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Assessing Spatio-temporal Variations and Trends of Rainfall over Somalia from 1991 to 2020

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ABSTRACT

This study aims to examine the spatiotemporal variability and trends of rainfall over Somalia using the Mann-Kendall (MK) test and Sen's slope estimator to investigate the trend and magnitude of the rainfall changes and the arithmetic mean and coefficient of variation (CV) to examine the rainfall variability. To achieve this aim, the gridded monthly satellite rainfall datasets from Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) for the period between 1991 and 2020 were used. Results show that annual rainfall generally exhibits bimodal rainfall distribution, March to May (Gu) and September to November (Deyr), though southern coastal regions receive extended Gu rains into July and northwestern regions experience early onset of Deyr rains. The study further showed that a low and moderate degree of inter-annual variability (CV<30%) is observed in most parts of the country, while on a seasonal basis, the short rainy season (Deyr) has a higher rainfall variability (CV>30%) compared to the primary rainy season (Gu) and most regions in the south receiving highest amounts of rainfall experience highest variability (CV>50%) during Deyr season. Furthermore, the trend analysis of the annual rainfall showed a non-significant increasing trend. On a seasonal basis, the trends of Gu rainfall decreased in some regions while trends for the Deyr season increased in most regions. However, rainfall trends observed were not statistically significant throughout the country at a significance level of 0.05.

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INTRODUCTION

Climate change poses a serious threat to sustainable development with adverse impacts on the environment, food security, human health, economic activities, natural resources and physical infrastructure (IPCC, 2007). Rainfall is one of the most important defining characteristics of the climate and has excellent spatial and temporal variability (Stocker *et al*., 2014). The effects of changes in precipitation are undeniably clear, with impacts already affecting ecosystems, biodiversity, and people (Case, 2006). Somalia is characterized by substantial rainfall variability in space and time (NAPA, 2013). Hence, floods and droughts are standard features all over the country. The country's agriculture and food security sectors are considered rain-dependent and, therefore, can be affected negatively by rainfall variability. Due to the high vulnerability, drought hazards quickly develop into disasters with severe consequences (Mutua and Zoltan, 2009). In Somalia, rainfall is critical for water availability for livestock keeping and agricultural production, both rainfalls dependent. However, the country has a limited adaptive capacity to mitigate the negative impacts of rainfall variability. Variability in rainfall over the last decades is the leading cause of crop failure and water scarcity due to the late onset of rainfall, short dry spells and multi-annual droughts.

East Africa is identified as one of the most vulnerable regions to rainfall variability in the world, and Somalia is inclusive, where most of the agricultural activities are rain-fed. Major synoptic systems that influence the rainfall of Eastern Africa include Inter Tropical Convergence Zone, El Niño Southern Oscillation and Indian Ocean Dipole (Kuya, 2016; Zhongming *et al.*, 2015; Owiti *et al.*, 2008). Rainfall in East Africa, including Somalia, is strongly influenced by the Inter-tropical Convergence Zone (ITCZ) that passes the Equator twice a year, and its passages coincide with the two distinct rainy seasons experienced in the region (Kuya, 2016). In addition, El Niño also affects rainfall in the region; in years when this phenomenon prevails, Eastern Africa receives more rainfall, especially during the first rainy season of the year. In contrast, if La Niña is prevailing, the southern parts of the sub-region usually experience a drier-than-normal period between November and March (Zhongming *et al.*, 2015). Moreover, it has been demonstrated that some extreme rainfall conditions over East Africa are also associated with Indian Ocean Dipole (IOD). The positive/negative phase tends to enhance/diminish the region's October-December (OND) rainfall (Owiti *et al.*, 2008).

Apart from synoptic systems, it must be noted that local factors such as orographic and coastal influences are also significant and cause a high degree of rainfall variability in Somalia. According to Muchiri (2017), one of the local factors that influence this variability is the overall descending motion of the air, and the consequent low humidity as the country is also located on the leeward side of the Kenyan and Ethiopian highlands that, subjecting it to further low rains. Various researchers have studied recent trend analysis of rainfall over the East African region. Nicholson (2017) has found that over much of eastern Africa, the long rains have declined in recent decades while the short rains have increased. This variability has been associated with the MJO having a strong influence on year-to-year variations and with the relative strength of ENSO and IOD playing a significant role in the downward trend (Nicholson, 2017).

Studies have shown that although the rainfall shortage is stressful, the most significant problem is often inter-seasonal and intra-seasonal rainfall variability. In fact, the performance of a rainy season depends on the overall total amount and needs an adequate distribution of the rains throughout the year (Camberlin *et al.*, 2009). Therefore, detailed knowledge of rainfall distribution and variability is essential for agricultural planning (Yamusa *et al.*, 2015). Therefore, analysis of rainfall variability and trends in Somalia is a vital concern for communities in arid and semiarid regions that largely depend on rain-fed agriculture and rangelands for their livelihoods. Trend analysis is also crucial for detecting rainfall trends at regional and national levels as it provides vital information about the possibility of future changes.

MATERIALS AND METHODS

Study Area

This study is conducted in Somalia, which is situated within latitudes 1.5º S – 12.0º N and longitudes 41.0º E – 51.0º E and has a land area of 637,540 km^2, as shown in Figure 1. Somalia is part of the Greater Horn of Africa and is bordered by Kenya to the south, Ethiopia to the west, Djibouti to the northwest, the Gulf of Aden to the north, and the Indian Ocean to the east.

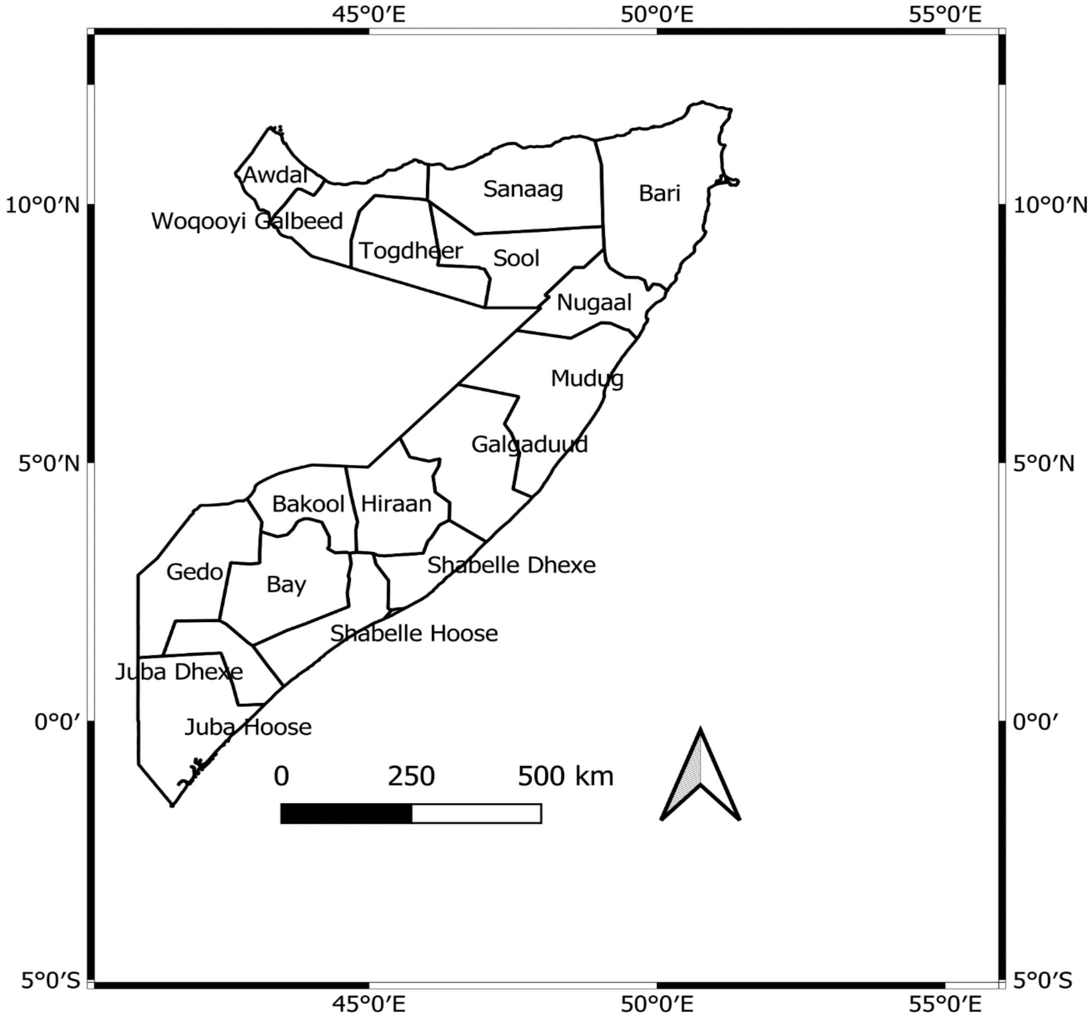

Figure 1: Map of the study area with administrative regions

Somalia is divided into four climatic zones: the desert zone in the north, mainly along the red sea; the arid zone in the central part; and the semi-arid and humid zones in the south and parts of the northwest (NAPA, 2013). 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. Rainfall is the most crucial factor in the country as most of the population depends on the rainfall seasons for their livelihood.

Data Collection

The study used monthly gridded observation/satellite blended Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset from 1991 to 2020. CHIRPS is a satellite rainfall product with relatively high spatial and temporal resolutions and quasi-global coverage. It is available online at https://data.chc.ucsb.edu/products/CHIRPS-2.0/. The CHIRPS rainfall product was evaluated over the Greater Horn of Africa, including Somalia and recommended to be used in the region as it performed significantly better than other satellite products with higher skill, low or no bias, and lower random errors (Dinku *et al.* 2018).

Coefficient of variability (CV)

The coefficient of variability (CV) was used in this study to evaluate rainfall variability on an annual and seasonal basis. This is a measure of the degree of variability expressed as a percentage. CV is the percentage ratio of the standard deviation to the mean. The seasonal and annual CV for each pixel was calculated, and the resulting gridded data was mapped to display the variability of rainfall.

$$\mathrm{CV} = \frac{\sigma}{\bar{X}} * 100 \qquad (1)$$

where $\bar{X}$= average (or arithmetic mean) of rainfall, σ = standard deviation

High CV values indicate higher variability, and low CV values indicate lower variability. According to Hare (2003) and Alemu (2019), the degree of variability in rainfall is categorized into low (CV < 20%), moderate (20% < CV <30%) and high (CV > 30%).

The Mann–Kendall (MK) Test

The Mann–Kendall (MK) trend test was employed to assess the statistical significance of the trends in rainfall. It is a non-parametric test with no prerequisite conditions for the data to be normally distributed (Kendall, 1938). The MK test is grounded on a null hypothesis (H_0), which indicates that there is no trend that the data are independent and randomly ordered and the alternative hypothesis (H_a) is that the data follow a monotonic trend over time.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \qquad (2)$$

for which the following holds,

$$Sgn(\theta) = \begin{cases} +1 \ldots\ldots \theta > 0 \\ 0 \ldots\ldots \theta = 0 \\ -1 \ldots\ldots \theta < 0 \end{cases} \qquad (3)$$

where: x_1, $x_2 \ldots x_n$ represent n data points, xj represents the data point at time j and S is the Mann-Kendall statistic.

Under the hypothesis of independent and randomly distributed random variables, when $n \geq 8$, the S statistic is approximately normally distributed, with zero mean and variance as follows:

$$\sigma^2 = \frac{n\,(n-1)(2n+5)}{18} \qquad (4)$$

Therefore, the standardized Z statistics follow a normal standardized distribution:

$$Z = \begin{cases} \frac{S-1}{\sigma} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sigma} & if\ S < 0 \end{cases} \qquad (5)$$

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. The critical Z values at a 95% confidence level are -1.96 and +1.96 standard deviations. The null hypothesis is rejected when the Z value computed falls outside that range at a significance level of 0.05 (p<0.05). If the Z value is within the range at the significance level (p>0.05), the null hypothesis cannot be rejected (Kendall, 1945).

Sen's Slope Estimator

To estimate the magnitude (actual slope) of an existing trend, Sen's non-parametric method was used (Sen, 1968). This method assumes a linear model in a time series to calculate the change of slope, and the variance of the residuals should be constant in time.

The function of Sen's model is:

$$f(t) = Qt + B \qquad (6)$$

where 'Q' is the slope, and 'B' is the intercept and 't' is the time.

The slope 'Q' is calculated using the formula:

$$Q_i = \frac{x_j - x_k}{j-k} \qquad (7)$$

where x_j and x_k are data values at time j and k (j > k) respectively. If there are n values in the time sequence, there will be as many as N = n (n-1)/2 slope estimates Q_i. Positive value of Q_i indicates an increasing trend while a negative value of Q_i represents a decreasing trend in the time series of the data. The unit of Q_i is the slope magnitude per year e.g., mm per year. The null hypothesis is tested at 95% confidence level for the rainfall data on annual and Seasonal timescales.

RESULTS AND DISCUSSION

Annual Rainfall Cycle

The rainfall over Somalia shows a bimodal distribution, as shown in Figure 2. The first rainy season generally occurs between March and May (MAM), and the second rainy season extends from September to November (SON), peaking in April and October, respectively. Figure 2 indicates that the second rains mainly occur in October and November and are shorter and less in quantity than the MAM rains. In addition, two distinctive seasons of dry periods are also depicted in Figure 2, which occur from December to February and June to August.

However, it was found that different parts of the country exhibit different rainfall patterns, as indicated in Figure 3. Figure 3a shows that southern coastal regions along the Indian Ocean (Banadir, Middle Shabelle, Lower Shabelle, Lower Jubba and Middle Jubba) experience *Gu* rainy season, which extends into June-August. This is mainly due to Haggai rains produced by the onset of moist onshore winds because of the prevailing southwesterly monsoon wind (NAPA, 2013). Moreover, the *Deyr* season in northwestern regions starts much earlier than in other regions. As shown in Figure 3b, *the Deyr* season starts as early as July or August in Awdal, Waqoyi Galbeed, Togdheer and Sanaag regions. This is mainly due to the movement of the ITCZ from the north, and the influence of topography. Highland areas around the Golis Mountain range (NAPA, 2013; Muchiri, 2007). Apart from these areas, the rest of the country exhibits the general rainfall regime in both seasons (MAM and SON) as shown in Figures 3c.

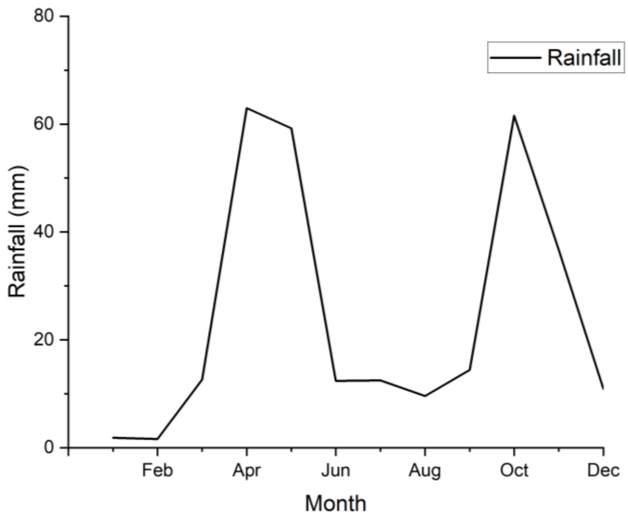

Figure 2: Annual rainfall cycle over Somalia calculated from the long-term annual rainfall (1991-2020).

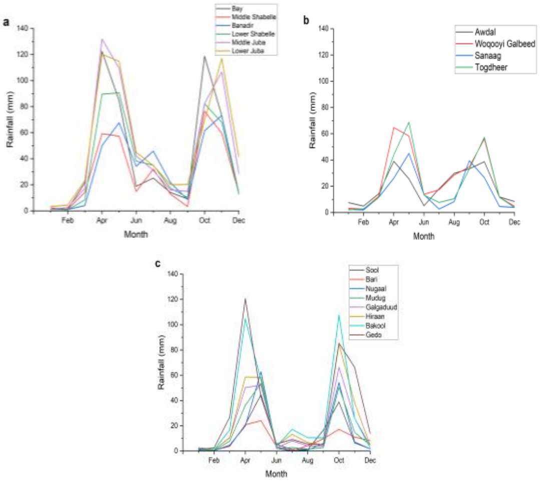

Figure 3: Annual rainfall cycle over different regions in Somalia

Spatial Variability of Rainfall

The spatial distribution of rainfall was assessed based on long-term means (1991-2020). As shown in Figure 4, the annual rainfall amount varies spatially from less than 150 mm in the northeastern regions to over 500 mm in the south. Northeastern regions such as Sool, Bari and parts of Sanaag receive the lowest amounts of annual rainfall (51-150 mm), while lower Jubba and middle Jubba regions in the south receive the highest amounts (>550 mm). Generally, annual 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.

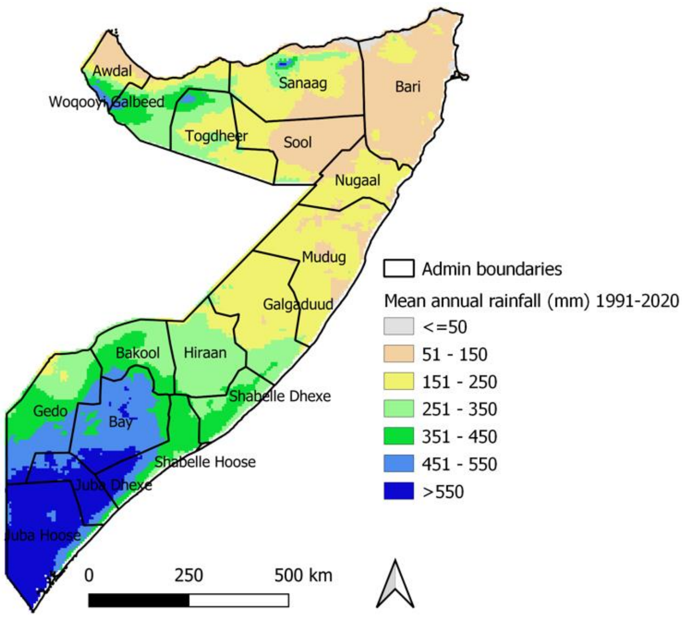

Figure 4: Spatial distribution of mean annual rainfall (1991-2020).

The spatial distribution for the two rainy seasons, MAM and SON, was also assessed (Figure 5). During MAM (Figure 5a), rainfall ranges from less than 50 mm in the Bari region to around 300 mm in Lower Jubba and Middle Jubba. This is consistent with other studies that indicated that lower and middle Jubba receive high amounts of seasonal rainfall in Somalia during the MAM season (Muchiri, 2007). However, as shown in Figure 5b, the southern coastal regions receive significant amounts of rainfall (50-150 mm) in JJA as the primary (*Gu*) season extends into June-July because of the Haggai rains, which are produced by the onset of moist onshore winds (NAPA, 2013).

During the SON season (Figure 5c), rainfall ranges from less than 50 mm in Bari and Sool regions (Northeast) to about 200 mm in the south. This shows a slight decrease in rainfall compared to MAM rainfall. However, as the *Deyr* season starts much earlier in the northwest of the country compared to other regions, Awdal, Waqoyi-Galbeed, and mountainous areas in Togdheer and Sanaag, receive a significant amount of rainfall (51-150 mm) in June-August as shown in Figure 5b.

This study assessed inter-annual and seasonal rainfall variability over Somalia using the coefficient of variation. The spatial distribution of the coefficient of variation of the annual rainfall is shown in Figure 6. The values of CV show the change from the mean values of rainfall. Low and moderate inter-annual rainfall variability (with CV less than 30%) is observed in most parts of the country.

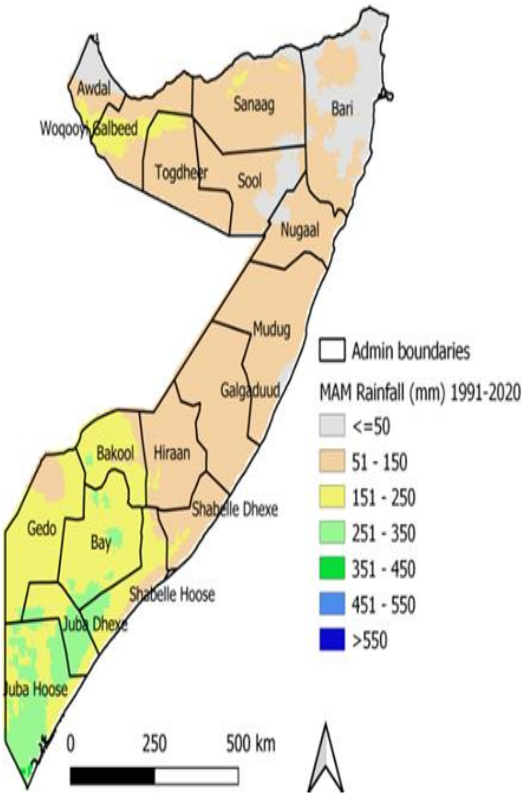

Figure 6a: Spatial distribution of mean seasonal rainfall (1991-2020): MAM.

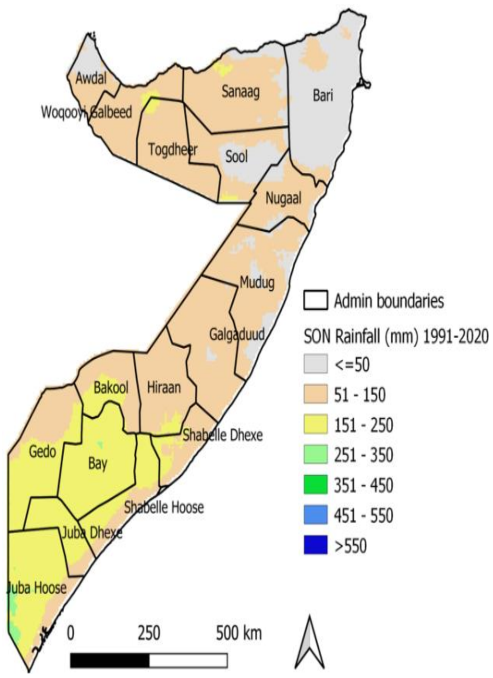

Figure 5c: Spatial distribution of mean seasonal rainfall (1991-2020): SON.

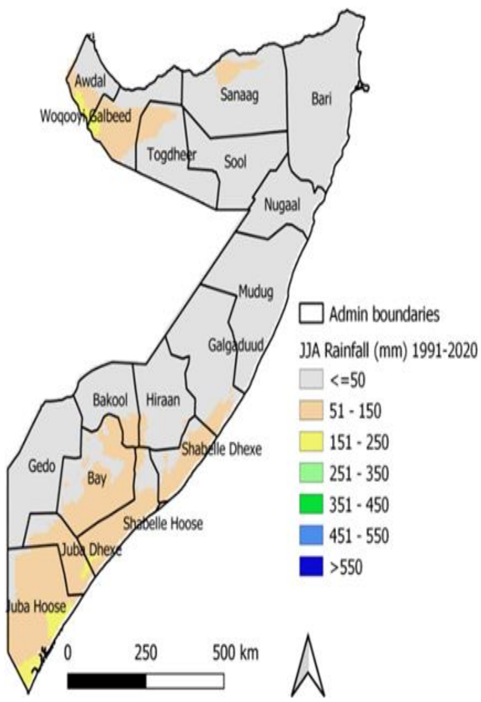

Figure 7b: Spatial distribution of mean seasonal rainfall (1991-2020): JJA.

Temporal Variability of Rainfall

That means annual average rainfall varies less than +/- 30% from its long-term average. On the other hand, high inter-annual variability of rainfall (with CV 30-50 %) exists on the northwestern coast along the Gulf of Aden and most central/southwestern regions (Galgaduud, Hiraan, Bakool, Bay and Gedo). Gedo region indicated the highest inter-annual rainfall variability with CV 40%, which is often associated with frequent and severe droughts.

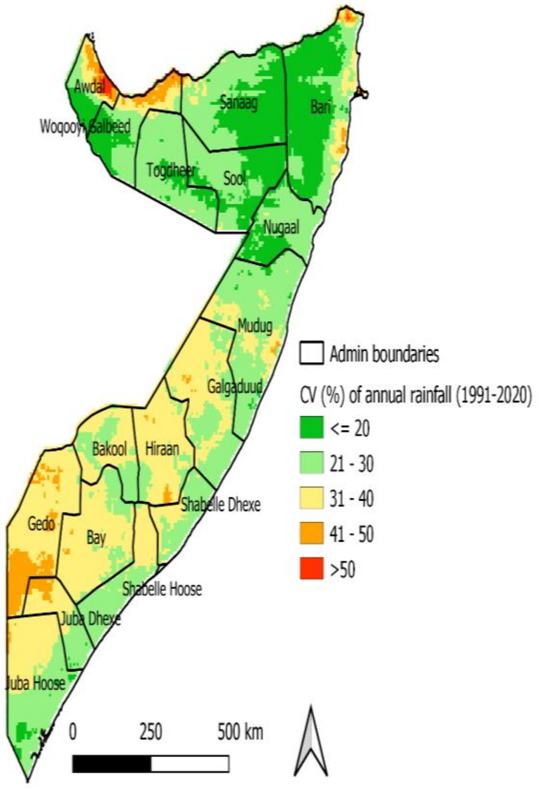

Figure 8: Spatial map of coefficient of variation (%) of mean annual rainfall (1991-2020).

The seasonal rainfall variability was also assessed through the Coefficient of Variation. Overall, the primary rainy season (*Gu*) has a lower rainfall variability compared to the short rainy season (*Deyr*), indicating that *Gu* is more reliable throughout the country. As shown in Figure 7, analysis of *Gu* rainfall indicated that low and moderate variability of rainfall (with CV < 30%) was observed in most parts of the country except northern coasts along the Gulf of Aden and areas in the south (Gedo and Lower Jubba) with CV >30%. Analysis of *Deyr* rainfall (Figure 8) indicated that a high variability of rainfall (with CV > 30%) was observed in most parts of the country. Low and moderate variability (CV<30%) is observed in the northern regions such as Awdal, Waqoyi-Galbeed, Sanaag, Sool and Bari, which means *Deyr* rainfall in these regions is most reliable. On the other hand, a very high variability (CV>50%) was observed in the central and southern parts of the country. This means that regions (lower/Middle Jubba and Bay) with the highest amounts of rainfall experience the highest rainfall variability during the *Deyr* season.

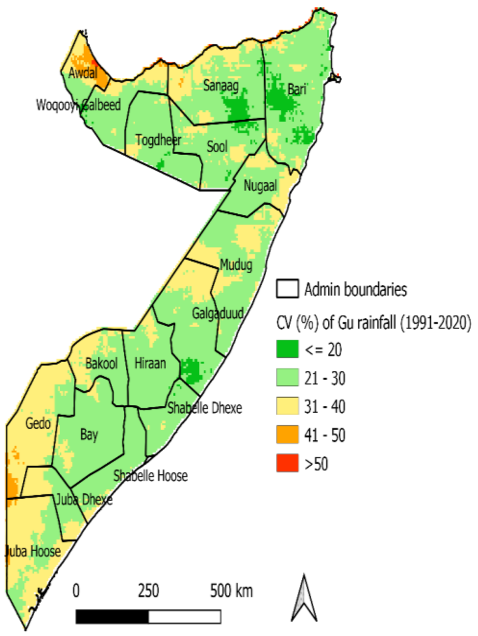

Figure 9: The coefficient of variation for the Gu rainfall (1991-2020).

Trend Analysis of Rainfall

Statistical methods were used to test the significance of the trend. In the study, trend analysis on regionally averaged rainfall data was analyzed on a seasonal and annual basis using the Mann-Kendall test and Sen’s Slope estimator at a 95% confidence level.

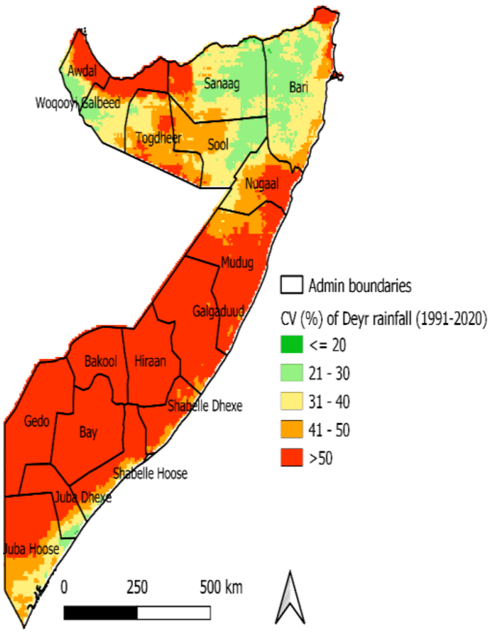

Figure 10: The coefficient of variation for the Deyr rainfall (1991-2020).

The trend analysis of annual rainfall data (Table 1) shows that there are decreasing (negative) trends for Banadir and Middle Shabelle regions, while all other regions indicate increasing trends. However, the annual rainfall trends in all regions are statistically insignificant at a significance level of 0.05, except for Sanaag and Sool, which indicate a statistically significant increasing annual rainfall trend at a confidence level of $p<0.05$.

Trend analysis of *Gu* rainfall (Table 2) shows increasing or decreasing trends for some stations. A rainfall decrease is observed in Awdal and Waqoyi Galbeed, Hiraan, Banadir, Middle Shabelle, Lower Shabelle and Bakool regions. This result agrees with some East African studies showing a declining rainfall trend during the long rains (Nicholson, 2017; Ogallo *et al*., 2017; Omondi *et al*., 2014). However, results from statistical significance tests indicate that the rainfall trends in all regions for *the Gu* season are not statistically significant at a confidence level of $p<0.05$. The annual rainfall trends for Sanaag and Sool were statistically significant, increasing at a 90% confidence level ($p<0.1$). Trend analysis of *Deyr* rainfall (Table 3) shows that a generally increasing trend in rainfall is quite evident in all regions except Banadir and Waqoyi galbeed, which indicated negative trends for both seasons.

Table 1: Trend analysis of areal average annual rainfall (1991–2020)

Region	Z-value	p-value	Trend	Significance	Sen's Slope
Awdal	0.39	0.69	Increasing	Not significant	0.59
Waqoyi Galbed	0.14	0.88	Increasing	Not significant	0.16
Togdheer	0.89	0.37	Increasing	Not significant	0.67
Sanaag	1.92	0.05	Increasing	Not significant	1.19
Sool	2.03	0.04	Increasing	Significant	1.08
Bari	1.92	0.05	Increasing	Not significant	0.75
Nugal	1.07	0.28	Increasing	Not significant	0.72
Mudug	0.74	0.45	Increasing	Not significant	0.78
Galgadud	1.42	0.15	Increasing	Not significant	1.79
Hiraan	1.42	0.15	Increasing	Not significant	2.00
Middle Shabelle	-0.28	0.77	Decreasing	Not significant	-0.28
Lower Shabelle	0.39	0.69	Increasing	Not significant	0.80
Banadir	-1.07	0.28	Decreasing	Not significant	-1.70
Bay	1.49	0.13	Increasing	Not significant	4.71
Bakool	1.49	0.13	Increasing	Not significant	3.56
Gedo	1.53	0.12	Increasing	Not significant	3.47
Middle Jubba	1.71	0.08	Increasing	Not significant	5.31

Lower Jubba	1.89	0.05	Increasing	Not significant	5.12

Table 2: Trend analysis of areal average Gu rainfall (1991–2020)

Region	Z-value	P-value	Trend	Significance	Sen's Slope
Awdal	-0.64	0.52	Decreasing	Not significant	-0.43
Waqoyi Galbeed	-0.17	0.85	Decreasing	Not significant	-0.22
Togdheer	0.53	0.59	Increasing	Not significant	0.38
Sanaag	1.67	0.09	Increasing	Not significant	0.77
Sool	1.83	0.06	Increasing	Not significant	0.74
Bari	1.17	0.23	Increasing	Not significant	0.26
Nugaal	1.03	0.30	Increasing	Not significant	0.49
Mudug	0.24	0.80	Increasing	Not significant	0.25
Galgaduud	0.39	0.69	Increasing	Not significant	0.30
Hiraan	-0.53	0.59	Decreasing	Not significant	-0.47
Middle Shabelle	-1.39	0.16	Decreasing	Not significant	-1.25
Banadir	-1.49	0.13	Decreasing	Not significant	-1.82
Lower Shabelle	-0.39	0.69	Decreasing	Not significant	-0.45
Bay	0.46	0.64	Increasing	Not significant	0.66
Bakool	-0.39	0.69	Decreasing	Not significant	-0.39
Gedo	0.57	0.56	Increasing	Not significant	0.97
Middle Jubba	1.33	0.18	Increasing	Not significant	2.40
Lower Jubba	1.53	0.12	Increasing	Not significant	2.81

These results are generally consistent with the studies done in the East African region that has shown an increasing trend in the short rains (Nicholson, 2017; Ogallo *et al.*, 2017; Omondi *et al., 2014*). However, results from statistical significance tests indicate that the rainfall trends in all regions for *the Deyr* season are also not statistically significant at a significance level of 0.05.

Table 3: Trend analysis of areal average Deyr rainfall (1991–2020)

Region	Z-value	P-value	Trend	Significance	Sen's Slope
Awdal	0.57	0.57	Increasing	Not significant	0.38
Waqoyi Galbeed	-0.28	0.77	Decreasing	Not significant	-0.14
Togdheer	0.67	0.49	Increasing	Not significant	0.27
Sanaag	1.03	0.30	Increasing	Not significant	0.43
Sool	0.91	0.36	Increasing	Not significant	0.40
Bari	0.35	0.72	Increasing	Not significant	0.09
Nugaal	0.74	0.45	Increasing	Not significant	0.37
Mudug	0.89	0.37	Increasing	Not significant	0.84
Galgaduud	1.14	0.25	Increasing	Not significant	1.43
Hiraan	1.67	0.09	Increasing	Not significant	2.24
Middle Shabelle	1.10	0.26	Increasing	Not significant	0.98
Banadir	-0.28	0.77	Decreasing	Not significant	-0.34
Lower Shabelle	0.49	0.61	Increasing	Not significant	0.54

Bay	0.98	0.32	Increasing	Not significant	1.83
Bakool	1.47	0.19	Increasing	Not significant	2.19
Gedo	1.32	0.18	Increasing	Not significant	2.01
Middle Jubba	0.67	0.49	Increasing	Not significant	1.22
Lower Jubba	0.57	0.56	Increasing	Not significant	0.69

CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to assess rainfall variability and trends over Somalia. The analysis results indicated that annual rainfall over the country exhibits bimodal distribution, peaking in April and October during *Gu* (MAM) and *Deyr* (SON) seasons, respectively. However, it was found that the southern coast and northwestern regions exhibit different rainfall patterns. Southern coastal regions along the Indian experience *the Gu* rainy season, which extends into July due to Haggai rains produced by the onset of moist onshore southwesterly monsoon, while *Deyr* in northwestern highland areas around Golis Mountain range starts much earlier in comparison to other regions.

In addition, results from spatial analysis indicated that annual rainfall in northern and central Somalia is considerably lower than in the South, except for the northwestern highland regions, due to the influence of topography. However, because of the rainfall received in June-August, the northwestern and southern regions along the Indian ocean receive considerably more rain, which contributes to agricultural production in Somalia as these two areas have a high potential for crop production. The study further showed a moderate and high degree of inter-annual and seasonal variability with recurrences in weather extremes often associated with floods or droughts. The short rainy season (*Deyr*) has a higher rainfall variability (CV>30%) compared to the primary rainy season (*Gu*), and most regions in the South with the highest amounts of rainfall experience the highest variability (CV>50%) during *Deyr* season. This indicates that *Gu* is more reliable, particularly in the southern part of the country.

Furthermore, the trend analysis of annual rainfall showed a non-significant increasing or decreasing trend. On a seasonal basis, the trends of *Gu* rainfall decreased in some regions while trends for *the Deyr* season increased in most regions. However, rainfall trends observed were not statistically significant throughout the country at a significance level of 0.05, with few stations showing a significantly increasing annual rainfall trend at a 90% confidence level. Since there is a high variability of rainfall during *the Deyr* season, which is often associated with droughts, it is recommended that effective drought mitigation measures and early warning systems should be put in place, mainly in the southern part of the country. The study also recommends further research to investigate the extreme rainfall events during *Gu* and *Deyr* seasons and weather systems associated with the extreme rainfall over Somalia.

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