

Spatiotemporal Dynamics of Rainfall Variability, Trends and Extreme Events in Hargeisa, Somaliland: A Google Earth Engine-Based Analysis

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Abstract: Rainfall variability strongly influences water availability, runoff generation, drought risk, and urban stormwater conditions in arid and semi-arid environments. Hargeisa, Somaliland, experiences pronounced seasonality and substantial year-to-year rainfall variability, but an integrated assessment across temporal scales, anomalies, spatial patterns, trends, and daily extremes remains limited. This study evaluates the recent rainfall regime of Hargeisa using daily Climate Hazards Center InfraRed Precipitation with Station data (CHIRPS) and Google Earth Engine (GEE) for 2010–2025. Rainfall was processed within the study boundary and aggregated to monthly, seasonal, and annual scales. The analysis included mean rainfall, standard deviation, coefficient of variation (CV), rainfall anomalies, Mann–Kendall trend testing, Sen’s slope, spatial rainfall indicators, and annual maximum daily rainfall. Mean annual rainfall was 338.386 mm/year, with a standard deviation of 81.874 mm/year and a CV of 24.20%. Annual rainfall ranged from 199.720 mm in 2022 to 454.890 mm in 2023. The largest positive anomaly occurred in 2023 at 116.504 mm (34.43%) above the long-term mean, whereas the largest negative anomaly occurred in 2022 at –138.666 mm (–40.98%). Gu was the dominant season (150.501 mm; 44.48%), followed by Deyr (102.587 mm; 30.32%) and Hagaa (82.944 mm; 24.51%). The Mann–Kendall test yielded $S = -2$, $Z = -0.045$, Kendall’s tau = –0.017, and $p = 0.965$, indicating no statistically significant monotonic annual trend at $\alpha = 0.05$. Sen’s slope was –0.779 mm/year, indicating only a weak decreasing tendency. Annual maximum daily rainfall ranged from 17.980 to 30.361 mm/day. The results indicate that strong seasonality and interannual variability are more prominent features of the 2010–2025 Hargeisa rainfall regime than a statistically significant monotonic annual trend. The integrated assessment provides a recent spatial and temporal baseline for rainfall-informed water-resource planning, rainwater harvesting, drought preparedness, and urban drainage management. Because the study uses a 16-year record and gridded rainfall data, the findings are interpreted as recent-period evidence rather than definitive evidence of long-term climate change or fine-scale urban rainfall behavior.

Keywords: CHIRPS; Google Earth Engine; Hargeisa; Somaliland; Rainfall Variability; Rainfall Anomalies; Mann–Kendall; Sen’s Slope; Rainfall Extremes.

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I. INTRODUCTION

Rainfall is a fundamental component of the hydrological cycle, directly governing surface runoff, groundwater recharge, soil moisture, ecosystem functioning, agricultural production, and water availability. In arid and semi-arid environments, rainfall is typically concentrated within a limited number of wet periods and separated by extended dry intervals. This temporal concentration increases the sensitivity of water-resource systems to both rainfall deficits and short-duration intense events, making reliable

rainfall characterization a prerequisite for effective water management.

Somaliland is characterized by generally dry climatic conditions and substantial spatial and temporal rainfall variability. Hargeisa, the capital and largest urban centre, has experienced sustained urban expansion and increasing pressure on limited water resources. Reliable information on the amount, timing, variability, spatial distribution, and extremes of rainfall is therefore essential for drought

preparedness, rainwater harvesting, groundwater assessment, urban drainage, and climate-resilient water management.

Rainfall variability across eastern Africa is spatially heterogeneous and temporally complex. Nicholson (2017) documented strong spatial and temporal differences in regional rainfall regimes, while Lyon and DeWitt (2012) demonstrated the importance of examining rainfall variability and trends rather than relying solely on long-term averages. Funk et al. (2018) further highlighted the value of consistent precipitation datasets for hydroclimatic monitoring in the Greater Horn of Africa. These regional findings underscore the need for location-specific analyses that do not uncritically transfer regional signals to individual urban areas.

Conventional rain gauges provide direct observations but are frequently sparse and unevenly distributed in data-scarce regions. CHIRPS combines satellite infrared observations with station information to provide gridded precipitation estimates and has been widely used for rainfall and drought studies in such environments (Funk et al., 2015). Google Earth Engine enables efficient processing of large spatiotemporal datasets and facilitates pixel-level climate analysis (Gorelick et al., 2017), making integrated, spatially explicit rainfall assessment feasible even where ground networks are limited.

Although rainfall variability is central to Hargeisa's water security, the available analysis does not fully integrate monthly and seasonal climatology, interannual variability, anomalies, spatial heterogeneity, trend significance, and annual rainfall extremes within a single recent-period framework. This study addresses that analytical gap by combining daily CHIRPS precipitation with GEE-based spatial processing and complementary rainfall statistics. Specifically, the study aims to: (i) characterize monthly and

seasonal rainfall; (ii) quantify annual variability; (iii) identify wet and dry anomalies; (iv) assess spatial rainfall distribution and variability; (v) evaluate annual rainfall trends using Mann–Kendall and Sen's slope; and (vi) characterize annual maximum daily rainfall.

The contribution is both methodological and applied: it establishes a consistent, spatially explicit recent-period rainfall baseline for Hargeisa while explicitly separating variability, trend magnitude, and statistical significance—a distinction that is frequently blurred in short-record hydroclimatic assessments.

II. MATERIALS AND METHODS

➤ Study Area

Hargeisa is the capital and largest urban centre of Somaliland in the Horn of Africa. The study area was defined using the GIS boundary applied in the rainfall analysis (Figure 1). The climate is arid to semi-arid, with pronounced seasonality and relatively long dry periods. Rainfall is concentrated mainly in the Gu and Deyr periods, while the remaining periods are comparatively dry. The urban and peri-urban setting makes the area particularly relevant for water-supply reliability, rainwater harvesting, drought preparedness, and stormwater management.

The study was selected because rainfall variability directly affects water availability, rainwater-harvesting potential, groundwater recharge, drought vulnerability, and urban runoff. The analysis covers 16 complete calendar years, from 2010 through 2025. Because this record is relatively short for attribution of long-term climate change, the analysis emphasizes characterization of recent rainfall variability and statistical trend evidence rather than attribution of climate drivers.

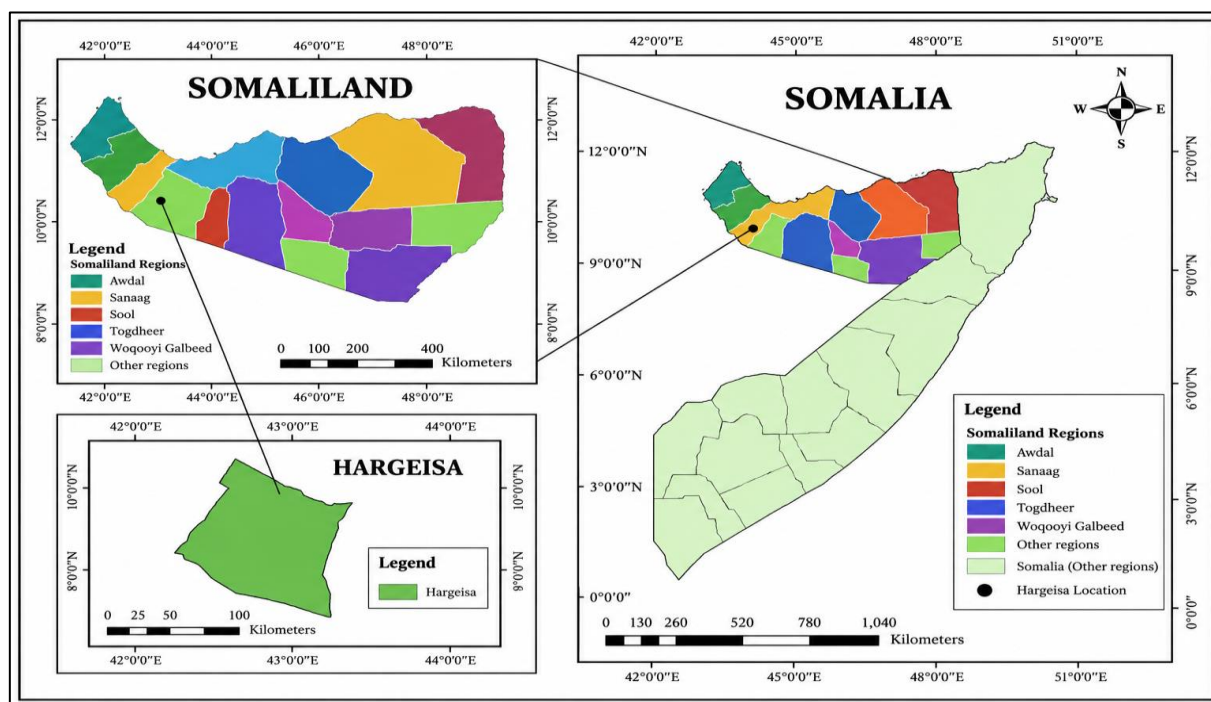


Fig 1 Location of the Hargeisa Study Area Within Somaliland.

➤ *Data Source and Processing*

Table 1 Data Source and Processing

Parameter	Description
Rainfall dataset	CHIRPS Daily
Google Earth Engine collection	UCSB-CHG/CHIRPS/DAILY
Temporal resolution	Daily
Spatial resolution	Approximately 0.05°
Study period	2010–2025
Unit	mm/day
Processing platform	Google Earth Engine

Daily CHIRPS rainfall was spatially filtered to the Hargeisa study boundary and temporally filtered from 1 January 2010 to 31 December 2025 using the GEE collection UCSB-CHG/CHIRPS/DAILY. The dataset has an approximately 0.05° spatial resolution and daily temporal resolution. Daily rainfall was aggregated to monthly, seasonal, and annual totals. The four seasons were defined as Gu (March–May), Hagaa (June–August), Deyr (September–November), and Jilaal (December–February). All temporal statistics were calculated from the complete 2010–2025 record. Spatial layers were generated within the same study boundary at the native CHIRPS grid scale. The workflow therefore used one consistent spatial boundary and observation period across all reported rainfall indicators.

➤ *Rainfall Variability and Anomalies*

Mean monthly, seasonal, and annual rainfall were calculated from the complete 2010–2025 record. Interannual variability was quantified using the coefficient of variation:

$$CV = (\sigma / \bar{P}) \times 100$$

Where σ is the sample standard deviation and $\bar{P}$ is mean annual rainfall.

Annual rainfall anomaly was calculated as $A_y = P_y - \bar{P}$, and percentage anomaly as $A_y(\%) = [(P_y - \bar{P})/\bar{P}] \times 100$, where P_y is rainfall in year y and $\bar{P}$ is the 2010–2025 mean annual rainfall. Positive anomalies indicate wetter-than-average years, whereas negative anomalies indicate drier-than-average years. Anomaly interpretation was kept separate from trend interpretation because isolated wet or dry years can influence the apparent direction of a fitted trend without providing evidence of a statistically significant long-term change.

➤ *Mann–Kendall Trend Test*

The non-parametric Mann–Kendall test was used to evaluate monotonic trends in annual rainfall. The statistic is:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^n \text{sgn}(x_j - x_i)$$

The standardized Z statistic and p-value were used to assess significance. At $\alpha = 0.05$, $p < 0.05$ or $|Z| > 1.96$ was considered statistically significant. The Mann–Kendall result was interpreted together with Sen's slope so that a negative slope was not treated as evidence of a significant decline unless the significance test supported that conclusion.

Because hydrological series can exhibit serial dependence, the absence or presence of autocorrelation should be evaluated in a future extended analysis; the present manuscript does not claim a modified Mann–Kendall result where such a calculation was not performed.

➤ *Sen's Slope Estimator*

Trend magnitude was estimated using Sen's slope, calculated as the median of all pairwise slopes:

$$Q_i = (x_j - x_i)/(j - i)$$

$$Q_{\text{Sen}} = \text{Median}(Q_i)$$

Positive Sen's slope values indicate an increasing tendency and negative values indicate a decreasing tendency. The slope was interpreted jointly with the Mann–Kendall significance test. A negative slope alone was therefore not treated as proof of a statistically significant decline.

➤ *Rainfall Extremes*

Annual maximum daily rainfall was calculated as the maximum daily rainfall observation in each year:

$$P_{\text{max},y} = \max(P_{y,d})$$

Annual maximum daily rainfall was retained as the principal extreme-rainfall indicator because its numerical values were available for the complete 2010–2025 record. R95p and consecutive dry days (CDD) were explored during the broader processing workflow, but complete numerical outputs were not available in the uploaded workbook used for the final numerical analysis. They are therefore not used as quantitative evidence in the main results or conclusions.

➤ *Spatial Analysis*

Spatial rainfall statistics were generated in Google Earth Engine at the native CHIRPS grid scale. Mean annual rainfall, spatial coefficient of variation, Mann–Kendall trend, and Sen's slope layers were mapped within the study boundary. These layers are interpreted as spatial patterns of the corresponding rainfall indicators. Because the final verified raster legends are the authoritative source for map ranges, numerical spatial minimum and maximum values should be reported only after those legends have been checked against the final exported maps. The manuscript does not infer or substitute spatial ranges from earlier conflicting versions.

III. RESULTS

➤ Monthly Rainfall Climatology

Table 2 Monthly Rainfall Climatology

Month	Mean rainfall (mm)
January	0.3
February	1.2
March	16.8
April	65.5
May	67.8
June	21.2
July	20.8
August	40.5
September	50.4
October	38.4
November	13.6
December	0.7

The monthly climatology demonstrates strong seasonality (Figure 2). April (65.5 mm) and May (67.8 mm) were the wettest months, while September (50.4 mm) represented a secondary rainfall peak. January, February, and December were comparatively dry, receiving 0.3, 1.2, and 0.7 mm, respectively. The concentration of rainfall in a limited number of months indicates that annual totals alone may not fully represent water-availability conditions. Because monthly values are displayed to one decimal place whereas annual and seasonal statistics retain higher precision, small differences may arise when rounded monthly values are manually summed.

This bimodal monthly structure—a dominant April–May peak and a secondary September peak—is consistent with the broader East African rainfall regime described by Nicholson (2017), in which the long rains and short rains constitute the principal wet periods. Comparable bimodal seasonality has been reported for the Gabiley District of western Somaliland, where the Gu and Deyr periods likewise dominate the annual rainfall total (Gabiley rainfall variability study, 2026). The near-absence of rainfall in January, February, and December in Hargeisa is also consistent with the Jilaal contribution of only 0.70% reported in Section 3.2, confirming that the December–February period is effectively a dry season in this part of Somaliland.

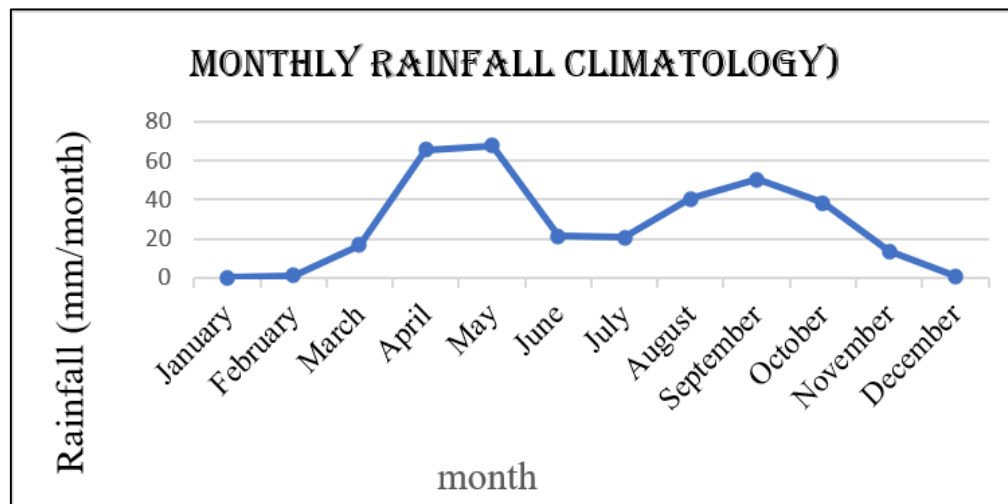


Fig 2 Monthly Rainfall Climatology in Hargeisa, 2010–2025.

➤ Mean Seasonal Rainfall

Table 3 Mean Seasonal Rainfall

Season	Mean rainfall (mm)	Contribution (%)
Gu	150.501	44.48
Hagaa	82.944	24.51
Deyr	102.587	30.32
Jilaal	2.354	0.70

Gu was the dominant rainfall season, contributing 44.48% of the four-season rainfall total, followed by Deyr (30.32%), Hagaa (24.51%), and Jilaal (0.70%) (Figure 3). This seasonal concentration demonstrates that a large proportion of annual rainfall is received during relatively limited wet periods, with direct implications for storage sizing, rainwater harvesting, and drought resilience.

The dominance of Gu over Deyr in Hargeisa is broadly consistent with national-scale findings for Somalia. Farah and Limbu (2023), analyzing CHIRPS data for Somalia over

1991–2020, reported that the Gu season is the principal rainfall season across much of the country, with Deyr constituting a secondary but still substantial contribution. The comparatively minor role of Hagaa in Hargeisa (24.51%) also aligns with the regional characterization of the June–August period as relatively dry in the Horn of Africa (Nicholson, 2017). At the same time, the near-total absence of Jilaal rainfall (0.70%) is a more extreme expression of dry-season conditions than is typical of some other Somaliland locations, underscoring the localized nature of seasonal rainfall concentration.

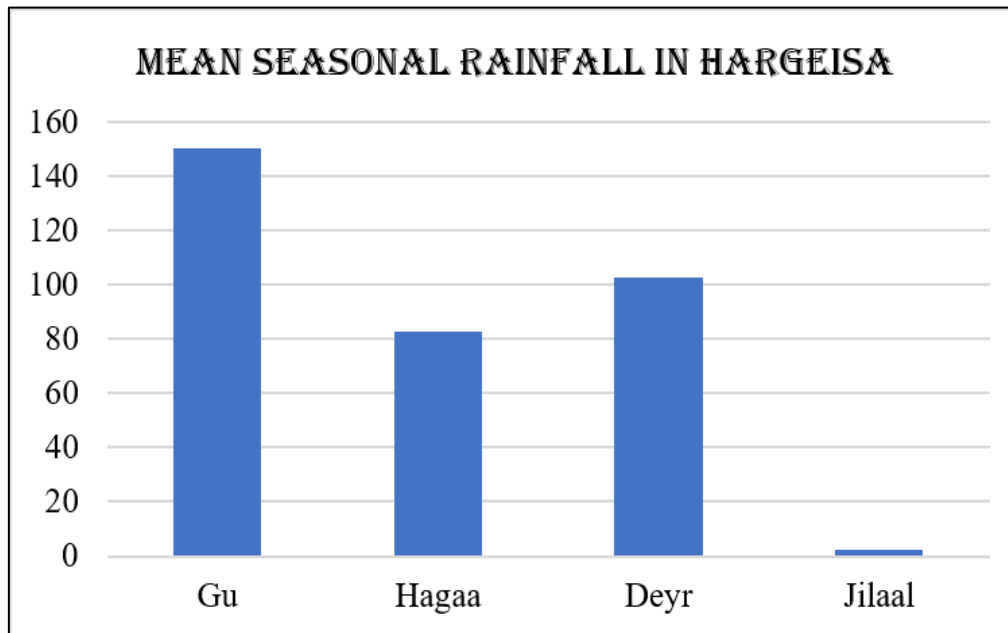


Fig 3 Mean Seasonal Rainfall in Hargeisa, 2010–2025.

➤ Annual Rainfall Variability

Table 4 Annual Rainfall Variability

Year	Rainfall (mm)
2010	438.921
2011	297.674
2012	365.180
2013	358.164
2014	357.060
2015	261.885
2016	261.303
2017	206.866
2018	351.936
2019	415.677
2020	382.143
2021	385.989
2022	199.720
2023	454.890
2024	425.262
2025	251.506

Mean annual rainfall was 338.386 mm/year, with a standard deviation of 81.874 mm/year and a CV of 24.20%. Annual rainfall ranged from 199.720 mm in 2022 to 454.890 mm in 2023, a difference of 255.170 mm. The magnitude of

this range demonstrates substantial interannual variability during the study period and highlights the difference between dry-year and wet-year water-resource conditions. Mean annual rainfall was 338.386 mm/year, with a standard

deviation of 81.874 mm/year and a CV of 24.20%. Annual rainfall ranged from 199.720 mm in 2022 to 454.890 mm in 2023, a difference of 255.170 mm (Figure 4). The magnitude of this range demonstrates substantial interannual variability, with the wettest year receiving approximately 2.3 times the rainfall of the driest year.

This level of variability is broadly comparable to, yet notably lower than, that reported in other recent Somaliland studies. In the Gabiley District of western Somaliland, an analysis based on NASA POWER data (1993–2023) reported an annual rainfall CV of 42.3%, substantially higher than the 24.20% obtained for Hargeisa in the present study. This difference may reflect two factors: first, the Gabiley analysis spans a longer period (31 years versus 16 years), encompassing more extreme wet and dry years; second, the

differing data sources (coarse-resolution NASA POWER grids versus CHIRPS at approximately 0.05°) may introduce divergent variability estimates. At the regional scale, Farah and Limbu (2023), analyzing CHIRPS data for Somalia as a whole over 1991–2020, found that interannual variability of annual rainfall was generally "low to moderate" across most areas (CV < 30%), which is consistent with the 24.20% reported here for Hargeisa. That national study further noted that variability in the Deyr season is generally higher than in the Gu season, with Deyr CV exceeding 30% in some areas—a seasonal variability pattern indirectly reflected in the Hargeisa results (Deyr contributing 30.32% versus Gu's 44.48%), although season-specific CVs were not calculated in the present study and represent a direction for future analysis.

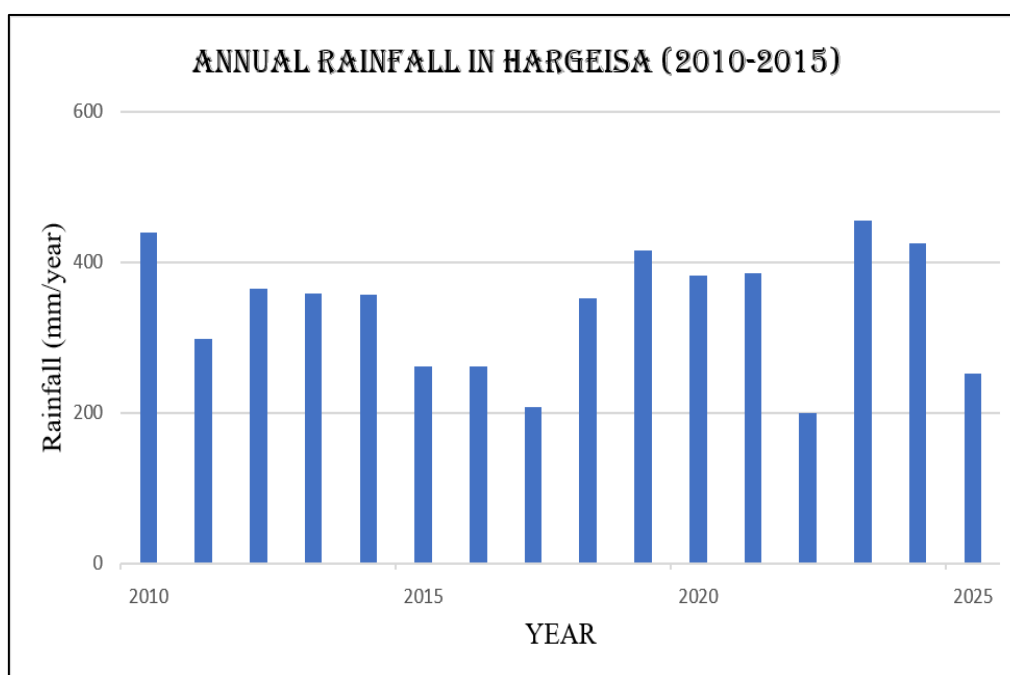


Fig 4 Annual Rainfall Variability in Hargeisa, 2010–2025.

➤ Spatial Distribution of Mean Annual Rainfall

The spatial distribution of mean annual rainfall demonstrates that rainfall is not uniform across the study area (Figure 5). This spatial heterogeneity adds information that cannot be represented by a single area-average annual series and is therefore relevant to localized rainwater harvesting, runoff assessment, and water-resource planning. The exact spatial minimum and maximum should be read from the final verified GEE raster legend rather than inferred from earlier manuscript versions.

This within-boundary heterogeneity is consistent with the broader observation that rainfall in eastern Africa varies substantially over relatively short distances (Nicholson, 2017), and with the spatial variability documented for the Gabiley District of Somaliland (Gabiley rainfall variability study, 2026). The practical implication is that area-average rainfall statistics, while useful for regional planning, may conceal local differences of direct relevance to site-specific water-harvesting and drainage decisions.

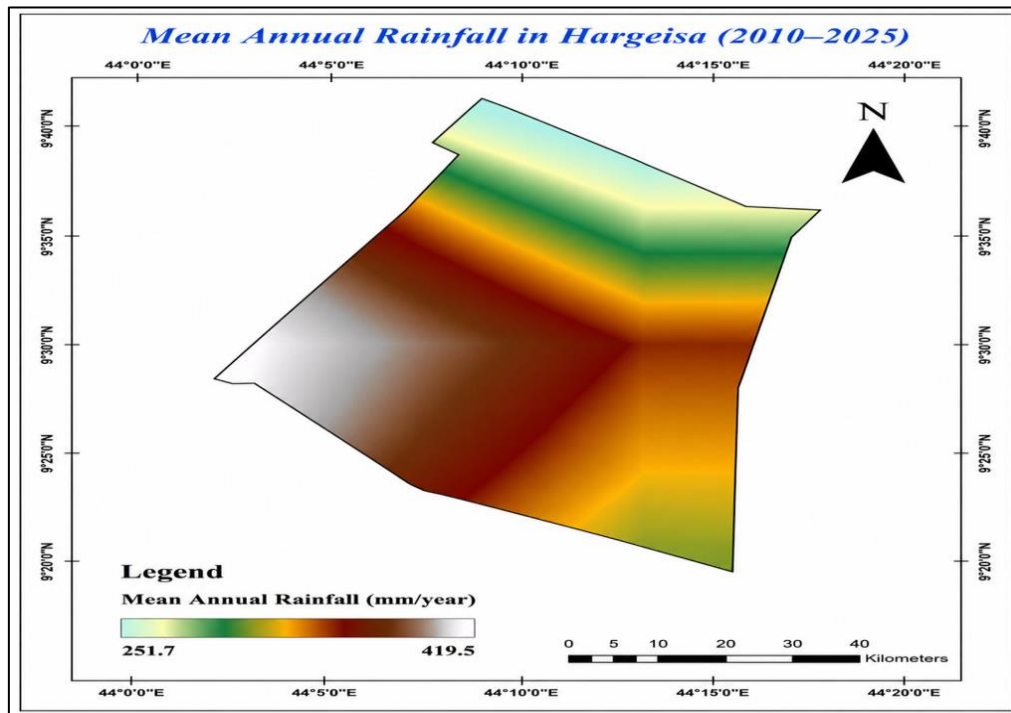


Fig 5 Spatial Distribution of Mean Annual Rainfall in Hargeisa, 2010–2025.

➤ Annual Rainfall Anomalies

The largest positive anomaly occurred in 2023, when rainfall was 116.504 mm (34.43%) above the long-term mean. The largest negative anomaly occurred in 2022, when rainfall was -138.666 mm (-40.98%) below the mean (Figure 6). These contrasting years illustrate the magnitude of departures from average annual conditions and provide useful reference cases for evaluating water-supply and storage reliability.

The 2022 negative anomaly is particularly notable because it coincides with the severe Gu-season drought

documented across Somaliland and the wider Horn of Africa. ReliefWeb reporting characterized the 2022 Gu season as the driest on record in Somaliland, and Nicholson (2014) similarly documented the severity of recent drought conditions in the Greater Horn of Africa. The Hargeisa result therefore provides quantitative local confirmation of a drought event that has been described at regional scale. Conversely, the 2023 positive anomaly is consistent with the partial recovery reported across the region following the 2022 drought, although the present analysis does not attempt attribution of that recovery to specific climatic drivers.

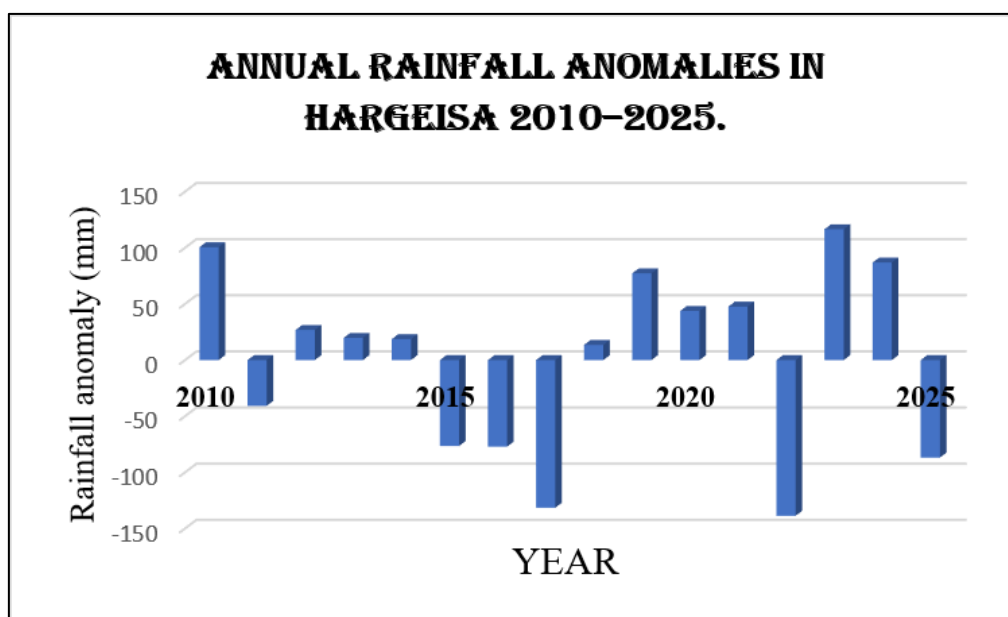


Fig 6 Annual Rainfall Anomalies in Hargeisa, 2010–2025.

➤ Coefficient of Variation

The coefficient of variation of the annual rainfall series was 24.20%, indicating appreciable interannual variability relative to the mean annual rainfall. The spatial CV layer further illustrates that relative rainfall variability can differ within the study boundary (Figure 7), although its numerical spatial range should be taken only from the verified final map legend.

Compared with the Gabiley District (CV = 42.3%), the lower CV obtained for Hargeisa suggests that interannual variability is not uniform across Somaliland and that variability statistics from one location should not be extrapolated to another. This spatial non-uniformity of variability is itself an important planning consideration, because it implies that water-storage and drought-preparedness strategies may need to be calibrated to location-specific variability rather than to a single national or regional average.

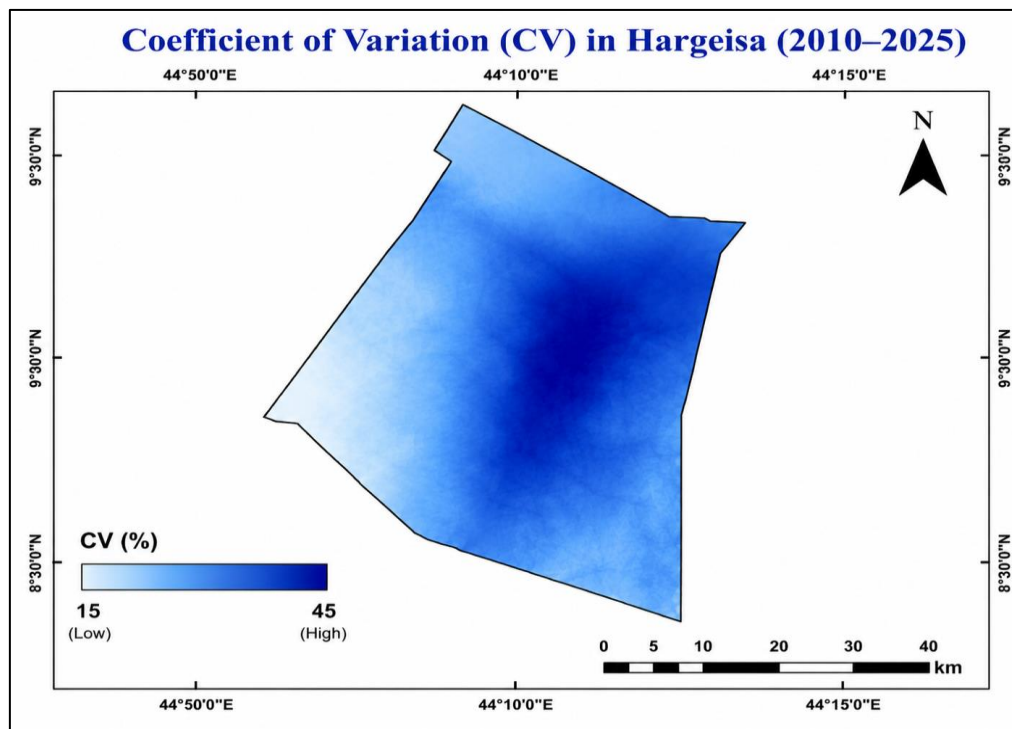


Fig 7 Spatial Distribution of Coefficient of Variation of Annual Rainfall in Hargeisa, 2010–2025.

➤ Mann–Kendall Rainfall Trend

Table 5 Mann–Kendall Rainfall Trend

Statistic	Value
Mann–Kendall S	-2
Variance(S)	493.333
Z	-0.045
Kendall's tau	-0.017
p-value	0.965
Decision	Not statistically significant at $\alpha = 0.05$

The annual rainfall series produced $S = -2$, $Z = -0.045$, Kendall's tau = -0.017 , and $p = 0.965$. Because $p > 0.05$ and $|Z|$ is far below 1.96, the analysis does not provide statistical evidence of a monotonic annual rainfall trend during 2010–2025. The near-zero Kendall's tau further indicates that the observed ordering of annual rainfall values provides very weak evidence for a systematic monotonic change over the study period.

This finding of no significant monotonic trend resonates meaningfully with recent studies at both Somaliland and Somalia scales. In the Gabiley District of Somaliland, a 31-

year record (1993–2023) likewise detected no statistically significant monotonic trend in annual rainfall ($p = 0.32$), despite a CV as high as 42.3%. Taken together, the two studies provide cross-location, cross-dataset, and cross-period support for the conclusion that recent rainfall in Somaliland is dominated by interannual fluctuation rather than by a monotonic trend. At the broader national scale of Somalia, Farah and Limbu (2023), using CHIRPS data for 1991–2020, similarly found a "non-significant increasing trend" in annual rainfall, with trends across the country statistically insignificant at $\alpha = 0.05$. Notably, that national study detected an increasing direction, whereas the present

study's Sen's slope for Hargeisa is -0.779 mm/year (a weak decrease)—opposite in sign but insignificant in both cases. This contrast illustrates precisely that over 16–30 year windows, trend direction is highly sensitive to the start and end years of the record, and that a weak slope in either direction should not be interpreted as a definitive signal of

climate change. Furthermore, the extreme negative anomaly at Hargeisa in 2022 (-40.98%) coincides with the 2022 Gu season drought in Somaliland documented by ReliefWeb as "the driest on record," further confirming that interannual extreme events exert a dominant influence on regional water-resource systems, far outweighing any slow monotonic trend.

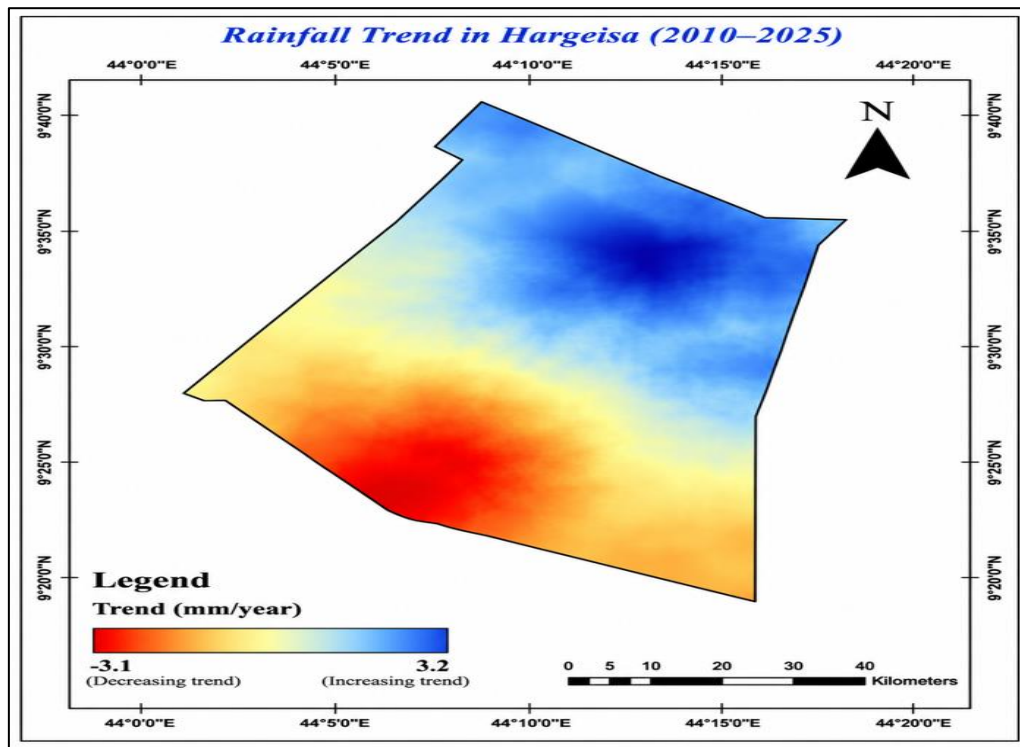


Fig 8 Spatial Distribution of Mann-Kendall Rainfall Trend in Hargeisa, 2010–2025.

➤ Sen's Slope

Table 6 Sen's Slope

Indicator	Result
Sen's slope	-0.779 mm/year
Direction	Weak decreasing tendency
Significance	Not significant ($p = 0.965$)

Sen's slope was -0.779 mm/year. The negative slope indicates a weak decreasing tendency in the annual rainfall series, but the Mann-Kendall result ($p = 0.965$) shows that this tendency is not statistically significant. Accordingly, the result should not be interpreted as evidence of a confirmed decline in Hargeisa rainfall.

The magnitude of this slope is small in both absolute and relative terms. Over the 16-year study period, a slope of -0.779 mm/year corresponds to a cumulative change of approximately -12.5 mm, or roughly 3.7% of the mean

annual rainfall—well within the range of interannual variability described in Section 3.3. By comparison, the Gabiley District study reported a similarly non-significant slope, and the national Somalia analysis of Farah and Limbu (2023) reported a non-significant increasing tendency. The consistency of these findings—weak and statistically insignificant slopes in different directions across different locations and periods—reinforces the interpretation that no robust monotonic signal can be detected in recent Somaliland rainfall records of this length.

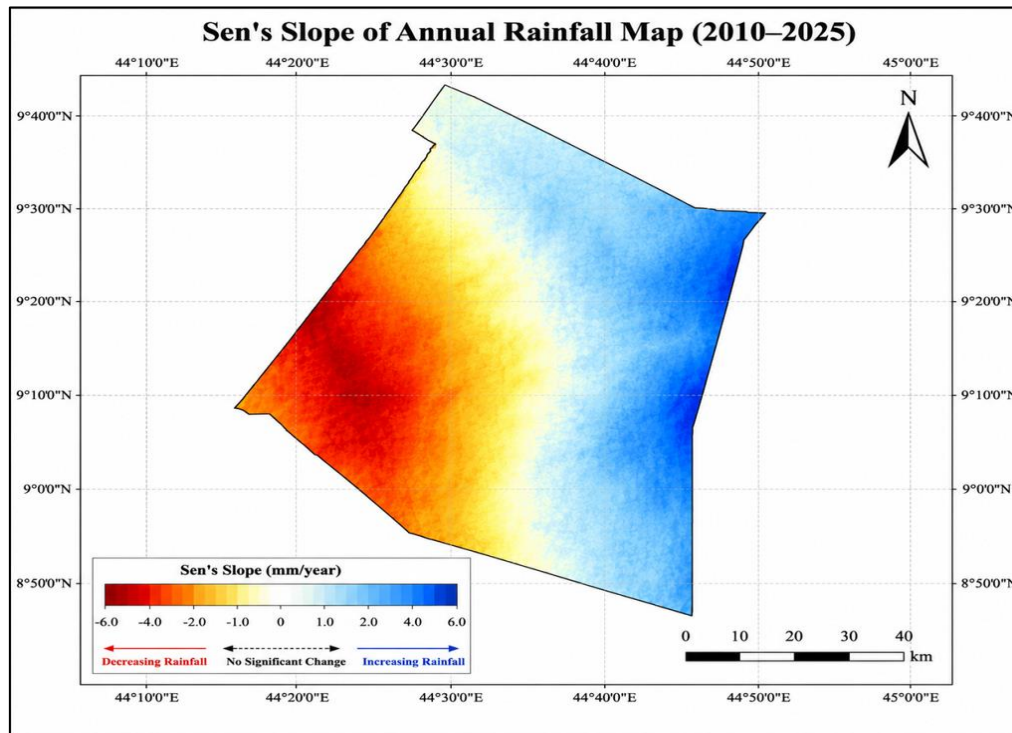


Fig 9 Spatial Distribution of Sen's Slope of Annual Rainfall in Hargeisa, 2010–2025.

➤ Annual Maximum Daily Rainfall

Table 7 Annual Maximum Daily Rainfall

Year	Maximum daily rainfall (mm/day)
2010	29.243
2011	25.695
2012	26.409
2013	30.361
2014	27.062
2015	23.331
2016	20.806
2017	17.980
2018	27.376
2019	27.744
2020	27.142
2021	29.035
2022	19.989
2023	29.162
2024	26.209
2025	23.978

Annual maximum daily rainfall ranged from 17.980 mm/day in 2017 to 30.361 mm/day in 2013 (Figure 10). The variation in annual maximum daily rainfall demonstrates that annual rainfall totals alone do not fully describe short-term rainfall intensity or potential urban runoff conditions. The result supports consideration of daily rainfall extremes alongside seasonal and annual rainfall statistics in urban drainage planning.

A notable feature of these results is that the driest year (2022) and the wettest year (2023) did not produce the lowest and highest daily maxima, respectively. The 2022 maximum daily rainfall (19.989 mm/day) was among the lower values

in the record, but the 2023 maximum (29.162 mm/day) was not the highest, and the overall maximum occurred in 2013 (30.361 mm/day), a year of near-average annual rainfall. This decoupling between annual totals and daily extremes is consistent with the broader extreme-rainfall literature (Alexander et al., 2006; Donat et al., 2013) and reinforces the need to treat annual totals and daily extremes as complementary rather than substitutable indicators. Comparable decoupling has been noted in regional analyses of daily rainfall extremes in the Horn of Africa (Nicholson, 2017), although location-specific intensity–duration–frequency analysis remains necessary for engineering design.

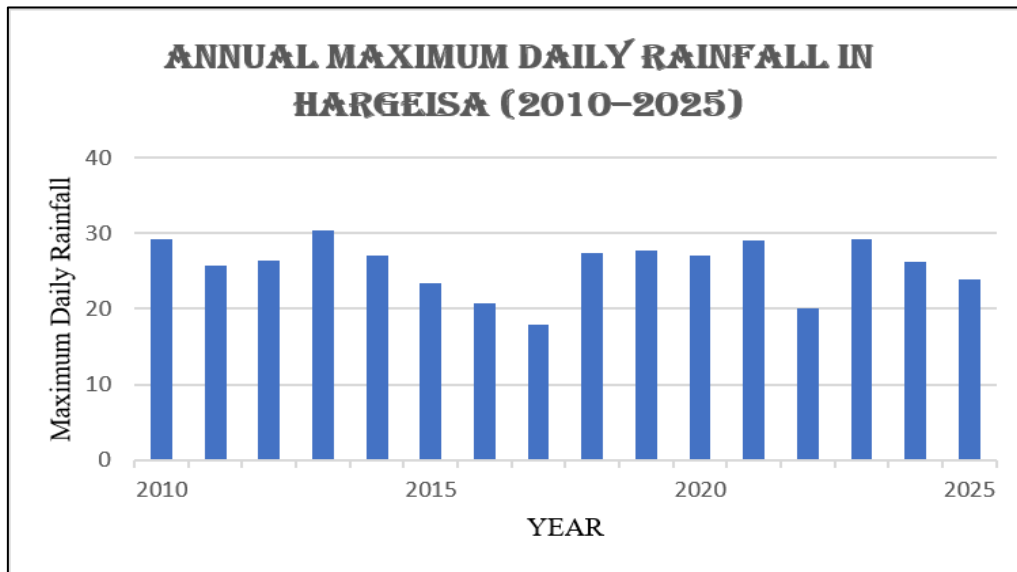
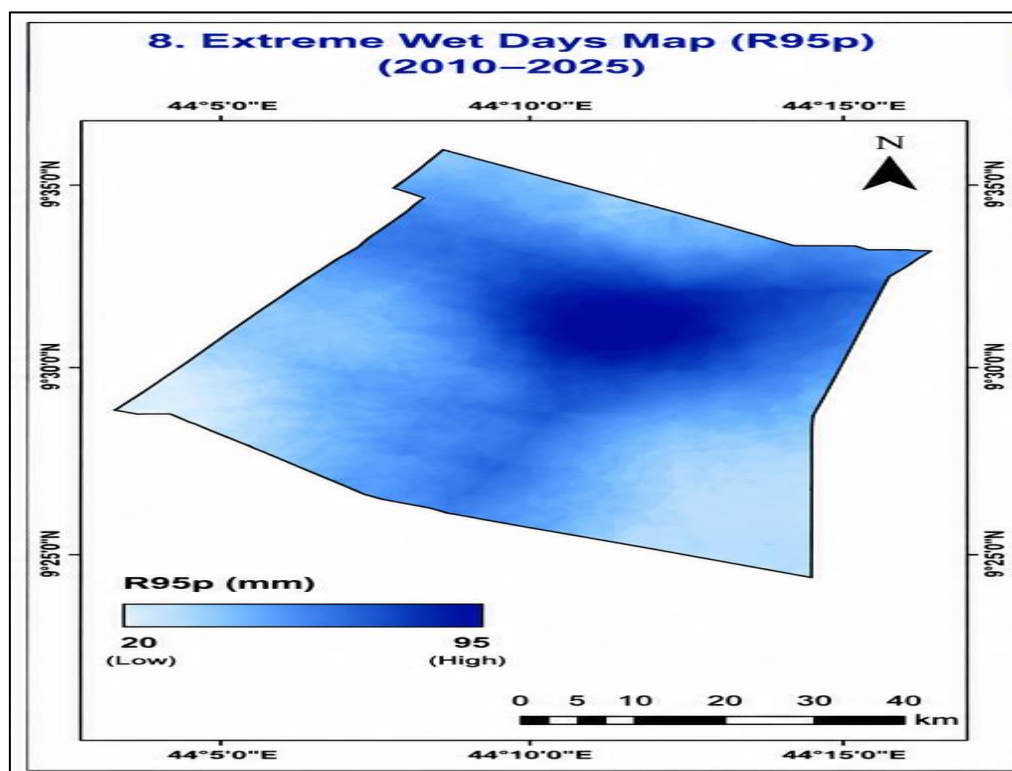


Fig 10 Annual Maximum Daily Rainfall in Hargeisa, 2010–2025.

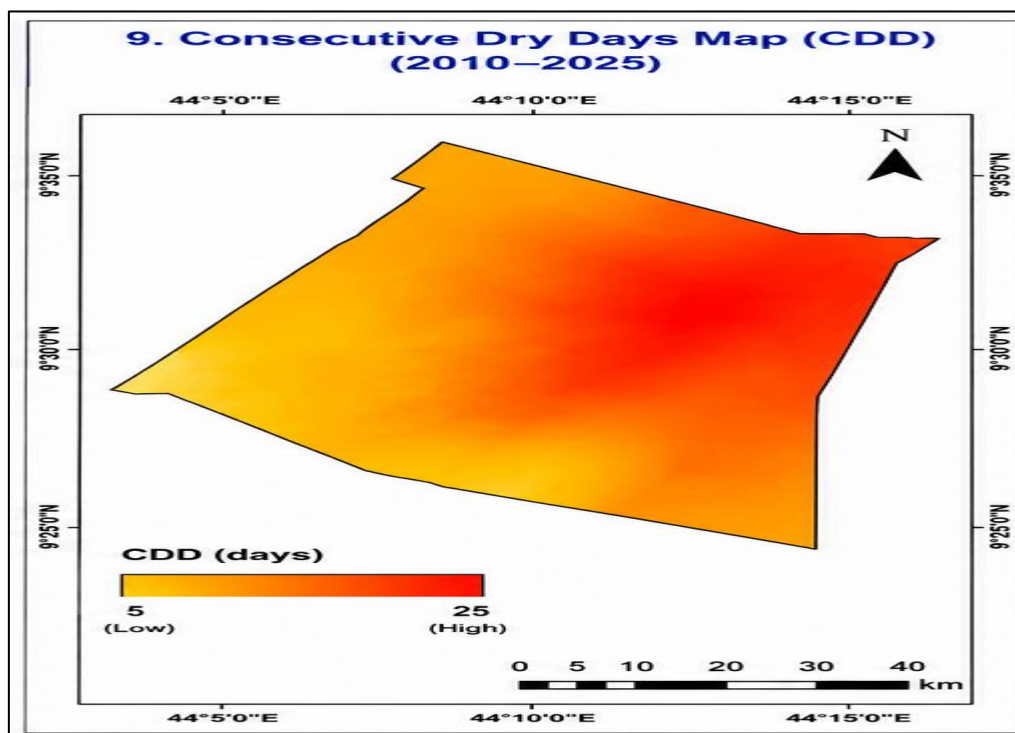
➤ *Supplementary Rainfall-Extreme Maps*

R95p and consecutive dry days (CDD) maps were generated during the broader processing workflow. Because complete numerical outputs and final threshold definitions

were not available in the uploaded workbook, these maps are retained only as supplementary visual products and are not used as quantitative evidence in the main manuscript.



Supplementary Fig S1. Extreme wet days (R95p) in Hargeisa, 2010–2025.



Supplementary Fig S2. Consecutive dry days (CDD) in Hargeisa, 2010–2025.

IV. DISCUSSIONS

➤ Rainfall Seasonality and Variability

The monthly and seasonal results demonstrate a strongly seasonal rainfall regime. Gu accounts for 44.48% of the four-season rainfall total, while Jilaal contributes only 0.70%. The annual CV of 24.20% further indicates substantial interannual variability. The combination of concentrated wet-season rainfall and marked year-to-year variation means that water-resource reliability depends not only on the long-term mean but also on the timing and magnitude of individual wet and dry years.

From a water-management perspective, the concentration of rainfall into limited wet periods means that the timing of rainfall may be as important as the annual total. Storage capacity, harvesting efficiency, and drought preparedness should therefore be designed around wet-season capture and dry-season persistence. In practical terms, the 2022 dry year and 2023 wet year provide useful contrasting conditions for stress-testing water resource planning.

➤ Spatial Rainfall Distribution

The spatial rainfall layer demonstrates that rainfall conditions vary within the study area. Such spatial heterogeneity is important because an area-average rainfall value can conceal local differences that influence rainwater harvesting, urban runoff, and groundwater-recharge potential. Spatially explicit CHIRPS analysis therefore provides additional planning information, although interpretation should remain consistent with the approximately 0.05° spatial resolution of the dataset.

➤ Rainfall Anomalies

The largest positive and negative anomalies occurred in 2023 and 2022, respectively. Such interannual departures are important for drought and water-security planning because a rainfall deficit can reduce runoff and recharge while increasing dependence on stored and groundwater supplies. Conversely, wetter years can increase opportunities for water harvesting and recharge but may also increase runoff and drainage demand.

Anomaly analysis should complement, rather than replace, trend analysis. A sequence containing both wet and dry years can produce a negative or positive slope even when no statistically significant long-term trend is present. The Hargeisa results illustrate this distinction clearly: the record contains pronounced wet and dry years, but the Mann–Kendall test does not support a statistically significant monotonic trend.

➤ Rainfall Trend and Statistical Significance

The Mann–Kendall test produced $p = 0.965$, while Sen's slope was -0.779 mm/year. Therefore, the study does not provide statistical evidence for a significant monotonic annual rainfall decline during 2010–2025. The negative Sen's slope should be reported as a weak decreasing tendency rather than a confirmed climate-driven reduction in rainfall. This interpretation is particularly important because the 16-year record is relatively short for drawing strong conclusions about long-term climate change.

Trend magnitude and statistical significance answer different questions: Sen's slope estimates the direction and rate of change, whereas the Mann–Kendall test evaluates whether the observed monotonic tendency is statistically distinguishable from random variation. The two measures

should therefore be interpreted jointly. In this study, the very high p-value (0.965) means that the weak negative slope should not be interpreted as a statistically supported long-term decline. A longer record, local gauge validation, and an explicit assessment of serial dependence would strengthen future trend attribution.

➤ *Extreme Rainfall and Urban Water Management*

Annual maximum daily rainfall varied from 17.980 to 30.361 mm/day. These results show that years with similar annual rainfall totals may still experience different peak daily rainfall conditions. For a rapidly growing urban area such as Hargeisa, extreme daily rainfall should therefore be considered in drainage planning alongside annual and seasonal rainfall.

Rainwater harvesting and drainage planning should account for both water scarcity and excess water. Wet-season rainfall can be captured and stored, while intense events require sufficient conveyance and drainage capacity to reduce localized flooding and erosion. The annual maximum daily rainfall indicator used here is useful for screening, but engineering design would benefit from longer records and intensity-duration-frequency analysis.

➤ *Implications for Water-Resource Planning*

The combined findings suggest that Hargeisa's water-resource planning should prioritize rainfall variability, seasonal storage, drought preparedness, and spatial targeting rather than relying only on mean annual rainfall. Rainfall information can guide the timing and potential sizing of rainwater-harvesting systems, while anomaly monitoring can support early identification of unusually dry years. Spatial rainfall products can additionally support prioritization of areas for localized water-management interventions.

Rainfall alone, however, cannot quantify groundwater recharge. Recharge assessment should integrate rainfall with geology, soil characteristics, land cover, topography, runoff, and groundwater-level observations.

➤ *Comparison with Previous Studies*

The strong seasonality and spatiotemporal variability observed in Hargeisa are consistent with the broader rainfall characteristics reported for eastern Africa. Nicholson (2017) emphasized substantial regional rainfall variability, while Lyon and DeWitt (2012) showed that rainfall behavior can change across time and that regional signals should not automatically be transferred to individual locations. CHIRPS has also been widely used for precipitation monitoring in data-scarce environments (Funk et al., 2015; Funk et al., 2018).

Within Somaliland specifically, the present results align closely with the Gabiley District study, which likewise reported strong seasonality, high interannual variability (CV = 42.3%), and no statistically significant monotonic trend ($p = 0.32$) over a 31-year record. The agreement between two studies using different data sources (CHIRPS versus NASA POWER), different periods (2010–2025 versus 1993–2023), and different locations within Somaliland strengthens the

conclusion that the dominant recent rainfall signal in the region is variability rather than monotonic change. At the same time, the marked difference in CV between the two locations (24.20% versus 42.3%) indicates that variability itself is spatially non-uniform, which is an important consideration for extrapolating findings across Somaliland.

At the national scale, Farah and Limbu (2023) analyzed CHIRPS data for Somalia over 1991–2020 and reported generally low-to-moderate interannual variability, with non-significant trends across most of the country. Their finding of a non-significant increasing tendency contrasts in direction with the weak decreasing tendency found here, but the two results are consistent in the more important respect that neither is statistically significant. This directional disagreement between studies is itself instructive: it demonstrates that trend direction in short records is sensitive to the specific period analyzed, and it cautions against interpreting any single weak slope as evidence of a regional climate signal.

Within that broader context, the present study provides a consistent 2010–2025 Hargeisa baseline that combines climatology, anomalies, spatial indicators, trend statistics, and annual maximum daily rainfall. Its main value is therefore the integration and local application of complementary indicators, rather than the introduction of a new statistical test or precipitation dataset.

➤ *Study Contribution and Practical Significance*

The principal contribution of this study is the integration of multiple rainfall diagnostics within one consistent 2010–2025 spatial and temporal framework for Hargeisa. The results distinguish three practically different signals: seasonality, interannual variability, and inferential evidence for monotonic change. This distinction prevents large wet and dry years from being misinterpreted as evidence of a statistically significant long-term decline. The framework is directly relevant to water-resource screening and planning, while its limitations indicate where future gauge validation, longer records, and more detailed extreme-rainfall analysis are needed.

V. CONCLUSIONS

This study assessed the recent spatiotemporal characteristics of rainfall in Hargeisa using daily CHIRPS rainfall data and Google Earth Engine for 2010–2025. Mean annual rainfall was 338.386 mm/year, with a standard deviation of 81.874 mm/year and a CV of 24.20%. Annual rainfall ranged from 199.720 mm in 2022 to 454.890 mm in 2023, confirming substantial interannual variability.

Rainfall was strongly seasonal, with Gu contributing 44.48% of the four-season total and Jilaal contributing only 0.70%. The largest positive anomaly occurred in 2023 and the largest negative anomaly in 2022. The Mann–Kendall analysis produced $Z = -0.045$ and $p = 0.965$, indicating no statistically significant monotonic annual rainfall trend. Sen's slope of -0.779 mm/year represents only a weak decreasing

tendency. Annual maximum daily rainfall ranged from 17.980 to 30.361 mm/day.

These findings are consistent with recent Somaliland and Somalia-scale studies that likewise report no statistically significant monotonic trend despite substantial interannual variability, including the Gabiley District analysis (CV = 42.3%, $p = 0.32$) and the national Somalia CHIRPS analysis of Farah and Limbu (2023). The convergence of these independent studies strengthens the conclusion that the dominant recent rainfall signal in the region is variability rather than monotonic change.

Overall, the dominant characteristics of the recent Hargeisa rainfall regime are strong seasonality and substantial interannual variability rather than a statistically significant monotonic annual trend. These findings support integrated rainfall monitoring, wet-season water harvesting and storage, drought preparedness, and rainfall-informed urban drainage planning. The study should be interpreted as a recent-period assessment rather than definitive evidence of long-term climate change, given the 16-year record and the limitations of gridded rainfall data at fine urban scales.

➤ *Management Implications and Recommendations*

- Expand rainwater harvesting and seasonal storage during the principal rainfall periods, particularly Gu and Deyr.
- Use dry-year rainfall and negative anomalies, including the 2022 condition, when evaluating water-supply reliability and storage requirements.
- Integrate rainfall anomaly monitoring into drought early-warning and water-resource management systems.
- Where reliable Hargeisa rain-gauge observations are available, validate CHIRPS using correlation, bias, MAE, and RMSE before operational application.
- Continue rainfall monitoring as additional complete years become available to improve the robustness of trend detection.
- Use annual maximum daily rainfall as a screening indicator and, with sufficiently long records, develop intensity-duration-frequency information for urban drainage design.
- Combine rainfall with geology, soil, land cover, topography, runoff, and groundwater observations for future recharge and water-security assessments.

VI. LIMITATIONS

Several limitations should be considered when interpreting the results. CHIRPS is a gridded satellite–station precipitation product and therefore contains uncertainty relative to direct rain-gauge observations. Its approximately 0.05° spatial resolution also limits interpretation at very fine urban scales. The 2010–2025 record contains 16 complete years, which is useful for recent variability assessment but relatively short for definitive attribution of long-term climate change. The final spatial rainfall ranges must be read from the verified GEE raster legends because earlier manuscript versions contained conflicting ranges. Complete numerical

R95p and CDD outputs were not available in the final workbook and are therefore not used as quantitative evidence. Finally, the present trend analysis does not report a modified Mann–Kendall result for serial correlation. Future work should prioritize longer records, gauge-based validation, explicit autocorrelation testing, and a fully reproducible extreme-rainfall index analysis.

➤ *Data Availability*

The temporal rainfall statistics reported in this article were calculated from the uploaded ARTICL.xlsx dataset. CHIRPS Daily data were processed using Google Earth Engine. The final study boundary, GEE processing script, and spatial raster outputs should be archived with the manuscript to facilitate reproducibility.

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• *Clinical Trial Registration*

Clinical trial registration: not applicable.

• *Consent to Publish*

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• *Ethics and Consent to Participate*

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• *Author Contributions*

Ahmed Abshir: conceptualization, data processing, statistical analysis, spatial analysis, interpretation, and manuscript preparation.

• *Conflict of Interest*

The author declares no conflict of interest.

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