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Monthly and Seasonal Rainfall Concentrations and Predictability in Tanzania

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Abstract

This study aimed at determining the monthly and seasonal rainfall concentration, predictability and the changes in rainfall seasons in Tanzania. Rainfall predictability was determined using Colwell's indices, Rainfall Concentration Index (RCI) and Coefficient of Variation (CV). Results showed that rainfall in December–February (DJF), January–March (JFM) and February–April (FMA) has predictability due to constancy of 60%, RCI $\leq$ 9 and CV < 0.4 in Lake zone, Central zone, Southern Coast zone, Western and Southern Highlands zone. Rainfall in October to December (OND) was reliable in the Island zone, North-Eastern highlands zone and Northern coast zone with an average predictability due to constancy of 65%. In the Lake zone, all seasons (DJF, JFM, FMA, MAM, OND and DJFMAM) had uniform rainfall distribution (RCI = 8.7, CV = 0.35) and predictability due to constancy of 80% which leads to the conclusion that Lake Zone has unimodal rainfall distribution. Rainfall predictability in Tanzania has a West-East gradient. The western zones had an average predictability due to constancy of 68%. In general, rainfall in Tanzania is observed to be highly variable; only 20% of the predictability is concerned with reliability in the rainfall occurrence within the seasons and 80% is due to seasonality.

Keywords: Rainfall concentration index; predictability; coefficient of variation; seasonality; constancy.

Introduction

Predictability of rainfall and its distribution in time and space within a season is crucial in preparing and planning for agricultural activities, particularly in the context of climate changes. Quantification of rainfall predictability is determining the extent to which future rainfall trends and states can be predicted by using the knowledge about current and past rainfall trends; this is possible if there is reliability in rainfall variability. Rainfall is considered to be predictable if its cycles and trends are consistent in their occurrence in time and space such that future trends follow the previous patterns and distributions (Młyński et al. 2018).

There are basically two rainfall seasons in East Africa, the long rains of March to May (MAM) and the short rains of October to December (OND). However, a study by

Nicholson (2016) suggested that MAM should not be considered as a single season because in each month the rainfall is driven by different factors and teleconnections. In the case of Tanzania, there are MAM and OND rainfall seasons in the northern and northeastern parts of the country, while in the southern and southwestern highlands there is a unimodal rainfall season from around November to April. Most of the studies on rainfall in Tanzania have considered rainfall variability and prediction (Kabanda and Jury 1999, Mapande and Reason 2005, Kijazi and Reason 2009, Ng'ongolo and Smyshlyaev 2010), but did not determine the state of rainfall predictability. A recent study (Mwinuka and Uiso 2017) considered prediction of OND and MAM rainfall in the southern highlands and found that there is a difference in predictability between the two seasons. A difference in predictability between MAM and OND indicates that rainfall in this region is not a continuous single season from November to April, suggesting that rainfall in these periods is driven by different factors and teleconnections. However, the status of rainfall predictability and concentration within the season in Tanzania is not known. Predictability used in this case means the reliability of the variability of the states of a system. It is concerned with the regularity of the recurrence of events of the within cycle (within a year or a season) (Tonkin et al. 2017). The current study aimed at first quantifying the predictability of the monthly and seasonal rainfall together with their concentration indices in Tanzania, and also to determine whether the long rain season from November to April in the known unimodal areas is still a one single season or some seasonal shifts have occurred due to climate change impacts.

Materials and Methods

The study area is Tanzania, divided into its basic climate zones (Heale et al. 2018), namely: The Coastal zone which includes the Northern coast, Southern coast and the Islands of Unguja and Pemba, the Lake zone, Western highlands zone, Southern highlands zone, Central zone and the North-Eastern highlands zone, as shown in Figure 1.

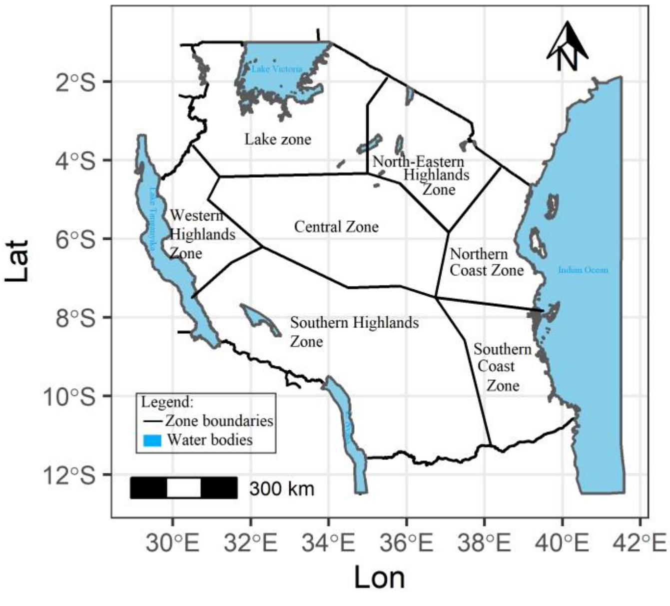

Figure 1: Map of Tanzania showing the study zones and water bodies (Heale et al. 2018).

Two monthly rainfall data were considered in this study, the Global Precipitation Climatology Center (GPCC)-Full Data Monthly version 2018 (Schneider et al. 2018) and the Precipitation Reconstruction over Land (PRECL). PRECL is derived from the Global Historical Climatology Network version 2 (GHCN2) and the Climate Anomaly Monitoring System (CAMS) (Chen et al. 2002). Both GPCC and PRECL rainfall data are gauge observations-based products. GPCC rainfall data have been used in East Africa, and Tanzania in particular and found to reproduce well the rainfall trend and cycles of this region (Yang et al. 2015, Borhara et al. 2020). The end date of availability of GPCC is 2016 and that of PRECL is the near present. A comparison was made between GPCC and PRECL monthly rainfall data by using Pearson, Spearman and Distance correlations (Székely et al. 2007, Bishara and Hittner 2017). A decision was made to use PRECL from 1979 to March 2019. The choice of PRECL was based on the comparison results of PRECL and GPCC, which are shown in Table 1 and Figure 2, where PRECL was found to be very close to GPCC, which is the most used gridded rainfall data in East Africa and Tanzania in particular (Yang et al. 2015, Borhara et al. 2020). GPCC data were compared to station data in Tanzania and found to agree with observed rainfall (Chang'a et al. 2020). The data were re-gridded from the regular grid of 0.5 x 0.5 to 0.25 x 0.25 longitude and latitude grid and the point data were extracted using the *cmsaf* r package (Kothe et al. 2019), Climate Data Operator (CDO) (Schulzweida 2019) and R software (R Core Team 2019).

The coefficient of variation (*CV*) of the seasonal and monthly rainfall was determined by using

$$CV = \frac{\sigma}{\mu} \quad (1)$$

where σ and μ are the standard deviation and mean rainfall, respectively. The interpretation of CV used here is as given by Asfaw et al. (2018): CV values more than 0.3 indicate high variability, CV between 0.2 and 0.3 indicate moderate variability and CV values less than 0.2 indicate low variability. The Colwell predictability (*P*), constancy (*C*) and contingency (*M*) (Colwell 1974), were calculated for seasonal and annual rainfall. Predictability (P), Constancy (*C*) and Contingency (*M*) are respectively given by (Tonkin et al. 2017),

$$P = 1 - \frac{[H(TR) - H(T)]}{\log k} \quad (2)$$

$$C = 1 - \frac{H(R)}{\log k} \quad (3)$$

$$M = \frac{[H(T) + H(R) - H(TR)]}{\log k} \quad (4)$$

where *T* is time in months in columns, *R* is the amount of the rainfall in the month in rows equivalent to state category (*k*), *H(T)* is uncertainty in the time, *H(R)* is uncertainty in state *k*, *H(TR)* is uncertainty in the interaction between time and states, *k*. *P* indicates regularity of occurrence of periodic events; it is given by $P = M + C$. *M* indicates the seasonality degree; higher values imply strong differences across the seasons. *C* is maximum when the rate of change of rainfall events is constant in a given year or season and *P* is maximum when rainfall has a consistent seasonal variation in a year, and hence *P* is concerned with within-season rainfall predictability (Tonkin et al. 2017).

Rainfall Concentration Index (RCI) (Oliver 1980, de Luis et al. 2011) was calculated from zone average rainfall for seasonal time scale by using Equation (5), from December to May using Equation (6) and for whole year by using Equation (7)

$$RCI.3month = \frac{25\sum_{1}^{3} R_i^2}{\left(\sum_{i=1}^{3} R_i\right)^2} \quad (5)$$

$$RCI.6month = \frac{50\sum_{1}^{6} R_i^2}{\left(\sum_{i=1}^{6} R_1\right)^2} \quad (6)$$

$$RCI.12month = \frac{100\sum_{i=1}^{12} R_i^2}{\left(\sum_{i=1}^{12} R_i\right)^2} \quad (7)$$

where R_i is the *i-th* month rainfall. In this paper, the term Rainfall Concentration Index is used instead of using Precipitation Concentration Index, because in Tanzania normally the type of precipitation that we get is in the form of water. According to Oliver (1980), RCI < 10 shows uniform rainfall distribution across the months of season, RCI value of 16.7 indicates that rainfall is concentrated in half of the season and RCI value of 25 indicates that rainfall is concentrated in one third of the season, 11< RCI < 15 shows moderate rainfall concentration, 16 < RCI < 20 shows irregular rainfall distribution and 20 < RCI indicates stronger rainfall irregularity.

Results and Discussions

GPCC and PRECL comparison results

The comparisons of GPCC and PRECL monthly rainfall data are presented in Table 1 and Figure 2. Table 1 and Figure 2 show the average results averaged over the climate zones of Tanzania. In Table 1, since the value of the Pearson and Spearman correlations are almost equal, it means that GPCC and PRECL rainfall had a normal distribution because Pearson performs better for normal distribution while Spearman is a distribution free statistic (Bishara and Hittner 2017). Also, the distance correlation coefficient is not far from the Pearson and Spearman, showing that GPCC and PRECL have linear relationships with very little nonlinearity (Székely et al. 2007). Figure 2a shows the GPCC and PRECL trends from 1979 to 2016 and Figure 2b shows the GPCC and PRECL monthly cycles. From Table 1 and Figure 2, it was decided to use PRECL which runs from 1979 to the present rather than GPCC which ends in 2016.

Table 1: Correlation between GPCC and PRECL monthly rainfall in Tanzania

Parameter 1	Parameter 2	Spearman corr	Pearson corr	Distance corr
GPCC	PRECL	0.95	0.94	0.96
p-values		4.50E-238	2.90E-216	0

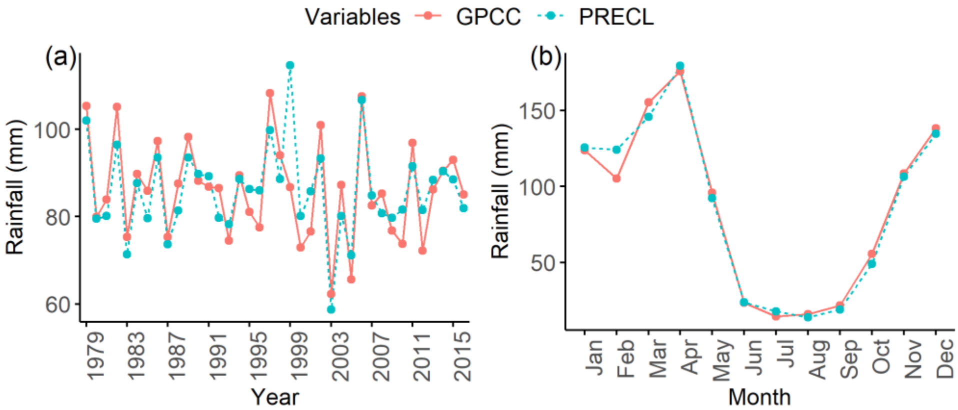

Figure 2: Comparison between GPCC and PRECL rainfall data (a) trend (b) monthly cycle.

Rainfall concentration

The seasonal Rainfall Concentration Index (RCI) values for DJF, OND, SON, FMA, MAM and December to May (DJFMAM) are shown in Figure 3. The results show that DJF, JFM and FMA have RCI ≤ 9 in the Lake zone, Western zone, Southern highlands zone and Central zone; 10 < RCI < 12.5 in the North-Eastern highlands, Northern coast and in the Islands of Unguja and Pemba (Figure 3a, b, and c). Therefore, DJF, JFM and FMA rainfall is uniformly distributed in the months in the Lake, Central, Western highlands, Southern highlands and Southern coast zones; and is distributed in more than half of the season in the North-Eastern highlands, Northern coast and the Islands zones as 10 < RCI < 12.5 is closer to RCI < 10 than RCI =16.7.

The RCI ≤ 9 for DJF, JFM and FMA in the mentioned zones imply that it rains from December to April, meaning that these zones have a unimodal rainfall distribution. Rainfall is uniformly distributed across the months of the MAM season (RCI < 10) in Lake, North-Eastern highlands, Northern coast and in the Islands and Coast zones (Figure 3d), while OND has RCI < ~10 in the Lake, Western highlands, North-Eastern highlands, Northern coast and the Island zones. Both MAM and OND rainfall have RCI ≤ 10.7) in the North-Eastern highlands, Northern coast and Islands of Unguja and Pemba, suggesting that these zones are the only ones which receive two distinct rainfall seasons, and therefore, are the only distinct bimodal zones. MAM and OND rainfall are moderately concentrated in more than half the season length with 10 < RCI < ~13.5 in the Central zone, Southern highlands zone and in the Southern coast zone. DJFMAM rainfall in the Lake zone, Western highlands and in the Southern highlands is uniformly distributed across the months of the season as it has RCI < 10 (Figure 3e), suggesting that on average, as it was observed for the DJF, JFM and FMA, the Lake zone, Western highlands and the Southern highlands are the only zones for which it rains from December to April/May. DJFMAM rainfall is moderately concentrated in more than half of the season length in the Eastern zones and the Central zone with 10 < RCI < ~13.

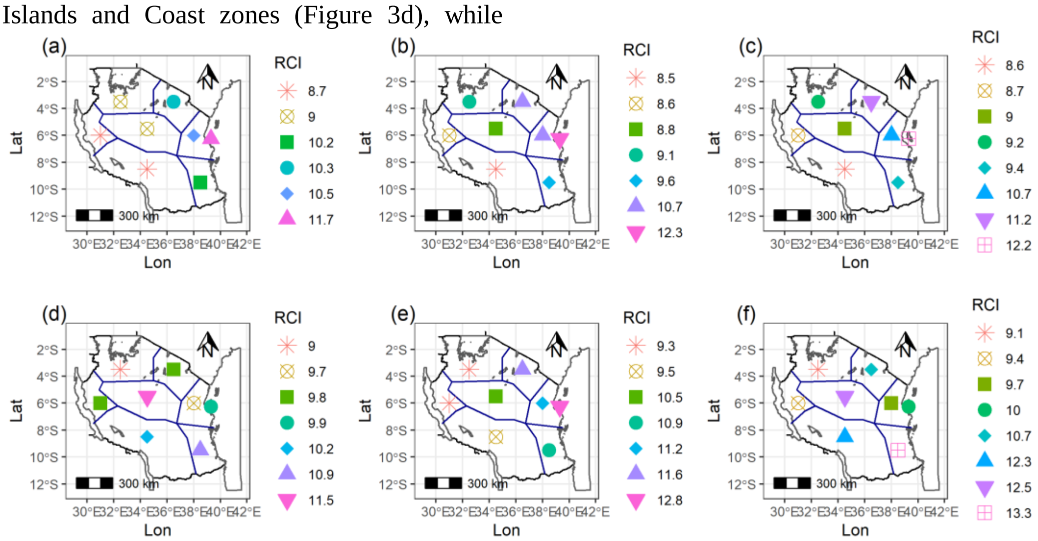

Figure 3: Spatial zone average seasonal rainfall concentration from January 1979 to March 2019 for (a) DJF, (b) JFM, (c) FMA, (d) MAM, (e) DJFMAM and (f) OND.

Zone area average annual rainfall concentrations are shown in Figure 4. Rainfall in the Lake zone, Western highlands, Southern highlands, Northern coast and in the Islands of

Unguja and Pemba had 11< RCI ≤ 15, which indicates moderate rainfall concentration in more than half of the year. On average, the annual average RCI showed that rainfall in the Southern coast, Central zone and in the North-Eastern highlands zone has an irregular distribution across the year with RCI in the range of 16 < RCI < 20 and higher CV > 1.00 which indicates higher variability.

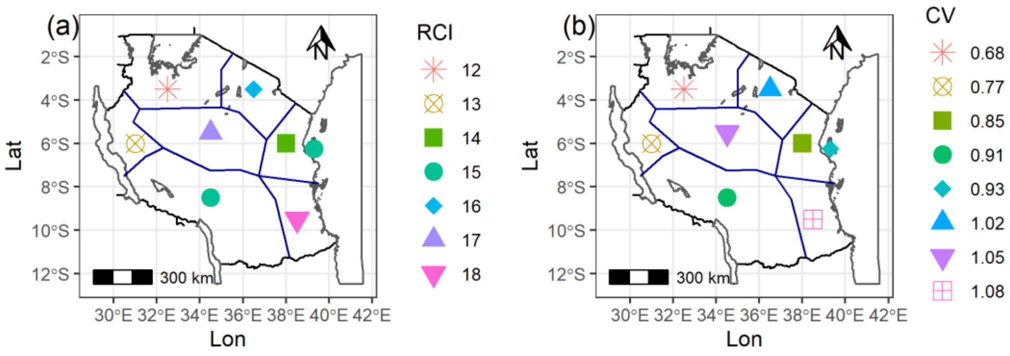

Figure 4: Zone average (a) annual rainfall concentration index (b) annual Coefficient of Variation (CV) from January 1979 to March 2019.

Rainfall predictability

Figure 5 shows the spatial seasonal zone area average rainfall variation from January 1979 to March 2019. JFM and FMA have CV < 0.4 in the Western highlands and Southern highlands zone. DJF rainfall has CV < 0.4 in the Lake zone, Western highlands zone and in the Southern highlands zone. In the North-Eastern highlands zone, Northern coast, Southern coast and the Islands of Unguja and Pemba, the DJF, JFM and FMA rainfall has CV > 0.4 and in the Central zone rainfall in DJF has also CV > 0.4. MAM and OND rainfall have CV < 0.5 in the Lake zone and Western highlands zone, while DJFMAM has CV ≤ 0.4 in the Lake zone, Western highlands zone and in the Southern highlands zone.

The coefficients of variation for the zone average monthly rainfall are shown in Figure 6. The CV for January and February (Figure 6a and b) rainfall are CV ≤ 0.3 in the Western highlands and Southern highlands zones, ~ 0.3 < CV < ~ 0.5 in the Lake and Central zones and CV > ~ 0.5 in the remaining zones which are located to the East of the country. March rainfall has CV < 0.2 in the Southern highlands zone and 0.2 < CV < 0.3 in the Lake zone, Central zone, Western highlands zone. April rainfall has CV < ~ 0.3 in the Lake zone, Western zone and in the Southern highlands zone. March rainfall has ~ 0.3 < CV < ~ 0.48 in eastern zones while April rainfall has ~ 0.3 < CV < ~ 0.45 in the eastern zones.

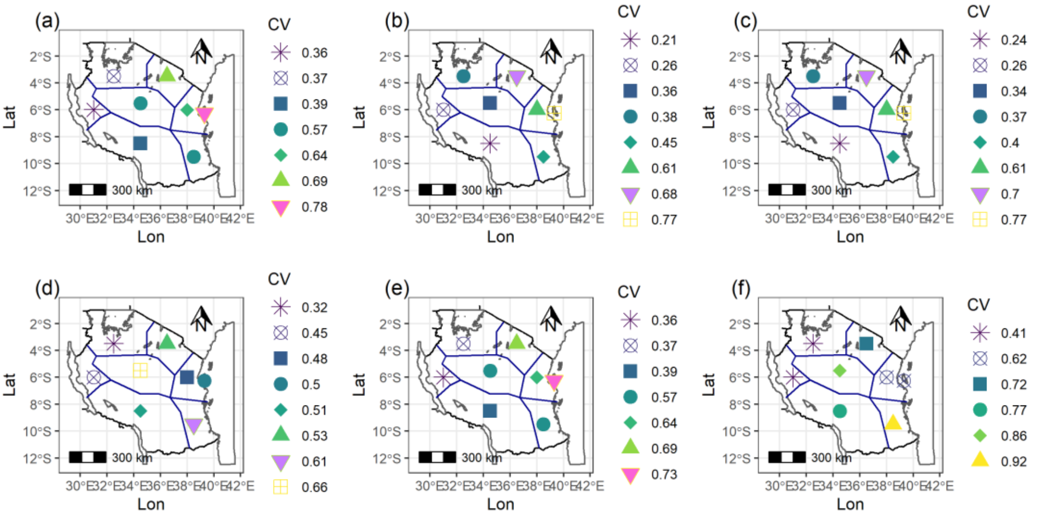

Figure 5: Seasonal zone average rainfall variations for the period from January 1979 to March 2019 for (a) DJF, (b) JFM, (c) FMA, (d) MAM, (e) DJFMAM and (f) OND.

Rainfall in May has CV < 0.3 in the Lake zone and 0.4 < CV < 0.7 in other remaining zones, with higher CV ~ 0.67 in the Central and South coast zones (Figure 7 a). October and November rainfall (Figure 7 b and c) has CV < ~ 0.41 in the Lake and Western highlands zones, respectively. December rainfall has CV < ~ 0.3 in the Western highlands zone and 0.3 < CV < ~ 0.33 in the Southern highlands zone (Figure 7d).

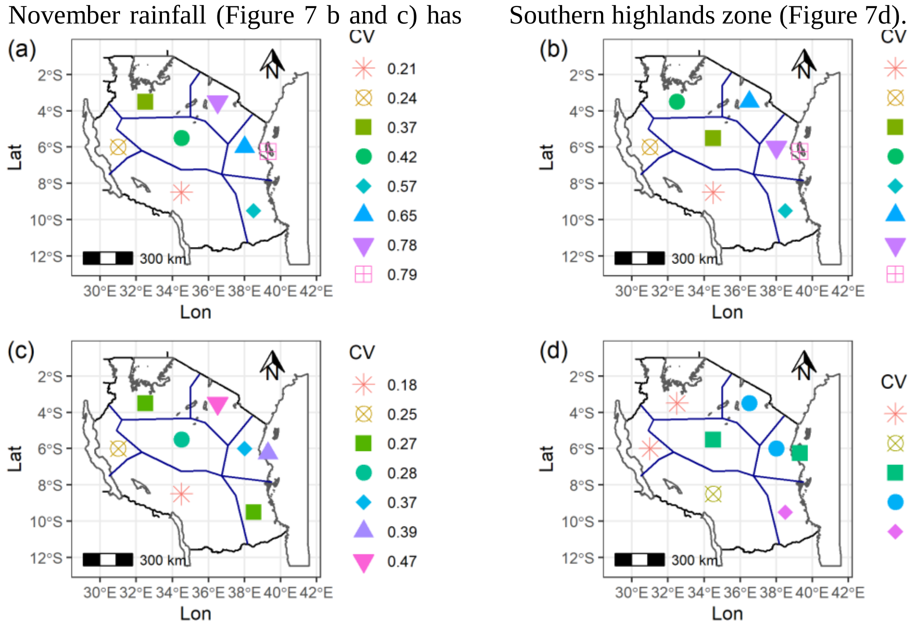

Figure 6: Zone average monthly rainfall variations for the period from January 1979 to March 2019 for (a) January (b) February (c) March (d) April.

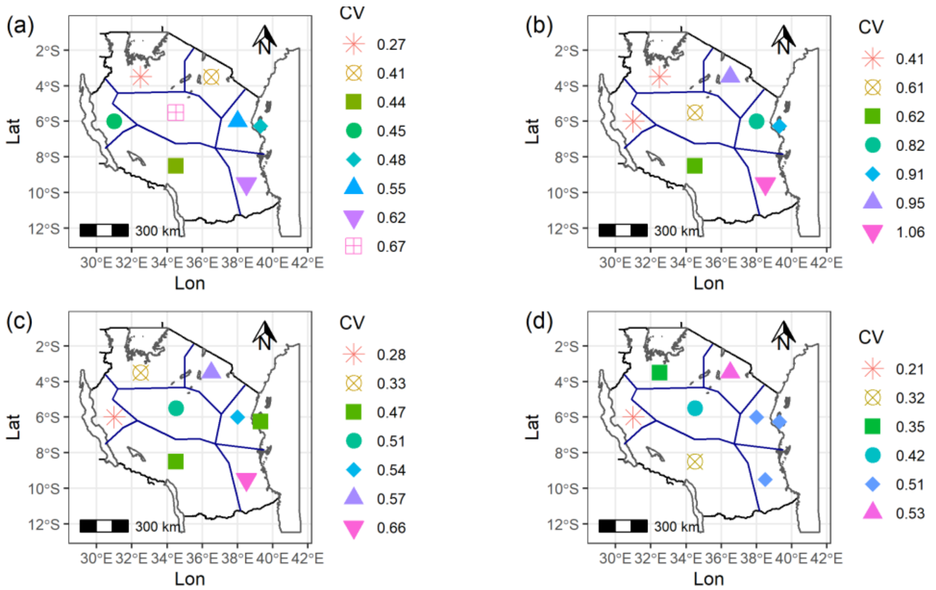

Figure 7: Zone average monthly rainfall variations for the period from January 1979 to March 2019 for (a) May (b) October (c) November and (d) December.

Seasonal rainfall predictability in terms of Colwell indices is shown in Figures 8, 9 and 10. Predictability due to constancy (PC) and predictability due to seasonality (PM) are the contributions of Constancy (C) and Contingency (seasonality) (M) to the rainfall predictability (P) and are determined as C/P and M/P, respectively. In Figure 8a, b and c, higher predictability of DJF and JFM is mainly contributed by Constancy (C) than Contingency (M). In Figure 5, the Central, Western highlands, Southern highlands and the South coast had low CV values for DJF and JFM, the same zones in Figure 8a, b and c have higher predictability due to constancy, which implies that the occurrence of rainfall events in DJF and JFM is constant. Based on these results, it is possible to predict with certain the future rainfall occurrence in DJF and JFM seasons by using the past rainfall events. Predictability P and the contribution of Constancy to predictability PC for DJF and JFM in Figure 8a, b and c, have the same distribution as that of CV (Figure 5). In this case, the observed low CV values (less variable) are indicators of the nearly constant rate of change of rainfall events within the season.

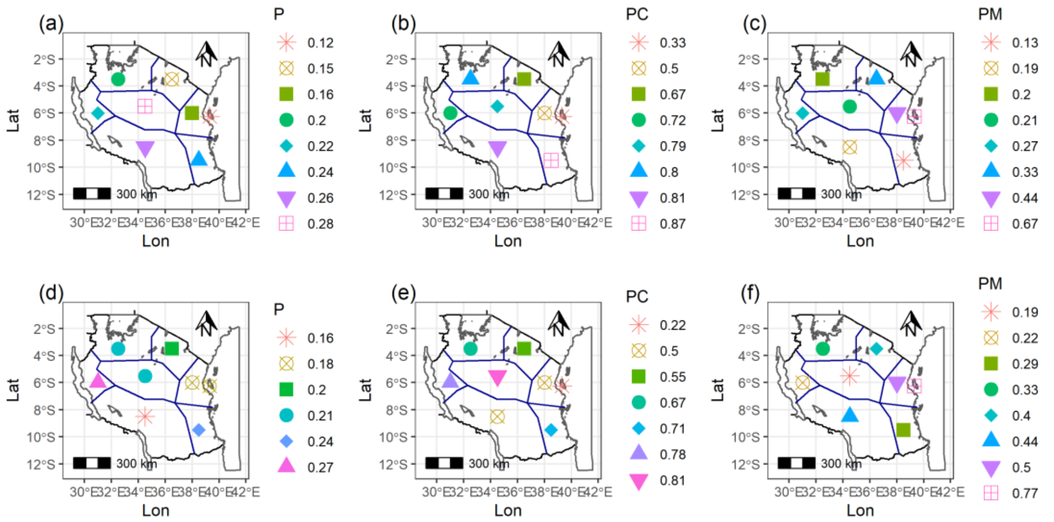

Figure 8: Zone average seasonal rainfall Predictability (P), Predictability due to Constancy (PC) and Predictability due to seasonality (PM) for DJF (a, b, c) and JFM (d, e, f) from 1979 to March 2019.

The FMA rainfall season has almost equal contribution of PC and PM to the predictability in the Southern highlands and in the Central zone (Figure 9a, b, c). FMA rainfall season in the Lake zone and the Western highlands zone has higher Constancy contribution to predictability as PC > PM (Figure 9 a, b, c). In the North-Eastern highlands zone, Northern coast and the Islands of Unguja and Pemba, the FMA rainfall has higher contingency contribution to predictability as PM > PC (Figure 9a, b, c), in these zones the CV value for FMA is also high. The predictability due to constancy for DJF, JFM and FMA when averaged over the western zones (Lake zone, Western zone, Southern highlands zone and the Central zone) are 0.77%, 0.69% and 0.61%, respectively (Figures 8b, e, and 9b). MAM and OND have predictability due to constancy of 42% and 0.35%, respectively, when averaged over the western zones (Lake zone, Western zone, Southern highlands zone and the Central zone) (Figures 9e and 10e). The high predictability for MAM in the Southern highlands, Central and Western highlands is mainly contributed by seasonality or contingency as PM > PC (Figure 9d, e, f). In this way, MAM and OND rainfall seasons seem to be quite different from the DJF, JFM and FMA in terms predictability distribution and its nature. MAM and OND have high predictability due to constancy in the eastern zones (Northern coast, Islands of Unguja and Pemba and in the North-Eastern zone) (Figures 9e and 10e).

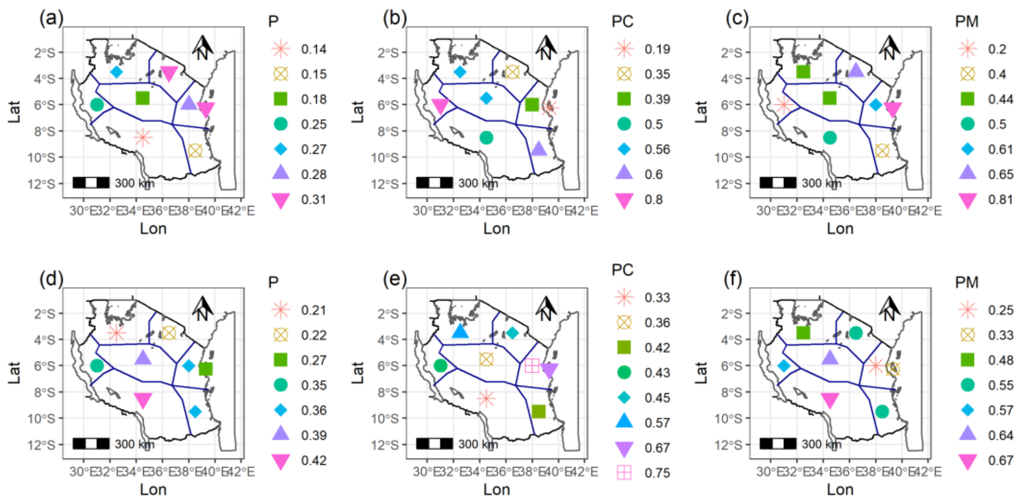

Figure 9: Zone average seasonal rainfall Predictability (P), Predictability due to Constancy (PC) and Predictability due to seasonality (PM) for FMA (a, b, c) and MAM (d, e, f) from 1979 to March 2019.

The predictability of OND rainfall has nearly equal contributions from constancy and contingency in the Lake zone, Western zone and in the North-Eastern highlands zone (Figure 10 d, e, f). In the Islands, the contribution of PC to predictability is higher than that of PM indicating that the occurrence of OND rainfall within the season in the Islands has a consistent rate (Figure 10 a, b, c). In the Central zone, Southern highlands zone and Southern coast, OND has predictability mainly contributed by the seasonality (PM) which means that the season occurrence is reliable but occurrence of rainfall events within the season has low constancy and hence less reliable; this is evident from the higher CV which range from about 0.75 to about 0.91 (Figure 5).

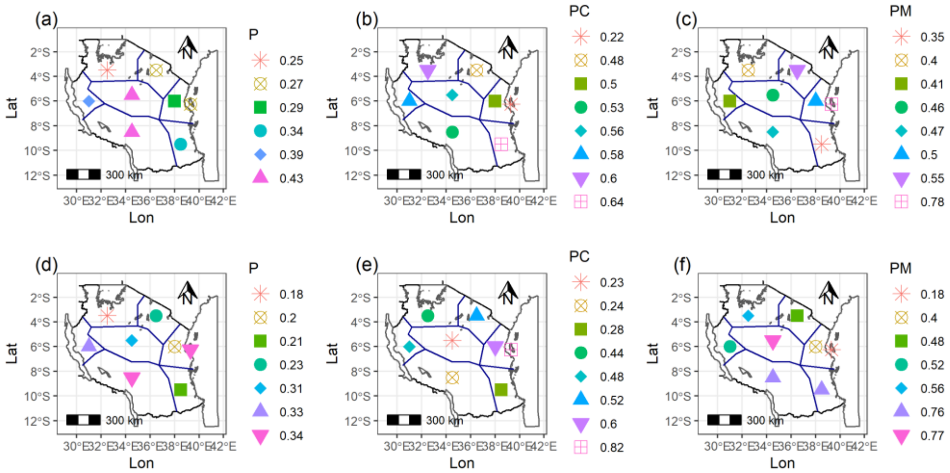

Figure 10: Zone average seasonal rainfall Predictability (P), Predictability due to Constancy (PC) and Predictability due to seasonality (PM) for DJFMAM (a, b, c) and OND (d, e, f) from 1979 to March 2019.

The predictability of DJFMAM rainfall in the North-Eastern highlands zone, Northern coast and in the Islands of Unguja and Pemba is due to relatively higher PM than PC which implies that there is less constancy in the occurrence of rainfall events within the season, this is because these seasons have bimodal rainfall distribution (Figure 10 d, e, f). The remaining zones have higher PC than PM, meaning that rainfall occurrence within the DJFMAM months is consistent, and this suggests that rainfall distribution is unimodal.

Figure 11 shows the predictability of zone area average annual rainfall. The predictability P values range from about 082 to 0.93 (Figure 11a) and indicate how consistent are the occurrence of rainfall events across a year. The main contributor to this high predictability is the Colwell contingency whose value is given by PM as PM > PC (Figure 11b, c). Hence, the observed high predictability is mainly due to consistency occurrence of rain seasons on their yearly tied times. The constancy in the occurrence of rainfall events across the seasons is low as indicated by low PC contribution to predictability.

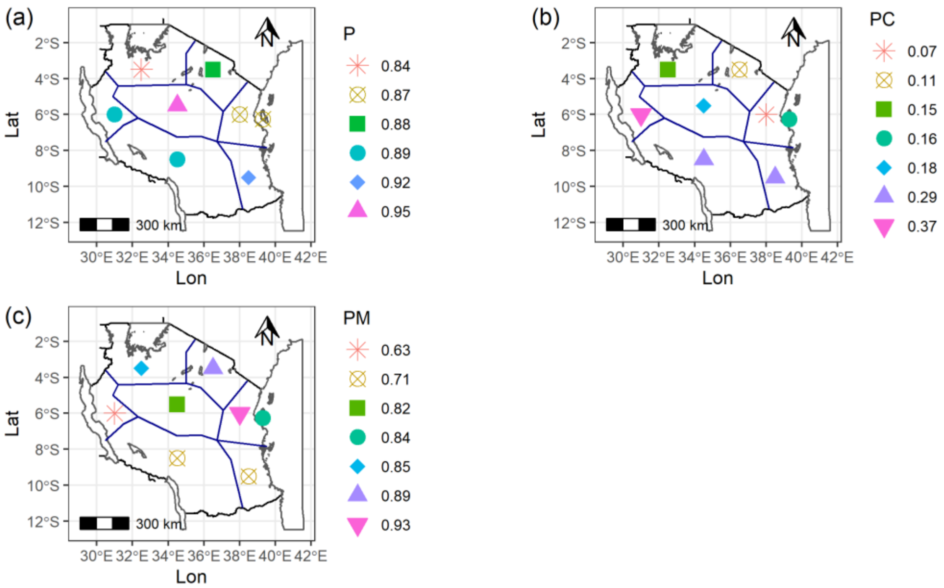

Figure 11: Zone average (a) Annual rainfall Predictability (P), (b) Predictability due to Constancy (PC) and (c) Predictability due to seasonality (PM), from 1979 to March 2019.

From the results of rainfall concentration and predictability, it can be noted that if the rates of variations of rainfall events in time and space are consistent and in well-known cycles within a season or a year, then the system under consideration is said to be predictable. Therefore, predictability and variability or variation explain each other. The results also suggest that another term which can be used to explain predictability of periodic phenomena such as rainfall is the concentration index. In Figure 3, it was observed that DJF, JFM and FMA rainfall seasons have RCI ≤ 9 and CV < 0.3 which indicate uniform rainfall distribution across the season and moderate variability, respectively. DJF and JFM in Figure 6 were observed to have high predictability due to constancy, which means that Colwell constancy is related to RCI and CV, low values of RCI and CV implies constancy in the rate of change of rainfall events across the year or season. The constancy part of rainfall predictability is more important than the seasonality part. Constancy of rainfall determines the reliability of the rain seasons within a year or rainfall occurrence events within a season (Tonkin et al. 2017)

The rainfall seasons DJF, JFM and FMA have been determined to have low RCI (RCI < 9), CV and high predictability due to constancy in the Lake zone, Western highlands zone, Southern highlands zone, Southern coast zone and to a lesser degree in the Central zone (Figures 3, 5, 6 and 7). This observation shows that rainfall in these zones is less variable from December to April (DJFMA). The results that rainfall in these zones rains mainly during the DJFMA are consistent with past results (Cioffi et al. 2016) which indicated that rainfall in Tanzania is centered on DJFMA. All seasons (DJF, JFM, FMA, MAM and DJFMAM) in the Lake zone had almost the same RCI $= 9 < 10$ (Figure 3) and same CV $< \sim 0.38$ (Figure 5) and higher predictability due to constancy (Figures 8, 9 and 10), indicating uniform rainfall distribution and low variability and hence reliable. Lake zone has been classified by past studies as bimodal zone (Cioffi et al. 2016), but the results of this study suggested categorizing it as a unimodal zone. The predictability and distribution of rainfall in the

Lake zone are influenced by the Lake Victoria, topography to the east and west of the lake, moist Congo airmass from Congo basin (Anyah et al. 2006). Lake-land temperature contrast creates circulation patterns which bring rainfall over the lake surface and the surrounding areas (Song et al. 2004). Orographic induced circulations and lake water surface temperature are also among the factors influencing rainfall in Lake zone (Kizza et al. 2009). All these factors act together to enhance rainfall from October to May as results in the present study showed constant and uniform rainfall distribution for the DJF, JFM, FMA and DJFMAM in the Lake zone.

The MAM rainfall shows lower CV (Figure 5) and RCI (Figure 3) ranges than OND, showing that OND rainfall is more variable than MAM, consistent with results from past studies that MAM rainfall in East Africa is less variable than OND rainfall (Zorita and Tilya 2002). The predictability of January and February have nearly the same distribution (Figure 6). March, April and May rainfalls have different predictability distributions, March is less variable than April rainfall, whereas May rainfall is the most variable of the three with quite different predictability distribution (Figure 6 and 7). This observation points to the results from past studies that the long rain (MAM) in East Africa seems to be not a single rain season because each month rainfall has its own characteristics and causal factors are markedly different for each month (Zorita and Tilya 2002, Nicholson 2017).

The average contribution of seasonality (PM) to the predictability of zone area average rainfall is about 80%. Predictability due to constancy (PC) is only about 20%. This means that we expect 20% of the rainfall events across the year to recur as they did last year. This observation is likely to be observed in the Western highlands zone, Southern highlands zone, Southern coast zone, and to a lesser degree in the Central zone (Figure 11b).

The predictability results as determined by seasonal and annual RCI and CV, monthly CV, and the Colwell's predictability P and the contribution to predictability due to constancy PC, have the west-east gradient distribution. The Lake zone, Western highlands zone, Southern highlands zone, Southern coast and to a lesser degree the Central zone, have high predictability by having low RCI, CV and high constancy, which imply reliable rainfall. The eastern part rainfall predictability is featured by high seasonality and low constancy, showing that it is less predictable (Tonkin et al. 2017). The observed west-east predictability gradient can be explained by considering the factors which influence rainfall and the bimodal and unimodal distributions in East Africa. Tanzania is a tropical country and its rainfall is affected by the monsoon winds and, being near to the Congo basin and due to the west-east pressure gradient (Camberlin 1977), the Congo airmass plays a role in the advection of moisture from the Congo basin to the western part of the country (Camberlin 1977, Nicholson 2017, Borhara et al. 2020). Other factors are topography (Lyon 2014) and its proximity to water bodies such as the Indian Ocean and the great Lakes of Victoria, Tanganyika and Nyasa. Topography affects the low-level wind flows and finally affects the distribution and transport of atmospheric moisture (Cioffi et al. 2016). The monsoons have the southeast and northeast flow patterns. These monsoons are thermally stable and characterized with subsidence of air which makes them relatively dry (Kizza et al. 2009). Therefore, we suggest that the southeasterly and northeasterly trade winds being relatively dry cause high variability of rainfall over the east and northeast parts of Tanzania. Variability of sea surface temperatures (SSTs) may also act together with the monsoons to enhance rainfall variability over the eastern and northeastern parts of Tanzania (Yang et al. 2014). On the other hand, the Congo airmass with its westerly and southwesterly motions, and because they are humid and thermally unstable, they act to enhance rainfall in the Lake zone, Western highlands zone, Southern highlands zone, some parts of Southern coast and to a lesser degree in the Central zone thereby leading to less variable rainfall in these western zones. The annual cycles of the bimodal rainfall distribution is proposed to be due to the annual cycles of the monsoon winds and together with the annual cycle of the SSTs from the Indian Ocean, with the aid of the import of the low moist static energy air flow from the cold northern Indian Ocean which hinders rainfall during the winter (Yang et al. 2015).

Conclusion

The predictability of zone average rainfall has been determined for each zone. The results show that DJF, JFM and FMA rain seasons have RCI < 10, CV < ~ 0.4 and high predictability due to constancy in the Lake zone, Western highlands zone, Southern highlands zone, Southern coast and, to a lesser degree, in the Central zone. Low RCI (RCI < 10) and CV < ~ 0.4 is related to high predictability due to Colwell's Constancy (PC) which implies reliable rainfall. In the Lake zone, all seasons (DJF, JFM, FMA, MAM, OND and DJFMAM) were found to have uniform rainfall distribution and high predictability due to constancy which leads to the conclusion that Lake zone has unimodal rainfall distribution. The predictability of rainfall in Tanzania has a West-East gradient for the DJF, JFM and FMA. Rainfall in the eastern and north-eastern parts has high seasonality and less reliable or predictable. In the unimodal zones, rainfall is predictable for DJF, JFM and FMA, which means rainfall is centered in DJFMA.

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