

OCCURRENCE PATTERNS AND EXPLORATORY RETURN PERIODS ANALYSIS OF SEVERE COLD HARMATTAN (SCH) EPISODES IN NORTHERN NIGERIA

Alex Folorunsho^{1*}, Adewale Francis Olatunde², Samuel Ibbi Ibrahim², Idris Shaib², Nokshuwan Emmanuel Jidauna³, Oluwabunmi Aderonke Simeon¹

¹Department of Geography, Faculty of Environmental Sciences, Confluence University of Science and Technology, Osara, Kogi State, Nigeria

²Department of Geography, Faculty of Environmental Sciences, Federal University Lokoja, Nigeria

³Department of Geography, College of Arts and Social Science, Federal University of Education Pankshin, Plateau State, Nigeria

*Corresponding author: folorunsho.alex66@gmail.com

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Abstract

This study examined the occurrence patterns and exploratory return periods of Severe Cold Harmattan (SCH) episodes in Northern Nigeria between 1965 and 2024. Monthly minimum mean temperatures during the harmattan season, spanning November to February, were analysed for seven stations in Northwestern Nigeria and six stations in Northeastern Nigeria using the Standard Anomaly Index to identify SCH events. Standard Anomaly Index values between -1.29 and -1.65 were used to delineate SCH conditions. A total of 167 SCH events were identified across Northern Nigeria, comprising 85 in the Northwest and 82 in the Northeast. Sokoto recorded the highest frequency in the Northwest with 17 occurrences, while Bauchi and Jalingo jointly recorded the highest frequencies in the Northeast with 16 occurrences each. Kaduna and Maiduguri registered the lowest frequencies in their respective regions. SCH occurrences were most frequent in December and January, with the highest decadal totals observed during 1965 to 1974 in the Northwest and 1995 to 2004 in the Northeast. Notably, SCH events occurred at all stations during 2015 to 2024, indicating their continued persistence. Exploratory return period analysis revealed greater spatial variability in the Northwest, where some stations showed three year recurrence intervals, compared with a uniform five year return period across the Northeastern stations. These findings point to the need for enhanced climate monitoring, early warning systems, preparedness, adaptation planning, and the development of a comprehensive Harmattan Weather Plan to anticipate anomalous events, assess health risks, and guide response planning, so as to reduce the public health and socioeconomic impacts of SCH conditions in Northern Nigeria.

Keywords: Northwestern Nigeria; Northeastern Nigeria; decadal; exploratory return period; Severe Cold Harmattan; Standard Anomaly Index; Harmattan Weather Plan

1. Introduction

Studies on cold season anomalies have attracted increasing scholarly attention in recent years, driven by mounting evidence of climate variability and climate change and their associated health consequences (Contosta et al., 2024; Gonzalez Herrero et al., 2024). Globally, severe cold events and winter anomalies have continued to occur despite rising average global temperatures, indicating that a changing climate can simultaneously produce warming trends and extreme cold episodes across different regions (Stergiou et al., 2025). Investigations across Europe, Asia, and North America show that climate instability disrupts atmospheric circulation and generates abnormal winter conditions and cold outbreaks that significantly affect human health (Nie et al., 2025; Walkowiak et al., 2024). Comparable irregularities are increasingly observed across Africa, particularly within the Sahelian belt where the seasonal cold and dry harmattan wind influences environmental and health conditions (Folorunsho et al., 2023). Yet the absence of estimates of the exploratory return periods of such unusual events limits understanding of their potential recurrence and future risk, with important implications for early warning, preparedness, climate risk assessment, and adaptation planning (Bloin-Wibe et al., 2025).

At the regional scale, West Africa experiences the harmattan season between November and February, a period defined by cold, dry, and dust laden north easterly winds that originate from the Sahara Desert (Folorunsho et al., 2023). The intensity and variability of harmattan conditions have become increasingly erratic owing to desertification, deforestation, and broader climatic change across the Sahel (Ibrahim et al., 2022). Empirical studies across the region indicate that harmattan related cold episodes contribute to a wide range of adverse health outcomes, including pneumonia, hypothermia, asthma, frostbite, bronchitis, and sore throat, which in severe cases may result in death (Okeahialam, 2016; Obokoh, 2019). Northern Nigeria, and particularly its Northwestern and Northeastern regions, remains among the most vulnerable areas because of its semi arid climate, proximity to the Sahara Desert, comparatively weak healthcare systems, and widespread socioeconomic vulnerability (Makinde et al., 2018; PADEAP, 2020; Yahaya et al., 2024).

Several studies have examined the occurrence patterns and regional variation in the severity of cold season conditions. The World Meteorological Organization (2021) reported pronounced spatial variation in cold season severity across the United States during the February 2021 cold wave, when parts of Texas experienced temperatures lower than those recorded in Alaska, producing widespread fatalities and infrastructural disruption. Skrzynska and Twardosz (2023) further showed that Central and Eastern Europe recorded the highest frequencies of exceptionally cold months, with fifty three occurrences each, followed by Western Europe with fifty one and Northern Europe with forty eight, while Southern Europe experienced the lowest frequency at thirty seven. Central Europe emerged as the most vulnerable region because of frequent intrusions of Arctic and continental cold air masses, whereas the lower occurrence in Southern Europe was linked to mountain barriers limiting cold air advection.

In Asia, studies have documented strong regional contrasts in cold season anomalies. Zhang et al. (2012) reported increased frequencies of extreme cold events across western and eastern Asia, associated with intensified anticyclonic conditions and weakened cyclone activity, while Zhu et al. (2024) observed that northern and northwestern China experienced the highest frequencies of unusual cold events between 1989 and 2021, demonstrating clear regional disparity in cold weather vulnerability. In Africa, empirical study of severe cold events is comparatively limited and concentrated in Southern Africa. Crossett and Metz (2017) revealed that the strongest cold surges extended northward toward equatorial regions, underscoring the ability of cold air outbreaks to penetrate tropical latitudes, and Chikoore et al. (2024) examined anomalous cold events in South Africa between 1981 and 2020, documenting four hundred and seventy six snow events, of which seventy per cent occurred during winter and were concentrated in elevated mountainous areas.

Decadal analyses reveal marked variation in unusual cold events across different climatic periods. Twardosz et al. (2015) found that Europe experienced the highest frequency of exceptionally cold winters during the 1960 to 1970 decade, and Johnson et al. (2018) reported increased winter cold extremes across the Northern Hemisphere during 2002 to 2014, suggesting that extreme cold can persist even under warming conditions. In contrast, Clark and Egan (2026) reported a decline in unusual cold events across parts of the United States during the most recent decade, a trend linked to global warming, while Yin et al. (2025) observed increasing frequencies and intensification of cold weather events in China since the 1990s. Dong et al. (2025) further reported an increasing occurrence of anomalous cold events during the latter half of 2015 to 2024 across parts of China and Japan. Despite these continental trends, empirical evidence and reports point to rising public concern regarding SCH conditions in Northern Nigeria in the most recent decade, particularly in the Northwestern and Northeastern regions (Adunwoke, 2018; Chime, 2022), although such observations rest on evidence with limited spatial and temporal coverage.

Recent climatological research demonstrates that return period analysis offers useful insight into the rarity and potential recurrence of anomalous temperature events under a changing climate. Ye et al. (2025) found that the record breaking cold event over eastern China in 2023 had an estimated return period of 94.3 years under the 2023 climate state, compared with substantially shorter periods of 14.2 and 25.0 years under the 1975 and 1985 climate states. In Africa, Menna and Waktola (2022) assessed extreme temperature trends and return periods in the Upper Tekeze River Basin of northern Ethiopia,

projecting increases of roughly 0.2 to 3.4 degrees Celsius during 2022 to 2051 relative to the 1980 to 2009 baseline. In Nigeria, available evidence has focused mainly on other classes of climate extremes; Oyegoke et al. (2020), for instance, developed rainfall intensity, duration, and frequency relationships for Northern Nigerian stations using two, five, ten, twenty five, fifty, and one hundred year return periods.

Against this background, a systematic assessment of the regional and decadal occurrence patterns of SCH events, together with an estimation of their exploratory return periods across Northern Nigeria, is timely and necessary. The Northwestern and Northeastern regions are frequently exposed to intense harmattan winds owing to their proximity to the Sahara Desert, and the associated cold episodes carry significant health implications, contributing to increased cases of pneumonia, hypothermia, asthma, bronchitis, and sore throat, particularly among children, the elderly, and low income populations that lack adequate shelter and healthcare access (D'Amato et al., 2018; Muanya, 2017). Understanding the occurrence patterns and exploratory return periods of SCH events is therefore essential for improving climate adaptation, developing harmattan early warning systems, strengthening public health preparedness, and protecting vulnerable populations whose livelihoods and wellbeing are increasingly threatened by climate variability.

2. Study Area

Northern Nigeria comprises the Northwestern and Northeastern geopolitical zones, which together cover approximately forty per cent of the national land area. The Northwestern region consists of seven states, namely Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara, spanning about 216,065 square kilometres (World Bank, 2023), while the Northeastern region comprises six states, namely Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe, covering about 272,395 square kilometres. Together, the two regions form the heart of the national savanna belt, stretching from the Guinea Savanna in the south to the Sudan and Sahel Savanna in the north (Etor and Asekhauno, 2024). The Northwestern region lies between latitudes 9 degrees North and 13 degrees 28 minutes North and longitudes 3 degrees 28 minutes East and 10 degrees 37 minutes East (Folorunsho et al., 2023), while the Northeastern region is located between latitudes 9 degrees North and 13 degrees North and longitudes 9 degrees East and 14 degrees East (Etor and Asekhauno, 2024). The distribution of the thirteen study stations across the two regions is shown in Figure 1.

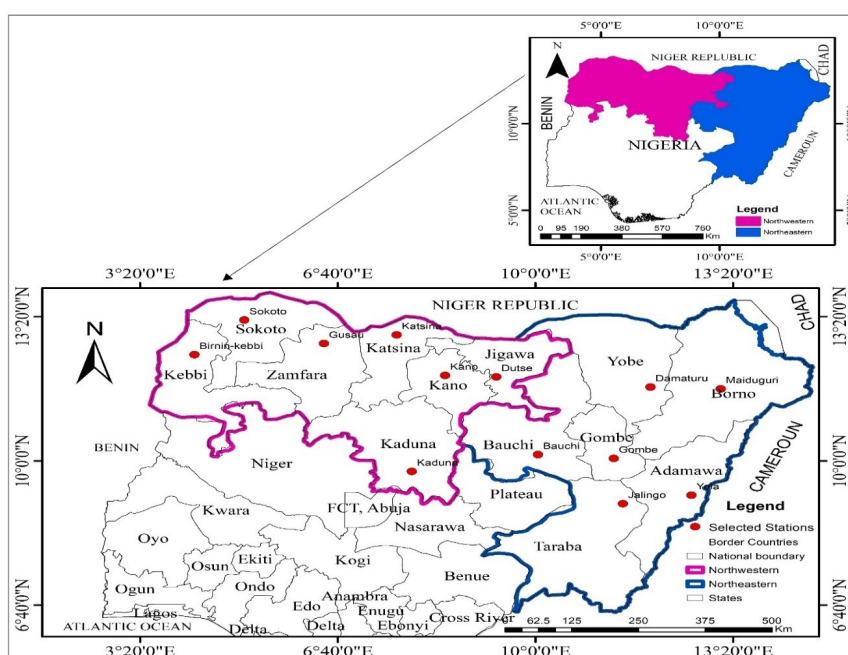


Figure 1: The study area showing the seven Northwestern and six Northeastern meteorological stations analysed for SCH events. Source: Adapted and modified from Folorunsho et al. (2023).

The two regions exhibit considerable climatic diversity, encompassing hot semi arid, tropical savanna, and hot desert climates. A substantial proportion of both regions falls within the hot semi arid zone of the Koppen classification, which occupies the northern fringes of the Sudan savanna and is prevalent in Kano, Katsina, Jigawa, Zamfara, Kebbi, and Sokoto in the Northwest, and in southern Yobe, southern Borno, Bauchi, Gombe, Adamawa, and Taraba in the Northeast. These areas typically receive between 800 and 1,000 millimetres of annual rainfall, concentrated between June and September (Mobolade and Pourvahidi, 2020). The southern portions of the study area, such as Kaduna in the Northwest and parts of Bauchi in the Northeast, experience a tropical savanna climate with well defined wet and dry seasons and comparatively higher rainfall (Edokpa et al., 2024). The extreme northeastern parts, particularly northern Yobe and northern Borno within the Lake Chad Basin, are dominated by a hot desert climate marked by low and highly variable rainfall; Maiduguri, for example, receives less than 600

millimetres annually (Edokpa et al., 2024; Mobolade and Pourvahidi, 2020). The harmattan season, occurring from November to February, is characterised by cool to cold temperatures, low humidity, and reduced visibility, with minimum temperatures typically lowest in January (Diamond, 2021).

3. Materials and Methods

The study employed sixty years of mean monthly minimum temperature records for the harmattan season, covering November to February between 1965 and 2024. Data were sourced from the World Bank Group Climate Change Knowledge Portal and from earlier researchers, including Abdussalam (2015), Folorunsho et al. (2025), and Olatunde et al. (2026). The analysis encompassed thirteen meteorological stations, comprising seven in the Northwestern region, namely Birnin Kebbi, Sokoto, Gusau, Katsina, Kano, Dutse, and Kaduna, and six in the Northeastern region, namely Damaturu, Maiduguri, Bauchi, Gombe, Yola, and Jalingo. Station selection was guided by the availability of complete meteorological records and the need to achieve adequate geographical representation, and the datasets were complete and consistent, with no missing observations across the study period.

A modified Standard Anomaly Index was employed to identify SCH events across all harmattan months. The index has been widely used in climatological studies to assess temperature and precipitation variability (Koudahe et al., 2017; Mareln, 2020), and is expressed as:

$$x_i = (r - r_i) / \sigma \quad (1)$$

where r is the temperature mean of the year, r_i is the long term mean, and σ is the standard deviation of the annual mean temperature for the long term (Koudahe et al., 2017). The index has been modified by several researchers to suit local environmental conditions (Dilip et al., 2012; Jaranilla-Sanchez et al., 2011). The classification of the Standard Anomaly Index adopted here follows the SCH thresholds established by Folorunsho et al. (2024), who identified values between -1.29 and -1.65 as indicative of SCH events (Table 1). Unlike that earlier study, which focused on five urban centres in the Northwest over 1961 to 2020, the present research examines thirteen stations across both regions over 1965 to 2024, with specific emphasis on occurrence patterns and exploratory return periods. For the decadal analysis, the sixty year dataset was partitioned into six consecutive decades: 1965 to 1974, 1975 to 1984, 1985 to 1994, 1995 to 2004, 2005 to 2014, and 2015 to 2024.

Table 1: Intensity classes of minimum temperature during the harmattan season based on the Standard Anomaly Index.

Minimum temperature intensity	Range of SAI category
Extreme Warm Harmattan	1.66 to 2.00
Severe Warm Harmattan	1.29 to 1.65
Moderate Warm (or Mild) Harmattan	0.85 to 1.28
Near Normal Harmattan	-0.84 to +0.84
Moderate Cold (or Cool) Harmattan	-0.85 to -1.28
Severe Cold Harmattan	-1.29 to -1.65
Extreme Cold Harmattan	-1.66 to -2.00

Source: Adopted from Folorunsho et al. (2023).

In this study, SCH events are treated as synonymous with anomalous cold events, since they represent unusually cold conditions that deviate from typical harmattan characteristics. The frequency and percentage of SCH occurrences were computed for each station, decade, and region using:

$$\text{Percentage (\%)} = (n / \Sigma n) \times 100 \quad (2)$$

where n is the number of SCH occurrences at a particular station or decade and Σn is the total number of occurrences across all stations or decades. Cross regional comparison was conducted by analysing the frequency and percentage of SCH events in both regions across each decade to identify patterns of similarity and divergence. Finally, the return period, or recurrence interval, was used to investigate the recurrence of SCH events, following the formulation developed by Shuaibu and Oladipo as presented in Olatunde (2013):

$$T = (N + 1) / r \quad (3)$$

where N is the total number of events, the value one is the rank of the largest occurrence, and r is the rank of the occurrence whose recurrence is to be determined. The resulting estimates should be regarded as an exploratory indication of potential recurrence rather than a precise prediction, particularly because future climatic conditions may differ from historical patterns; the projections are therefore subject to uncertainties associated with future climate variability and change.

4. Results and Discussion

4.1 SCH Events and Return Periods in Northwestern Nigeria

An overview of SCH events across the seven Northwestern stations during the sixty year study period is presented in Table 2. The results reveal that SCH events occurred a total of eighty five times across the region, with notable variation in both spatial distribution and monthly occurrence. Sokoto recorded the highest frequency with seventeen occurrences, representing 20.00 per cent of the regional total, followed closely by Kano and Katsina with sixteen events each, or 18.82 per cent. Dutse recorded fifteen events at 17.65 per cent, while Birnin Kebbi had eleven events at 12.94 per cent, and Gusau and Kaduna experienced the lowest frequencies with six and four events, or 7.06 and 4.71 per cent respectively. The prominence of SCH events at Sokoto, Kano, and Katsina reflects their position at the northernmost extent of the study area, where proximity to the Sahara Desert intensifies harmattan conditions.

Table 2: Frequency and percentage distribution of SCH events in Northwestern Nigeria (1965–2024).

Station	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
Birnin Kebbi	–	–	8	21.62	3	6.38	–	–	11	12.94
Sokoto	1	100.00	6	16.22	10	21.28	–	–	17	20.00
Gusau	–	–	2	5.41	4	8.51	–	–	6	7.06
Katsina	–	–	8	21.62	8	17.02	–	–	16	18.82
Kano	–	–	4	10.81	12	25.53	–	–	16	18.82
Dutse	–	–	7	18.92	8	17.02	–	–	15	17.65
Kaduna	–	–	2	5.41	2	4.26	–	–	4	4.71
Total	1	100	37	100	47	100	–	–	85	100

Source: Authors' analysis of data (2025).

Of the eighty five recorded events, thirty seven, or 43.53 per cent, occurred in December and forty seven, or 55.29 per cent, in January, while only one event, at Sokoto, was recorded in November and none in February. This pronounced concentration in December and January indicates that anomalous cold conditions were most severe during the peak of the harmattan season, revealing a marked temporal clustering of severe cold events across the Northwest (Figure 2).

Monthly distribution of SCH events, Northwestern Nigeria (1965–2024)

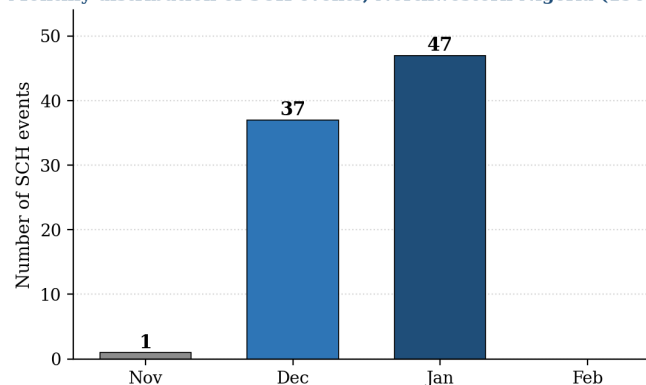


Figure 2: Monthly distribution of SCH events in Northwestern Nigeria (1965–2024). Source: Authors' analysis of data.

The decadal distribution of SCH events across the Northwest is presented in Table 3. The first decade, 1965 to 1974, recorded the highest frequency with twenty events at 23.53 per cent, followed by the second decade, 1975 to 1984, with eighteen events at 21.18 per cent. These findings are consistent with global studies indicating that the 1960s and 1970s witnessed heightened frequencies of exceptionally cold winters across various regions (Twardosz et al., 2015). The third and fourth decades recorded thirteen and twelve events respectively, while the fifth decade, 2005 to 2014, recorded the lowest frequency with only eight events at 9.41 per cent, suggesting a period of relatively milder harmattan conditions. SCH events nonetheless persisted into the most recent decade, 2015 to 2024, during which fourteen events, or 16.47 per cent, were recorded. The recurrence of events across all stations during this period, including locations situated farther from the principal harmattan air mass such as Kaduna, provides further evidence that severe cold anomalies continue to manifest across the region.

Table 3: Frequency and percentage of SCH events among decades in Northwestern Nigeria.

Decade	Total frequency of occurrence	Percentage (%)
1965–1974	20	23.53
1975–1984	18	21.18
1985–1994	13	15.29
1995–2004	12	14.12
2005–2014	8	9.41
2015–2024	14	16.47

Decade	Total frequency of occurrence	Percentage (%)
Total	85	100

Source: Authors' analysis of data (2025).

The exploratory return period analysis reveals spatial variability in the recurrence of SCH events across the Northwest (Table 4). Birnin Kebbi, Gusau, Dutse, and Kaduna exhibited the longest estimated return period of five years, suggesting less frequent recurrence, whereas Sokoto, Katsina, and Kano recorded shorter estimated periods of three years, indicating comparatively higher recurrence. On the basis of these historical intervals, exploratory projections suggest that SCH events may reoccur around 2027 at Sokoto, Katsina, and Kano, and around 2029 at Birnin Kebbi, Gusau, Dutse, and Kaduna. These estimates differ from those of Ye et al. (2025), who reported return periods of 14.2 and 25.0 years for comparable anomalous cold events over parts of China under the 1975 and 1985 climate states, indicating that the exploratory return periods for SCH events in the Northwest are comparatively shorter.

Table 4: Exploratory return periods of SCH intensity in Northwestern Nigeria.

Station	Return or recurrence interval	Likely year of reoccurrence
Birnin Kebbi	Five years	2029
Sokoto	Three years	2027
Gusau	Five years	2029
Katsina	Three years	2027
Kano	Three years	2027
Dutse	Five years	2029
Kaduna	Five years	2029

Source: Authors' analysis of data (2025).

4.2 SCH Events and Return Periods in Northeastern Nigeria

The distribution of SCH events across the six Northeastern stations is provided in Table 5. A total of eighty two events occurred across the region during the study period. Bauchi and Jalingo experienced the highest frequency with sixteen occurrences each, or 19.51 per cent, followed by Damaturu with fourteen events at 17.07 per cent and Gombe with thirteen events at 15.85 per cent. Yola recorded twelve events at 14.63 per cent, while Maiduguri had the lowest frequency with eleven events at 13.41 per cent. The high frequency at Bauchi and Jalingo, despite their more southerly locations relative to Damaturu and Maiduguri, highlights the complex interplay of elevation, topography, and regional atmospheric dynamics governing harmattan intensity. The presence of Lake Chad may exert a moderating influence on harmattan temperatures at Maiduguri by dampening the intensity of unusual temperature variation (Kaznowska et al., 2025).

Table 5: Frequency and percentage distribution of SCH events in Northeastern Nigeria (1965–2024).

Station	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
Damaturu	–	–	2	5.13	11	26.83	1	50.00	14	17.07
Maiduguri	–	–	7	17.95	4	9.76	–	–	11	13.41
Bauchi	–	–	9	23.08	7	17.07	–	–	16	19.51
Gombe	–	–	4	10.26	9	21.95	–	–	13	15.85
Yola	–	–	5	12.82	6	14.63	1	50.00	12	14.63
Jalingo	–	–	12	30.77	4	9.76	–	–	16	19.51
Total	–	–	39	100	41	100	2	100	82	100

Source: Authors' analysis of data (2025).

Seasonal analysis revealed that SCH events in the Northeast were overwhelmingly concentrated in the core harmattan months. January recorded the highest number of occurrences with forty one events, or 50.00 per cent, closely followed by December with thirty nine events at 47.56 per cent. February contributed only two events, both confined to Damaturu and Yola, while no SCH events were observed in November throughout the study period. This pattern underscores the predominance of severe cold anomalies during the peak of the harmattan season and demonstrates a pronounced temporal concentration of events across the region (Figure 3).

Monthly distribution of SCH events, Northeastern Nigeria (1965–2

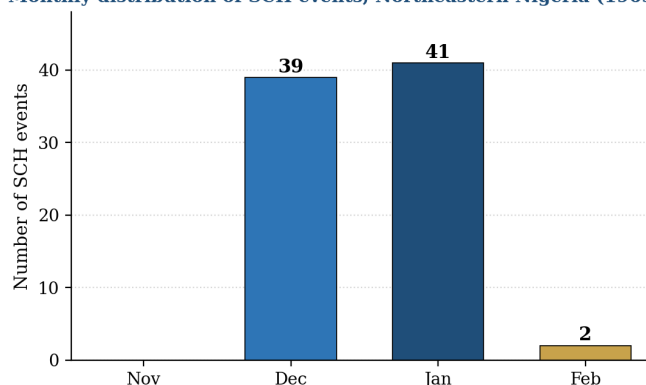


Figure 3: Monthly distribution of SCH events in Northeastern Nigeria (1965–2024). Source: Authors' analysis of data.

The decadal variation in the Northeast is presented in Table 6. Unlike the Northwest, where the first decade recorded the highest frequency, the Northeast experienced its peak during the fourth decade, 1995 to 2004, with eighteen events at 21.95 per cent, followed by the third decade with sixteen events and the second decade with fourteen events. The first decade, 1965 to 1974, recorded the lowest frequency with eight events at 9.76 per cent, in sharp contrast with the Northwest. The most recent decade, 2015 to 2024, recorded fifteen events at 18.29 per cent, an increase over the eleven events, or 13.41 per cent, of the preceding decade. The continued occurrence of SCH events across all decades indicates that SCH conditions remain a persistent climatic phenomenon whose associated risk has not diminished.

Table 6: Frequency and percentage of SCH events among decades in Northeastern Nigeria.

Decade	Total frequency of occurrence	Percentage (%)
1965–1974	8	9.76
1975–1984	14	17.07
1985–1994	16	19.51
1995–2004	18	21.95
2005–2014	11	13.41
2015–2024	15	18.29
Total	82	100

Source: Authors' analysis of data (2025).

The exploratory return period analysis for the Northeast revealed a uniform recurrence pattern across all stations (Table 7). Damaturu, Maiduguri, Bauchi, Gombe, Yola, and Jalingo each recorded an estimated return period of five years, indicating no apparent spatial variation within the region. Exploratory projections accordingly suggest that SCH events could recur around 2029 across the six stations, provided that historical occurrence patterns remain broadly unchanged. While these estimates should be read cautiously given the uncertainties of future climate variability, they provide useful indicative information for climate risk assessment, early warning, and long term preparedness planning.

Table 7: Exploratory return periods of SCH intensity in Northeastern Nigeria.

Station	Return or recurrence interval	Likely year of reoccurrence
Damaturu	Five years	2029
Maiduguri	Five years	2029
Bauchi	Five years	2029
Gombe	Five years	2029
Yola	Five years	2029
Jalingo	Five years	2029

Source: Authors' analysis of data (2025).

The relative standing of individual stations across both regions is summarised in Figure 4, which places Sokoto at the head of the distribution and Kaduna at its base, and shows how the Northeastern stations occupy the middle of the frequency range.

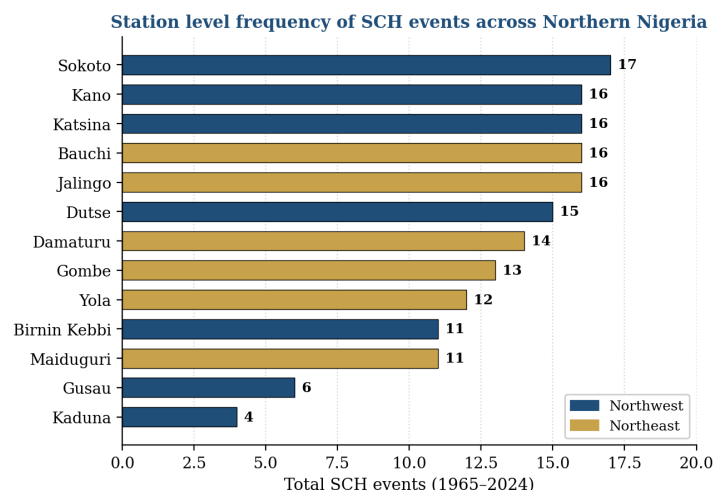


Figure 4: Station level ranking of SCH event frequency across the thirteen stations of Northern Nigeria. Source: Authors' analysis of data.

4.3 Cross Regional Comparison

During the sixty year study period, a total of 167 SCH events were identified across Northern Nigeria, of which the Northwest accounted for eighty five events, or 50.90 per cent, and the Northeast recorded eighty two events, or 49.10 per cent (Figure 5 and Table 8). This near equal distribution suggests that both regions are similarly vulnerable to SCH conditions despite differences in geography and proximity to the harmattan winds. The comparable frequencies are broadly consistent with the findings of Skrzynska and Twardosz (2023), who reported similar frequencies of exceptionally cold months in Central and Eastern Europe.

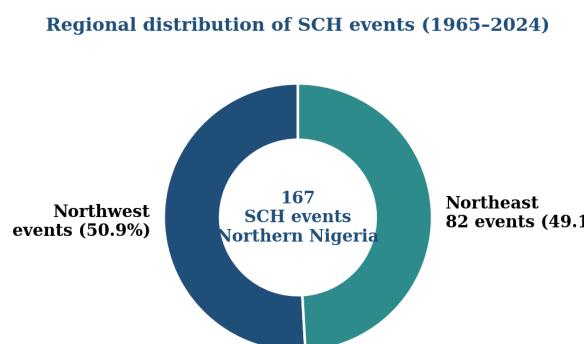


Figure 5: Regional distribution of the 167 SCH events identified across Northern Nigeria (1965–2024). Source: Authors' analysis of data.

The most notable contrast between the two regions lies in their decadal occurrence. While the Northwest recorded its highest frequency during 1965 to 1974 with twenty events, the Northeast experienced its lowest frequency in the same decade with only eight events. Conversely, the highest frequency in the Northeast occurred during 1995 to 2004 with eighteen events, whereas the Northwest recorded only twelve events during that period. Both regions subsequently exhibited a marked decline during 2005 to 2014, recording eight and eleven events respectively (Table 8 and Figure 6). This reduction broadly coincides with the global warming slowdown described by Johnson et al. (2018), during which the rate of surface warming temporarily moderated, potentially contributing to the observed decrease in anomalous cold events.

However, the most recent decade, 2015 to 2024, was characterised by a resurgence of SCH events in both regions, with the Northwest recording fourteen events and the Northeast fifteen, a combined total of twenty nine events across Northern Nigeria. This finding is particularly significant, as it indicates that SCH events remain an ongoing phenomenon. The recurrence of these events across all thirteen stations in the most recent decade challenges expectations of a linear decline in cold extremes under global warming and supports the view that climate variability may increase the frequency of unusual events at both ends of the temperature spectrum (Cohen et al., 2020). Both regions also exhibited similar seasonal patterns, with events concentrated in January and December, reflecting the peak harmattan period when minimum temperatures are typically lowest (Diamond, 2021).

Table 8: Cross regional comparison of SCH events between Northwestern and Northeastern Nigeria (1965–2024).

Decade	NW frequency	NW %	NE frequency	NE %	Total frequency	Total %
1965–1974	20	23.53	8	9.76	28	16.77
1975–1984	18	21.18	14	17.07	32	19.16
1985–1994	13	15.29	16	19.51	29	17.37
1995–2004	12	14.12	18	21.95	30	17.96
2005–2014	8	9.41	11	13.41	19	11.38
2015–2024	14	16.47	15	18.29	29	17.37
Total	85	100	82	100	167	100

Source: Authors' analysis of data (2025).

When both regions are considered together, the highest combined frequency occurred during 1975 to 1984 with thirty two events at 19.16 per cent, followed by 1995 to 2004 with thirty events at 17.96 per cent, while the lowest combined occurrence was during 2005 to 2014 with nineteen events at 11.38 per cent. Notably, SCH events remained present in every decade in both regions, including the most recent decade (Table 8 and Figure 6). This continued occurrence suggests that severe cold harmattan conditions are a persistent feature of the regional climate rather than a relic of earlier periods, while the contrasting decadal patterns indicate temporal variability, with the Northwest generally recording higher frequencies during earlier decades and the Northeast during several later decades.

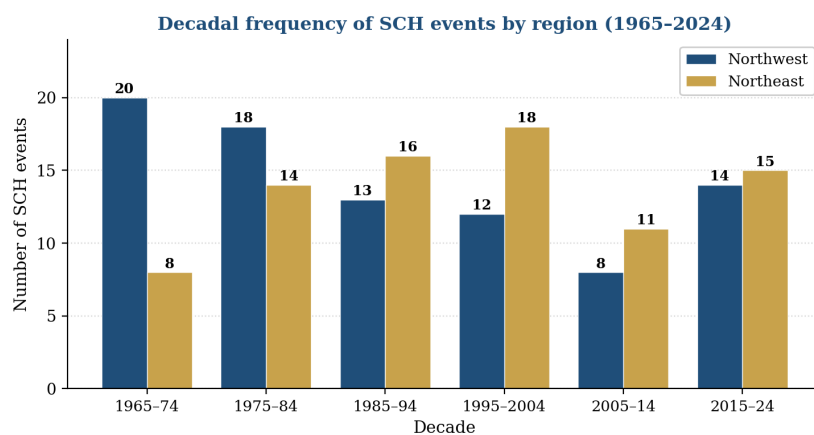


Figure 6: Decadal frequency of SCH events in Northwestern and Northeastern Nigeria (1965–2024). Source: Authors' analysis of data.

The temporal behaviour of the two regional series is compared directly in Figure 7. The Northwestern series declines from its early maximum before recovering in the final decade, whereas the Northeastern series rises to a mid period peak; the combined series remains comparatively stable, which masks the opposing regional tendencies that the disaggregated analysis reveals.

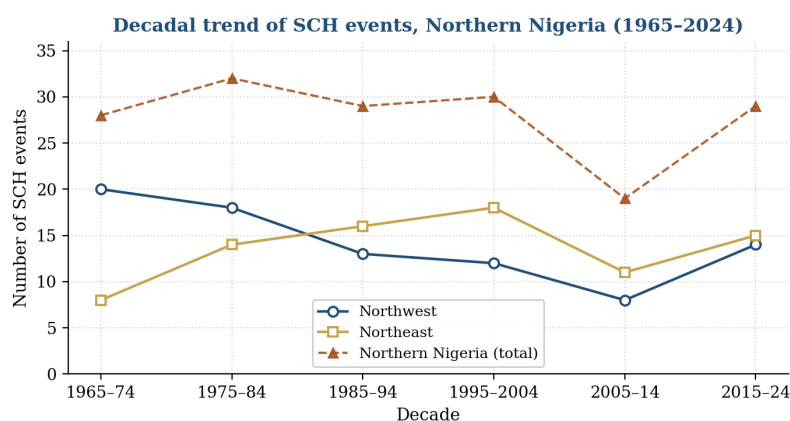


Figure 7: Decadal trend of SCH events in the two regions and across Northern Nigeria as a whole. Source: Authors' analysis of data.

The exploratory return period analysis reveals a clear regional contrast in the recurrence of SCH events. In the Northwest, Birnin Kebbi, Gusau, Dutse, and Kaduna recorded five year intervals, while Sokoto, Katsina, and Kano exhibited shorter three year intervals, indicating relatively more frequent recurrence at these locations. In the Northeast, all six stations recorded a uniform five year interval with no apparent spatial variation. The Northwest therefore contains a greater proportion of stations with shorter three year intervals, suggesting comparatively more frequent recurrence in parts of the region. Exploratory projections indicate possible reoccurrence around 2027 at Sokoto, Katsina, and Kano, and around 2029 across the remaining Northwestern and all Northeastern stations, although these should be interpreted as indicative scenarios rather than

deterministic forecasts (Figure 8).

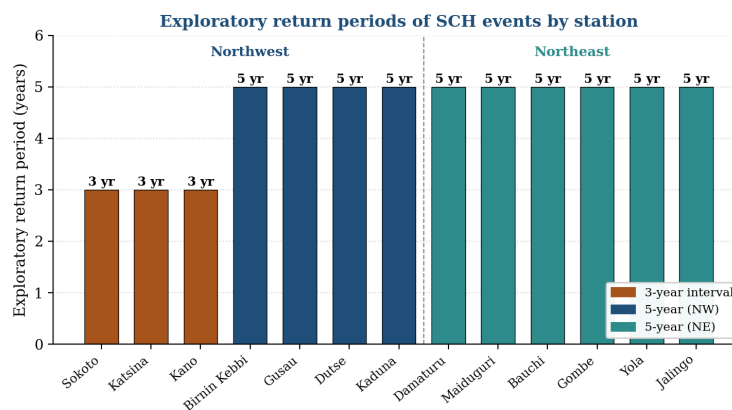


Figure 8: Exploratory return periods of SCH events by station across the two regions. Source: Authors' analysis of data.

These findings underscore the need for proactive preparedness. Sokoto, Katsina, and Kano should prioritise readiness for possible SCH recurrence within three years from 2024, while the Northeastern stations and the remaining Northwestern stations should strengthen preparedness for possible recurrence within approximately five years. Such anticipatory planning, incorporating early warning, climate risk assessment, and targeted public health preparedness, is essential for reducing the potential health and socioeconomic consequences of severe cold harmattan events across Northern Nigeria.

5. Conclusion

This study examined the occurrence patterns and exploratory return periods of SCH episodes in Northern Nigeria from 1965 to 2024. Harmattan months with Standard Anomaly Index values between -1.29 and -1.65 were identified as SCH events. The findings revealed that such events occurred eighty five times in the Northwest and eighty two times in the Northeast, giving a total of 167 events across the region over the sixty year period. In the Northwest, Sokoto recorded the highest frequency with seventeen events, followed by Kano and Katsina with sixteen each, while Kaduna had the lowest with four, and the first decade witnessed the highest occurrence with twenty events. In the Northeast, Bauchi and Jalingo recorded the highest frequencies with sixteen each, Maiduguri the lowest with eleven, and the fourth decade the highest frequency with eighteen events.

A critical finding is that the most recent decade witnessed SCH events across all thirteen stations, with the Northwest recording fourteen events and the Northeast fifteen, an increase over the preceding decade. This pattern is consistent with the influence of a changing climate, which can increase the occurrence of anomalous events at both ends of the temperature spectrum. The exploratory return period analysis indicated greater spatial variability in the Northwest, where three stations recorded shorter three year intervals against a uniform five year interval across the Northeast, implying relatively more frequent recurrence in parts of the Northwest. The associated health implications are significant, since severe cold during harmattan seasons can jeopardise human health, particularly among children, the elderly, and those without adequate protective resources, through outcomes such as pneumonia, hypothermia, asthma, and bronchitis (Meade and Emch, 2010; Van der Walt et al., 2023).

On the basis of these findings, it is recommended that the Federal Government and the relevant state governments should establish and strengthen early warning systems for severe harmattan events; develop climate change adaptation strategies that address both warming and extreme cold; provide support for vulnerable populations, including shelter, protective clothing, and heating resources; develop and implement a comprehensive Harmattan Weather Plan to anticipate anomalous events, assess health risks, and define response protocols; and invest in climate research to improve understanding of the drivers of increased variability in harmattan conditions. SCH events in Northern Nigeria display pronounced spatial and temporal variability, and their continued occurrence in the most recent decade, together with the relatively short exploratory return periods in parts of the Northwest, underscores the need for enhanced monitoring, preparedness, and targeted intervention. Further research is recommended to investigate the atmospheric dynamics driving these patterns and to project future trends under different climate change scenarios.

Data Availability Statement

The datasets used in this study were obtained from the World Bank Group Climate Change Knowledge Portal and from earlier researchers, including Abdussalam (2015), Folorunsho et al. (2025), and Olatunde et al. (2026). The analysis covered all thirteen major meteorological stations located in the state capitals of Northern Nigeria, with complete datasets available for the study period and no missing observations. The raw datasets can be obtained from the corresponding author upon reasonable request.

Conflict of Interest and Funding Statement

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