East African Journanl Of Science And Technology

Journal Homepage: https://eajst.unilak.ac.rw/index.php/east

Assessing Variability in Monthly Rainfall and Water Balance in Kayonza District, Eastern Rwanda

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ABSTRACT

The distribution and variability of rainfall are crucial factors in understanding climate change, especially for regions reliant on rain-fed agriculture. This study investigates the variability in monthly rainfall and water balance in Kayonza district from 1983 to 2021 by using the coefficient of variation. The results show that monthly rainfall varies between 0 mm and 25 mm in June-July-August, and 75 mm to 200 mm in the rainy months of March, April, October, and November, primarily concentrated in the southern, central, western, and eastern parts of the district. Water balance ranges from 0 mm to 70 mm, with higher water balance in the southwest during April and May. Rainfall exhibits higher variability (100-160%) in June and July, while lower variability (0-40%) is observed in March, April, October, and November. Water balance shows non-uniform variability, with the southwestern, southern, central, and eastern parts showing variability of 30-80%, while other months are ranging from 100 to 150%. On a pentad and dekadal time scale, rainfall and water balance are concentrated in pentad 12 to 31, pentad 51 to 72, decadal 6 to 16, and decadal 25 to 35, with less precipitation in other periods. Region one receives more rainfall compared to region two. These findings are crucial for developing mitigation strategies to combat the impacts of climate change on agriculture, emphasizing water conservation and integrating climate data into decision-making processes.

Keywords: Dry spell, Kayonza, Rainfall, Variability, Water balance

ARTICLE INFO

Received:30 February 2024, Accepted: 30 Appril 2024, Published: 09 May 2024

1. Introduction

Rainfall is a fundamental weather element (Mumo et al., 2019) that exhibits varying magnitudes across different regions due to mesoscale activities (Hansen et al., 2010**)** leading to frequent hazards such as floods, landslides, and droughts in the East Africa region (Nicholson, 2017; Understanding rainfall patterns and variability in the context of a changing climate at sub-national, national, regional, and global scales is essential for estimating the impa**cts** of climate change on agriculture and water resources and for developing effective mitigation strategies (Gornall et al., 2010; Austin et al., 2020**).** The tropical region, including East Africa, exhibit**s** a bimodal rainfall pattern, with the timing of the bimodality depend on the position of the Intertropical Convergence Zone (ITCZ). This results in locations closer to the equator experiencing two rainy seasons and two dry seasons**,** while those farther away exhibit a unimodal seasonal rainfall pattern **(**Ongoma et al., 2018; Ayugi et al., 2018; Siebert et al., 2019). Recent studies indicate that March-April-May (MAM) rainfall contributes to 40% of the annual total rainfall, with 30-40% coming from the September–October-November-December (SOND) seasonal rainfall, and 15 to 20% from the January-February (JF) dry season, while the long dry season of June-July-August (JJA) contributes to only 5% of the total annual rainfall (Muhire and Ahmed, 2015**)**. The spatial distribution of annual and seasonal rainfall reveals a southwest to northwest rainfall gradient (Jonah et al., 2021)**.** Abnormal numbers of days, whether with or without rain, can lead to floods and droughts respectively, with their intensity and duration being directly correlated (Seneviratne et al., 2012**)**. Dry days, defined as days with rainfall less than 1mm (Gitau et al., 2013), and dry spells serve as indicators of drought and impact various socio-economic sectors, including agriculture (Mwangi et al., 2014; Chimimba et al., 2023).

The dry spell and drought can lead to a global loss of up to 25% of crop yields (Bankole et al., 2017), with 36 million inhabitants in sub-saharan Africa experiencing food shortages due to dry spells that result in severe droughts (Nazareth, 2016). The risk of floods is directly proportional to the increase and the prolonged wet days, while the risk of droughts and their impacts are proportional to the increase in dry spells (Ndehedehe et al., 2023; Omay et al., 2023). A study in the east african region highlights the significance of dry and wet spells during rainfall peaks in the country (Omay et al., 2023), where their changes affect total rainfall and water balance (Gobin and Van de Vyver, 2021), resulting in negative impacts on rain-fed agriculture (Gitau et al., 2013). Their persistence, when combined with other factors, whether economic or social, may lead to reductions in crop yields, water scarcity, and food insecurity (Yapo et al., 2020). Understanding the characteristics of monthly rainfall and water balance will aid in determining and assessing rainfall variability, which will inform better management and monitoring of the impacts of climate variability or change on food security, as well as inform proper sustainable development intervention measures for the present and future. Several recent studies have been conducted to better understand the variability and trends in

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

rainfall throughout Rwanda (Muhire and Ahmed, 2015; Muhire et al., 2015; Ntwali et al., 2016; Siebert et al., 2019; Sebaziga *et al*, 2020; Kazora et al., 2021; Umutoni et al., 2021; Ngarukiyimana et al., 2021; Safari et al., 2022; Uwimbabazi et al., 2022; Twahirwa et al., 2022; Sebaziga et al., 2022), in the eastern region (Sebaziga et al., 2020), and in the Kayonza District (Sebaziga et al., 2023) at both the seasonal and annual time scales. The current study was conducted to analyze rainfall and water balance variability at a timescale lower than the seasonal scale with the goal of expanding existing knowledge on rainfall characteristics in the studied area. The resulting information from this study will serve as a basis for informing decision-making and policy formulation regarding the integration of climate variability and climate change information into the development of policies and strategies that support different sectors such as agriculture, water resources, among others.

2. Materials and Methodology

2.1 Study area

Kayonza district **(Fig. 1)** is one of the seven Districts of the Eastern Province in Rwanda and is located at (1°51'S, 30°39'E). Its altitude ranges between 1400 and 1600m with an area coverage of 1,937 square kilometers (km^2) (Mushonga et al., 2019; NISR, 2023), with a total population of 457,156 people and a population density of 338 inhabitants per square kilometer. In terms of gender distribution, 51.6% of the Kayonza population are women and 48.4% are men. The majority of the population in Kayonza District live in rural areas (85.8%), while 14.2% live in urban areas (NISR, 2023. Interior lakes such as Kivuba, Shakarani, Kibare, Ihema, Hago, Rwibishuhe, Kabigabiro, and Cyabatanzi are located in Kayonza, with Lake Muhazi serving as a boundary from other neighboring Districts (Sebaziga et al., 2023). Similar to other parts of Rwanda, Kayonza District experiences bimodal rainfall, with March-April-May (MAM) and September-October-November-December (SOND) being the two main rainy seasons, while June-July-August (JJA) and January-February (JF) are the two dry seasons (I Muhire, Ahmed, & Abutaleb, 2015 ; Muhire et al., 2015; Ntwali et al., 2016; Siebert et al., 2019; Sebaziga *et al*, 2020; Kazora et al., 2021; Umutoni et al., 2021; Sebaziga et al., 2023) with rainfall characteristics mainly controlled by the movement of the ITCZ, passing through twice a year (Mutai et al., 2000). Agriculture, subsistence pastoralism and small-scale trading are the main economic activities on which the majority of the population depend for their daily livelihood (Niyonasenze S et al., 2017). The southeastern parts of the district exhibit more rainfall variability during dry seasons compared to rainy seasons and annual rainfall, while the rest of the district observes low variability during both annual and rainy seasons, with the central parts of the district showing a statistically significant increase in rainfall (Sebaziga et al., 2023). Additionally, rainfall over Kayonza District shows a negative correlation with the NDVI (Ndayisaba et al., 2016), with a lower frequency of rain days, expected to increase during the 21st century (Mohammed et al., 2016). In terms of climatic zones, a previous study (Sebaziga et al., 2023) has delineated Kayonza district's climate into four climate zones. The first climate zone (R1) is located in the southwestern part of the district in the sectors of Rwinkwavu, Kabare, Murama, Kabarondo, Ruramira, Nyamirama, and Mukarange. The second climate zone (R2) separates the remaining zones and is located in the central parts of the district, extending from the western parts of Ndego, southwestern and northwestern parts of Mwiri, northeastern parts of Kabare and Rwinkwavu, extending to the southern, western, central, and eastern parts of Gahini sectors. The third climate zone (R3) encompasses the eastern part of the district in the areas of Akagera National park, extending from the southern part of Ndego district all along the eastern part of Mwiri to the eastern part of Murundi sector. The fourth climate zone (R4) covers the northern and northwestern part of the district, including the entire Rukara sector, the northern and extreme western parts of Gahini sector, and most parts of Murundi sector except its eastern side. More information on the generation of near-homogeneous climate zones over Kayonza district can be found in (Sebaziga et al., 2023).

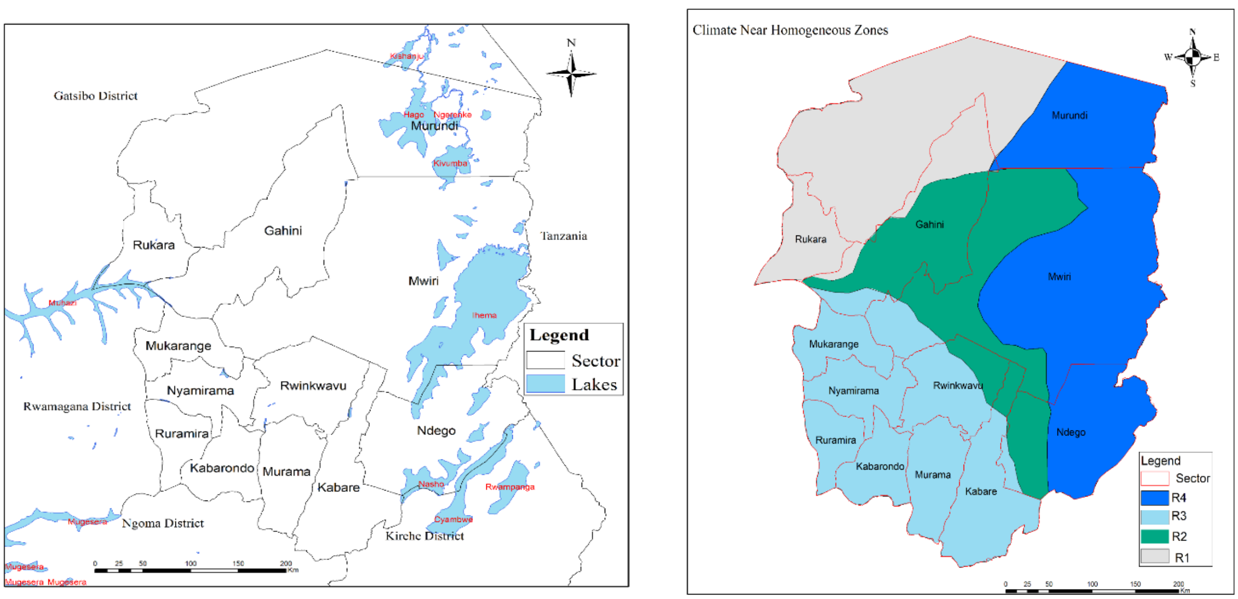

Fig. 1:*Administrative map of Kayonza district and its hydrological network (left) and Climate zone over Kayonza District based on the 1983-2021data adapted from (Sebaziga et al., 2023) (right).*

Fig. 2:Administrative map of Kayonza district and its hydrological network (left) and Climate zone over Kayonza District based on the 1983-2021data adapted from (Sebaziga et al., 2023) (right).

2.2 Dataset

This study uses daily gridded rainfall dataset extending from 1983 and 2021 with a spatial resolution 0.0375 degrees (~ 4km) obtained from Rwanda Meteorology Agency (METEO

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

RWANDA). The dataset was generated by merging satellite rainfall estimates data from Tropical Applications of Meteorology using SATellite (TAMSAT) with quality-controlled observed data. The dataset has been extensively used in previous studies on the entire Rwanda (Siebert et al., 2019; Ngarukiyimana et al., 2021; Safari et al., 2022; Uwimbabazi et al., 2022; Twahirwa et al., 2022; Sebaziga et al., 2022), over the eastern region (Sebaziga et al., 2020) and over Kayonza District (Sebaziga et al., 2023).

2.3 Methodology

In the present study, daily rainfall and water balance were aggregated to pentad, decadal and monthly rainfall and water balance which were in turn used to generate the corresponding mean and standard deviation for each grid using the equation (1 and 2).

$$\mu = \frac{\sum_{i=1}^{n} X_0}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$\sigma = \sqrt{\frac{\Sigma(X_0 - \mu)}{n}} \ldots\ \ldots\ldots\ldots\ldots\ldots(2)$$

Where μ is the mean rainfall and X_0 indicating individual rainfall for each time step, σ is the standard deviation and n is the number of points. The availability of the soil water balance (WB) and evapotranspiration (E) are key criteria for agricultural practices and decision–making. The computation of WB requires E as input. To calculate E, numerous meteorological parameters such as solar radiation, wind, temperature, rainfall, and humidity are required as inputs. The commonly used method is the Penman–Monteith method where data are available (Droogers and Allen, 2002, Beguería *et al*., 2014; Valipour, 2015; Awal *et al*., 2020). However, due to limited meteorological data, the modified Hargreaves technique, which requires temperature (maximum and minimum) and precipitation data similar to that employed by (Uwimbabazi *et al*., 2022) in their study over Rwanda, is used to compute the E. More information on the mathematical equation for the modified Hargreaves technique can be found in Valipour, 2015) and Droogers and Allen, 2002). In the present study, the value of the WB on a particular day is evaluated by its value on the previous day and then adding the rainfall on the current day and subtracting the E as indicated in Stern *et al*., 1982). More information on WB can be obtained in Stern and Cooper, 2011), Nugroho *et al*., 2019), Niaghi and Jia, 2019), and Fries *et a*l., 2020). To understand the variability in rainfall, the coefficient of variation measure ()CV, which measures the degree of variability in a dataset, was employed in the present study. The mathematical representation $CV$of is illustrated in equation (3).

$$CV = \frac{\sigma}{\mu} * 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

The availability of soil water balance (WB) and evapotranspiration (E) are crucial factors for agricultural practices and decision–making. Calculating WB necessitates E as an input. To determine E, various meteorological parameters such as solar radiation, wind, temperature, rainfall, and humidity are necessary. The Penman-Monteith method is commonly utilized where data is accessible (Droogers and Allen, 2002; Valipour, 2015; Awal *et al*., 2020). However, in cases of limited meteorological data, the modified Hargreaves technique, as described by Droogers and Allen, 2002), which requires temperature and precipitation data similar to that used by Uwimbabazi *et al*., 2022) in their study in Rwanda, is employed to compute E.

$$E = 0.0005304\, R_a(T + 17)(Tmax - Tmin - 0.0123P)^{0.76} \quad (4)$$

Where R_a is the extraterrestrial radiation (MJ $m^2 day-1$), T is the average daily air temperature (◦C), $Tmin$ is the minimum air temperature (◦C), $Tmax$ is the maximum air temperature (◦C), P is the precipitation (mm).

In the present study, the value of the WB on a particular day (W_n) is evaluated by its value on the previous day (W_{n-1}) and then adding the rainfall on the current day (P_n) and subtracting the E as indicated in (Stern *et al*., 1982). More information on WB can be obtained in (Stern and Cooper, 2011; Nugroho *et al*., 2019; Niaghi and Jia, 2019; Fries *et a*l., 2020).

$$W_n = W_{n-1} + P_n - E \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

3. Results

3.1 Monthly rainfall and water balance distribution

Fig. 2 presents the monthly rainfall distribution over Kayonza District. It is shown that main parts of Kayonza District receive rainfall ranging between 25 to 100 mm in the month of January and February, with small portion on Northwestern parts of Kayonza which receive a deficit of rainfall below 25mm in month of January. The rainfall ranging between 75 to 200mm is recorded in every month of March and April; SW and SW receive the highest rainfall over recorded with range of 175 to 200mm. The month of April having more rainfall over the part of south, and seems to have more rainfall for all zones. The month of May record rainfall ranging between 75 to 150 mm rainfalls with northern parts receive more compare to the rest. The results indicated that monthly rainfall ranges between 0 mm and 25 mm during June-July-August, except small portion of eastern parts which goes up to 50mm in Month of August, and 50 mm to 200 mm during the rainy months October and November and spatially concentrated over the south western. Central toward south is showing reduction of rainfall in the month of December, the same as September which has minima of rainfall ranging between 25 to 100mm, with big parts shows deficiency of rainfall.

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

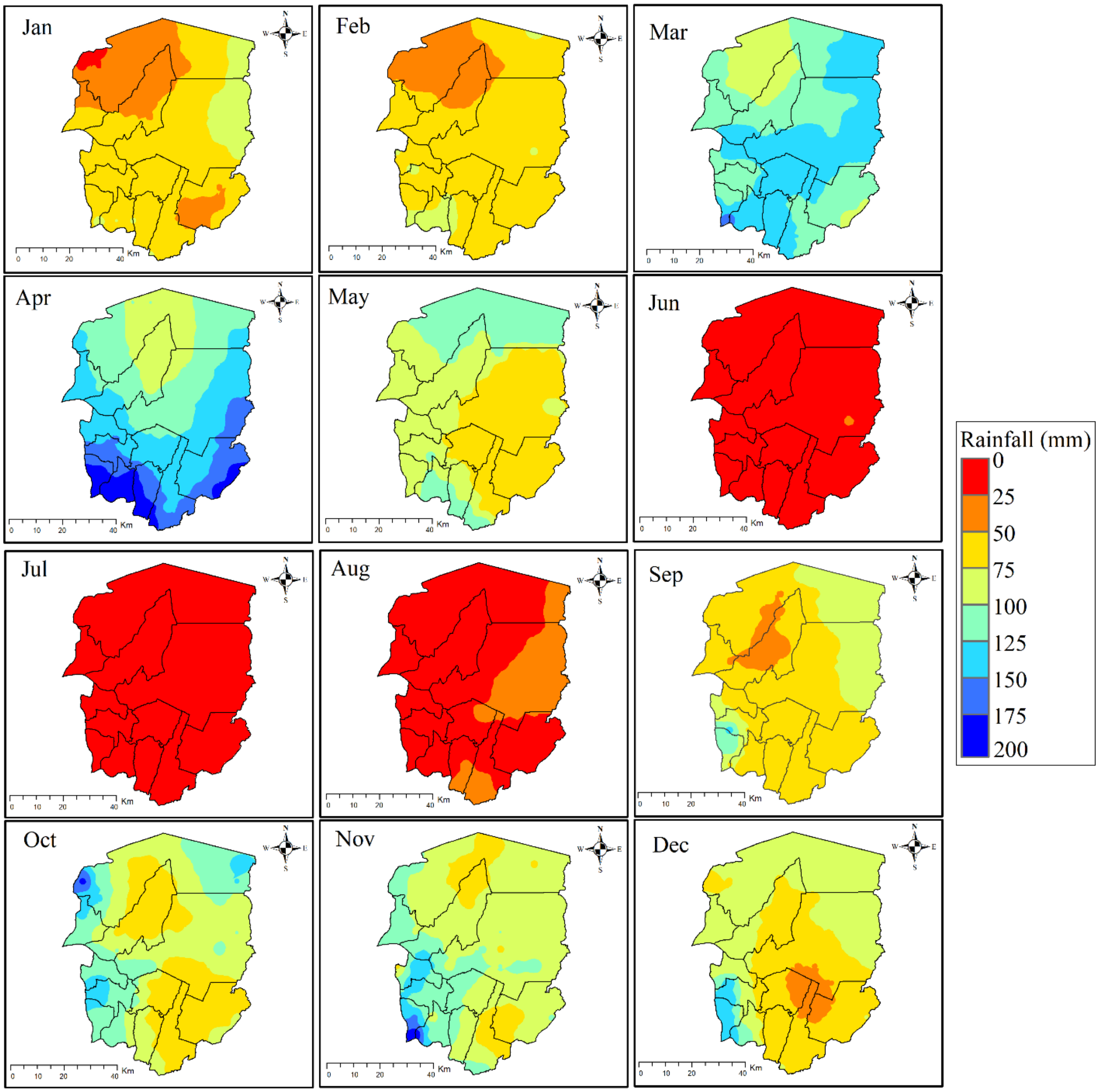

Fig. 2: Spatial Distribution of Monthly rainfall over Kayonza district during the period of 1983–2022.

Fig.3 indicates the monthly distribution in water balance over Kayonza District. The results indicate that during the month of July and August no water budget available to sustain plant, means those months are the driest months in the year, the water balance is almost zero. The month of February and June, a few amounts of water supply not exceeding 20mm is only available in South toward west, while the rest of District no water budget available. The month of March, April and May, water budget is increasing reasonably with water balance exceeding 70mm/months except Northern parts of District where dryness and dehydration, contrary to May where water balance is increasing over that area, From The month of September to January, shows a less water balance mostly in central with worseness toward western, and enhancement toward SW and W for the months of October, November and December.

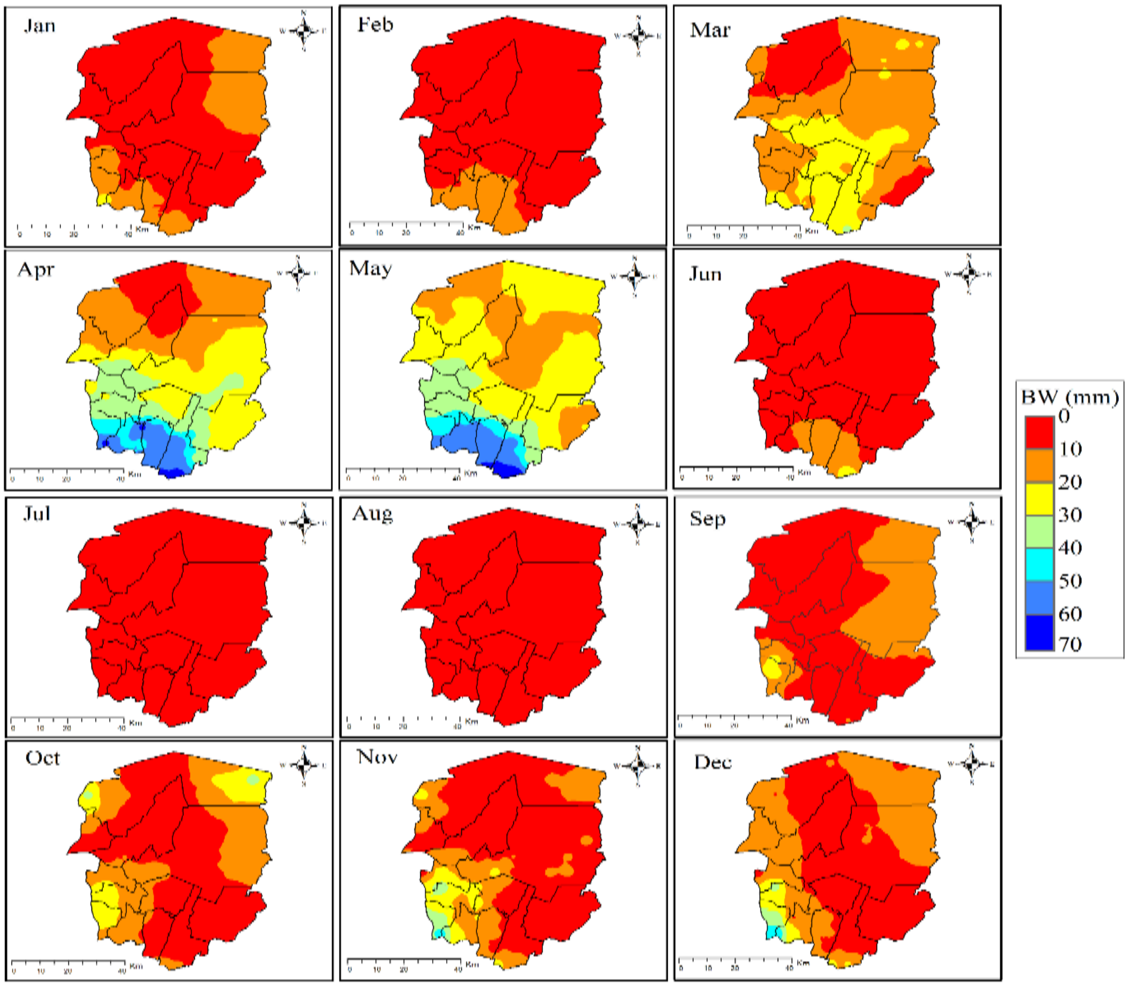

Fig. 3: *Spatial Distribution of Monthly water balance over Kayonza district during the period of 1983–2022*

Fig. 4 shows the variability in monthly rainfall over Kayonza District. It is observed that the month of March, April and November which receive high rainfall showed the less rainfall variability of less than 20% in most parts of District. The months of May and December registered rainfall variation ranging between 40 and 80%, October shows the rainfall variation between 20 and 60%. June, July and August shows higher dispersion compared to other months with CV ranging 80 to 160 and above, the month of January, February and September has variable rainfall variation with more than 60% in Eastern and southern parts of District in January, and between 60 to

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

100% in Sin general, the variability has increased with decreasing of monthly rainfall.

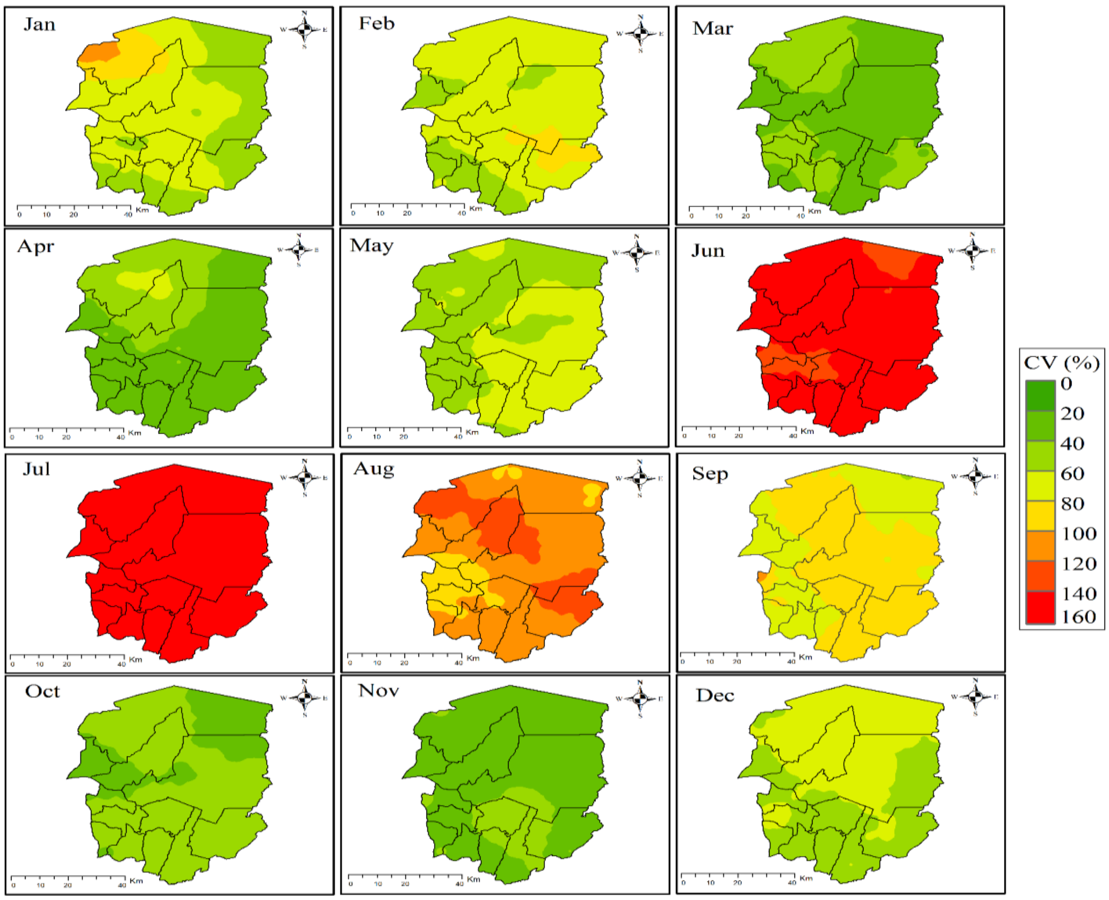

Fig. 4: Spatial Distribution of Monthly rainfall variation over Kayonza district during the period of 1983–2022.

Fig.5 illustrates the variability of the monthly water balance in Kayonza District. The results indicate that from June to September and in month of February, the water balance variation ranges between 100-150%. In January, October, November, and December, there is a slight decrease but still remains relatively high with values between 80-130%. The northern part of the District exhibits higher coefficients of variation, with values reaching 150% in January, October, and November, as well as in December in the central and southern areas of the district.

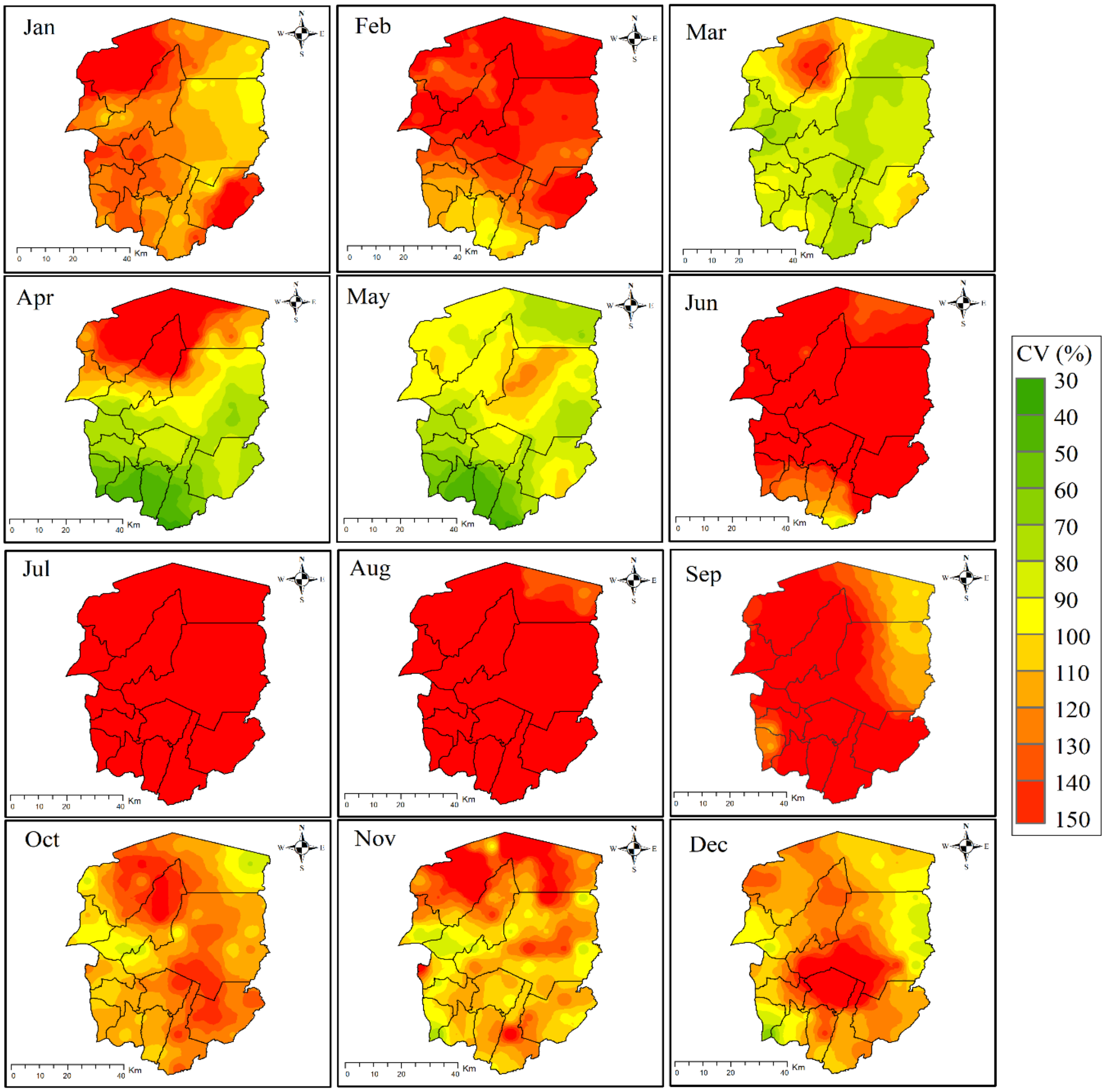

Fig. 5: Spatial Variation of Monthly water balance over Kayonza district during the period of 1983–2022.

3.2. Daily to Dekadal rainfall and water balance distribution.

The connection between monthly and its daily, pentad, and decadal time scales is crucial for agricultural activities. The following section demonstrates the behavior of rainfall and water balance on time scales shorter than a month. The daily rainfall climatology for the study area, as shown in **Fig.6**, reveals that climatologically R2 do not record any extreme daily rainfall, while R4 and R3 exhibit outliers in daily rainfall climatology, particularly on D146 and D269 respectively. R1 also experiences higher daily rainfall climatology with more significant rainfall compared to other regions

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

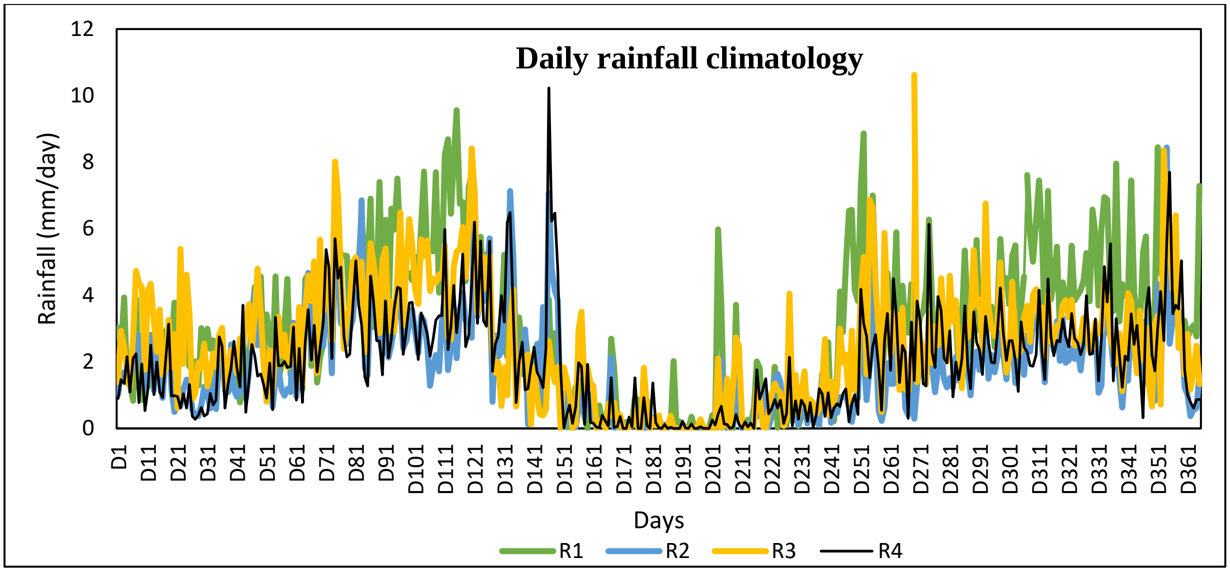

Fig. 6: Daily rainfall climatology over Kayonza district during the period of 1983–2022.

R1 to R4: Climate homogeneous zone.

On the pentad time scale (Fig.7), R1 experiences higher rainfall compared to the other regions. The highest pentad rainfall amounts are 41, 23.8, 30.39, and 29.5 for R1, R2, R3, and R4, respectively.

The pentad rainfall peaks are 41, 23.8, 30.39, and 29.5 for R1, R2, R3, and R4, respectively.

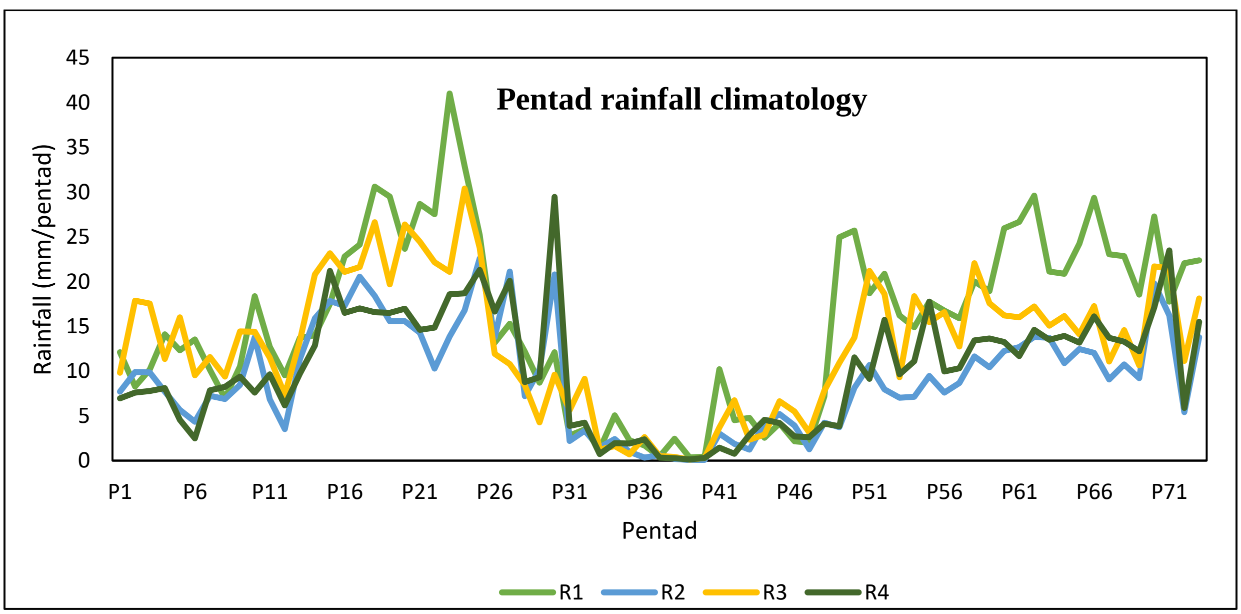

Fig. 7: Pentad rainfall climatology over Kayonza district during the period of 1983–2022.

Similar to daily and pentad climatology, the decadal rainfall climatology **(Fig. 8)** indicates that all the zones registered their peak of decadal rainfall climatology between D10 to D15, which corresponds to the peak of monthly climatology rainfall analysis and is consistent with Sebaziga et al., 2023). Although the rainfall recorded is not the same across the four zones, R1 and R3 have the highest decadal rainfall compared to the rest, and D2 receives the lowest decadal rainfall.

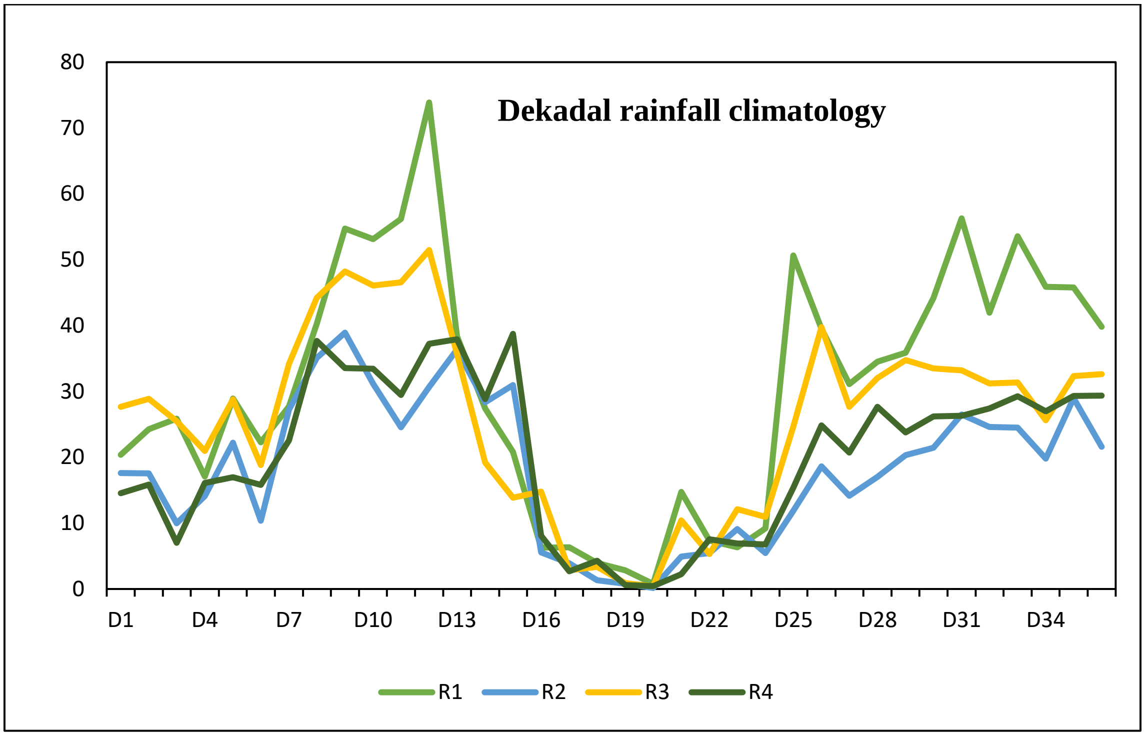

Fig. 8: Dekadal rainfall climatology over Kayonza district during the period of 1983–2022.

R1 to R4: climate homogeneous zone.

In terms of water balance, the daily mean of water balance **(Fig. 9)** shows that most days with sufficient water balance are between D91 and D141, and from D281 to the end of the year. Zone R1 stands out with more days having enough water balance compared to other zones, while zones R2 and R4 appear to have fewer days with sufficient water balance, making it challenging to grow crops in those areas.

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

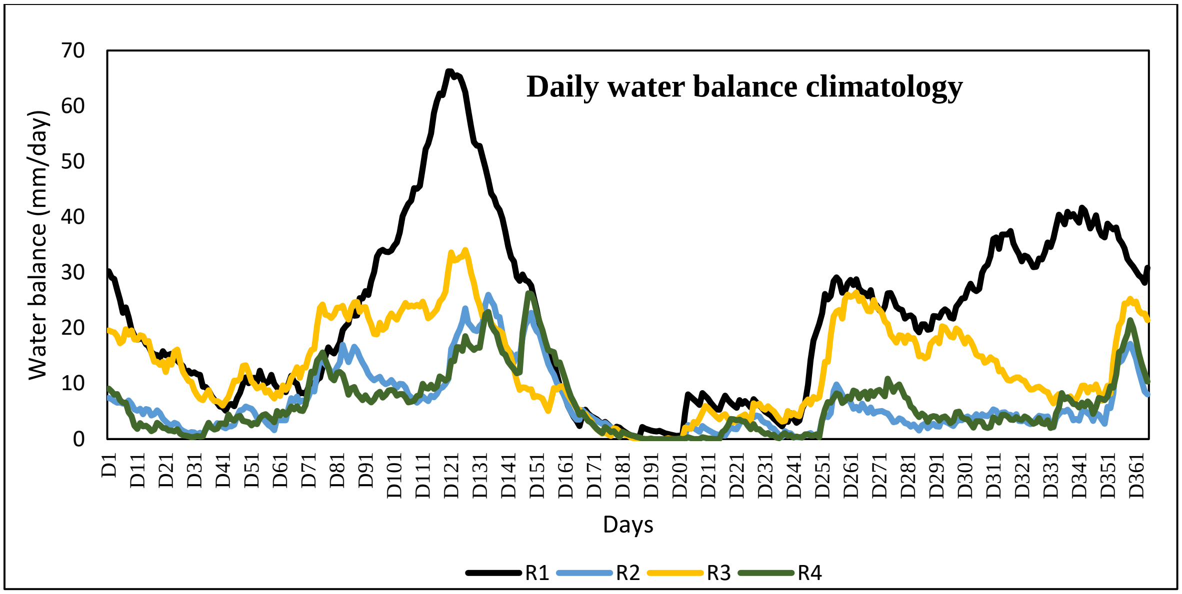

Fig. 9: Distribution of Daily water balance climatology over Kayonza district during the period of 1983–2022. *R1 to R4: Climate homogeneous zone.*

The pentad water balance climatology shown in **Fig. 10** indicates that all regions experienced higher water balance between P20 and P28. The majority of pentad rainfall was observed in R1 regions in all pentads, followed by the R3 region throughout the study period. From P51 to P69, R2 and R4 showed a deficiency of rainfall for the pentad, which is in contrast to R1 and R3.

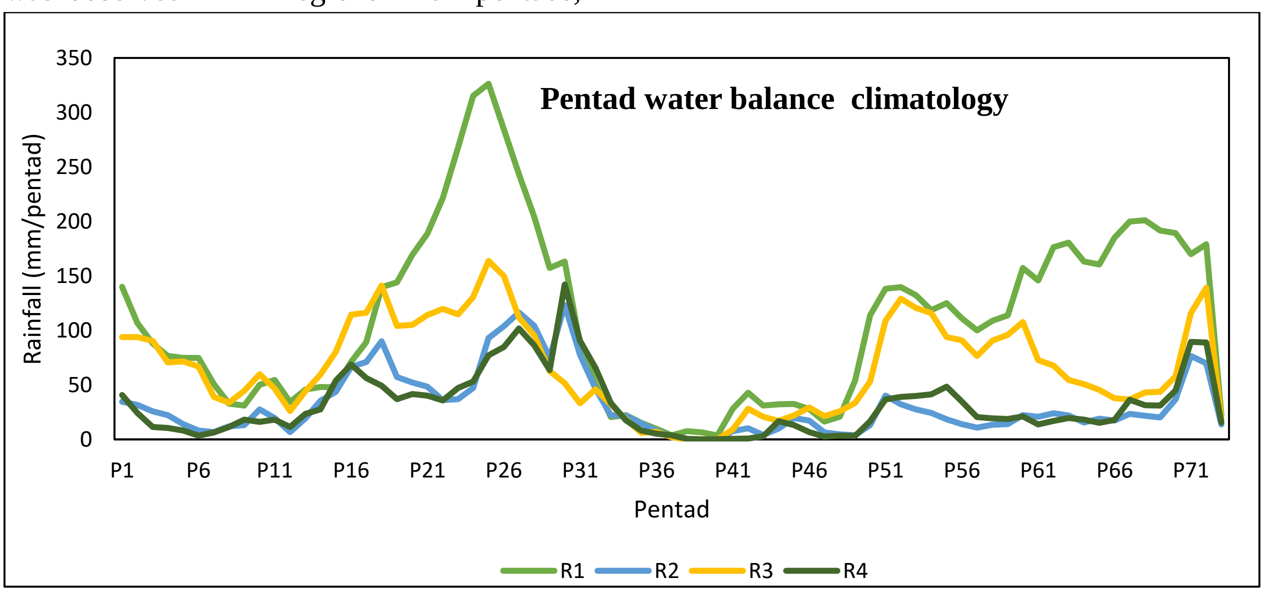

Fig. 30: Pentad water balance climatology over Kayonza district during the period of 1983–2022. P1 to P72: Pentad period.

Analysis of decadal water balance climatologically as indicated in **Fig. 11**, shows that regions R1 and R3 record the highest decadal LTM rainfall compared to the other two regions. Specifically, D13 recorded the highest rainfall for R1 with 610mm. On the other hand, regions R2 and R4 registered lower water balance, with almost less than 200mm throughout the year.

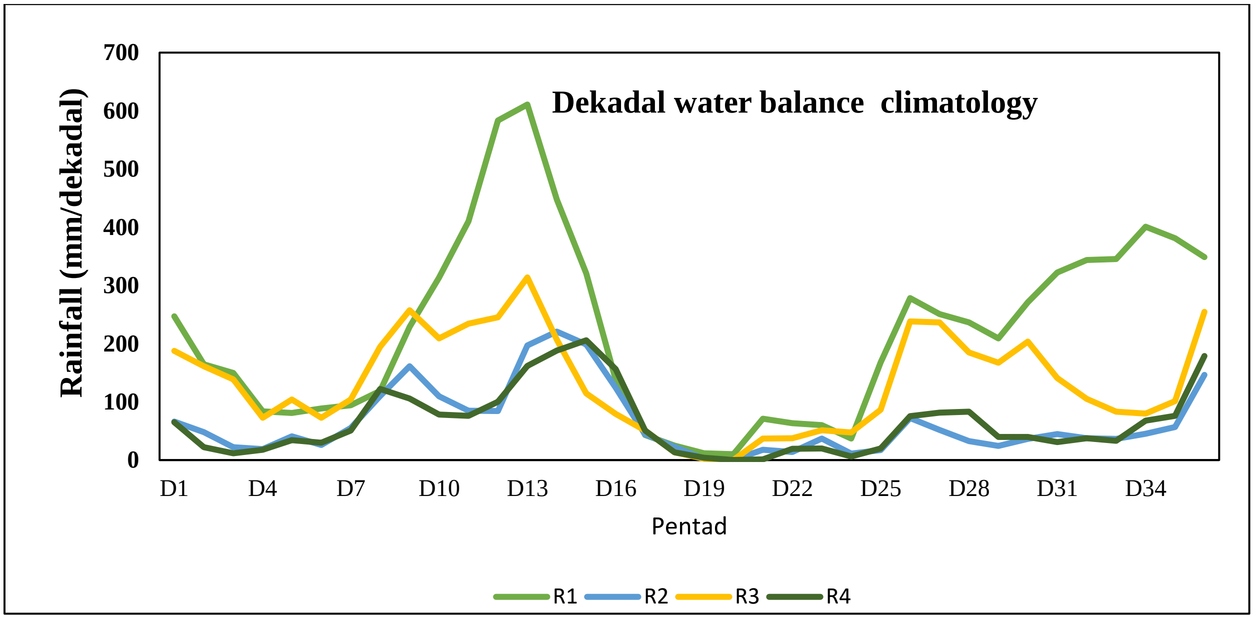

Fig. 41: Distribution of Dekadal water balance climatology over Kayonza district during the period of 1983–2022. *R1 to R4: Climate homogeneous zone.*

3.3.Seasonal rainy days, dry spells, and exceedance probability

Fig. 12 shows the seasonal rain days and seasonal rain day variations. Both MAM and SOND rain seasons indicate 15 to 20 rain days over central toward Northern, over the same area also that season has CV beyond 100%. A big part of Eastern central, south and Northern has rain days between 20 and 25 days for MAM and less than 5 days for SOND, over the same area the CV is between 25 and 75%, for MAM and 50 to 100 for SONDs seasons. The parts towards the entire west of Kayonza District shows rainy days between 30 and above 45 days for both seasons, with a bit more for SOND over small portion of SW. The CV over that area is between 25 and 50%.

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

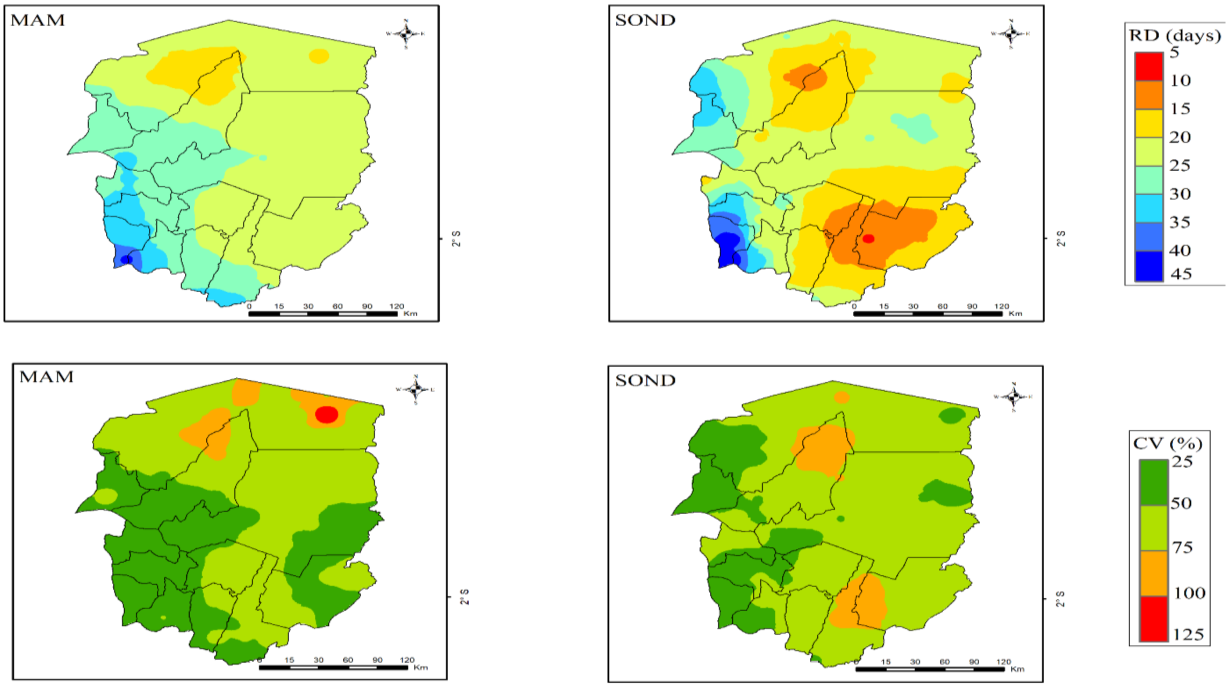

Fig. 52: Spatial Seasonal rainy days distribution and variation over Kayonza district during the period of 1983–2022.

The number of rainy days for the MAM season, as shown in **Fig. 13** and analyzed in the homogeneous zone by Sebaziga et al., 2023), exhibit varying patterns throughout the study periods. Notably, R1 experiences a high number of rainy days, while the other zones show inconsistencies. Over a span of ten years from 1995 to 2005, rainy days are notably scarce in almost all zones, ranging from 19 to 35 for R1, 6 to 30 for R2, and 5 to 31 for both R3 and R4. In contrast, during the SOND season, **Fig. 14** illustrates that the number of rainy days is consistently high in R1, peaking at 76 days in 2011, compared to the other zones. However, starting from 2013, the number of rainy days in that area has been decreasing, with R2 and R4 consistently experiencing fewer rainy days compared to the other zones. Interestingly, from 2014 onwards, the number of rainy days in those zones has been on the rise.

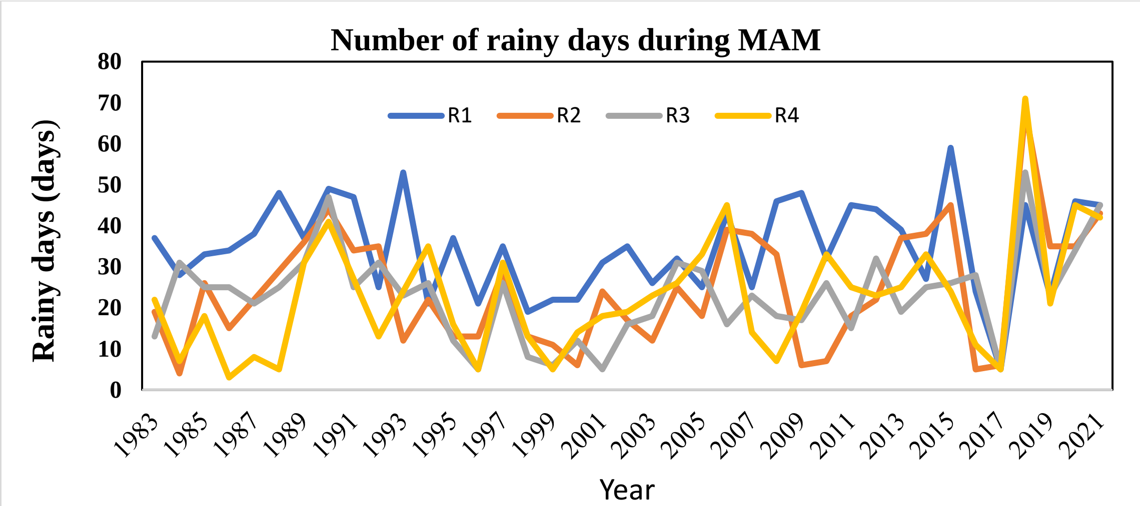

Fig. 63: Number of rainy days during MAM Season over Kayonza district during the period of 1983–2022. *R1 to R4: Climate homogeneous zone*

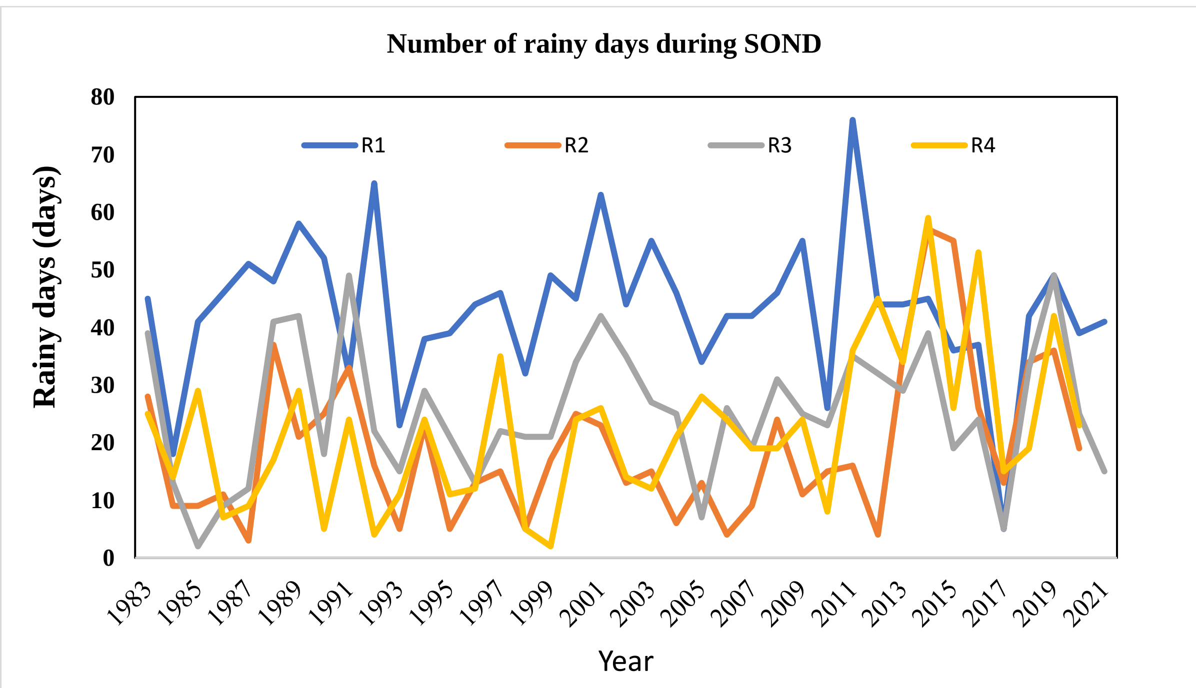

Fig. 74: Number of rainy days during SOND Season over Kayonza district during the period of 1983–2022. *R1 to R4: Climate homogeneous zone.*

In the first ten years of the study period, all four zones experienced almost equal dry spells ranging from 4 to 15 days during the MAM season (**Fig. 15**). Subsequently, significant variation was observed, with R3 experiencing the longest dry spell, followed

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

by R4, and R1 having the shortest dry spell. The longest dry spell periods recorded were 34 and 30 days for zones 3. Analysis of the longest dry spells during the SOND season (**Fig.16**) across the study area shows minimal variation in R1, except for a slight increase in the middle of the study period. In the first 20 years of the study period, both R2, R3, and R4 experienced the longest dry spells, with exceptions for R4 and R3 from 1998 to 2001. In the last ten years of the study period, both zones showed a reduction in dry spells compared to the rest of the study period.

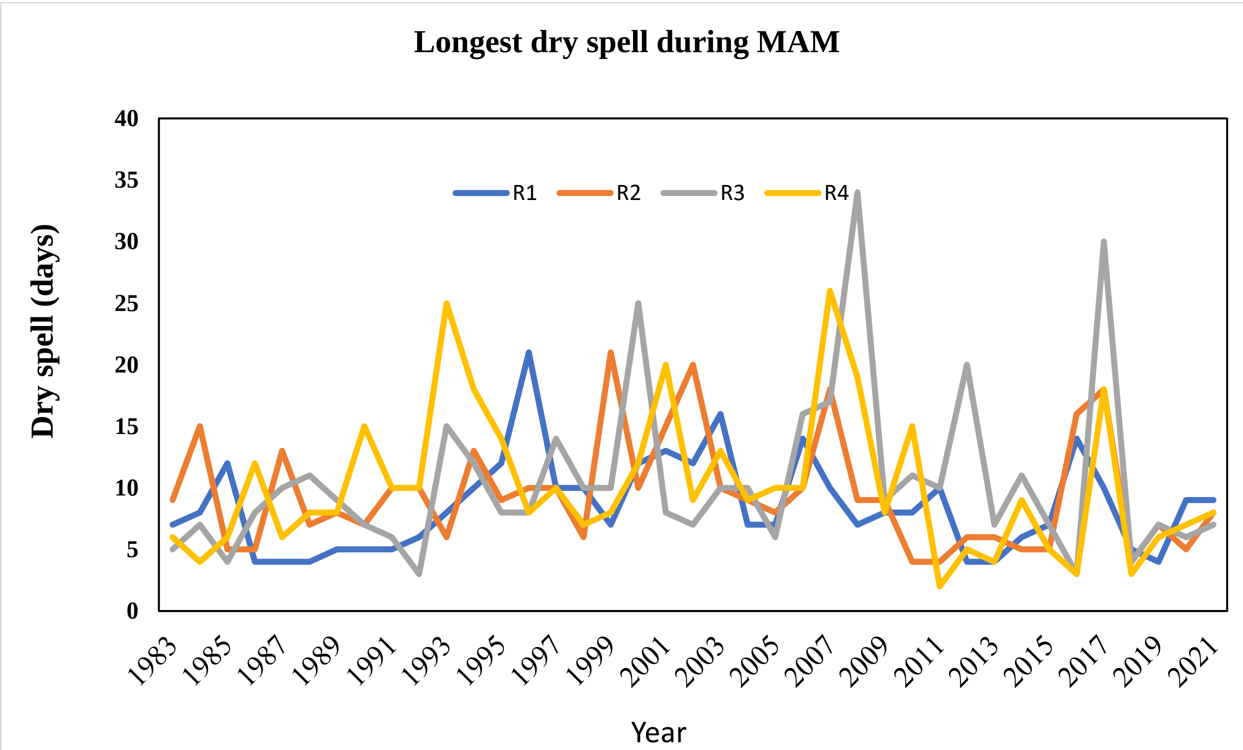

Fig. 85: Longest dry spell during MAM Season over Kayonza district during the period of 1983–2022.

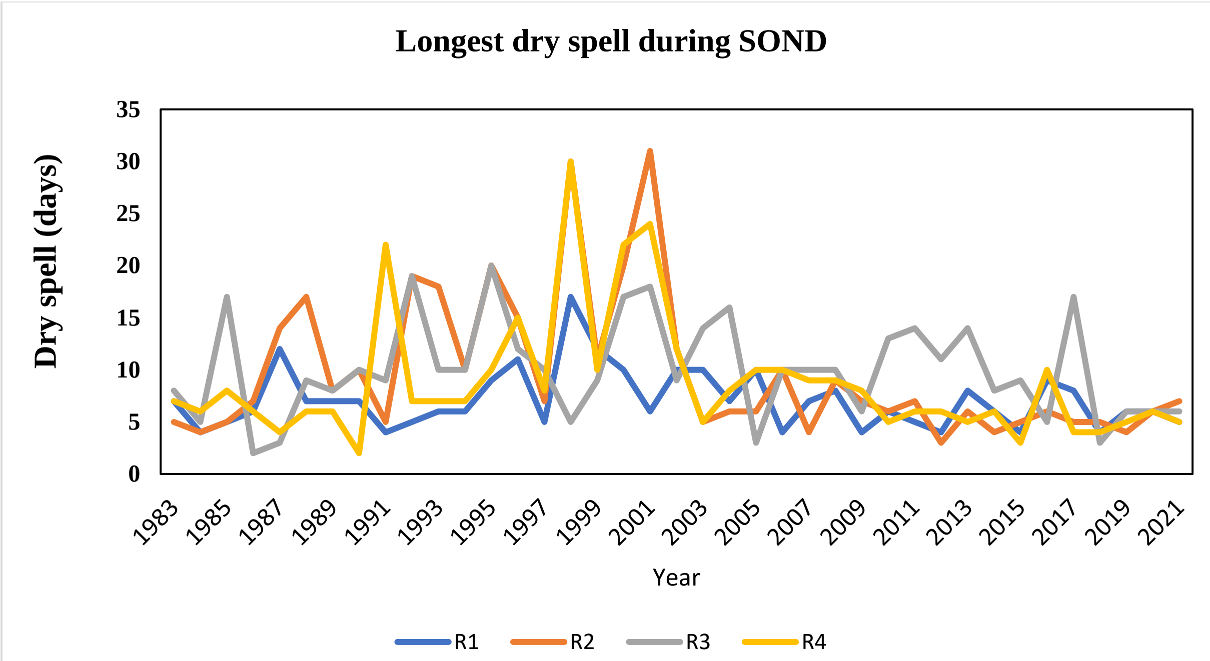

Fig. 96: Longest dry spell during SOND Season over Kayonza district during the period of 1983–2022. *R1 to R4: Climate homogeneous zone.*

Fig. 17 illustrates the probability of rainfall exceedance during the MAM rain season. It is evident that the probability of exceeding certain rainfall thresholds is not evenly distributed across all regions. Specifically, the probability of exceeding 200mm during the MAM season is 94% for R1, 88% for R2, 93% for R3, and 85% for R4. For the 300mm threshold, the probabilities are 82% for R1, 31% for R2, 73% for R3, and 40% for R4. When it comes to exceeding 400mm in a single MAM season, the probabilities are 45% for R1, 10% for R2, 20% for R3, and 10% for R4. None of the regions show a high probability of exceeding 600mm, with only a 10% chance for R1 and almost zero for the other regions. In comparison to MAM rainfall exceedance probabilities, **Fig. 18** for the SOND rain season indicates a higher likelihood of receiving significant rainfall. The probability of exceeding 400mm in the SOND season is approximately 55% for R1, 2% for R2, 50% for R3, and 18% for R4. For exceeding 600mm of rainfall, the probabilities are 35% for R1, 3% for R3, and close to zero for the other regions. Only R1 shows a probability of exceeding 700mm and above in a single SOND season.

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

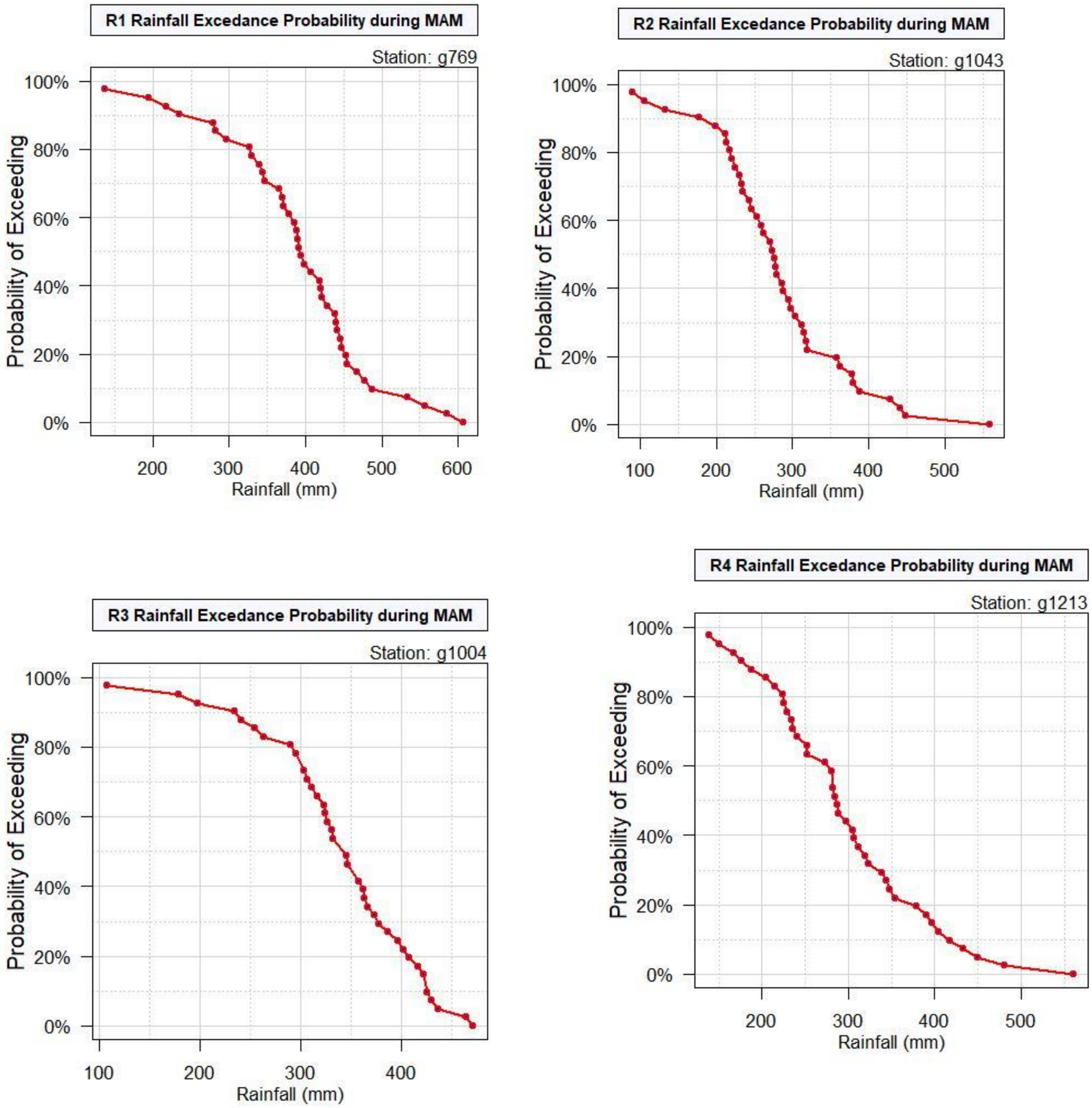

Fig. 107: Probability of exceedance during MAM season over Kayonza district during the period of 1983–2022.

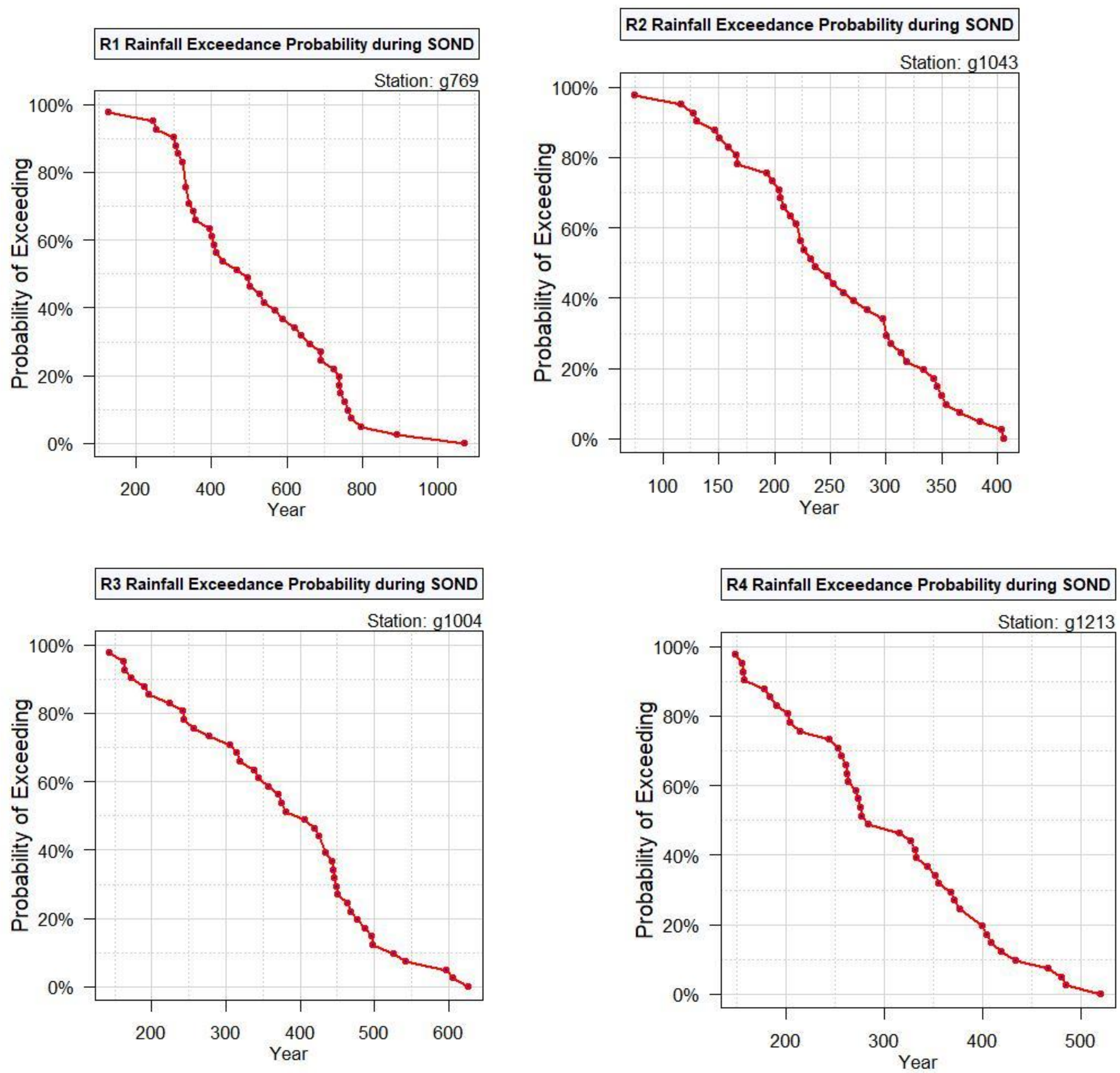

Fig. 118: Rainfall of exceedance probability during SOND season over Kayonza district during the period of 1983–2022.

4. Discussion

The months of June, July, and August record the lowest amounts of rainfall, which range from 0 to 25 mm. This corresponds to a dry season in the study area, during which no agricultural activity can be carried out on the hillside. However, due to many inland lakes in Kayonza, some irrigated scheme can be applied. These months corresponds to the lowest water balance in the soils. The higher water balance in the soils that are favorable for agricultural productivity are observed during March, Apr, May, Oct, Nov and

Eajst. 2024, 14, 237. https://doi.org/10.62103/unilak.eajst.14.1.237

December months with monthly rainfall reaching nearly to 200 mm per month.

between 60 – 70 mm during April and May over the southwestern parts of Kayonza in R3 zone. The variation of monthly rainfall is higher (100 % -160%) during the dry season from June to September, which implies that unexpected heavy rainfall may occur during that season. This rainfall may be dangerous on farmland in the valleys. During the rainy season; the higher variation in monthly rainfall is observed in May and December with CV of 60 %-80%, September with CV of 80 %-100% respectively. These variations can be linked to fluctuations in rainfall amount, onset and cessation that in return affect crop productivity where stable and good rainfall are linked with good crop productivity whereas high variable and poor rainfall are associate with poor crop productivity (Kumi et al., 2023). The variation of monthly Water Balance (WB) range between 30% and 150%. the March-Apr-May exhibit lower variability (less than 90%) in the soil water balance whereas the remaining months exhibit higher variability between 90% -150%. sufficient water in the soils is associated with good crop conditions. Daily, pentad and decadal rainfall as well as water balance in the soil contribute to the monthly rainfall and water balance performance in rain fed agriculture.

The number of rainy days in a season contributes to the seasonal rainfall performance in terms of the seasonal length. The highest number of rainy days ever recorded for both seasons was 71 days in 2018 for MAM and 76 days in 2011for SOND. This suggests that crops requiring

The highest water balance in the soils range

more rainy days than these may not be viable in Kayonza District without irrigation schemes. The variation in the number of rainy days ranges between 25% and 75% in many places in Kayonza, impacting the seasonal length, with some seasons having fewer than 10 rainy days. This affects the crop growing period and can lead to crop failure (Bedane et al., 2022). The longest dry spells ever recorded within a season in Kayonza were 31 and 34 days in 2001 and 2008 during SOND and MAM, respectively. The second longest dry spells were 30 days recorded during SOND of 1998 and MAM of 2017. Prolonged dry spells within the season reduce the water balance in the soil and can result in crop failure, as seen in the 2017 MAM season (Markos et al., 2023). The probability of exceeding 200 mm in a season ranges between 85% and 94%; the probability of exceeding 300 mm ranges between 40% and 82%; the probability of exceeding 400 mm ranges between 10% and 45%; while the probability of exceeding 500 mm ranges between 0% and 10% for the MAM season. For the SOND season, the probability of exceeding 400 mm ranges between 18% and 55%, and the probability of exceeding 600 mm ranges between 0% and 35%. A lower probability of exceeding a certain amount of rainfall implies that it is less likely to have that amount of rainfall during the season. Therefore, Kayonza is likely to experience a scarcity amount of rainfall in the season, significantly affecting crop productivity and resulting crop yield.

5. Conclusion

The purpose of this paper is to assess the variability in monthly rainfall, water balance, and dry spells over Kayonza District, Eastern Province, Rwanda, from 1983 to 2021. The results showed that the rainfall and water balance variability in the four climatic zones is not homogeneous. Zone 1 exhibits less variability, while other regions experience sporadic and limited rainfall distribution. Regarding water balance, the majority of water balance is concentrated within D91 and D141, corresponding to the MAM seasons. The longest dry spells during the seasons were observed to be 31 and 34 days in 2001 and 2008 during SOND and MAM, respectively. The 30-day dry spells in SOND 1998 and MAM 2017 are the second longest on record. The probability of receiving more than 400mm in a single season is higher in SOND than in MAM, but the number of rainy days is higher in MAM than in SOND, with 71 days recorded in MAM 2018 and 76 days recorded in SOND 2011. Crops require a greater number of rainy days, necessitating the use of irrigation mechanisms to ensure successful crop growth and prevent crop failure. Given that Kayonza region is semi-arid with high rainfall variability in different climatic zones, and many people engage in agriculture and other socioeconomic activities dependent on rainfall for sustenance or profit, the findings of this research are crucial for informing individuals to plan accordingly. Adequate mitigation strategies should be developed to mitigate potential losses resulting from rainfall deficits.

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