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Assessing the Variability of Heavy Rainfall Events during Gu Rainfall Season in Somalia

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Abstract

The occurrence of heavy rainfall is a significant contributing factor to the occurrence of flooding in Somalia during the rainy season, resulting in substantial socio-economic consequences. This study investigates the spatial-temporal variations of Heavy Rainfall Events (HREs) occurring from March to May (MAM), commonly referred to as the *Gu* rainy season, in Somalia from 1991 to 2020. The analysis employed the Empirical Orthogonal Function method to investigate the spatial-temporal variations of HREs. The findings indicate that there is an unequal distribution HREs throughout the country, with the southern regions exhibiting the highest concentration of HREs of about 340 HREs, while the northwestern regions had a relatively lower number of HREs. It was found that there is a notable variation in HREs on a monthly basis, with April and May exhibiting a higher prevalence compared to March, which appears to have a lower impact. The prevalence of HREs has been seen to be more prominent and rapidly escalating, particularly in the southern region, with a statistically significant level of 95%. Moreover, it has been found that the recurrence rate of HREs in the southern region of the country is around once every decade, whilst in the central region, the average return time of HREs is three years. Conversely, the northern region experiences HREs on an almost annual basis. Therefore, it is imperative to comprehend the spatial and temporal variations of heavy rainfall in order to effectively strategize agricultural practises and implement mitigation measures for extreme weather phenomena such as droughts and floods.

Keywords: Rainfall Variability; Heavy Rainfall Events; Gu Rainfall Season; Somalia

Introduction

The Intergovernmental Panel on Climate Change (IPCC) has recently reported an observed rise in the occurrence and strength of extreme precipitation events in various regions, including Eastern Africa (Lyon and Vigaud 2012, Niang et al. 2017, Ajuang et al. 2018, Mechler et al. 2020). Somalia, during a prolonged state of violence and political instability, has encountered distinctive climate variability and climate change issues (Gummadi et al. 2018, Gebrechorkos et al. 2020). The country is predominantly characterised as arid and semi-arid, making it more susceptible to climate variability, including frequent floods and droughts. These climatic events have been linked to several socio-economic hardships (Kuya 2016, Abdulkadir 2017, Mohamed et al. 2022). Consequently, the region frequently experiences significant food insecurity and conflicts related to resources (Maystadt and Ecker 2014, Gebrechorkos et al. 2020). The rainfall patterns in Somalia are significantly impacted by the movement of the Inter-Tropical Convergence Zone (ITCZ) in both northward and southward directions. This movement aligns with the occurrence of two distinct rainy seasons in the region: the 'Gu' season from March to May, and the 'Deyr' season from September to December (Muchiri 2007, Kuya 2016). The Gu season, which is the primary period for rain-fed agriculture in most regions, is characterised by higher levels of precipitation. However, the variability of rainfall does have an impact on the yields throughout the Gu season (Adloff et al. 2022, Ahmed 2023).

In the past ten years, Somalia has witnessed a rise in the occurrence and severity of Heavy Rainfall Events (HREs) throughout various regions, resulting in higher casualties and property damage. Heavy Rainfall Events are a significant factor contributing to the occurrence of floods in Somalia. These events are observed to be recurrent during the Gu rainy season, resulting in the unfortunate loss of human lives and damage to properties. Somalia is highly susceptible to the impacts of climate variability and climate change, leading to an escalation in the occurrence and severity of floods and droughts. Notably, the country has witnessed significant events of floods and droughts with strong hydrological and meteorological events in 2004/2005, 2009/2010, and 2014/2015/2016 (Sebhat 2015, Maidment et al. 2015). The country has significant variations in annual rainfall, ranging from extended periods of drought to episodes of heavy flooding (Muchiri 2007, Ajuang et al. 2017, Adloff et al. 2022). Furthermore, the temporal fluctuation of intense precipitation in Somalia is likewise significant and unpredictable (Billi 2022).

Despite the fact that floods and droughts are the most catastrophic natural hazards in the country (Muse and Limbu 2023), mapping the distribution and trend of HRE is still not well documented. Consequently, investigating and gaining a better understanding of historical spatiotemporal drought patterns is crucial for assessing extreme weather event risk and mitigation (Tian et al. 2022) and is essential for building resilience to future droughts and floods (Bile and Limbu 2020). In Somalia, there is a scarcity of research examining the spatio-temporal variability of HREs during the *Gu* rainfall season. Specifically, the analysis of temporal and spatial variability of HREs over the region are the prerequisites of this study. Therefore, this study aimed to bridge this knowledge gap and contribute to a better understanding of the distribution and frequency trend of HRE in the country.

Materials and Methods

Study area

This study is conducted in Somalia, which is situated within latitudes 1.5° S–12° N and longitudes 41° E–51° E and has a land area of 637,540 km^2. Kenya to the south, Ethiopia to the west, Djibouti to the north-west, the Gulf of Aden to the north, and the Indian Ocean to the east are Somalia's neighbors and are all a part of the Greater Horn of Africa (Figure 1). The country's climate is warm and semi-arid. Rainfall in Somalia is generally low and erratic, with the average annual rainfall being 250 mm, moderate rainfall of about 400 mm in the northwest, and 700 mm in parts of the south (Muse and Limbu 2023). The average daily temperature is between 27 °C and 38 °C (Hartmann et al. 2009).

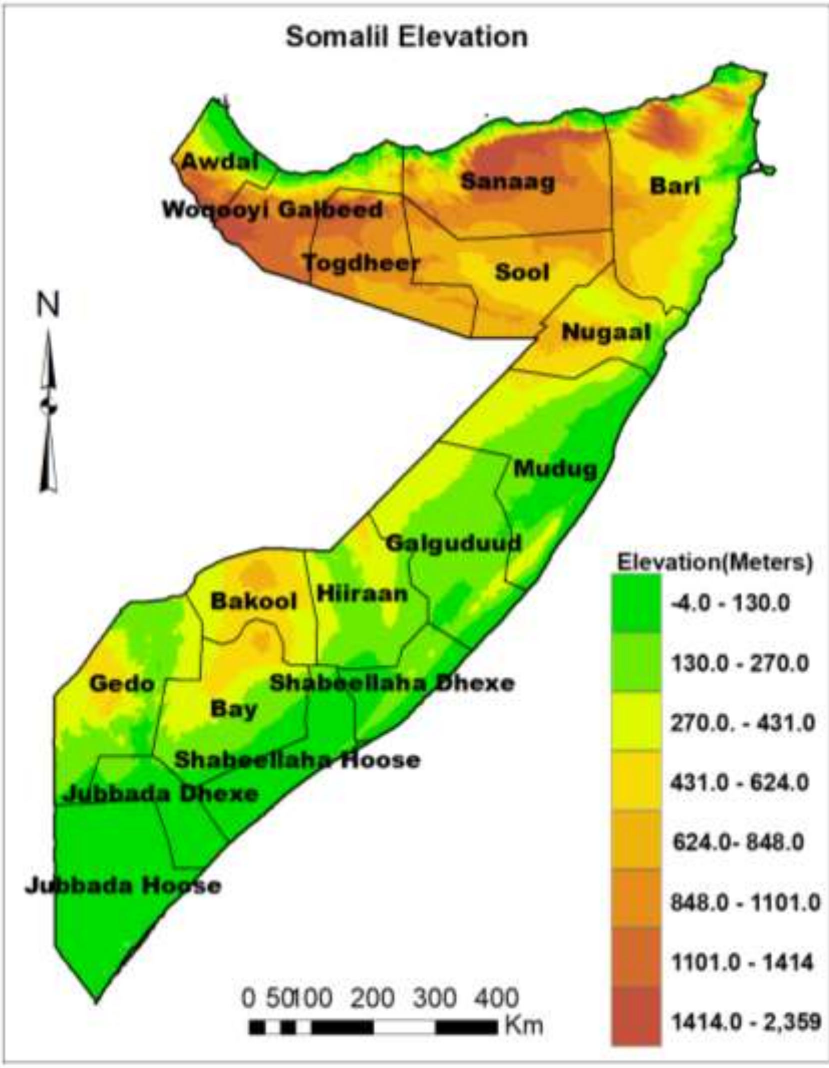

Figure 1: Map of the study area with administrative regions.

Data Source

The study used daily gridded observation satellite data from the NASA's data repository using the Geospatial Interactive Online Visualization and Analysis Infrastructure (GIOVANNI) web-based application and the Prediction of Worldwide Energy Resources (NASA POWER) dataset for MAM, spanning from 1991 to 2020. The Goddard Interactive Online Visualization and Analysis Infrastructure (Giovanni) has been used to conduct a variety of studies and explore data as well: environmental changes (Acker 2022, Ledari et al. 2022). The data used was from 18 gridded data points, which is equivalent to 18 number of synoptic stations, which Somalia contains. The horizontal resolution of the satellite dataset of 0.5°x 0.625° latitude and longitude grid, which was retrieved from https://power.larc.nasa.gov/data-access-viewer/ was re-gridded to fit a new grid or resolution to the horizontal synoptic stations before they were employed in this study.

Methodology

The heavy rainfall used in this study was defined as any number in which the amount of rainfall observed per day is equal to or exceeds

30 mm, as used by the Somalia Meteorological Agency, and a similar approach was used by Ayal et al. (2022). These heavy rainfall amounts were then aggregated on a monthly and seasonal basis. The study employed return period analysis and empirical orthogonal function (EOF) to investigate the spatial-temporal variations of HREs during the Gu rainy season. The return period is defined as the estimated recurrence time interval for a particular event to be equaled or exceeded in the future, relating the time interval in years to the likelihood of occurrence (Oliveira and Lima 2019). This study adopted the same procedure used by (Oliveira and Lima 2019, Pelosi et al. 2020) to compute the return period. The return period was obtained by calculating the reciprocal of relative frequency, which is calculated by dividing the total number of events (frequency) of the respective HRE by the total number of years used in the study. The EOF was used to analyse the spatial and temporal variability of HREs over the study domain. The principal component (PC) corresponding to the EOF provides the sign and its amplitude, and it is, on the other hand, marked as the HRE index in this study. The detailed description of the EOF analysis is found in Wilks (2011) and Dawson (2016). A number of researchers have also used the method extensively (e.g., Mafuru and Guirong 2018, Limbu and Guirong 2020, Kavishe and Limbu 2020, Kebacho and Chen 2022, Makula and Zhou 2022, Umutoni and Limbu 2023). The raw HREs data sets were de-trended before performing the EOF analysis.

Results and Discussion

Gu Rainfall Distribution over Somalia

The spatial distribution of MAM rainfall (Gu) was assessed based on long-term means (1991-2020). As shown in Figure 2, the seasonal rainfall mean amount varies spatially from less than 40 mm in the northeastern regions to over 300 mm in the south while the central and northwestern regions received average amount of rainfall of around 150mm. Generally, the seasonal mean rainfall in northern and central Somalia is considerably lower than in the south, except for the Northern highland regions, due to the influence of topography. Geographically, areas closer to the equator (Figure 1) may feel the effects of the ITCZ sooner, while those further away experience delayed or less frequent rainfall as the zone gradually migrates (Mafuru and Guirong 2018, Kebacho and Chen 2022).

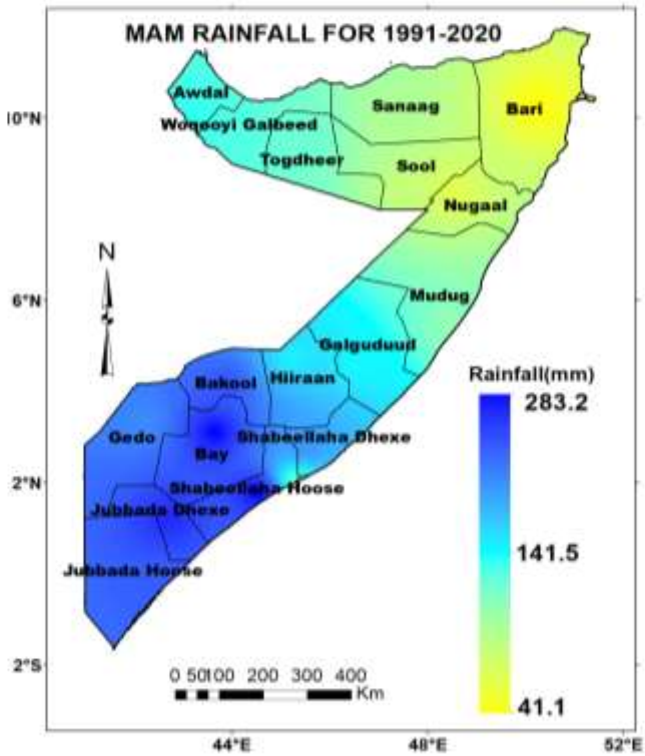

Figure 2: The spatial distribution of MAM rainfall (*Gu*) in Somaliland from 1991 to 2020.

Moreover, the temporal distribution of Gu rainfall during the period of study was determined. It was found that different parts of the country experienced different rainfall and temporal patterns, as shown in Figure 3. The Gu rainfall in some parts of the country (Kismayo, Garbaharey, and Baidoa) shows a significant increase at a 95% confidence level compared to other parts of the country (Buale, Qoryooley, Xudur, Mogadishu, Jowhar, and Beledweyne), where the rainfall was observed to decrease. A distinctive increase in rainfall observed over the southern parts indicates that there was an increasing trend in HREs. Generally, rainfall in Somalia has been highly variable over the last 30 years, with some regions experiencing an increasing trend while others have seen a gradual decrease. The trend in MAM rainfall for Somalia has been decreasing, particularly in the southern and central regions. This has been attributed to a combination of factors, including natural climate variability, deforestation, and land degradation (Mohamed et al. 2022).

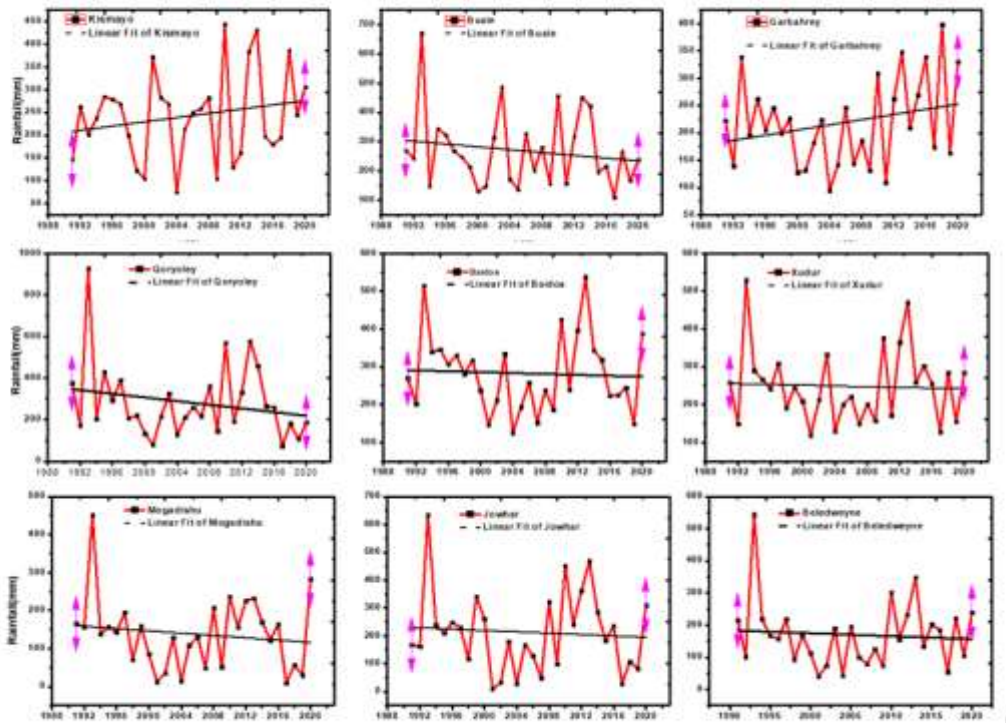

Figure 3: Temporal distribution of MAM rainfall (*Gu*) over different regions of Somalia.

Moreover, because of its aridity and semi-desert climate, the central and north-eastern regions received the least amount of rainfall in the country, as shown in Figure 4. The rainfall over these regions decreased substantially, with some areas experiencing even greater declines in rainfall, like Ceelbur, Hobyo, Garowe, Iskushuban, Ceelafweyne, Lascanod, and Burco, except for stations such as Hargeisa and Borama, which showed a constant trend during the study period.

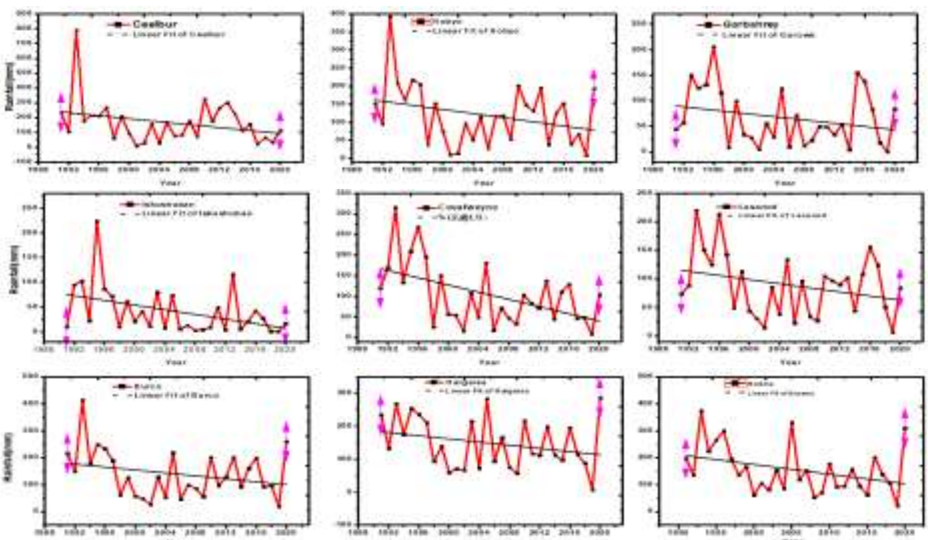

Figure 4: Temporal distribution of MAM rainfall over 9 regions of Somalia.

Frequency of Heavy Rainfall Events during Gu Rainy Season

Figure 5 shows the distribution of heavy rainfall events across regions of Somalia, which indicates that the southern regions experience the majority of heavy rainfall events. This concurs with Figure 2, which depicts that the rainiest areas are in the southern parts of the country. The analysis revealed the southern parts of Somalia are prone to more heavy rainfall events of about 30 HREs during the study period. Among all of the stations used in this study, the Shabeellaha region received the heaviest rainfall events across the country in the last 3 decades, which makes the region the wettest region in the country. Additionally, Jubadda Dhexe and Jubadda Hoose experienced relatively high numbers of heavy rainfall events. The rest of the country has received relatively few heavy rainfall events in the last 30 years.

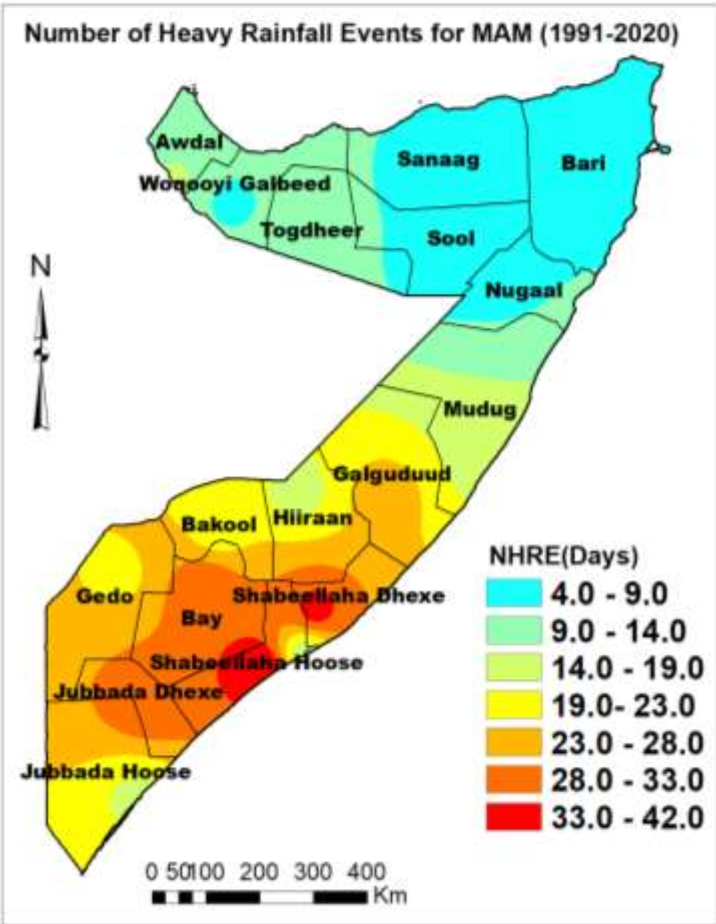

Figure 5: Distribution of heavy rainfall events during MAM rainfall season in Somalia.

Moreover, Figure 6 shows the number of heavy rainfall events per month in the Gu rainy season from 1991 to 2020. It shows that the month of April received the highest number of heavy rainfall events, which is almost 200 events across the 30 years of study. This is likely due to the peak influence of the Intertropical Convergence Zone (ITCZ), which shifts northward during this time, bringing moist air and increased convection, leading to intense rainfall. May also experienced a significant number of heavy rainfall events, around 120, as the ITCZ influence persists but begins to weaken. In contrast, March had the fewest heavy rainfall events, as the ITCZ's influence is still developing, resulting in less frequent heavy rain during the earlier part of the rainy season. This, however, is consistent with Somalia MAM rainfall patterns, in which the rainy season begins in late March and intensifies through April before ceasing around May (Fenta et al. 2017). During the period of study, April was more characterised by heavy rainfall and had a significant contribution of the total amount of rainfall to the season, which makes the southern part vulnerable to extreme rainfall events that result in floods, landslides, and other related hazards. The frequency and severity of such events have been increasing in recent years, likely due in part to climate change (Mohamed et al. 2022).

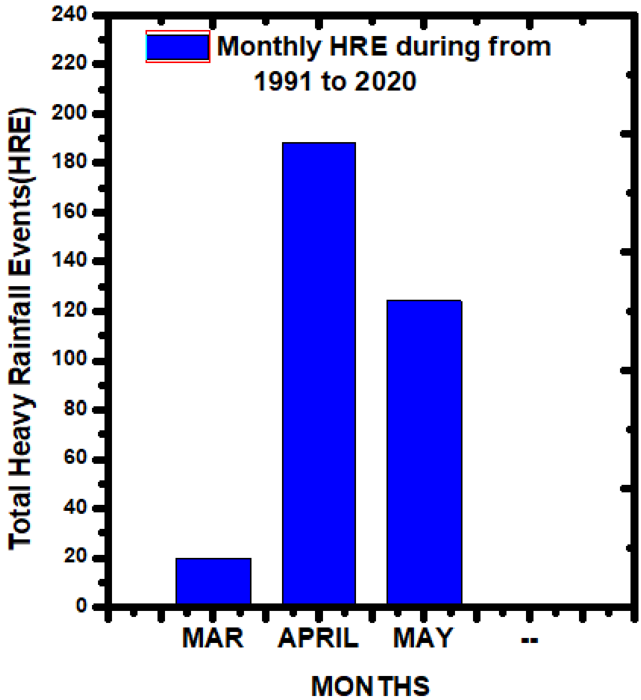

Figure 6: Seasonal-monthly heavy rainfall events over Somalia (1991-2020).

The analysis of the frequency of cluster maxima occurrence over a large threshold is addressed. Table 1 shows the occurrence frequency of heavy rainfall events over the study region above 30 mm/day in the periods 199–2020. The return period was obtained by calculating the reciprocal of relative frequency, which is calculated by dividing the total number of events (frequency) of the respective RE by the total number of years used in the study. It was found that Qoryoley has recorded the highest number of heavy rainfall events (42) in the country, with a return period of 1 year. This means that a heavy rainfall event equal to or greater than 30m is expected to occur every year. Similarly, Jowhar, which has the second highest number of heavy rainfall events (36), has a return period of 1year, indicating that such heavy rainfall is expected to occur in every year. The stations Baidoa, Buale, and Ceelbur have return periods of 2 years each. This indicates that these stations will have significant rainfall events every 2 years. These regions experience frequent convective activity because they are located in zones with consistent moisture availability or conducive conditions for convective rainfall. The remaining stations exhibit a high return period of more than 5 years or even 10 year, indicating that these stations are not frequently observed with heavy rainfall events. The differences in heavy rainfall frequency and return periods across regions can be attributed to a combination of large-scale atmospheric patterns (such as the ITCZ, monsoon systems, and ENSO), local topography, sea surface temperature influences, and possibly the effects of climate change. These factors work together to determine how often and how intensely a region experiences heavy rainfall events (Kavishe and Limbu 2020).

Table 1: Return period of heavy rainfall events across 18 stations

Stations	Frequency (Events)	Relative frequency	Probability of occurrence (%)	Returning time (year)
Qoryoley	42	0.74	73.7	1
Jowhar	36	0.68	68.4	1
Baidoa	33	0.63	63.2	2
Buale	32	0.58	57.9	2
Ceelbuur	26	0.53	52.6	2
Garbaharey	22	0.47	47.4	2
Xudur	20	0.42	42.1	2
Kismayo	17	0.37	36.8	3
Beledweyne	16	0.32	31.6	3
Mogadishu	15	0.26	26.3	4
Hobyo	15	0.21	21.1	5
Borama	14	0.16	15.8	6
Burco	12	0.11	10.5	10
Hargisa	8	0.05	5.3	19
Garowe	7	0.79	78.9	1
Ceelafweyn	7	0.84	84.2	1
Lasanod	6	0.89	89.5	1
Iskushuban	4	0.95	94.7	1

Spatial-temporal Variability of Heavy Rainfall during Gu Season in Somalia.

Figure 7 displays the spatial patterns of the first three EOF analyses of the HREs during the MAM season for 18 synoptic stations from 1991 to 2010. The mentioned EOF patterns explain more than 89% of the total variance and are more representative of the country's seasonal rainfall. The spatial pattern of the first EOF mode (EOF 1) of the heavy rainfall anomalies accounts for 54% of the total variance during the season. Most of its eigenvector coefficients are positive all over the country except the far southern part of the country, where a negative loading was observed, especially in areas around Kismayo. The highest values of positive coefficients are concentrated in the north-eastern part of the country. The spatial pattern represented by EOF 2 and EOF 3 in Figure 5 accounts for about 35% of the total variance of mean heavy rainfall during the MAM season. EOF 2 in Figure 7 shows that there is a positive loading observed in the southern parts and some central regions of the country, while it has shown a negative loading over the northwestern regions. On the other hand, EOF 3 has recaptured the two negative loadings over the deep southern parts and over the northwestern parts of the country. All of the three EOF modes are in agreement with the positive and negative climatological distribution of the number of HREs, especially over the deep southern and northwestern sectors (EOF1 and EOF 2), and the long-term mean climatological MAM rainfall observed over the southern and northwestern parts of the country (Figure 2).

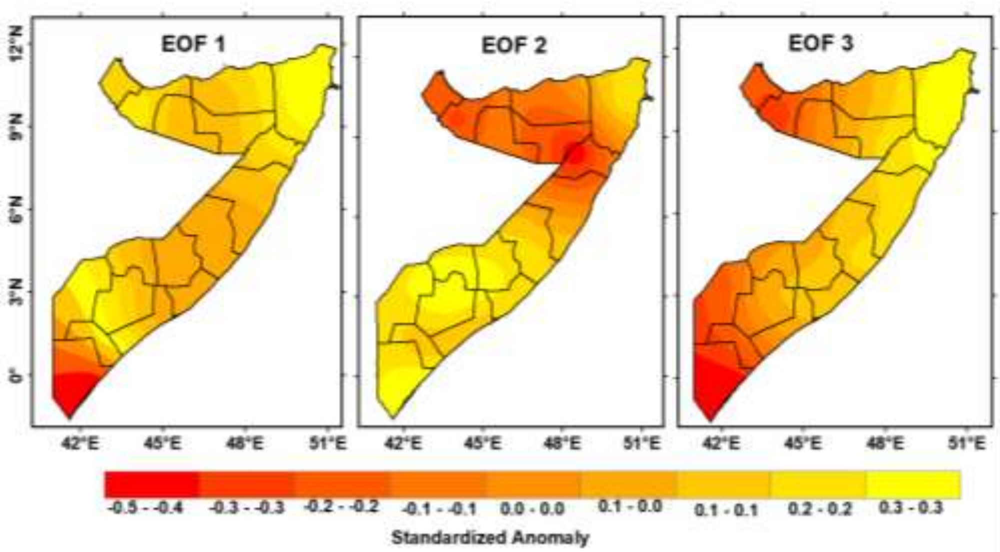

Figure 7: The Spatial distribution patterns of the first EOF (EOF 1), second EOF (EOF 2) and the third EOF (EOF 3).

It should be noted that the principal component score time series provides an insight into the strength of an EOF pattern over time (Figure 8). In the results obtained from the first mode, it shows that years with normalised heavy rainfall departures greater than one (>+1) of the standard deviation were mainly observed in 1992, 1994, 2011, 2012, and 2020. In this case, these years were selected as having anomalously enhanced HREs compared to the normal years, while 1991, 1993, 1997, 1998, 1999, and 2000 were considered years with suppressed HREs compared to the normal years. In general, the spatial patterns represented by EOF 1 to EOF 3 in Figures 7 are in agreement with the results obtained in Figure 2, which signifies credible areas of the country that were mostly affected by heavy rainfall.

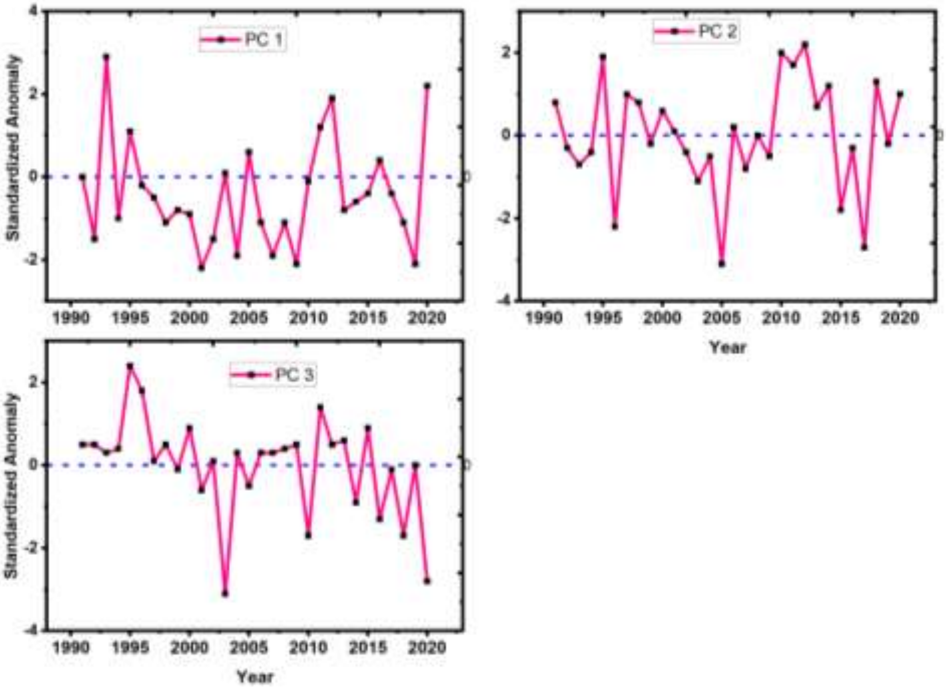

Figure 8: The principal component of time series of the first EOF (PCI 1), second EOF (PCI 2) and the third EOF (PCI 3).

Conclusion and Recommendations

The study aimed to assess the variability of heavy rainfall events during the MAM (Gu) rainy season in Somalia, yielding significant findings with critical implications for the region. The analysis indicates that the Gu rainy season begins in the latter half of March, peaks in April, and features notable regional rainfall disparities. Specifically, southern Somalia receives the most rainfall, exceeding 280 mm annually, largely due to abundant moisture and convection activities along the Indian Ocean. In contrast, the northeastern regions experience the least rainfall.

Moreover, the findings reveal that heavy rainfall events (HREs) are most prevalent in southern regions, particularly along the Shabeellah River, where stations such as Qoryoley and Jowhar recorded 42 and 35 events, respectively. The data shows a general positive trend in HREs across the country, with many stations exhibiting significant increases at a 95% confidence level. The study also indicates that the average return period for heavy rainfall events is approximately 10 years for certain stations, while areas with fewer events experience a return period of about 1 year.

The implications of these findings are substantial, as the heightened frequency of heavy rainfall elevates the risk of flooding, particularly in April and May. To mitigate these risks, it is imperative to implement effective flood management strategies and early warning systems to protect communities from potential disasters, including crop damage and infrastructure destruction. Additionally, further research is recommended to explore the connection between atmospheric warming and the intensification of precipitation extremes in Somalia. These steps will enhance resilience to climate variability and safeguard the livelihoods of affected populations.

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