



Spatiotemporal Patterns of Rainfall Variability and Their Influence on Agricultural Productivity in Somalia, 1983 to 2023

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Abstract

Rainfall variability is a central determinant of agricultural performance in Somalia, where the great majority of cultivated land depends entirely on seasonal precipitation. This study examines the spatiotemporal structure of rainfall across Somalia's eighteen administrative regions between 1983 and 2023 and evaluates its relationship with national crop production. Monthly precipitation totals were derived from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) archive and aggregated by season and region, while crop production records were obtained from the Food Security and Nutrition Analysis Unit for Somalia. Regional rainfall totals were compared across the four Somali seasons, and the association between annual rainfall and crop output was tested using Pearson correlation and linear regression. The results show a pronounced north to south precipitation gradient, with southern regions such as Bay and Lower Shabelle receiving more than 490 millimetres annually and northeastern and central regions such as Bari and Mudug receiving less than 350 millimetres. The Gu season contributed between 36.0 and 55.9 percent of annual rainfall across regions, the Deyr season contributed between 17.4 and 44.5 percent, and interannual variability, measured by the coefficient of variation, ranged from 12.3 to 27.5 percent. Annual rainfall was positively and significantly associated with crop production ($r = 0.68$, $p < 0.05$), with each additional millimetre of rainfall associated with an estimated increase of 285.7 metric tonnes in national output, although considerable scatter around this relationship indicates that non-climatic factors also shape production outcomes. These findings point to the need for region-specific water management and adaptation strategies rather than a single uniform national policy.

Keywords: Rainfall variability; Crop production; Somalia; CHIRPS; Spatiotemporal analysis; Climate adaptation; Food security

1. Introduction

Climate variability has intensified across much of the world over the past three decades, and rainfall fluctuation now ranks among the most consequential drivers of agricultural instability in regions that depend on rainfed cultivation (Alasow et al., 2025; Ayugi et al., 2022; Hamed et al., 2024, 2025; Tanimu et al., 2025). This instability bears most heavily on developing regions, where farming systems have limited capacity to buffer against precipitation shocks and where food security is already fragile (Muluneh, 2021; Omar et al., 2024; Pörtner et al., 2022). Across sub-Saharan Africa, more than 95 percent of cultivated land remains rainfed, leaving agricultural output closely tied to the timing and intensity of seasonal rains (Koning, 2017; Rady et al., 2025; Tesfay, 2024). The Horn of Africa is widely regarded as one of the most climate-sensitive parts of the continent, marked by rainfall that has grown increasingly erratic and by a rising frequency of extreme wet and dry events that complicate

agricultural planning (Alasow et al., 2024; Funk et al., 2019; Gebrechorkos et al., 2019). Long-term climate records across the region point to a shift toward more intense yet less predictable rainfall, a trend with direct consequences for food production and planning (Alasow et al., 2024; Awange, 2022; Nicholson, 2017).

Within this vulnerable region, Somalia offers a particularly instructive case. Agriculture contributes an estimated 65 percent of the country's gross domestic product and employs more than 70 percent of its workforce, almost entirely under rainfed conditions, since less than 5 percent of cultivated land is irrigated (FSNAU, 2022). Somalia's geography compounds this exposure. The country spans arid, semi-arid, and sub-humid agroecological zones, and its bimodal rainfall regime, the Gu rains from April to June and the Deyr rains from October to December, governs the timing of planting and harvest for the great majority of smallholder farmers (Alasow et al., 2024; Hunt et al., 2019; Nicholson, 2017). Recurrent droughts and periodic flooding have repeatedly disrupted this cycle, with consequences that extend from household food security to national economic stability (Pape & Wollburg, 2019; Warsame et al., 2022).

Despite a growing body of research on climate trends in the Horn of Africa, three gaps limit current understanding of how rainfall variability translates into agricultural outcomes in Somalia specifically. Most existing studies, including Funk et al. (2018) and Rady et al. (2025), examine climate patterns at a regional or continental scale and provide limited resolution on how rainfall behaves across Somalia's own diverse agroecological zones. Comprehensive long-term analysis linking rainfall variability directly to national crop production records also remains scarce, so the practical magnitude of the rainfall-yield relationship is not well quantified for the country. In addition, the interaction between Somalia's four distinct seasons, Gu, Xagaa, Deyr, and Jilaal, and their differing contributions to production risk has received little systematic attention. Pape and Wollburg (2019) note that the traditional agricultural knowledge Somali farmers have long relied upon is becoming a less reliable guide as rainfall patterns shift, and Omer (2024) similarly observes that current adaptation strategies remain constrained by an incomplete understanding of local rainfall-production dynamics.

To address these gaps, this study conducts a spatiotemporal analysis of rainfall variability and its relationship with crop production in Somalia between 1983 and 2023. High-resolution precipitation data from CHIRPS are combined with agricultural statistics from the Food Security and Nutrition Analysis Unit for Somalia to examine three questions: how rainfall varies across Somalia's administrative regions and seasons, how this seasonal distribution relates to crop production outcomes, and what role extreme rainfall years play in shaping national output. The findings contribute to a more regionally grounded understanding of climate-agriculture relationships in Somalia and are intended to inform the design of adaptation strategies that reflect the country's substantial internal climatic diversity rather than treating it as a single homogeneous unit.

The contribution of this study is both empirical and practical. Empirically, it provides the first region-by-region quantification of seasonal rainfall shares and interannual variability across all eighteen of Somalia's administrative regions over a four-decade period, extending earlier continental-scale assessments to a resolution that is directly usable for national planning. Practically, by linking this regional rainfall record to four decades of crop production statistics, the study offers policymakers, agricultural extension services, and humanitarian planners an evidence base for targeting water management and early warning investments to the regions and seasons where they are likely to matter most. This is particularly relevant given that Somalia's federal member states and regional administrations are increasingly expected to develop their own climate adaptation plans, for which nationally averaged rainfall statistics offer limited practical guidance.

2. Materials and Methods

This study combines satellite-derived precipitation estimates with national agricultural statistics to characterise rainfall variability across Somalia and to quantify its relationship with crop production over a 41-year period.

2.1 Study Area

Somalia is located in the Horn of Africa (Figure 1) and covers approximately 637,657 square kilometres, encompassing agroecological zones that range from arid conditions in the north to semi-arid and sub-humid conditions in the south (FSNAU, 2022). The country is administratively divided into eighteen regions, each with a distinct climatic and agricultural profile (FSNAU, 2022). Southern regions, including Bay, Bakool, and Lower Shabelle, receive comparatively high annual rainfall of around 500 millimetres or more and host the bulk of Somalia's rainfed cropping activity, while northeastern and central regions such as Bari, Nugaal, and Mudug are considerably drier and have limited arable land (Nicholson, 2017).

Rainfall in Somalia follows a bimodal pattern dominated by the Gu season from April to June and the Deyr season from October to December, which together account for 50 to 80 percent of annual precipitation and coincide with the country's principal planting and harvest windows for staple crops such as sorghum and maize (Nicholson, 2017). The intervening Xagaa season, from July to September, and the Jilaal season, from January to March, are typically dry, with Jilaal generally the driest period of the year and often associated with water scarcity and crop stress (Funk et al., 2019).

Somalia's agricultural system is dominated by smallholder rainfed cultivation. Sorghum is the principal cereal crop, occupying approximately 70 percent of rainfed cropland, while maize occupies a further 25 percent; cowpea, millet, groundnut, bean, and barley are grown on smaller, more marginal areas (Abdullahi & Arisoy, 2022). Sorghum production in particular has shown unstable trends over the past two decades, reflecting the combined pressures of drought, conflict, and a changing climate (Omar et al., 2025; Warsame et al., 2022), and national statistics point to declining productivity across several staple crops in recent years (Abdi et al., 2024). This dependence on precipitation timing, intensity, and distribution makes Somalia's food production system an appropriate setting in which to examine the practical, production-level consequences of rainfall variability.



Figure 1. Location of Somalia within the Horn of Africa, showing the national boundary and the position of Mogadishu.

2.2 Data Sources

Precipitation data were obtained from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) archive, which provides quasi-global precipitation estimates at a spatial resolution of 0.05 degrees by combining thermal infrared satellite observations with in-situ station records (Funk et al., 2015). CHIRPS pentad (five-day) estimates were retrieved for the period 1983 to 2023 and aggregated into monthly and, subsequently, seasonal and annual totals for each of Somalia's eighteen administrative regions.

Agricultural statistics, comprising total national crop production in metric tonnes for the period 1995 to 2023, were obtained from the Food Security and Nutrition Analysis Unit for Somalia, which compiles seasonal post-Gu and post-Deyr production assessments in collaboration with the Food and Agriculture Organization of the United Nations (FSNAU, 2022). These assessments represent the most consistent long-term record of national crop output available for Somalia and provided the basis for evaluating the relationship between rainfall and production at the national scale.

Because both data sources are drawn entirely from existing public archives, the study involved no human or animal subjects and required no primary field data collection. Basic quality checks were applied to both series before analysis: CHIRPS regional totals were screened for implausible year-to-year jumps that might indicate processing artefacts, and FSNAU production records were checked for internal consistency against the accompanying seasonal narrative reports. No values were excluded from the final analysis, as both series were found to be internally consistent across the study period.

2.3 Data Processing and Statistical Analysis

Regional and national administrative boundaries were delineated using the Google Earth Engine platform, within which CHIRPS pentad data were aggregated to monthly totals to construct a continuous time series for each region across the full study period. Seasonal totals were then computed for each of Somalia's four climatic seasons, Jilaal, Gu, Xagaa, and Deyr, and expressed both as absolute rainfall in millimetres and as a percentage of the corresponding annual total. Interannual variability in rainfall was summarised for each region using the

coefficient of variation, calculated as the ratio of the standard deviation to the mean of annual rainfall across the study period.

The relationship between annual rainfall and national crop production was assessed using Pearson correlation and ordinary least squares linear regression, with annual rainfall as the explanatory variable and total crop production as the response variable. Model fit was evaluated using the correlation coefficient, the coefficient of determination, and the associated F statistic, with statistical significance assessed at the conventional threshold of $p < 0.05$. Ninety-five percent confidence intervals were computed around the fitted regression line to characterise the precision of the estimated relationship across the observed range of rainfall values. All spatial processing was carried out in Google Earth Engine, and statistical analyses were conducted using standard regression procedures appropriate for time series of moderate length.

A single national-level regression was chosen over a fully disaggregated regional model because the crop production series compiled by FSNAU is reported as a national aggregate for the period examined, rather than broken down consistently by region across the study period. This choice means that the fitted relationship should be interpreted as describing the average national response of production to rainfall rather than a region-specific elasticity, a distinction that is returned to in the discussion of the study's limitations. Where regional patterns are described in the results, these relate specifically to the distribution of rainfall itself, which is available at full regional resolution throughout the study period, rather than to region-specific production outcomes.

3. Results

Figure 2 presents mean annual rainfall by region for the period 1983 to 2023. The highest long-term averages were recorded in Bay (525 millimetres), Lower Shabelle (500 millimetres), and Lower Juba (495 millimetres), while the lowest averages occurred in Bari (330 millimetres), Mudug (340 millimetres), and Nugaal (345 millimetres). Most southern regions received close to or in excess of 490 millimetres annually, whereas the northeastern and central regions of Bari, Mudug, Nugaal, and Sool remained below 370 millimetres, confirming a pronounced rainfall gradient from the south towards the northeast; the northwestern regions of Awdal, Woqooyi Galbeed, and Togdheer were intermediate, at approximately 390 to 420 millimetres.

Table 1 summarises the seasonal distribution of rainfall and the coefficient of variation for each of Somalia's eighteen regions. The Gu season was the largest contributor to annual rainfall in sixteen of the eighteen regions, ranging from 36.0 percent in Awdal to 55.9 percent in Nugaal; in Gedo (44.5 against 43.4 percent) and Middle Shabelle (41.7 against 40.2 percent), the Deyr season slightly exceeded the Gu. The Deyr season contributed between 17.4 percent in Sanaag and 44.5 percent in Gedo and was the second largest contributor in most regions, its relative importance being greatest in southern and central regions; in Awdal, Sanaag, and Woqooyi Galbeed, the Xagaa season exceeded the Deyr. The Xagaa season showed marked regional variation, contributing as much as 32.0 percent of annual rainfall in Awdal and 27.5 percent in Sanaag but falling below 5 percent in Mudug (2.8 percent) and Nugaal (3.0 percent). The Jilaal season contributed less than 12 percent of annual rainfall in every region, falling as low as 1.0 percent in Banadir, and was the driest season in most regions, although in Gedo and Mudug the Xagaa season was drier. The coefficient of variation ranged from 12.3 percent in Middle Juba to 27.5 percent in Lower Juba, with Bakool (27.2 percent) and Nugaal (25.3 percent) also among the more variable regions.

Grouping the eighteen regions by their dominant seasonal profile reveals two clear patterns at the extremes. A first group, comprising Gedo, Mudug, Galgaduud, and Nugaal, combines strong Gu and Deyr dominance with a negligible Xagaa contribution below 6

percent, indicating a rainfall regime concentrated almost entirely within the two principal rainy seasons. A second, contrasting group, comprising Awdal, Sanaag, and Woqooyi Galbeed in the northwest, shows a markedly larger Xagaa contribution, each exceeding 26 percent of annual rainfall, indicating a more evenly distributed precipitation regime across three seasons rather than the two-season pattern assumed in conventional agricultural calendars. The coefficient of variation showed no simple association with total rainfall amount: Lower Juba, one of the wetter regions in absolute terms, recorded the highest interannual variability in the dataset (27.5 percent), while Sool, a comparatively drier region, recorded among the lowest (12.9 percent), underscoring that regions cannot be ranked on climate risk by mean rainfall alone.

Figure 4 presents the regression of total crop production on annual rainfall across the 1995 to 2023 record. The relationship was positive and statistically significant ($p < 0.05$), with an estimated increase of 285.7 metric tonnes in national production for each additional millimetre of annual rainfall across the observed range of approximately 200 to 600 millimetres. Considerable scatter was evident around this trend, particularly in the 300 to 400 millimetre range, where production varied by as much as 150,000 metric tonnes at similar rainfall levels, and the 95 percent confidence band widened noticeably at both the low and high ends of the rainfall distribution.

Figure 5 extends this comparison through 2023 and reports a Pearson correlation coefficient of $r = 0.68$ ($p < 0.05$) between annual rainfall and crop production. Notable extreme years included 1997, when a rainfall peak of 575 to 585 millimetres coincided with strong El Niño conditions, and 2016 and 2022, when rainfall fell to approximately 210 millimetres during periods of severe drought. In 2023, rainfall of approximately 495 millimetres coincided with the highest production of the record, and analysis of the 2023 season identified rainfall in October and November that deviated substantially from the long-term seasonal mean.

Table 1. Seasonal Rainfall Contribution, Annual Total, and Coefficient of Variation (CV%)
Across Somali Regions, 1983 to 2023

Region	Deyr (%)	Gu (%)	Jilaal (%)	Xagaa (%)	Annual Total (%)	CV (%)
Awdal	20.8	36.0	11.2	32.0	100.0	18.0
Bakool	37.2	47.7	4.7	10.5	100.1	27.2
Bari	36.5	49.0	2.8	11.7	100.0	23.7
Bay	39.2	46.9	4.4	9.5	100.0	21.6
Gedo	44.5	43.4	7.7	4.4	100.0	14.5
Mudug	38.0	54.9	4.3	2.8	100.0	14.5
Sool	32.5	52.0	2.5	13.0	100.0	12.9
Banadir	32.1	42.1	1.0	24.8	100.0	25.9
Galgaduud	41.1	48.6	4.7	5.6	100.0	21.6
Hiraan	43.1	45.1	3.7	8.1	100.0	23.3
Middle Juba	35.5	50.3	3.4	10.8	100.0	12.3
Lower Juba	35.6	47.0	4.7	12.7	100.0	27.5
Nugaal	39.5	55.9	1.6	3.0	100.0	25.3
Sanaag	17.4	47.3	7.7	27.5	99.9	15.4
Middle Shabelle	41.7	40.2	4.3	13.8	100.0	14.9
Lower Shabelle	33.4	50.9	1.6	14.1	100.0	14.9
Togdheer	26.4	49.9	4.9	18.9	100.1	16.9

Region	Deyr (%)	Gu (%)	Jilaal (%)	Xagaa (%)	Annual Total (%)	CV (%)
Woqooyi Galbeed	21.8	47.1	4.8	26.3	100.0	20.4

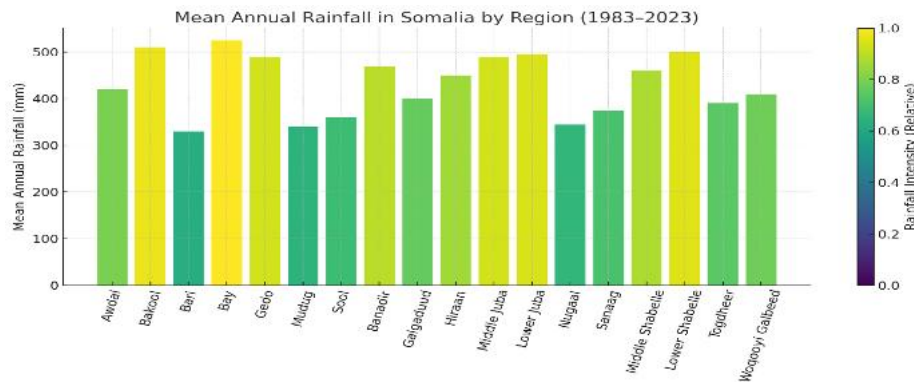


Figure 2. Mean annual rainfall (1983-2023) across Somali regions, illustrating the spatial gradient in precipitation intensity.

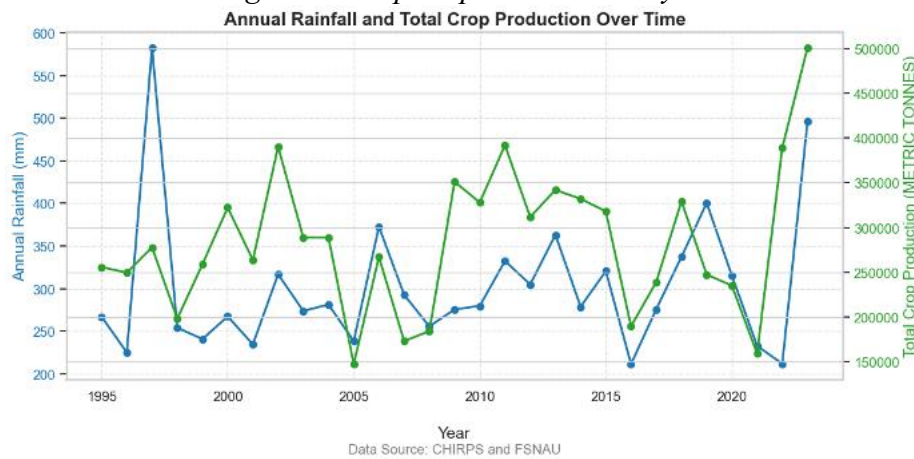


Figure 3. Combined time series of annual rainfall and total crop production in Somalia, 1995 to 2023.

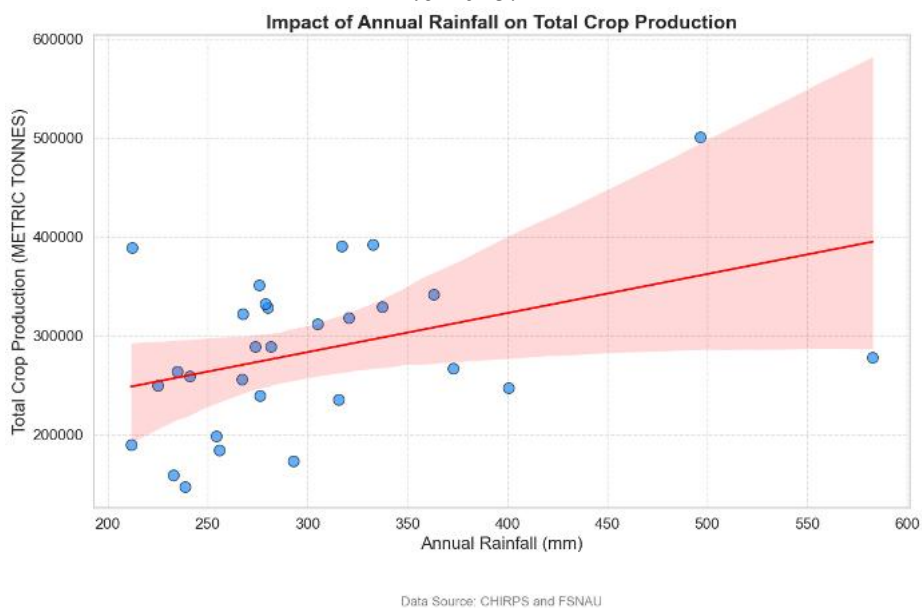


Figure 4. Regression of total crop production on annual rainfall in Somalia, with 95 percent confidence band.

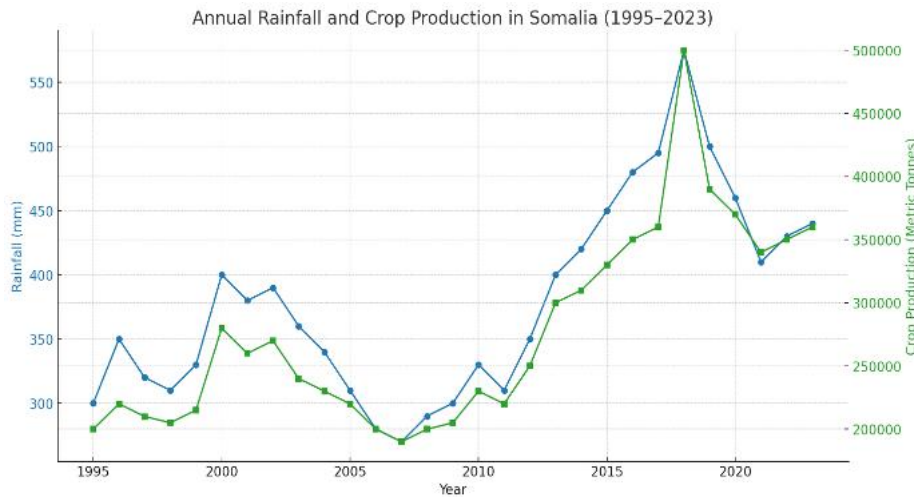


Figure 5. Annual rainfall and total crop production in Somalia, 1995 to 2023.

4. Discussion

The pronounced north to south rainfall gradient identified in this study is consistent with, and extends, the broad climatic pattern described by Nicholson (2017), while providing more granular, region-level detail than has previously been available for Somalia. This gradient corresponds to markedly different agricultural environments: the higher and more reliable rainfall of the southern regions supports the bulk of the country's rainfed cropping but also increases exposure to flooding and soil erosion during intense rainfall events, while the drier northern regions face persistent water scarcity that constrains cropping options and favours pastoral livelihoods. These divergent conditions reinforce the case made by FSNAU (2022) for region-specific, rather than nationally uniform, agricultural planning.

The seasonal results similarly point beyond a simple two-season, wet-dry characterisation of Somalia's climate. The substantial Xagaa contribution observed in Awdal and Sanaag, in particular, indicates that a meaningful share of annual rainfall in parts of northern Somalia falls outside the two principal rainy seasons, a pattern with direct implications for planting calendars that are conventionally built around Gu and Deyr alone. This finding extends the seasonal characterisation offered by Funk et al. (2019) by quantifying, for the first time at this resolution, how unevenly the four Somali seasons contribute to annual totals across the country's eighteen regions, and it suggests that locally tailored agricultural calendars would likely outperform standardised national guidance in these areas.

The positive and statistically significant relationship between annual rainfall and national crop production ($r = 0.68$, $p < 0.05$) confirms that precipitation remains a central determinant of agricultural output in Somalia's overwhelmingly rainfed system, in line with the broader continental pattern described by Muluneh (2021) and Nhemachena et al. (2020). At the same time, the considerable scatter around this relationship, especially in the 300 to 400 millimetre range where production varied by up to 150,000 metric tonnes at comparable rainfall levels, indicates that rainfall alone does not determine agricultural outcomes. Soil conditions, agricultural management practices, and socio-economic factors, including conflict and market access, plausibly account for a substantial share of this residual variation (Abdi et al., 2024; Warsame et al., 2022), consistent with the observation of Rishmawi et al. (2016) that vegetation responses to rainfall in semi-arid Africa are frequently non-linear and shaped by factors beyond precipitation itself.

The 2019 and 2022 seasons illustrate this complexity clearly. In 2019, comparatively high annual rainfall of approximately 400 millimetres coincided with below-average crop production, suggesting that the timing and distribution of rainfall within the growing season,

rather than the annual total alone, may exert a decisive influence on yields. Excessively concentrated or poorly timed rainfall can be as damaging to production as drought, through waterlogging, delayed planting, or increased pest and disease pressure, even where cumulative totals appear favourable. Conversely, in 2022, one of the driest years of the record, recorded production remained comparatively high, a divergence that may reflect the contribution of riverine irrigated and recession farming, which depends on river flows originating outside Somalia rather than on local rainfall. These patterns are broadly consistent with regional projections from Pörtner et al. (2022) of increasing climate variability in the Horn of Africa, and the deviations identified in the 2023 seasonal record suggest that such disruptions to established seasonal timing may already be underway.

These national-scale patterns sit within a broader East African context in which rainfall variability is projected to increase further. Ayugi et al. (2022) project rising exposure of East African populations to precipitation extremes under future warming scenarios, and Nhemachena et al. (2020) similarly document growing pressure on water and agricultural systems across Southern and Eastern Africa. The regional disparities documented here for Somalia, where interannual variability already ranges from 12.3 to 27.5 percent depending on region, suggest that the practical burden of any further increase in variability will not be distributed evenly across the country. Regions that already combine relatively high variability with low absolute rainfall, such as Nugaal (approximately 345 millimetres; CV 25.3 percent) and Bari (approximately 330 millimetres; CV 23.7 percent), are likely to face the most acute additional stress, while the wetter but highly variable Lower Juba and Bakool regions illustrate that abundant average rainfall does not by itself confer resilience against production shocks.

The crop-level implications of these patterns also merit attention. Sorghum, which occupies approximately 70 percent of Somalia's rainfed cropland, has already shown unstable production trends linked to the combined pressures of drought, conflict, and climate variability (Omar et al., 2025; Warsame et al., 2022), and its concentration in regions with a pronounced Gu and Deyr dependence, including Bay and Bakool, where the Gu and Deyr together supply about 85 percent of annual rainfall, makes it particularly exposed to any disruption of these two seasons. Maize, grown on a further 25 percent of rainfed land, and the smaller areas planted with cowpea, millet, groundnut, and bean, are distributed across a wider range of seasonal regimes (Abdullahi & Arisoy, 2022), which may offer some degree of aggregate buffering at the national level even where individual regions experience acute seasonal failure. This distinction suggests that crop diversification strategies calibrated to each region's specific seasonal profile, rather than a single national crop mix, would likely offer greater resilience than current cropping patterns provide.

Translating these findings into practice points toward several concrete priorities. In regions with a concentrated two-season rainfall regime and low Xagaa contribution, such as Mudug and Nugaal, water storage infrastructure capable of carrying Gu and Deyr surplus through the long dry periods would directly address the core constraint identified here. In the northwestern regions where Xagaa contributes a substantial share of annual rainfall, by contrast, agricultural extension guidance that formally incorporates a third planting window, rather than treating Xagaa rainfall as incidental, could capture productive potential that current two-season calendars overlook. Across all regions, the scatter observed around the rainfall-production relationship, and the counterintuitive 2019 case in which comparatively high rainfall coincided with below-average production, point to a continued need for within-season weather advisories, delivered close enough to planting decisions to help farmers respond to how a season is actually unfolding rather than relying solely on long-term seasonal averages.

Several limitations should be considered when interpreting these findings. First, the crop production record compiled by FSNAU reflects national totals and does not permit disaggregation of the rainfall-production relationship by individual crop or by region, which

would allow a more precise attribution of production variability to local rainfall conditions. Second, while CHIRPS provides a consistent, high-resolution precipitation record, its accuracy in data-sparse settings such as Somalia depends on the density of the in-situ station network used for calibration, and localised discrepancies cannot be ruled out. Third, the regression analysis presented here captures a linear association between annual rainfall and production and does not explicitly model non-climatic drivers such as conflict, market prices, or input availability, all of which are known to influence Somali agricultural output independently of rainfall. Future research that integrates crop-specific yield data, sub-seasonal rainfall timing, and socio-economic covariates would help to isolate the distinct contribution of rainfall variability from these other factors.

5. Conclusion

This study characterized the spatiotemporal structure of rainfall across Somalia's eighteen regions between 1983 and 2023 and quantified its relationship with national crop production. The results confirm a stark north to south precipitation gradient, with mean annual rainfall in the wettest southern regions roughly 1.6 times that of the driest northeastern and central regions, alongside substantial regional variation in the seasonal contribution of the Gu, Deyr, Xagaa, and Jilaal seasons. Annual rainfall was positively and significantly associated with crop production, with an estimated increase of 285.7 metric tonnes per additional millimetre of rainfall, though the considerable unexplained variation in this relationship underscores the role of non-climatic factors in shaping agricultural outcomes. Given the scale of Somalia's dependence on rainfed agriculture, these findings support a shift toward region-specific adaptation strategies rather than uniform national policy. Priorities consistent with the evidence presented here include the expansion of water harvesting and small-scale irrigation in the drier north, flood mitigation measures in the higher-rainfall south, strengthened seasonal weather advisory services for farmers, and continued investment in drought-tolerant sorghum and maize varieties suited to Somalia's distinct agroecological zones. Future work that links these rainfall patterns to crop-specific and sub-national production data would further sharpen the targeting of such interventions.

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None

Conflict of Interest Statement

The author declares no conflict of interest.

Data Availability Statement

The precipitation data that support the findings of this study are openly available from the Climate Hazards Group InfraRed Precipitation with Station data archive at <https://www.chc.ucsb.edu/data/chirps>. Agricultural production data are openly available from the Food Security and Nutrition Analysis Unit for Somalia at <https://fsnau.org>.

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