Article

An Investigation on Spatiotemporal Variability of Drought Events under Different Climate Change Scenarios, Case Study: Rakai District

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Abstract: Drought occurrences in Rakai district take a strange model and it has been rampantly increasing causing reduced income levels for farmers, reduced farm yields, increased food insecurity and migration, wetland degradation, illness and loss of livestock. The purpose of this study was to investigate past and future characteristics of drought due to climate change in Rakai district. Datasets used include dynamically downscaled daily precipitation and temperature data from Coordinated Regional Climate Downscaling Experiment (CORDEX) at 0.44°×0.44° resolution over the Africa domain. R software (Climpact2 package), was used to generate SPI values, Mann Kendall trend test and Inverse Distance Weighting methods were used to examine temporal and spatial drought characteristics respectively. Results depicted more extreme and severe drought conditions for SPI12 under historical compared to SPI3,Kakuto, Kibanda and Lwanda sub counties were the most drought hot spot areas, positive trends of drought patterns for both time scales were observed, though only significant under SPI12. Projected results revealed extreme and severe drought conditions will be observed under RCP8.5 SPI12, and the least will be under RCP8.5 SPI3 and SPI12. Results further reveal that Kakuto, Kibanda, Kiziba, Kacheera, Kyalulangira, Ddwaniro and Lwanda sub counties will be the most drought hot spot sub counties across all time scales. Generally projected results reveals that the district will experience more drought conditions under RCP8.5 compared to RCP4.5 for time scale SPI12 and therefore urgent actions are needed.

Keywords: Spatio-temporal; Drought; Climate Change; SPI; RCP; Rakai

1. Introduction

Drought is widely recognized as costly disaster that affects a large number of people every year round and known to be a complex and complicated phenomenon [1- 3]. Unlike many other natural hazards, drought develops slowly, making it difficult to pinpoint the onset and termination of an event. By definition, drought is a shortage of precipitation over an extended period of time [4]. Drought can be confused with other phenomena such as water scarcity, aridity, and desertification. However, unlike aridity drought is a temporary feature of climate that can be intensified by high temperatures, high winds, and low relative humidity [5-7] define drought as a climatic phenomenon that arises from a sustained and extended period of precipitation deficiency, causing serious hydrological imbalances that adversely affect the land resources and production systems. Drought is among the most damaging natural disasters, causing billions of dollars in damage and affecting millions of people in the world each year due to its uncertain frequency, duration and severity of unpredictable or difficult to predict occurrence, resulting in diminished water resources availability and carrying capacity of the ecosystems.

Drought risks like shortages of water for drinking and irrigation, consequent reductions in food production, and others contribute to social and political trouble, civil wars, and international conflicts [8, 9]. These negative consequences of long-duration droughts will intensify as the number of humans and domesticated animals grow and increase the demands on available water supplies. Managing vulnerability and enhancing resilience against drought are the major pressing issues particularly among the developing countries.

Drought greatly affects socio-ecological systems worldwide through scarcity of available water [10]. For example, from July 2011-August 2012, a severe drought affected the whole Eastern Africa causing food crisis across Somalia, Ethiopia, Kenya and Uganda among other countries. It was confirmed to have caused deaths estimated between 5000 to 26000 people across Eastern Africa and economic losses as a result coming from death of animals and drying of crops [11]. [12], reveals that East Africa, where Uganda falls has experienced at least one major drought per decade, and there is a tendency of an increasing frequency and intensity of these events [13]. For example, in the last decade, two major droughts of 2008-2009 and 2010-2011 affected the agricultural sector, which left the region exposed to the risk of famine and humanitarian crises [14]. However, extensive impacts of drought in the past decades at regional and global scales call for improved capability to cope up with drought [15].

In spite of the impacts of droughts in the region, the rural communities and the agricultural sector in particular, are well informed about climate extremes with good understanding of dry and wet periods as being part of seasonal phenomena [16]. In the case of Rakai district, drought occurrences take a strange model. The drought events in this district are manifested as prolonged dry spells that cause shifts in the onset of rainy seasons [5, 17]. The frequency and severity of drought episodes are perceived to be caused by changes in the climate pattern, wetland degradation, location in the rain shadow, changes in land use, poor farming methods and deforestation. Drought occurrences are also associated with deficit soil moisture, reduction of surface water sources, rotting of crops and reliance on imported food. Predictably, the most affected months are those from December – March and July – September of each seasonal calendar [18].

Notably, the most adverse effects of drought in this district are reduced income levels for farmers and district revenue, reduced farm yields, reduced inputs and investment in the agricultural sector, increases prices of staple food, food insecurity, migration, theft of crops in gardens, wetland degradation, famine, illness and loss of livestock with the severity and distribution of drought affecting all the Sub counties in particular Byakabanda, Rakai Town Council, Kiziba, Kyalulangira, Lwanda, Kibanda, Kifamba, Kagamba, Kacheera and Ddwaniro [18].In order to effectively mitigate the impacts of drought, timely information about their occurrences is needed. However, most studies [19, 20] over the cattle corridor where Rakai district is a member have focused on understanding the impacts of past droughts on livelihoods and not occurrences of future droughts.

Drought monitoring and disaster management centers throughout Uganda require future information on the prediction of future droughts in order to plan properly and issue early warnings to the public. In Uganda, works on spatio temporal variability of drought events and their trends under different climate change scenarios have been fruitless since the areas identified (i.e.; both the prone and un-prone) have not been analytically and individually studied making drought mitigation and adaptation efforts difficult.

In this study however, basing on two specific objectives; (i), to determine the spatial temporal trend of drought characteristics in Rakai district from 1981-2020 and (ii) to predict future scenarios of drought occurrences in Rakai district from 2021-2060, meteorological drought was considered. This occurs when precipitation received is below the expected normal or actual amount [21, 22]. Meteorological drought being the deficiency in rainfall, is not temporally and spatially uniform [21, 23]. This means that the magnitude of drought and its severity is different for different locations [24], a factor that would call for dynamic approaches in managing drought impacts in different areas [25]. Therefore in this study, to overcome this national challenge, drought occurrences within Rakai district in both the past and future will be examined and more emphasis will be put on the drought characteristics (trend, severity, duration and intensity) using the Standard Precipitation Index (SPI) developed by [26] and geospatial techniques using the inverse distance weighted interpolation (IDW) method.

2. Materials and Methods

To investigate the past and future characteristics of drought due to climate change in Rakai district, dynamically downscaled daily precipitation and temperature data from Coordinated Regional Climate Downscaling Experiment (CORDEX) at a grid resolution of 0.44°×0.44° over the Africa domain was used. The Global Climate Model simulation (GCMs) projections are forced by the Representative Concentration Pathways (RCPs), [27]. The RCPs are prescribed greenhouse-gas concentration pathways throughout the 21st century, corresponding to different radiative forcing stabilization levels by the year 2100.The RCM included sampled climate change scenarios of both RCP4.5 and RCP8.5 running from 1971 to 2099. However, in this study the major focus was on the study period from 1981 to 2060.

Rakai District (Figure 1) is located in the South Western region of Uganda, west of Lake Victoria, lying between longitudes 31°E, 32°E and Latitude 0°S. Its Southern boundaries are part of the international boundary between Uganda and Tanzania. It is bordered by Masaka District in the East, Kalangala District in the South-East and Isingiro District in the West and Lyantonde in the North. It has Sub counties like Byakabanda, Rakai Town Council, Kiziba, Kyalulangira, Lwanda, Kibanda, Kifamba, Kagamba, Kacheera and Ddwaniro with a total area of (sq km) 4908.7 [18]. Rakai is one of the districts located in the Uganda's Cattle Corridor having many semi-arid characteristics which include, high rainfall variability, periodic late onset rains/droughts [28] and daily maximum temperature ranges from 25-35°C, while the daily minimum range from 18-25°C throughout the year [29].

Figure 1. Map showing location of Rakai district.

In this study several methods were applied in order to examine the past and future drought characteristics (trend, duration, severity and the intensity).Standardized Precipitation Index (SPI) was computed using daily rainfall and temperature (maximum and minimum) data sets for both present and future years in order to identify drought duration, severity and intensity over the study area using climpact2, a package in R software. In addition, the Mann Kendall trend test and Inverse Distance Weighting (IDW) method were used to examine the temporal and spatial characteristics of drought respectively.

The Standardized Precipitation Index, SPI [26] is based on the probability distribution of precipitation. SPI can be used as valuable estimator of drought severity which requires fewer input data and efforts than other meteorological drought indices [30]. SPI calculations for any location require long-term precipitation and temperature data record for a desired period. The use of different time scales (3-, 6-, 12-, 24-, and 48-month) allows for the assessment of the effects of a precipitation deficit on various water resource components (groundwater, reservoir storage, soil moisture, streamflow) [26]. The SPI-3 is derived by averaging the 3-month values, i.e., (March–May) within a year, while SPI-12 is from accumulated 12-month timescale. In this study SPI values at SPI3 and SPI12 time scales were used to account for short and long-term drought events.

Positive SPI values indicate greater than median rainfall and negative values indicate less than median rainfall. The McKee classification system shown in the SPI value (Table 1) was used to identify droughts resulting from the SPI. Drought severity is expressed as a cumulative deficiency of a drought parameter below a critical level (SPI mean =0). Drought intensity is defined as the average value of a drought parameter below the threshold level, which is measured as the drought severity divided by the duration.

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Table 1. Interpretation of SPI values in accordance to wet or dry condition

Class	Condition description	SPI values
1	Extreme drought	SPI ≤ -2
2	Severe drought	-2 < SPI ≤ -1.5
3	Moderate drought	-1.5 < SPI ≤ -1
4	Near Normal	-1 < SPI <1
5	Moderately wet	1 ≤ SPI <1.5
6	Severely wet	1.5 ≤ SPI <2
7	Extremely wet	SPI ≥ 2

According to Yevjevich (1967), Duration (L) =is the number of deficits in the sequence, designated by L (L=1, 2, 3… j).

Mann Kendall (MK) trend test, is a non-parametric test for identifying trends in the time series data. The Mann Kendall **S** Statistic is computed as seen in equation (1);

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(T_j - T_i) \tag{1}$$

Where;

$$sgn(T_j - T_i) = \begin{cases} 1 & if \quad T_j - T_i > 0 \\ 0 & if \quad T_j - T_i = 0 \\ -1 & if \quad T_j - T_i < 0 \end{cases} \tag{2}$$

Where T_i and T_j are the consecutive series of data values, and n is the length of the dataset. A positive value of S will be an indicator of an increasing trend while a negative value will indicate a decreasing trend. When n ≥ 10, the statistic S is approximately normally distributed with the mean and the variance as seen in equation (3):

$$\sigma^2 = \frac{n(n-1)(2n-5) - \sum t_i(i)(i-1)(2i+5)}{18} \tag{3}$$

Where t_i denotes the number of ties to extent i. The summation term in the numerator is used only if the data series contains tied values. The standard test statistic Z_s equation (4) which is used for measuring significance of trend is calculated as follows:

$$Z_s = \begin{cases} \frac{S-1}{\sigma} & for\ S > 0 \\ 0 & for\ S = 0 \\ \frac{S+1}{\sigma} & for\ S < 0 \end{cases} \tag{4}$$

Time series graphs for both historical and projected drought SPI values under RCP4.5 and RCP8.5 under SPI3 and SPI12 time scales were plotted using graphical analysis to determine their trends. The IDW was adopted in this study to examine the spatial behavior of drought using the SPI values from (SPI3 and SPI12) time scales. It is assumed by IDW method that SPI value has more influence at a point area and it diminishes with distance. The spatial display maps for SPI values was prepared using the Arc GIS software to indicate areas that are prone to droughts. The IDW is used in many studies that present spatially varying patterns e.g. [31] who used the IDW in modeling the spatial and temporal patterns of precipitation in Northwestern Uganda.

3. Results

3.1 Spatial distribution of drought occurrence in Rakai district during historical period

According to the study results (Figure 2), extreme and severe drought conditions under historical period (1981-2019) are observed under time scale SPI12 compared to time scale SPI3. This applies majorly in the Southern and Eastern parts of the district compared to the Western and Northern parts for both SPI3 and SPI12 time scales. Furthermore, spatial results reveals that Kakuto,Kibanda and Lwanda sub counties are the most drought hot spot sub counties in Rakai district compared to other sub counties However, moderate drought is observed across all time scales throughout the district.

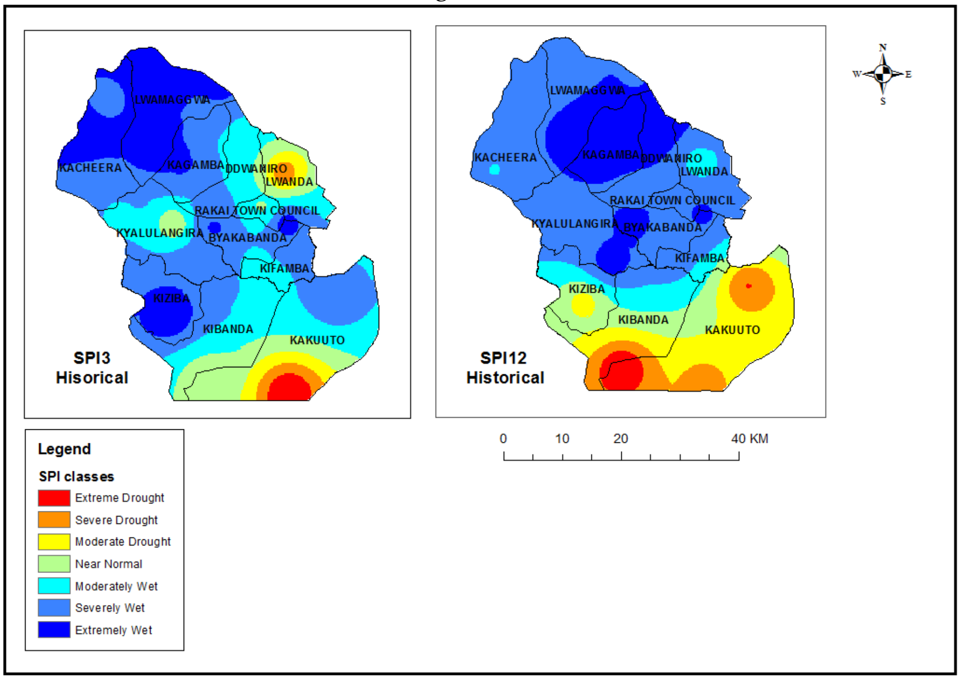

Figure 2: Spatial drought characteristics over Rakai district

3.2. Temporal distribution of drought occurrence in Rakai district during historical period

Temporal pattern results (Figure 3 (a-b)), show that the district observed enhanced dry conditions between 1981 to1982, 1991,1995, 2007 and 2018 under SPI3 for Historical and 1981 to 1983,1985, 1991 to 1992,1994 to 1996 and 2018 to 2019 under SPI12 for historical. Temporal pattern trends of historical droughts under both SPI3 and SPI12 showed positive trends for both time scales with gradients (0.0016 and 0.0168) respectively. These trends indicated that the district experienced a reduction in the drought conditions (Table 2), however, only significant at SPI12 time scale since its P-value (<0.05).

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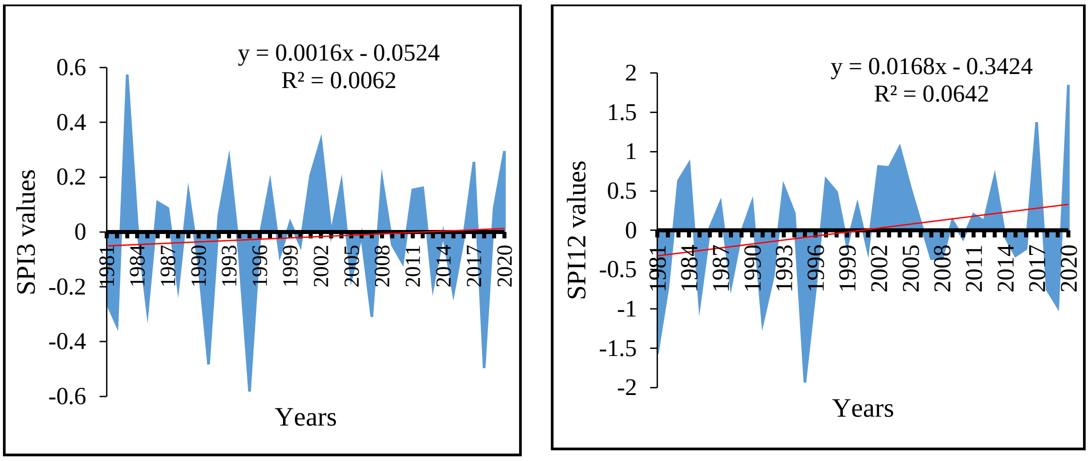

(**a**) (**b**)

Figure 3 (Historical). (**a**) Temporal trend of drought characteristics under SPI3; (**b**) Temporal trend of drought characteristics under SPI12

Table 2. Mann Kendall trend test results for Rakai district (historical)

Statistical parameters	SPI3	SPI12
Z	0.5863	3.7185
P-value	0.5577	0.0002*
Sen's slope	0.0003	0.0016
Status	decreasing dry conditions	decreasing dry conditions

* Statistically significant.

3.3 Projected spatial distribution of drought occurrence in Rakai district under scenarios

Study results (Figure 4) indicate that, extreme and severe drought conditions will be observed under RCP8.5 SPI12, while under RCP8.5 for time scale SPI3 less severity of drought conditions will be observed. This applies majorly in the Southern, Eastern and Western part of the district compared to the Northern part for both SPI3 and SPI12 time scales. Furthermore, spatial results reveals that Kakuto, Kibanda, Kiziba, Kacheera, Kyalulangira, Ddwaniro and Lwanda sub counties will be the most drought hot spot sub counties in Rakai district compared to other sub counties across all time scales.

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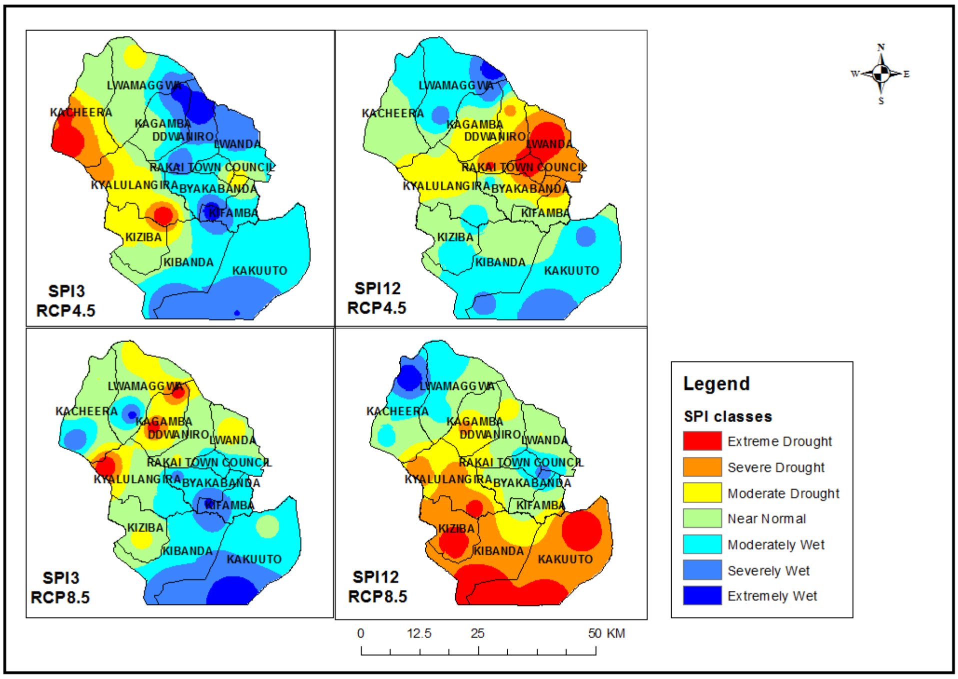
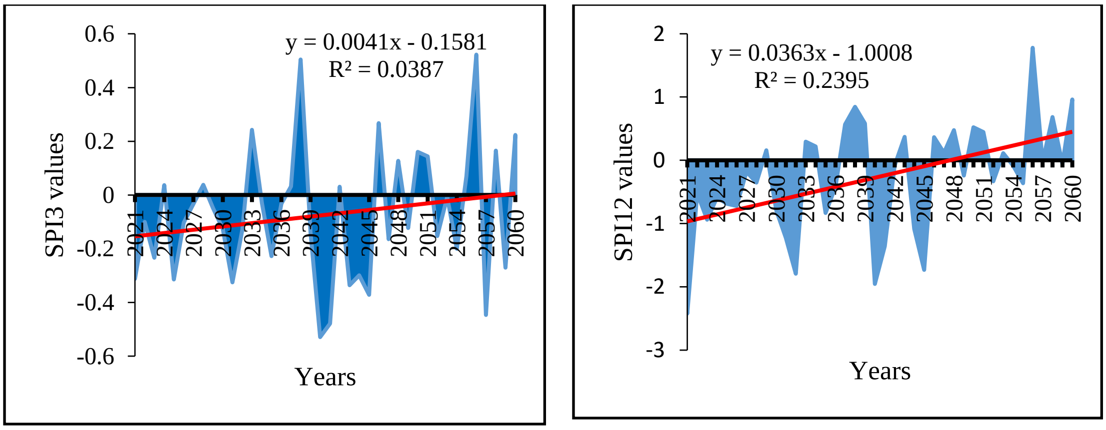


Figure 4: Projected Spatial drought characteristics over Rakai district

3.4 Projected temporal distribution of drought occurrence in Rakai district for RCP4.5

Projected temporal pattern (Figure 5 (a-b)), show that the district will experience dry conditions in 2021 to 2024, 2031,2039 to 2041,2043 to 2045 and 2057 under SPI3 and 2021 to 2029,2032 to 2034, 2039 to 2042 and 2044 to 2045 under SPI12. Temporal pattern trends of projected droughts for both SPI3 and SPI12 showed positive trends and this implies that the district will experience a reduction in the drought conditions (Table 3), however, significant reduction will only be at SPI12 time scale (p-value < 0.05).



(**a**) (**b**)

Figure 5 (Projected RCP4.5). (**a**) Temporal trend of drought characteristics under SPI3; (**b**) Temporal trend of drought characteristics under SPI12.

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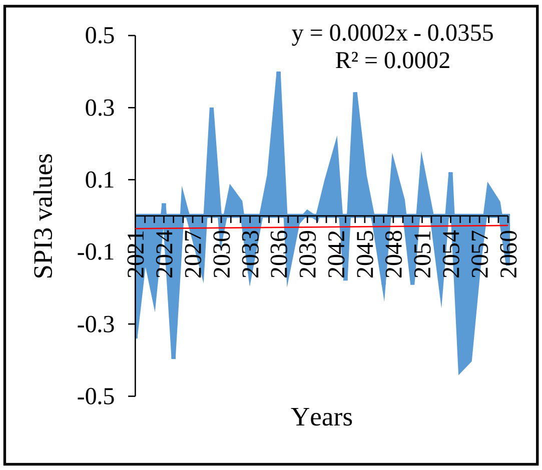
Table 3. Mann Kendall trend test results for Rakai district (projected, RCP4.5)

Statistical parameters	SPI3	SPI12
Z	0.3409	6.9324
P-value	0.7332	4.14x10^-12*
Sen's slope	0.0003	0.0035
Status	decreasing dry conditions	decreasing dry conditions

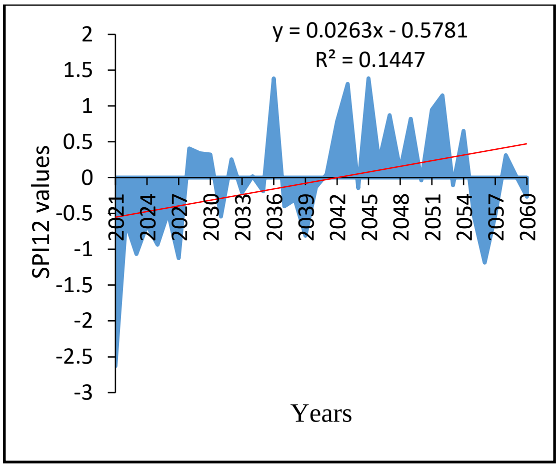
* **Statistically significant.**

3.5 Projected temporal distribution of drought occurrence in Rakai district for RCP8.5

Projected temporal pattern results (Figure 6 (a-b)), portrayed that the district will experience dry conditions in 2021,2023 ,2025, 2033,2037,2043,2047,2053 to 2041,2055 to 2057 under SPI3 and 2021 to 2028,2039,2055 to 2057 under SPI12. Temporal pattern trend of projected droughts for SPI3 showed negative trend (increasing dry conditions) while for SPI12 a positive trend (decreasing dry conditions) will be observed though in the two cases the trends will be insignificant (Table 4).



(a)



(b)

Figure 6 (Projected RCP8.5). (**a**) Temporal trend of drought characteristics under SPI3; (**b**) Temporal trend of drought characteristics under SPI12.

Table 4. Mann Kendall trend test results for Rakai district (projected, RCP8.5)

Statistical parameters	SPI3	SPI12
Z	-1.0119	3.2775
P-value	0.3116	0.7814
Sen's slope	-0.0005	0.0001
Status	increasing dry conditions	decreasing dry conditions

4. Discussion

This study has revealed outcomes in examining the spatiotemporal variability of drought events under different climate change scenarios in Rakai district. Spatial results depicted more extreme and severe drought conditions under historical period (1981-2019) for time scale SPI12 compared to SPI3 and that Kakuto, Kibanda and Lwanda sub counties were the most drought hot spot sub counties compared to other sub counties. According to temporal pattern results, the district received enhanced dry conditions between 1981 to1982, 1991, 1995, 2007 and 2018 under SPI3 and 1981 to 1983, 1985, 1991 to 1992, 1994 to 1996 and 2018 to 2019 under SPI12. Furthermore, temporal trends of historical droughts under both SPI3 and SPI12 showed positive trends for both time scales which indicated that the district experienced a reduction in the drought conditions, however, these trends were only significant under SPI12 time scale. Projected spatial results revealed extreme and severe drought conditions will be observed under both RCP8.5 and RCP4.5 for SPI12, and the least will be under SPI3 both RCP8.5 and RCP4.5 and these results reveal that Kakuto, Kibanda, Kiziba, Kacheera, Kyalulangira, Ddwaniro and Lwanda sub counties will be the most drought hot spot sub counties in Rakai district compared to other sub counties across all time scales. Temporal Projected results revealed that the district will experience dry conditions between 2021 to 2024, 2031, 2039 to 2041, 2043 to 2045 and 2057 under SPI3 for RCP4.5 and 2021 to 2029, 2032 to 2034, 2039 to 2042 and 2044 to 2045 under SPI12 for RCP4.5. Projected temporal pattern trends under RCP4.5 for both SPI3 and SPI12 showed positive trends and this implies that the district will experience a reduction in the drought conditions however, it will only be significant at SPI12 time scale.RCP8.5 projected temporal results, portrayed that the district will experience dry conditions between 2021 to 2023 to 2025, 2033, 2037, 2043, 2047, 2053 to 2041, and 2055 to 2057 under SPI3 for RCP8.5 and 2021 to 2028, 2039, 2055 to 2057 under SPI12 for RCP8.5. Temporal pattern trend of projected droughts under RCP8.5 for SPI3 showed negative trend (increasing dry conditions) but not statistically significant. Generally projected results reveals that the district will experience more drought conditions under RCP8.5 compared to RCP4.5 for time scale SPI12.

5. Conclusions

This study acts as a foundation for the current and future drought characteristics research throughout Uganda. As this study has shown, much more detailed information about spatiotemporal variability of drought events under different climate change scenarios in different regions is needed. Therefore, this study recommends that further study in relation to spatiotemporal variability of drought events under different climate change scenarios should be analyzed in terms of seasonal basis such as MAM, JJA, SON and DJF as frequency of drought events does appear to be related to seasonal rainfall and temperature variability. In addition, farmers' perceptions on drought trends throughout the study areas should be assessed as this can contribute to knowledge base as far as the contribution of drought characteristics in Ugandan and Africa is concerned.

6. Patents

This section is not mandatory but may be added if there are patents resulting from the work reported in this manuscript.

Author Contributions: Conceptualization, PW, JT and GS. Methodology, PW, GS and OM.; software, PW and KP. Validation, PW; formal analysis, PW. Investigation, PW and PK.; resources, HO.; data curation, PW. Writing—original draft preparation, P W ,PK and HN.; writing—review and editing, JT and GS. Visualization, Dr. OM and HO. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data used to support the findings of this study are readily available from the corresponding author upon request.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Tanner, Jane Louise. Understanding and modelling of surface and groundwater interactions. Diss. Rhodes University, 2013.
2. Okal, Harriette A., Felix K. Ngetich, and Jeremiah M. Okeyo. "Spatio-temporal characterization of droughts using selected indices in Upper Tana River watershed, Kenya." Scientific African 7 (2020): e00275.
3. Van Loon, A. F. "Hydrological drought explained, WIRES Water, 2, 359–392." (2015).
4. Qureshi, Asad Sarwar, and Mujeeb Akhtar. Analysis of drought-coping strategies in Baluchistan and Sindh provinces of Pakistan. Vol. 86. IWMI, 2004.
5. Ojara, Moses A., et al. "Trends and zonal variability of extreme rainfall events over East Africa during 1960–2017." Natural Hazards (2021): 1-29.
6. Wilhite, Donald A., ed. Drought and water crises: science, technology, and management issues. Crc Press, 2005.
7. Mishra, Ashok K., and Vijay P. Singh. "A review of drought concepts." Journal of hydrology 391.1-2 (2010): 202-216.
8. Sabiiti, Geoffrey, et al. "Adapting agriculture to climate change: suitability of banana crop production to future climate change over Uganda." Limits to climate change adaptation. Springer, Cham, 2018. 175-190.
9. Cooley, Heather, et al. "Global water governance in the 21st century." Pacific Institute, Oakland, CA 34 (2013).
10. Sheffield, Justin, Eric F. Wood, and Michael L. Roderick. "Little change in global drought over the past 60 years." Nature 491.7424 (2012): 435-438.
11. Hobson, Christopher. "Human security and fortuna: Preparing for natural disasters." Human security and natural disasters. Routledge, 2014. 181-188.
12. FAOSTAT, UN. "Statistics from: Food And Agricultural Organization of United Nations: Economic And Social Department: The Statistical Division." UN Food and Agriculture Organization Corporate Statistical Database (2011).
13. Massawa, Emily. "Guidebook: addressing climate change challenges in Africa: a practical guide towards sustainable development." (2011).
14. Mwangi, Emmah, et al. "Forecasting droughts in East Africa." Hydrology and Earth System Sciences 18.2 (2014): 611-620.
15. Smith, Adam B., and Richard W. Katz. "US billion-dollar weather and climate disasters: Data sources, trends, accuracy and biases." Natural hazards 67.2 (2013): 387-410.
16. Muyambo, Fumiso, Andries J. Jordaan, and Yonas T. Bahta. "Assessing social vulnerability to drought in South Africa: Policy implication for drought risk reduction." Jàmbá: Journal of Disaster Risk Studies 9.1 (2017): 1-7.
17. Alex, Nimusiima, et al. "A community perspective of flood occurrence and weather forecasting over Kampala City." African Journal of Environmental Science and Technology 15.5 (2021): 188-201.
18. Egeru, Anthony. "Role of indigenous knowledge in climate change adaptation: A case study of the Teso Sub-Region, Eastern Uganda." (2012).
19. Nimusiima, Alex, et al. "Nature and dynamics of climate variability in the Uganda cattle corridor." African Journal of Environmental Science and Technology 7.8 (2013): 770-782.
20. Wasswa, Peter. Assessment of March-May rainfall characteristics and effect on the stream flow of river Kafu in Masindi district catchment, Uganda. Diss. Makerere University, 2019.
21. Van Loon, Anne F., and Henny AJ Van Lanen. "A process-based typology of hydrological drought." Hydrology and Earth System Sciences 16.7 (2012): 1915-1946.
22. Logan, K. E., et al. "Assessing spatiotemporal variability of drought in the US central plains." Journal of Arid Environments 74.2 (2010): 247-255.
23. Gibbs, W. J. "The great Australian drought: 1982–1983." Disasters 8.2 (1984): 89-104.
24. Ramatsabana, Phatsimo, et al. "Evaluation of remote-sensing based estimates of actual evapotranspiration over (diverse shape and sized) Palmiet wetlands." Geosciences 9.12 (2019): 491.
25. McKee, Thomas B., Nolan J. Doesken, and John Kleist. "The relationship of drought frequency and duration to time scales." Proceedings of the 8th Conference on Applied Climatology. Vol. 17. No. 22. 1993.
26. Moss, Richard H., et al. "The next generation of scenarios for climate change research and assessment." Nature 463.7282 (2010): 747-756.

 doi:10.20944/preprints202108.0483.v1

27. Mfitumukiza, David, et al. "Smallholder farmers' perceived evaluation of agricultural drought adaptation technologies used in Uganda: Constraints and opportunities." Journal of Arid Environments 177 (2020): 104137.
28. Nimusiima, Alex, et al. "Predicting the impacts of climate change scenarios on maize yield in the cattle corridor of central Uganda." Journal of Environmental and Agricultural Sciences 14 (2018): 63-78.
29. Setiawan, Amsari Mudzakir, Woo-Seop Lee, and Jinyoung Rhee. "Spatio-temporal characteristics of Indonesian drought related to El Niño events and its predictability using the multi-model ensemble." International Journal of Climatology 37.13 (2017): 4700-4719.
30. Mulinde, Catherine, et al. "Meteorological drought occurrence and severity in Uganda." Disasters and Climate Resilience in Uganda: Processes, Knowledge and Practices; Nakileza, BR, Bamutaze, Y., Mukwaya, P., Eds (2016): 185-215.
31. Mugume, Isaac, et al. "Improving Quantitative Rainfall Prediction Using Ensemble Analogues in the Tropics: Case Study of Uganda." Atmosphere 9.9 (2018): 328.