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Characterization of Historical and Future Drought in Central Uganda Using CHIRPS Rainfall and RACMO22T Model Data

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Abstract Drought is one of the devastating natural events that affect sensitive sectors such as crop production. The overall aim of this study was to characterize historical and future drought in two districts located within Uganda's coffee growing region, that is Bukomansimbi and Mubende. The standardized precipitation index (SPI) was applied to both historical and model-projected future rainfall in order to characterize the drought events. Data from the Climate Hazards Group InfraRed Precipitation (CHIRPS) provided the historical rainfall observations while future rainfall for the period2021 to 2050 was obtained from projections of version 2.2 of the Regional Atmospheric Climate Model (RACMO22T). The results showed that for the historical period, the decade 2001 to 2010 had the highest drought frequency of 16.7% in Bukomansimbi and 20% in Mubende. It also had the highest records of drought duration, magnitude and intensity, and the pinnacle of these events was in the period 2005 to 2007. The future drought characterization showed that the decades 2021 to 2030 and 2041 to 2050 are anticipated to have the highest drought frequencies, which for RCP 4.5 are 11.9% in Bukomansimbi and 15.6% in Mubende while for RCP 8.5 they are 9.2% in Bukomansimbi and 9.1% in Mubende. It is likely that drought will decrease in the future periods, and thus loosen its grip on the most affected sectors such as crop production.

Keywords Drought, Standard Precipitation Index, Uganda

1. Introduction

Drought is one of the most catastrophic types of natural disasters, causing damage in the order of billions of US dollars to the farming community worldwide each year (FAO, 2017; Zhou et al., 2018). Agriculture is one of the sectors most affected by this phenomenon in that it causes long term shortage of water and extreme heat stress in crops, thus damaging them especially if the event occurs during vulnerable times of the plant life-cycle (FAO, 2017).

Drought stands out among natural disasters because it affects wide regions and extends over long periods of time, thus having disastrous impacts (Eslamian et al., 2017). In many developing regions of the world such as in East Africa, drought impedes production and income at a household level which in turn affects peoples' overall output and welfare (Gebremeskel et al., 2019). At a country level, severe drought has the potential to affect the gross domestic product and undermine a country's development efforts. This is much more pronounced in third world countries like Uganda where agriculture is a major pillar of the economy.

Drought is an important topic in Uganda's farming regions, and that is no exception for the coffee growing regions. With about 1.7 million smallholder farmers involved in coffee farming (Mulinde et al., 2019), occurrence of prolonged drought events can have disastrous implications on their income and well-being. The interest of this work, therefore, is to characterize drought in these coffee growing districts of the country and to understand its trend in both the historical and future perspectives.

Understanding and assessing the drought occurrences is an essential element in any country's drought management plan because it reduces on the production losses that may lead to the reduction of government tax revenues (Adhyani et al., 2017). So far, in Uganda, Mulinde et al. (2016) has done a scientific analysis of drought events covering the period 1943 to 1982. This leaves the question of the recent drought trends unanswered. This study therefore seeks to establish the recent and future drought trends in Central Uganda. Furthermore, for Uganda to achieve its commitment in the 2030 Agenda particularly on climate action, it is essential for

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the country to understand the dynamics of climate-related natural disasters such as drought.

2. Materials and Methods

Study area

The study was conducted in Mubende and Bukomansimbi which are main Robusta coffee growing districts in Central Uganda (Figure 1). The total population of Bukomansimbi district is 151,413 and households that depend on crop growing as the main source of livelihood are approximately 93% (Uganda Bureau of Statistics, 2017a). In Mubende, the total population is 684,348 and households engaged in crop growing are 89.3% (Uganda Bureau of Statistics, 2017b). In Central Uganda, the rainfall pattern is bimodal, having two seasons. The long rain season is from March to May (MAM) and the short rain season is from September to November (SON). The climatological zones in which Bukomansimbi lies receives an average annual rainfall amount of 1408.2mm, its maximum temperature ranges from 26.78 to 29.43℃ and its minimum temperature ranges from 15.69 to 17.53℃. On the other hand, the zone in which Mubende lies receives 938.8mm of rainfall, its maximum temperature ranges from 26.17 to 27.65℃ and its minimum temperature ranges from 13.41 to 14.40℃ (Majaliwa et al., 2015). These districts were chosen for the study because there have been reports such that by Ssekweyama and Nakkazi (2019) that highlight them as being severely affected by drought. They also lie in the drought prone cattle corridor of Uganda.

Data and its sources

Historical rainfall observations. These were provided by the Climate Hazards Group InfraRed Precipitation (CHIRPS) blended with ground station data (Funk et al. 2015). The observed rainfall data for Bukomansimbi and Mubende were obtained for a period of 38 years, 1981 to 2018.

Projected rainfall. The projected monthly rainfall dataset was obtained from the model output of version 2.2 of the Regional Atmospheric Climate Model (RACMO22T) provided by The Royal Netherlands Meteorological Institute (KNMI) (van Meijgaard et al., 2008) which according to Kisembe et al. (2019) is among the most skillful models over Uganda. Additionally, in the simulations done by Luhunga et al. (2016), considering a variety of driving global climate models, the RACMO22T regional model was found skillful in reproducing tropical rainfall.

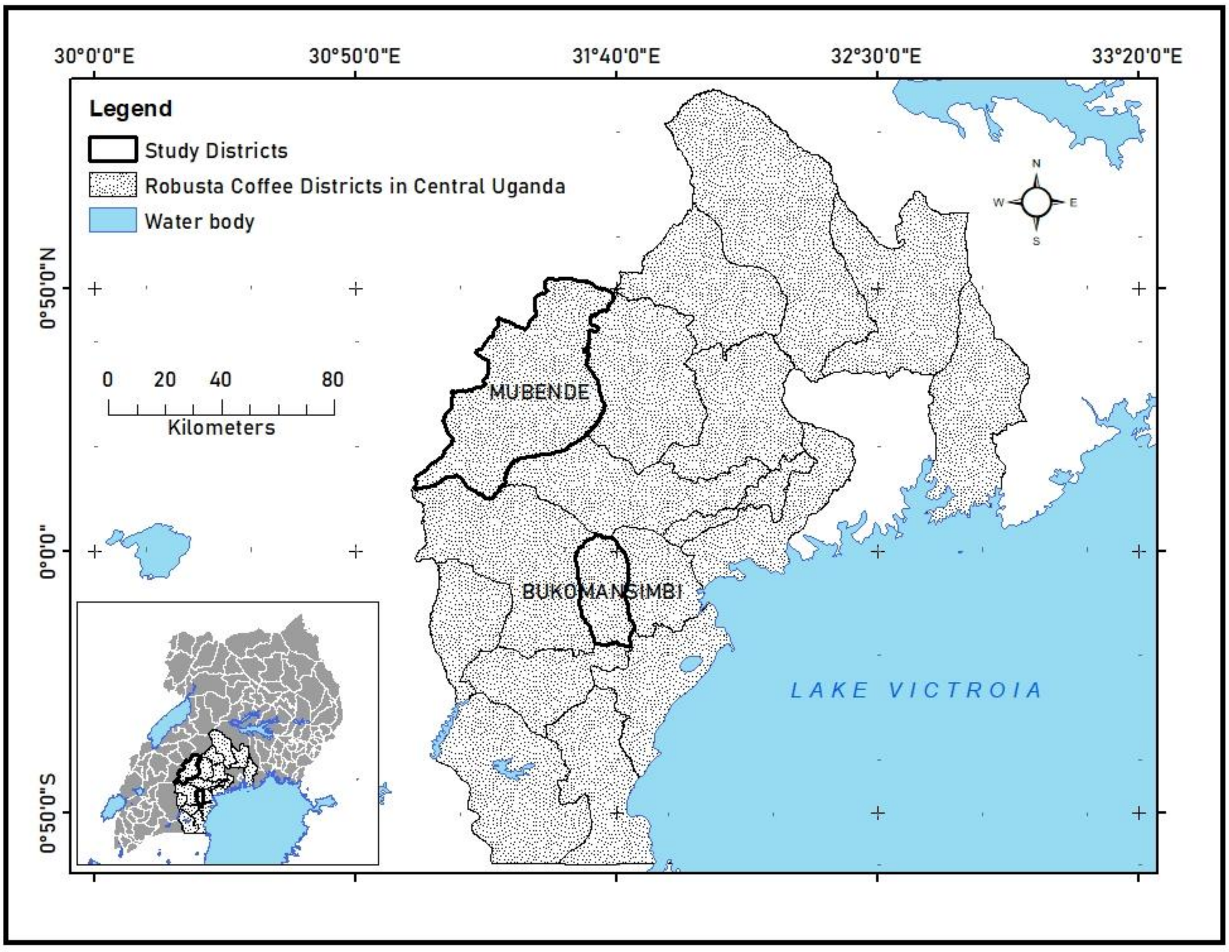

Figure 1. The position of Mubende and Bukomasimbi among the coffee growing districts in Central Uganda

Data analysis

The Standardized Precipitation Index (SPI). This method was used to categorize the drought events by their levels of severity. The statistic is described by Mckee et al. (1993) as a deviation from the mean value, normalized by the standard deviation of the entire range of data records. The index can have both positive and negative values as a measure of wet and dry conditions respectively. The focus was on the negative SPI values for those are the drought events. For this study, the 12-month SPI was used. The SPI for each particular year (SPI_{year}) was then calculated using equation 1. This calculation was applied to each year of the data series for both the historical and future periods, and results were categorized as shown in Table 1. In this work, emphasis was placed on the severe and extreme drought events because they potentially have more disastrous consequences on human livelihood.

$$SPI_{year} = \frac{Rainfall_{\ year} - Mean\ Rainfall_{\ (all\ years)}}{Standard\ \ Deviation_{\ (all\ years)}} \quad (1)$$

Drought frequency. This measure was calculated by dividing the number of drought events, n by the total number of months of the study, N and then multiplied by 100, as shown in equation 2.

$$Drought\ Frequency = \left(\frac{n}{N}\right) \times 100 \quad (2)$$

Drought intensity. This measure was calculated as the drought magnitude divided by the duration as shown in equation 3.

$$Drought\ Intensity = \frac{SPI\ Magnitude}{Duration} \quad (3)$$

Table 1. Drought categorization based on the SPI description of Mckee et al. (1993)

SPI value	Drought category
0 to -0.99	Mild drought
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2 and less	Extreme drought

Simple linear regression. This method was used to study the trend of drought. For two variables, the independent variable, x and dependent variable, y the linear regression equation takes the form of equation 4, in which a is a constant and b is the slope (Wilks, 2019). The R^2 determinant appended onto the results gives an indication of the strength of the relationship, it ranges from 0 to 1, and the closer the value is to 1, the stronger the relationship.

$$y = a + bx \quad (4)$$

3. Results and Discussion

Drought characteristics for the historical period

In figure 2 (a) and (b) the SPI index shows a similar pattern at both locations with notable variation across the years. It was observed that in both districts, the period 2004 to 2008 had the extreme and severe drought events, although in 2005 Mubende recorded a slightly higher extreme event (SPI = -2.8) than Bukomansimbi (SPI = -2.2).

Figure 2. Average Standardized Precipitation Index (SPI) for Bukomansimbi (a) and Mubende (b)

Table 2. Drought categories in Central Uganda from 1981 and 2018 calculated using a standard precipitation for a time scale of 12 months

Decade	Severe drought events	Extreme drought events	Drought frequency	Percentage drought frequency
	Bukomansimbi			
1981-1990	1	0	1	0.9%
1991-2000	0	0	0	0%
2001-2010	10	10	20	16.7%
2011-2018	0	0	0	0%
	Mubende			
1981-1990	1	3	4	3.7%
1991-2000	0	0	0	0%
2001-2010	5	19	24	20%
2011-2018	2	0	2	0.4%

Table 3. Drought characteristics for Bukomansimbi and Mubende

Year	Magnitude	Duration (months)	Intensity
Bukomansimbi			
1981-1983	1.90	1.00	1.90
2002-2004	3.96	2.00	1.98
2005-2007	39.15	19.00	2.06
2008-2010	1.18	1.00	1.18
2011-2013	1.50	1.00	1.50
Mubende			
1984-1986	7.96	4.00	1.99
2002-2004	3.91	2.00	1.96
2005-2007	54.12	22.00	2.46
2011-2013	3.41	2.00	1.71

Table 2 details the drought events by their categories. In both districts, the decade 2001 to 2010 had the highest percentage drought frequency of 16.7% in Bukomansimbi and 20% in Mubende. This is also highlighted by other literature such as WMO (2010)who noted that the Greater Horn of Africa in which these districts are located recorded severe and prolonged droughts in the decade, 2001 to 2010. This decade also had outstanding drought magnitudes, duration and intensities, and the pinnacle of these events was between 2005 to 2007 (Table 3). Generally, Mubende experienced drought events of a higher magnitude, lasting over longer periods and with higher intensity compared to Bukomansimbi.

For the historical period, a slightly increasing trend in drought magnitude was observed in both Bukomansimbi and Mubende (Figure 3). As highlighted in the previous characteristics, the period 2005 to 2007 had the driest conditions ever experienced in the region.

Drought characteristics for the future period

From the model projections (Figure 4), it is anticipated that under the low emission pathway, RCP 4.5, Bukomansimbi might experience a severe drought event (SPI = -1.76) in 2021 while Mubende might experience an extreme drought event (SPI = -2.66) in 2026. Under the high emission pathway, RCP 8.5, both districts will experience extreme drought events (SPI < -2) in the year 2043. The severe and extreme events are highlighted here for they are the ones which make profound damages. Notably, there are also years in which mild drought events (SPI > -1.49) might occur, some of which might not even be discernable across all locations in these districts.

The future drought categorization in Table 4 shows that for both districts, under RCP 4.5, potentially damaging drought events could be most frequent in the decade of 2021 to 2030 while under RCP 8.5 they could be most frequent in the decade 2041 to 2050. Although for Bukomansimbi, the decade 2021 to 2030 might also experience an equivalent frequency of such drought events. Under this high emission scenario, Bukomansimbi has a much higher risk of drought occurrence compared to Mubende.

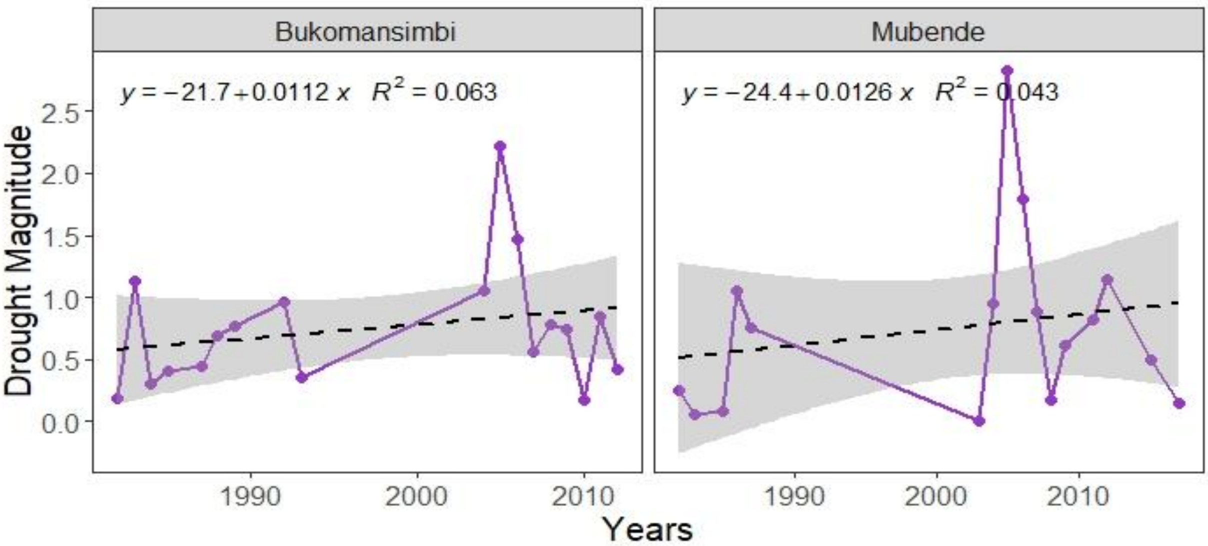

Figure 3. Historical drought trend in Bukomansimbi and Mubende

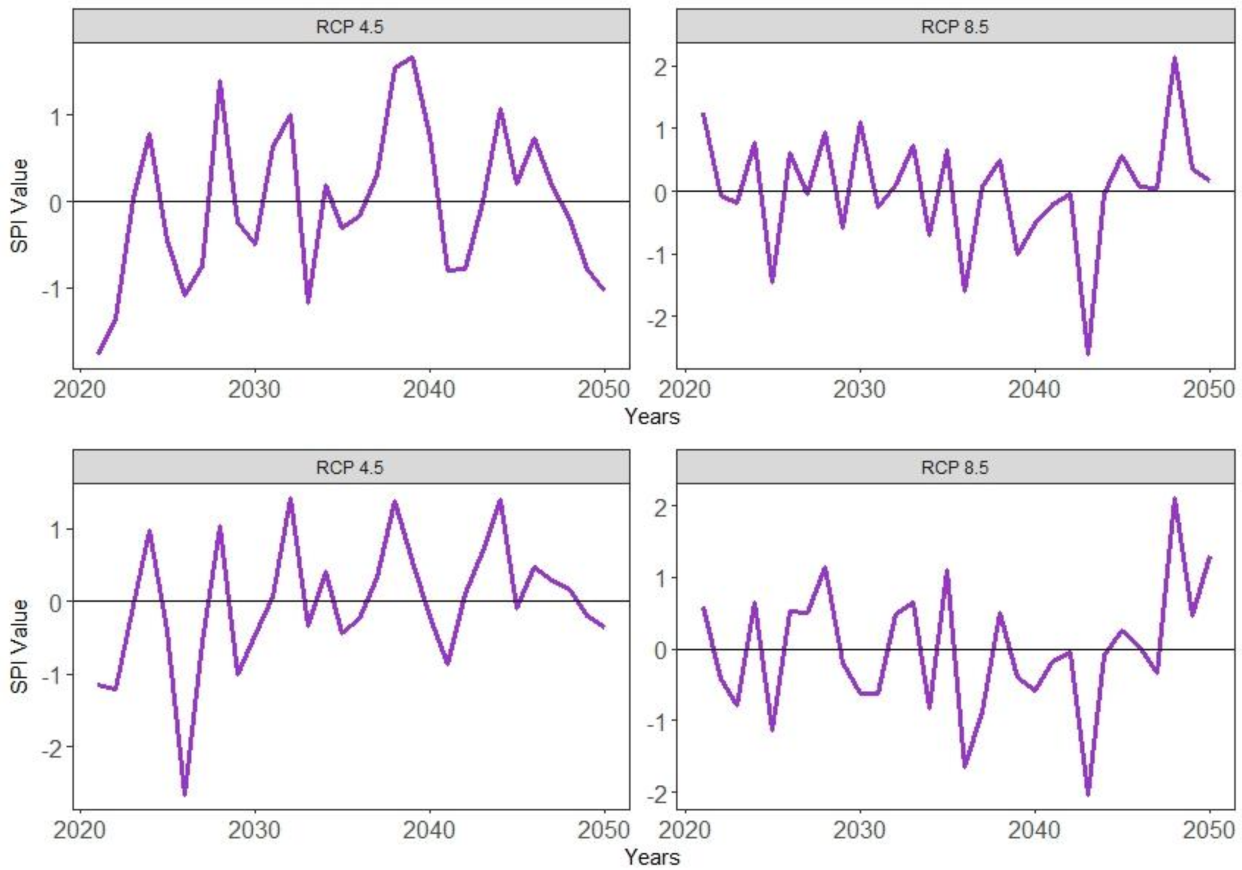

Figure 4. Projected drought magnitude for Bukomansimbi (upper row) and Mubende (lower row) under RCP 4.5 and RCP 8.5 emission pathways

Table 4. Projected drought categories in Central Uganda (2021-2050) using SPI at a time scale of 12 months

Decade	Severe drought events	Extreme drought events	Drought frequency	Percentage drought frequency
	Bukomansimbi			
RCP4.5				
2021-2030	6	7	13	11.9%
2031-2040	4	0	4	3.3%
2041-2050	3	0	3	0.3%
RCP8.5				
2021-2030	7	3	10	9.2%
2031-2040	8	0	8	6.7%
2041-2050	2	8	10	9.2%
	Mubende			
RCP4.5				
2021-2030	8	9	17	15.6%
2031-2040	1	0	1	0.8%
2041-2050	0	2	2	1.7%
RCP8.5				
2021-2030	2	0	2	1.7%
2031-2040	3	3	6	5.0%
2041-2050	3	8	11	9.1%

Further details of these events shown in Table 5 reveal that for both districts, under RCP 4.5, the peak of these drought events will most likely be from 2024 to 2026 and it could be more intense in Mubende compared to Bukomansimbi. On the other hand, under RCP 8.5, the peak of the drought events will most likely be from 2042 to 2044 and it could be more intense in Bukomansimbi than Mubende. Also, Bukomansimbi might not experience any drought events during 2021 to 2023 under RCP 8.5. However, for the years that follow after that, 2024 to 2026, this district will most likely experience intense drought events.

The analysis of trends in Figure 5 reveals a likely decreasing trend of drought events from 2021 to 2050, though it is only significant ($p < 0.05$) under the high emission pathway, RCP 8.5. Under this scenario, for both districts, the most intense drought events will most likely be experienced within the first half of the decade, 2021 to 2030. During that period, the drought magnitude will decrease sharply and then from about 2026 onwards, it will gradually decrease until the middle of the century in 2050. This decrease is likely to be more pronounced in Bukomansimbi than in Mubende. Furthermore, it is likely that this decrease in drought is associated with the projected increase in rainfall over this region that has been reported by Osima et al. (2018).

Table 5. Characteristics of projected drought for Bukomansimbi and Mubende

Bukomansimbi

RCP4.5				RCP8.5			
Period	Magnitude	Duration	Intensity	**Period**	Magnitude	Duration	Intensity
2021-23	7.63	4.00	1.91	**2024-26**	16.99	9.00	1.89
2024-26	19.23	9.00	2.14	**2027-29**	1.61	1.00	1.61
2033-35	6.74	4.00	1.67	**2033-35**	1.54	1.00	1.54
2039-41	1.55	1.00	1.55	**2036-38**	12.26	7.00	1.76
2048-50	3.43	2.00	1.72	**2042-44**	24.47	10.00	2.45

Mubende

RCP4.5				RCP8.5			
Period	Magnitude	Duration	Intensity	**Period**	Magnitude	Duration	Intensity
2021-23	5.37	3.00	1.79	**2021-23**	3.04	2.00	1.52
2024-26	32.26	12.00	2.67	**2024-26**	3.17	2.00	1.59
2027-29	3.15	2.00	1.58	**2036-38**	14.2	7.00	2.03
2029-41	5.79	3.00	1.93	**2042-44**	22.39	10.00	2.24
2048-50	1.51	1.00	1.51				

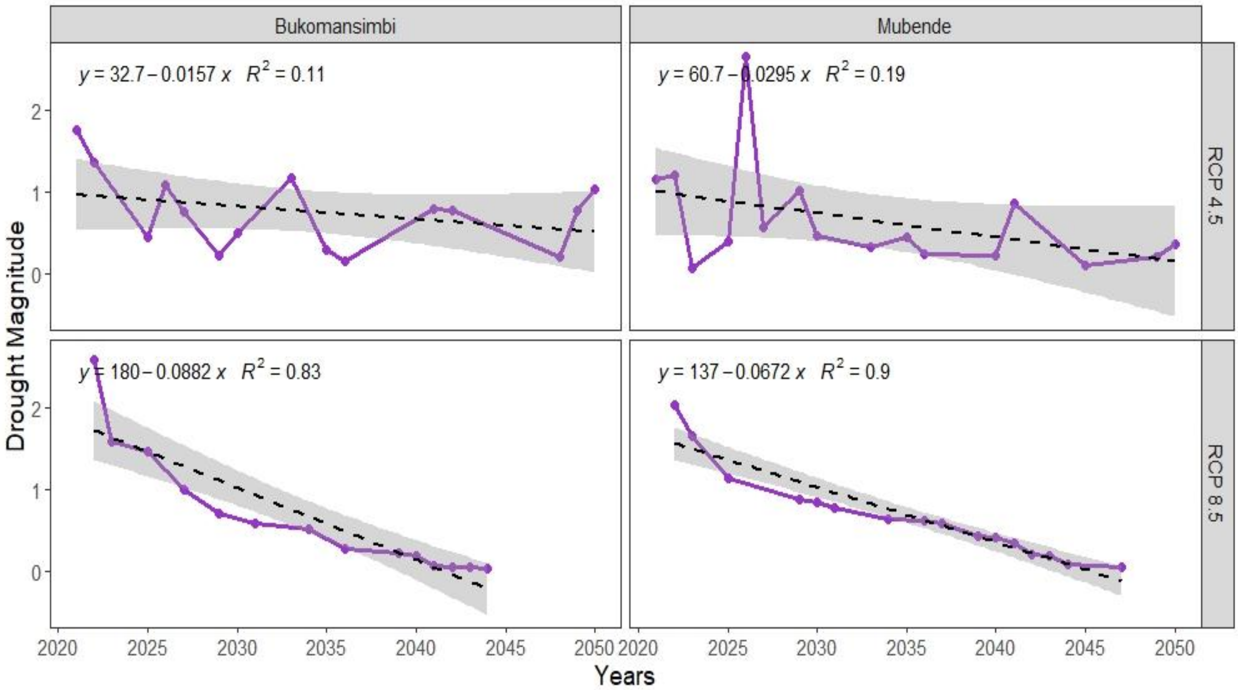

Figure 5. Trends of projected drought for Bukomansimbi and Mubende under RCP 4.5 and RCP 8.5

4. Conclusions

For the historical period, 1981 to 2018, the analysis revealed that the 2-year period from 2005 to 2007 was the peak of the drought events, having intensities of over 2. Also, during this period, Mubende experienced drought events of a higher magnitude, lasting over longer periods and with higher intensities compared to Bukomansimbi. Now during the future period, 2021 to 2050, the model projections reveal that under the low emission scenario (RCP 4.5), this situation could remain the same, however, under the high emission scenario (RCP 8.5), it is likely that Bukomansimbi could turn out to have stronger drought cases than Mubende. This affirms society's fears of climate change causing a shift in the spatial and temporal dynamics of natural disasters. Furthermore, since a decline in drought magnitude is projected under the high emission pathway, drought affected sectors such as agriculture could be alleviated from their severe impacts and consequently experience an increase in production. It is also possible that drought will most likely be a topic drawing lesser attention in future years.

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