266(268)	382(406)	146(258)	82(152)
2010	97 (89)	178(107)	2006(173)	68(58)	123(124)	139(147)	51(90)	11(10)
2016	253(232)	318(191)	209(180)	111(96)	114(115)	25 (27)	66(115)	109(204)
2018	123(112)	413(248)	72(62)	100(86)	67(68)	30(32)	16(27)	4(7)

stations including Karume Airport and Matangatuani were having seasonal DJF rainfall of 413.8 and 189 mm, while, Kizimbani Kisauni, Makunduchi, Victoria garden, Mahonda among others in Unguja (Figure 11a) had recorded DJF(2019 - 2020) rainfall of 508.3 mm (third in record from 1965), 649.5 mm (third in record from 1980), 557.8, 485.1, and 432.7, and 485 mm, respectively. These DJF(2019 - 2020) rainfall values for Unguja contribute to 218%, 158%, 298%, 215% of the DJF long term mean rainfall for Kizimbani, Kisauni, Makunduchi and Mahonda in Unguja, while that of Karume airport and Matangatuani in Pemba contributed to 253% and 114%, respectively. As for the mainland coastal stations results in Figure 8b reveals that Dar es Salaam followed by Morogoro, Handeni and Tanga had the DJF(2019 - 2020) rainfall of 663, 517.5, 447.3 and 336.6 mm which contributes to 280%, 191%, 203% and 227% of the long term (1993-2020 and 2004-2020) DJF rainfall. Moreover, these high rainfall records for Dar es Salaam and Morogoro are the first in the last 31 years (1990-2020), while that of Tanga is the second in records for the last 31 years (1990-2020), and that of Handeni is the first for the last 17 years (2004-2020) records.

Unlike the OND rainfall which was east - west aligned in most stations in Zanzibar ^[10] the DJF (2019 - 2020) rainfall was not oriented in any direction in Figure 8a. Moreover, reference ^[10] agreed with the results presented in Figure 11 that December, 2019 had higher rainfall ranged from 120.0 mm in Matangatuani (Pemba) to 322.1 in Makunduchi Unguja. Besides, Figure 8a revealed that January, 2020 had the highest and lowest rainfall records of 269.1 mm and 19.4 mm recorded in Mahonda and Matangatuani, while February had weak rainfall records ranged from 16.2 mm at Kilombero to 101.1 mm at Makunduchi, with the highest in Makunduchi followed by 95.9 mm at Kizimbani. As for comparison with the climatology ^[10]

agreed with the study results that December, 2019 had the highest rainfall which contributed to 230%, and 156% of the long term December rainfall for Karume airport and Matangatuani in Pemba, while in Unguja the contribution was 305%, and 221% of the December long term total mean for Makuduchi and Kizimbani, respectively. Also during January, 2020 the recorded rainfall contributed to 230% and 37 % of January long term at Karume airport and Matangatuani, while at Unguja the contribution was 356% and 283% at Kizimbani and Makunduchi, respectively. As for monthly contribution over the coastal mainland stations Figure 8b shows that December, 2019 had highest rainfall records of 294.6, 171.1, 230.7 and 187.2 mm for Dar es Salaam, Morogoro, Tanga and Handeni, respectively. These values contribute to 265%, 185%, 276% and 175% of the long term rainfall, and are first in 31 years record for Dar es Salaam and Tanga, and the second and fifth for Morogoro and Handeni. As for January, 2020 Figure 8b revealed that Dar es Salaam, Morogoro and Handeni had high rainfall records of 222.3 mm (526% and first in record), 295.1mm (296%, second in record) and 191.7 mm (258% first in record), respectively. Like in Figure 8a, Figure 8b has low rainfall records for February, 2000. Besides, these low rainfall, which ranges from 35.3 - 146.1 mm with a percentage contribution ranged from 52 - 198%. Moreover, comparison from Figure 8a and b shows that the sister Islands of Unguja and Pemba (Zanzibar) had higher rainfall records than northern coast mainland stations. The comparison in strength and percentage contribution of JF 2020 rainfall Figure 11a & 11b with previous JF rainfall presented in Table 1 show that the JF 2020 rainfall was the ever recorded amount in the history of most of the most NCT and Zanzibar rainfall stations. This highest rainfall contribution could be explained by the extending (from November, December to late January) influence of high DMI values during OND ^[10] which

proceeded to January and then sharply decreased during February to March, 2020 as supported by Figure 8b.

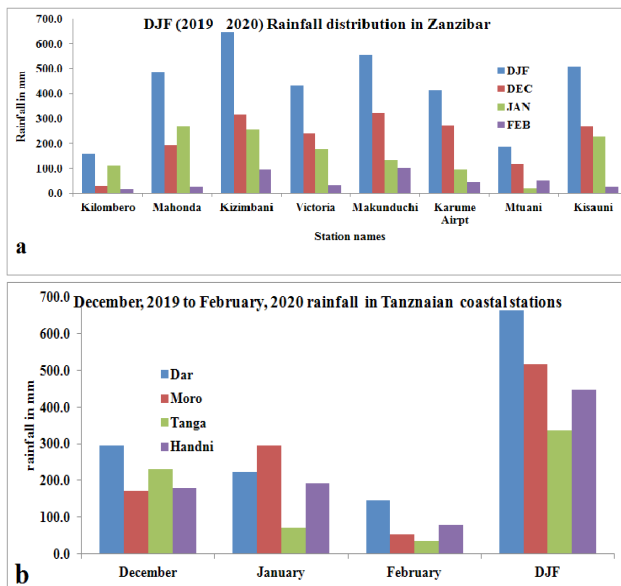


Figure 11. The spatial rainfall distribution December to February and DJF (2019/2020) for selected stations NCT including Zanzibar; where (a) is for stations in Zanzibar and (b) for mainland coastal stations

3.6 Socio Economic Implication of the January to February, 2020 and DJF (2019/2020) Rainfall

The impacts of the DJF (2019 - 2020) climate conditions could be explained based on the days of severe weather events and their impact on society. The results of the analysis of days with rainfall records which fits the severe weather index of issuing the weather warning used by region 1 (RA1) i.e. Rainfall ≥ 50 mm is presented in Figure 12. The highest number of 12 days of severe weather was recorded at Kizimbani station followed with Karume airport (Pemba). Also Figure 12 shows that January, 2020 had seven days of severe weather event of which two were recorded at Mahonda and the remaining station (i.e. Makunduchi, Victoria among others) had only 1 day, while February, 2020 had no recorded event of severe weather.

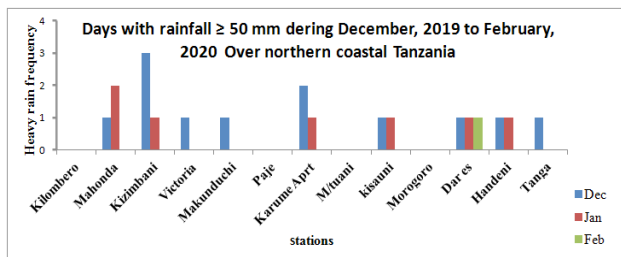


Figure 12. The frequency of Rainfall ≥ 50 mm across station in Zanzibar during December, 2019 to February 2020.

Additionally, the examination of the December to February data from 13 station listed in Figure 12 shows that most of the recorded events were between 16 and 20th December, 2019 where on 20th December, 2019 the highest recorded was 195.5 mm (185% percent of December long term mean) at Makunduchi, 141.7 mm (159% of the December long term mean) at Karume airport, 90.7 mm at Kisauni, 89.1 mm at Victoria garden and 55 mm at Mahonda, while on 16th December, 2019 the highest rainfall of 75.5 mm was recorded at Kizimbani. Other recorded events were on 18th and 19th January, 2020 where the highest rainfall of 82 mm was recorded at Mahonda, while for 19th January the highest record was 80.1, 75.8 and 66.2 mm at Karume airport, Kizimbani and Mahonda, respectively. As for the stations on the mainland coastal area Dar es Salaam had a highest rainfall of 95.5 and 112.5 mm was recorded on 15th December, 2019 and 16th January, 2020. As for the percentage contribution of the December, 2019 to February, 2020 of the long term rainfall for the mainland coastal station results show that the highest was 526% followed by 295% in Dar es Salaam. Indeed, results showed that Dar es Salaam and Zanzibar had higher rainfall records than the rest.

Besides, the results in Figure 11 & 12 reveals that Unguja and Dar es Salaam had more rainfall in December to January than Pemba, the phenomenon which could be due to the fact the onset of OND (*Vuli rains*) is normally on Pemba (due to northeasterly and northwesterly flow) and its cessation is more practiced in Unguja (the transition from *Vuli* to *Kaskazi*) i.e. *Vuli* rains start at Pemba and end at Unguja hence the *Vuli* off season rainfall could be more experienced in Unguja than at Pemba. The impacts of the December, 2019 and JF (2020), rainfall was not high in Zanzibar, but this rainfall has higher devastation in mainland coastal stations of Tanzania. For instance, during December (21st to 22nd), 2019 TMA issued a severe weather warning on heavy rainfall and strong winds for most regions of Tanzania. These regions includes Dar es Salaam, Songwe, Iringa, Njombe, Ruvuma, Zanzibar, Pwani, Morogoro, Singida, Dodoma, Lindi, Mtwara, Rukwa and Mbeya, respectively [23]. The outcome of this forecast was heavy rainfall and strong winds which left significant number of people homeless infrastructures (e.g. bridge was washed away in Dodoma, transport was stranded for several hours to days in Dar es salaam among others). For instance, the three days (28th December 2019 to 1st January, 2020) heavy rains and strong winds had damaged 57 houses leading to hundreds of families to be homeless at Sungaji village in Mvomero district in Morogoro region (<https://www.ippmedia.com/en/news/downpour-morogoro-ravages-least-57-homes>). Also reports from the offi-

cials of the Wami/Ruvu river basin noted a strong erosion of the river banks leading to destruction of the settlements due to flooding. Moreover on Lindi region Red Cross has reported a death toll of about 13 people in late January, 2020, and 5 people were missing, 1,746 houses were completely destroyed and about 1,074 latrines collapsed. Reports from the local government sources show that about 15,096 have been displaced by the flooding, with around 8,000 staying in evacuation centers, and among the affected local infrastructure include livelihoods and personal properties. Schools, roads and bridges and 495 acres of farmland were inundated (<http://floodlist.com/africa/tanzania-floods-leave-13-dead-thousands-displaced>). Other impacts based to ^[23] severe weather warning was a death toll of five people and more 2500 forced to leave their houses at Kyela, district western Tanzania. Also floods impact reports on late January and early February, 2020 rainfall in Tanzania have shown that at least 3 people died and around 300 were left homeless in Iringa and Dodoma regions (<http://www.rfi.fr/sw/eac/20190517-mafuriko-yaua-watano-tanzania-na-kuwaacha-maelfu-bila-makazi>)

4. Discussion

The analysis of the factors affecting the OND off season rainfall of the JF rainfall for 2001, 2004, 2010, 2016 and 2018 together with that of late December, 2019 and January to February, 2020 and seasonal 2019 - 2020 DJF rainfall over the NCT was conducted by refereeing the performance of the OND rainfall in Zanzibar ^[10] and the rainfall bringing mechanisms, where most parameters including mean SST anomaly, SLP, wind circulation at 850, 700, 5000 and 200 mb, vertical moisture distribution (Rh) at 850 and 700 mb, and DMI over WIO as well as the performance of the 2019 - 2020 DJF rainfall was also analysed. The presented SSTs results for 2004 and 2016 (Figure 1) revealed higher SST anomalies over the Tanzania coastal water and over the SWIO basin with the exception of 2001 which had slightly lower anomalies. These results and that of December, 2019 agreed with ^[10] that SST anomalies over SWIO which ranged from 0.5 -1.5°C over the Mozambican channel and the EACC region, and 1 - 1.5°C over eastern Madagascar indicating warm ocean conditions for unstable atmospheric condition where moisture advection take place to coastal and hinterlands of EA region Tanzania with NCT and Zanzibar in particular. These findings indicate that SWIO SST variability may influences inter annual variability over East African (NCT and Zanzibar in particular) rainfall during OND and DJF as noted by ^[18,41,22,15,10]. Moreover, the study considered the SST and its zonal gradient variability (DMI) but did not

take into consideration the interaction of ENSO events and SST based on the fact that El Nino in the Pacific did not directly control rainfall in East Africa as noted by ^[18]. Indeed, the presented results revealed a slight reduction in SST during January and February Figure 4b & 4c the phenomenon which could be explained by northwards propagation of low mean SST anomaly over the south-eastern Madagascar due to negative polarity Subtropical Indian Ocean Dipole (SIOD) and the quasi stationary Mascarene high pressure cell which induces high pressure over the Mozambican channel during January ^[34,42] hence, inducing a decline in moisture advection to the EA region. These perturbations of higher SST anomaly during JF of 2001, 2004, 2016 and December to JF over the SWIO region could be among the reason for higher observed JF rainfall during 2001, 2004, 2010, 2016 and during the late December, 2019 and JF (2020) rainfall which normally with the exception of the occurrence of TCs/TSS ^[15] or other teleconnections (e.g. MJO, ENSO +IOD) it seems to be dry period in most areas of NCT and Zanzibar in particular as noted by ^[18]. Also the increase in DMI indices during DJFs of 2001, 2004, 2010, 2016, 2018 and that of December and January (Figure 8b and 8d) could be the source of increased rainfall due to increasing of positive SST gradient towards SWIO region. Besides, the existence of low MSLP anomalies (Figure 3) and that of long term December and January low mean SLP of about 1014hPa which is further reduced to 1012 hPa during DJF(2019-2020) season (Figure 6) could be another factor which contributed to have strong off season rainfall of January to February, of 2001, 2004, 2010, 2016 2018 and that of 2020 over most NCT areas including Zanzibar. Moreover, the existence of 850 - 500 mb long term and short term (DJF 2019-2020) cyclonic flow over the north-eastern Madagascar (Figure 5), as well as the existence of well defined north easterlies along the NCT (Figure 5) and linearly convergent 500 mb westerly over western to eastern Tanzania could also be explained as another factor which contribute to the higher late December, 2019 to JF (2020) rainfall at NCT including Zanzibar and Tanzania at large. In addition the higher percentage increase in moisture content at 850 mb during DJF (2019 - 2020) over most areas in NCT and Tanzania (Figure 7 right most panel of second row) could be another factor which enhanced the December to JF rainfall in NCT and Tanzania at large. The study results is in agreement with ^[43] who noted that a reduction in sea level pressure over the western half of the Indian Ocean (e. g. Figure 6b and 6d) and converging wind anomalies over East Africa (e.g. Figure 5e - 5h) lead to moisture convergence and increased convective activity over the region.

As for the outcomes of the aforementioned rainfall dynamics results presented in Figure 10 & 11 as well as in Table 1 supports what has been presented as the sources of the abnormal heavy rainfall in JF of 2001, 2004, 2010, 2016, 2018 as well as the December, 2019 to JF (2020) over Zanzibar and Tanzania at large. For instance, Figure 11 shows that most station in Zanzibar had reported heavy rainfall ranged from 200-700 mm during the DJF (2019-2020), whereas for specific months of December, and January in Figure 11 revealed that Makunduchi and Kizimbani as well as Mahonda and Kizimbani had the highest recorded rainfall during December, 2019 and January, 2020 as noted by ^[10] Our results for December, 2019 to February, 2020 has been opposed with ^[9] who noted that precipitation on the islands is higher than on the mainland coast due to moisture convergence in sea breezes (i.e. during this period the rainfalls were either equal or higher in mainland than over the coastal especially in Zanzibar). This could be explained by the abnormal behavior of the JF (2001, 2004, 2010, 2016 and 2018) and December, 2019 to February, 2020 rainfall in NCT including Zanzibar and Tanzania at large. Moreover, Figure 10e & 10f had revealed the highest rainfall in most areas of NCT, where Pemba and Morogoro had 3 - 5 σ during 1998. This result is well agreed by ^[10] to the El Nino event. Indeed, Figure 10e & 10f have shown that since 1993 - 2020 inter annual variability of DJF rainfall has two distinct peaks of 1998 (i.e. December 1997 to February 1998) and 2020 (i.e. December 2019 to February 2020) which were higher than DJF average rainfall by 2 to 5 σ , indicating that though no El Niño condition was forecasted during DJF (2019 - 2020), but the existence of strong IOD, and strong DMI enhanced good moisture advection in NCT and Zanzibar resulting into strong December to JF rainfall. In conclusion the abnormal rainfall events (Figures 11, 10 and 12 and Table 1) which occurred during December, 2019 to February, 2020 (and during JFs of 2001, 2004, 2010, 2016 and 2018) leading to be very wet 2019/20 season similar to 1997/98 DJF season could be explained by the fact that unlike the 1997/98 DJF rainfall which was accelerated by the strong El Nino event, the 2019/20 DJF, 2004 and 2010 JF rainfall was accelerated by increased warmth of the Ocean, low decreasing speed of the positive DMI, the dominant low pressure and 850 mb northeasterly onshore flow, and linearly convergent 700 to 500 mb easterly over the coast and westerly over the highlands. Thus, the aforementioned arguments could be among the reasons behind the uniqueness of the 2001, 2004, 2010, 2018, 2018 and 2020 JF season rainfall which are normally dry except during the tropical cyclones and abnormal behaviors of the pertaining weather systems.

Thus based on the presented results and discussion the study concludes that:

Forecasting of wet and dry JF rainfall is of critical importance because the society is not aware that some JF seasons could be among the very wet ones

Detailed studies of what makes JF season over NCT (or bimodal regime areas) to be wet/dry should be conducted to assist the forecasting units in Tanzania.

The presented results should be extrapolated to the whole bimodal regime areas to understand what areas (regions) are more affected by JF wet /dry rainfalls.

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