# Severe Cold Harmattan Events in the Northwestern Region of Nigeria from 1961 to 2020

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## Abstract

*This study examined the occurrences of severe cold harmattan events in Northwestern Nigeria from 1961 to 2020. Monthly minimum temperatures of the harmattan seasons (November to February) for five (5) selected stations: Kaduna, Kano, Gusau, Katsina, and Sokoto, were collected and analyzed over 60 years. A modified Standard Anomaly Index (SAI) was applied to determine the severe cold harmattan (SCH) events for the harmattan seasons. Findings revealed that SCH events occurred 55 times in the study area throughout the study period. In terms of geographical distribution, Sokoto experienced the most frequent SCH events (16 times in 60 years), followed by Kano and Katsina (15 times each). Kaduna had the lowest frequency (3 times), next to Gusau (6 times). Among decades, the second decade (1971-1980) had the highest occurrences of SCH in the study area (15 times in 10 years or 27.27%). Sokoto experienced the highest occurrence in this decade, while both Kaduna and Gusau witnessed the lowest. In regards to total decadal frequency, the most recent decade (2011-2020) and the first decade (1961-1970) tied for second. In general, all stations experienced SCH in the most recent decade (2011-2020). The study suggests that measures should be put in place to mitigate against SCH events that focus on climate change abatement strategies such as conventional mitigation, reduction of negative emissions, and unpleasant land use practice because climate change can increase the frequency of SCH and may put human health at risk of cold related illnesses.*

**Keywords**: Northwestern Nigeria, Decadal, Minimum Temperature, Standard Anomaly Index, Harmattan Season

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## Introduction

Human beings have been warming the world's climate through the use of fossil fuel and other activities. This has resulted in variations, changes and unpredictability in weather/climate elements, and has been causing the occurrences of unusual and rare events (Trenberth, 2018; (Folorunsho et al., 2023). Furthermore, this climate variations and changes can manifest in several ways, producing opposite effects on a regional scale (Kretschmer, 2021; Climate Reality Projects, 2022; National Geographic Society, 2022). The occurrences of unusual events have become more frequent during the winter seasons (cold period around the world), and perhaps this is because the winter season is suggested to have the most variable thermal conditions (Twardosz & Kossowska-Cezak, 2015).

Globally, anomalous events such as severe cold weather and climate temperatures (especially during winter) have been occurring in different places despite the issue of global warming and have swung from one decade to another. Although the occurrences may not be uniform over space and time, it is projected to continue globally, and has been attributed to climate change (Twardosz et al., 2015; Jordan, 2016; Johnson et al., 2018; Letzing, 2023). People in regions like Europe, North America, and parts of Asia are finding this cold to be more and more dangerous to human lives and health (Zhang et al., 2012; Murage et al., 2018). This to some extent is the situation in Africa, especially in the Northern Cape of Southern Africa where severe winters have become frequent (Van der Wilt & Fitchett, 2021b). The Northwestern region of Nigeria is also not an exception, as the prevalence of severe cold during the harmattan seasons have been noted to be very disturbing (Bello, 2020; Mgboh et al., 2020).

There is evidence from different researches that severe events (of winter and harmattan) have tragic impacts on human health and comfort and can increase the risk of pneumonia,

hypothermia, asthma, frostbite, bronchitis, sore throat, and many other cold-associated illnesses, and may even result in death (Meade & Emch, 2010; Badmos, 2015; Okeahialam, 2016; Obokoh, 2019; Van der Wilt et al., 2023). This applies more to people living in developing countries like Nigeria, where some persons may not have access to shelters, cold protective cloths, medications, or cannot afford home heaters (Muhammad et al., 2020).

The harmattan season over West Africa lasts from November to February, and it is known for its chilly weather (Folorunsho et al., 2023). However, the season is also characterized by dust haze (McSweeney et al., 2010; Britannica, 2021). This season has become very unstable in Nigeria, and various intensities of cold harmattan have been noted to have occurred in various places in the Northwestern region (Folorunsho et al., 2023). For example, severe cold harmattan events were experienced in the latter half of the last decade (2011-2020) in this region (Adunwoke, 2018; Abu, 2019; Bello, 2020; Mfonobong, 2020; Chime, 2022). Most of these severe events were witnessed in the months of December and January, resulting in serious devastation to people's health. During one of the harmattan periods, in January 2020, the temperature dropped unseasonably in Kano to as low as $7^{O}$C, colder than London (with temperate climate) at $9^{O}$C. This was followed by the hospitalization of many residents and many people in the metropolis were forced to stay indoors (Mgboh et al., 2020). In general, such periods of notable reduction in temperature have a significant impact on human life (i.e., people's health) and socio-economic activities (Twardosz et al., 2015; Kretschmer, 2021; Yamagata, 2021).

There are very cursory works on severe cold harmattan events in scientific studies. However, a number of works majorly on winter seasons have examined the occurrences of severe events around the globe. Still, most of the studies focused on extreme events during winter seasons. Perhaps, this is because these studies were carried out in Temperate, Polar regions and extreme

Southern Africa (which are generally colder compared to West Africa), where people are at greater risks of extreme winters. For instance, Johnson et al. (2018) investigated the increasing occurrence of cold and warm extremes during the recent global warming slowdown over the Northern Hemisphere. The study revealed increased frequency of wintertime cold extreme in the study region, even in the 2002 to 2014 period. Twardosz et al. (2015) assessed the frequency, duration and spatial extent of exceptionally cold and mild winters in Europe from 1951 to 2010. Amongst the findings, the highest frequency of exceptionally cold winter events was observed in the 1960/1961-1969-1970 decade. Bednorz (2011) examined the occurrence of extreme winter air temperatures in Central Spitsbergen (Norway). The study noted that negative extremes were becoming less frequent, decreasing at a rate of approximately 5 days per decade. However, the study of Zhang et al. (2012) on extreme cold winter weather events in Eurasia showed increased frequencies of striking cold weather events between 1990s and 2000s.

Similarly, Wen et al. (2009) in a study on Large-Scale Climate Anomalies in China showed that the 2001-2010 decade (specifically in the year 2008) witnessed very severe events of minimum temperature. The event was noted to be devastating because it was accompanied by unusual snowfall. The study of Bhatla et al. (2016) on severe cold wave events during post-monsoon and winter season in India from 1971 to 2010 also revealed that the highest number of cold wave days was found in Kheri in the 2001-2010 decade. In addition, in the most recent decades (2011-2020), one research carried out by Stanford University noted that cold winters in Eastern United States have significantly increased (Jordan, 2016), but Cwienk (2021) noted that the occurrence of colder weather in this decade has decreased in many parts of Germany. In general, the World Meteorological Organization [WMO] (2013) noted that the 1900s and 2000s were the warmest

in history for both the North and South hemispheres, periods that witnessed unprecedented melting of glaciers.

In Africa, Van der Walt et al. (2021a) examined extreme temperature events (ETEs) in South Africa from 1960 to 2016. The study showed that the events of cold extremes are decreasing and becoming less frequent compared to earlier decades over the broad region. The study of Grab and Nash (2009) on climate variability during cold seasons in Lesotho also showed that the occurrence of severe cold seasons has reduced significantly through the study period. Similarly, a study by New et al. (2006) on trends in daily climate extremes over Southern and West Africa from 1961 to 2000 also revealed the decreased occurrences of extreme cold days.

Specifically in Nigeria and the Northwestern region, most research connected to the harmattan seasons has been centered on dust haze and poor visibility. For instance, McTainsh (1980) examined harmattan dust deposition in Northern Nigeria. Aweda et al. (2017) investigated the elemental concentration of harmattan dust samples in Iwo and Oyo Town (Southwestern Nigeria). Balarebe (2018) assessed the thirty years trend analysis of harmattan season visibility and temperature in the Sahel Zone of Nigeria. In addition, Danlami et al. (2018) carried out a study on temporal and spatial variations of ground surface visibility during the harmattan season in Northeastern Nigeria.

However, there have been several reports from the media about the occurrence and reoccurrence of severe cold harmattan in the most recent decade (2011-2020) in the Northwestern Nigeria. It is reported that these severe harmattan is a threat to the lives of people in the region (Abu, 2019; Guardian, 2020; Bello, 2020; Mgboh et al., 2020; Musa, 2021). This has caused serious devastations in the Northwestern states like Kano, Sokoto and Katsina, where the health of vulnerable people are more at increasing risk of related illnesses (Abu, 2019; Bello, 2020;

Mgboh et al., 2020). Yet, no known study has examined in detail the decadal occurrences of severe cold harmattan (SCH) events in Northwestern Nigeria. An analysis of SCH events is very crucial in mitigating its negative impacts. A decadal assessment of SCH will offer an opportunity to understand the short-term climatic occurrence of the events. Therefore, the objective of this study is to examine the decadal occurrence of severe cold harmattan events in the Northwestern region of Nigeria.

## Study Area

The Northwestern region is one of Nigeria's six geopolitical areas. The region makes up around 26% (216,065 km2) of the total land area of the nation. In the Northwestern region are seven of Nigeria's 36 states. These include; Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara. The North Eastern Geopolitical Zone of Nigeria, the Benin Republic, the North Central Geopolitical Zone of Nigeria, and the Niger Republic border this zone in the East, West, South, and North, respectively (Africaportal, 2020). According to Olatunde (2013), the study region is situated between Latitudes $9^{O}$ and $13^{O}$ 28' N of the Equator and Longitudes $3^{O}$ 28' E and $10^{O}$37' E of the Greenwich Meridian (Fig 1).

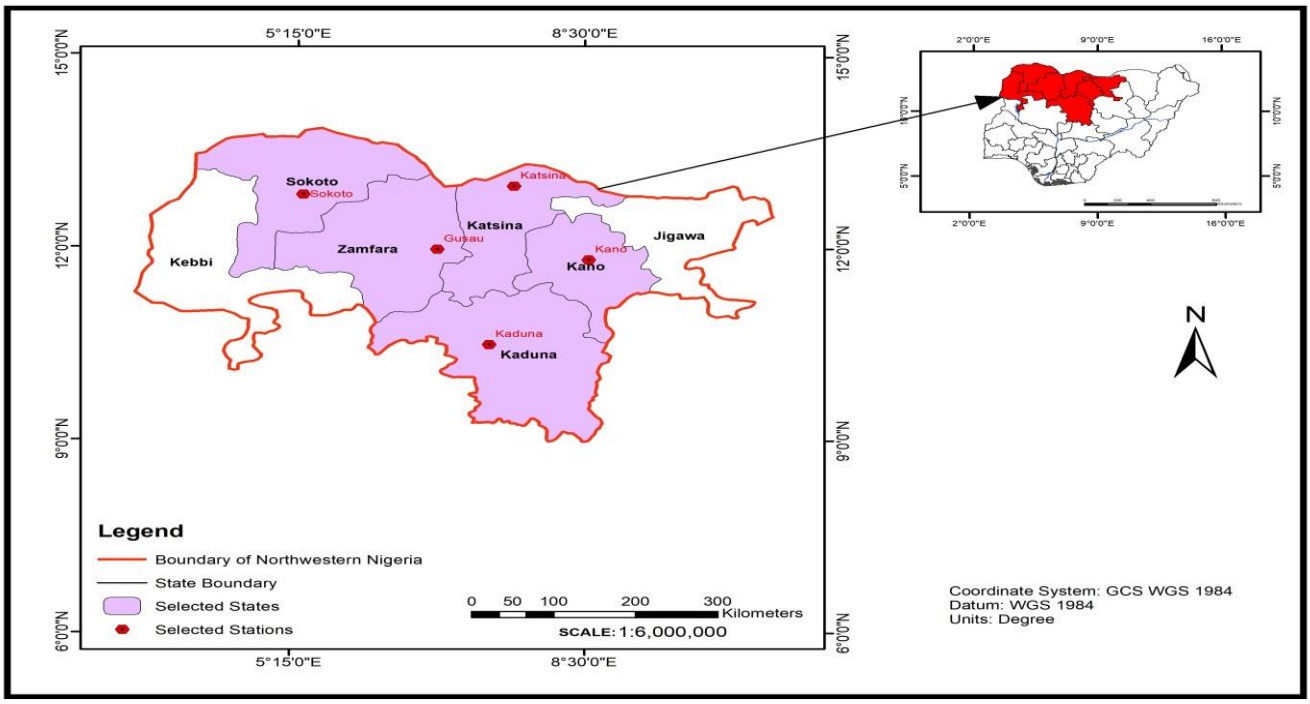


Figure 1: The Study Area

Adapted from: Malomo, 2014.

The climate of the Northwestern region is the tropical wet-and-dry type, which has been classified as the Köppen Aw climate. The climate is affected by the movement of the Inter-tropical convergence zone (ITCZ) (Folorunsho et al., 2023). This region experiences very mild weather all year long with a yearly average temperature that ranges from 25$^{O}$C in Kaduna State to about 28$^{O}$C in Sokoto. The study area has an average annual rainfall of about 500 mm in the extreme northern part to about 1000 mm in the southern part (Emeribe et al., 2017). Throughout November through to February, when the sun is overhead at the tropic of Capricorn, the pressure belt and wind system move south. Moreover, this is the time of the year when the Northwestern region of Nigeria experiences the harmattan season (Olatunde, 2013).

The study area's vegetation is of the Savanna type. While the southern portion of the study area is situated in the Guinea Savanna belt, which is characterized by woods and tall grasses, the

northern portion is in the Sudan Savanna belt, composed of grasslands with few and stunted trees (Class Notes, 2023). In the Northwestern region of Nigeria, about 80% of the people are involved in agriculture practices of different kinds, with cattle breeding being particularly common (Karkana et al., 2018). However, the majority of agriculture practices are fed by rainfall. The Northwestern region of Nigeria is the most populous region with a population of about 35,915,417, nevertheless, a high percentage of those who live here are uneducated and underprivileged (Africaportal, 2020).

## Materials and Methods

This study is based on the mean monthly minimum temperature of the Harmatan seasons (November and February) from 1961 to 2020. Data were sourced from The World Bank Group, Climate Change Knowledge Portal and other earlier researchers such as Eludoyin (2011), Abdussalam (2015) and Olatunde et al. (2019) across 5 meteorological stations in the study area. These stations included Kaduna, Kano, Gusau, Katsina, and Sokoto. These stations were selected based on data availability. A modified Standard Anomaly Index (SAI) was used to determine the severe cold harmattan (SCH) events for all of the harmattan months (November, December, January, and February). The formula for the SAI was noted in the work of Koudahe et al. (2017) in order to determine temperature variability in Southern Togo. However, the temperature categorizations were not given in the work. In the study, station temperature was expressed as a standardized departure from the long-term mean (i.e., the mean of the base period). Generally, the SAI is calculated as:

$$x_i = \frac{r - r_i}{\sigma} \quad \text{.....(1)}$$

Where r is the temperature mean of the year, $r_i$ is the long-term mean, and σ is the standard deviation of annual mean temperature for the long term (Koudahe et al., 2017).

This index is used for both temperature and precipitation data (European Union, 2020). However, because the polar and temperate regions have a colder winter compared to the tropics, the SAI ranges have been modified by researchers for proper studies of their local environments (Dilip et al., 2012; Koudahe et al., 2017; Marelign, 2020). Dilip et al. (2012), in a study on temporal variation and trends of temperature in India, used the following categorization below.

Table 1: SAI Criteria for Assessing the Intensities of Temperature Variability in India.

| Minimum Temperature Intensities | Range of SAI category |
|---|---|
| Extremely Hot | > 3 |
| Very Hot | > 2 |
| Hot | > 0.43 |
| Near | ─ 0.43 to + 0.43 |
| Cold | > ─ 0.43 |
| Very Cold | > ─ 2 |
| Extremely Cold | > ─ 3 |

Source: Dilip et al. (2012).

In another study on modeling rainfall/drought variability in the Pampanga Basin of the Philippines, Jaranilla-Sanchez et al. (2011) used another categorization. This is given in Table 2.

Table 2: SAI Criteria for Assessing the Intensities of Rainfall Variability in Pampanga Basin.

| Minimum Temperature Intensities | Range of SAI category |
|---|---|
| Extremely Wet | ─ 2 and less |
| Severely Wet | ─ 1.5 to ─ 1.99 |
| Moderately Wet | ─ 0.49 to ─ 1.0 |
| Near Normal | ─ 0.43 to + 0.43 |
| Moderately Dry | ─ 0.49 to ─ 1.0 |
| Severely Dry | ─ 1.5 to ─ 1.99 |
| Extremely Dry | ─ 2 and less |

Source: Jaranilla-Sanchez et al. (2011).

According to Jaranilla-Sanchez et al. (2011), there is no consensus on which categorization is optimal. The different categorizations are based on climatic suitability ─ in line with climatic environments. What may be very cold in the poles may not be the same for some temperate areas. Therefore, the study used the following categorization based on suitability for the study area:

Table 3: SAI Criteria for Assessing the Intensities of the Minimum Temperature of the Harmattan Seasons in the Study Area.

| Minimum Temperature Intensities | Range of SAI category |
|---|---|
| Extreme Warm Harmattan | 1.66 to 2.00 |
| Severe Warm Harmattan | 1.29 to 1.65 |
| Moderate Warm Harmattan | 0.85 to 1.28 |
| Near Normal Harmattan | ─ 0.84 to + 0.84 |
| Moderate Cold Harmattan | ─ 0.85 to ─ 1.28 |
| Severe Cold Harmattan | ─ 1.29 to ─ 1.65 |
| Extreme Cold Harmattan | ─ 1.66 to ─ 2.00 |

Source: Authors' modification, (2022).

The SAI categorization of harmattan intensities is given in Table 3, however, the present study focused on severe cold harmattan in the study area. Therefore, only the SAI minimum temperature range of ─1.29 and ─1.65 was used in data analysis. Similarly, the harmattan months with the SAI range of ─1.29 and ─1.65 were months in which severe cold harmattan (SCH) events had occurred.

Lastly, to determine the percentage of the occurrences of SCH events (i.e., share or proportion in relation to a whole) for the harmattan months in the study area, the number of occurrences of SCH events in a particular station was divided by the sum total of the occurrences of these events in all stations. This was then multiplied by one hundred. The formula is given as:

$$\text{Percentage} = \left(\frac{n}{\Sigma n}\right) \times 100 \quad \ldots\ldots.(2)$$

Where, n is the number of occurrences of SCH events in a particular station, $\Sigma n$ is the sum total of occurrences of SCH events in all stations, while one hundred (100) represents the hundredth part or the entirety.

## Results and Discussions

### *Frequency of Severe Cold Harmattan Events in Each Station*

*Kaduna Station:*

In this station, severe cold harmattan (SCH) events occurred 3 times (5.45%) in 60 years, 2 (8%) of these events occurred in the month of December, and 1 (3.33%) occurred in the month of January in the study area. This event did not occur at all in November and February throughout the study period (Table 4). The decadal frequency showed that SCH events were only recorded in the second, third and last decades, respectively (Table 5). These decades are the years 1971-1980, 1981-1990, and 2011-2020. These findings are in contrast with one study carried out in Europe (Twardosz et al., 2015), where the highest frequency of exceptionally cold events (during winters) occurred in the first decade (1961-1970); but in the Kaduna station, SCH events did not occur in this decade. The dis-uniformity in the occurrences of unusual climatic events in the same decades around the world may be the resultant effect of climate change, which sometimes causes opposite occurrences of these events on a regional scale (Climate Reality Projects, 2022; Kretschmer, 2021; National Geographic Society, 2022). In Kaduna station, for the decades in which SCH events occurred (decade 1971-1980, 1981-1990, & 2011-2020), findings showed that these events occurred 1 time (33.3%) each in these decades. Out of the total occurrences (which is 3 times), 2 occurred in the month of December. This represented 50% of each of the total occurrences (100%) for this month, while 1 occurred in the month of

January (representing 100% of the total occurrence for the month). Findings further revealed that SCH events had occurred in the most recent decade (2011-2020) in this station. This confirms the findings of Mgboh et al. (2020), who had earlier noted the occurrence of this event in January 2019.

Table 4: Summary of Occurrence of Severe Cold Harmattan (SCH) Events in Northwestern Nigeria throughout the Study Period (1961-2020).

| | Frequency and Percentage of Occurrence of SCH Events in Particular Month | | | | | | | | Total Occurrence for the Study Period | |
|---|---|---|---|---|---|---|---|---|---|---|
| Stations | Nov | % | Dec | % | Jan | % | Feb | % | Total | % |
| Kaduna | - | - | 2 | 8 | 1 | 3.33 | - | - | 3 | 5.45 |
| Kano | - | - | 5 | 20 | 10 | 33.33 | - | - | 15 | 27.27 |
| Gusau | - | - | 2 | 8 | 4 | 13.33 | - | - | 6 | 10.91 |
| Katsina | - | - | 9 | 36 | 6 | 20 | - | - | 15 | 27.27 |
| Sokoto | - | - | 7 | 28 | 9 | 30 | - | - | 16 | 29.09 |
| Total | - | - | 25 | 100 | 30 | 100 | - | - | 55 | 100 |

Source: Analysis of Data, (2022).

Table 5: Decadal Occurrence of Severe Cold Harmattan (SCH) Events in Kaduna (1961-2020).

| Kaduna station | Frequency and Percentage of Occurrence of SCH Events in Particular Month | | | | | | | | Total Occurrence for the Season | |
|---|---|---|---|---|---|---|---|---|---|---|
| Decades | Nov | % | Dec | % | Jan | % | Feb | % | Total | % |
| 1961-1970 | - | - | - | - | - | - | - | - | 0 | 0 |
| 1971-1980 | - | - | 1 | 50 | - | - | - | - | 1 | 33.3 |
| 1981-1990 | - | - | - | - | 1 | 100 | - | - | 1 | 33.3 |
| 1991-2000 | - | - | - | - | - | - | - | - | 0 | 0 |
| 2001-2010 | - | - | - | - | - | - | - | - | 0 | 0 |
| 2011-2020 | - | - | 1 | 50 | - | - | - | - | 1 | 33.3 |
| Total | - | - | 2 | 100 | 1 | 100 | - | - | 3 | 100 |

Source: Analysis of Data, (2022).

*Kano Station:*

In Kano, severe cold harmattan events occurred 15 times (27.27%) in 60 years, and this is shown in Table 4. Overall, 10 of these events (33.33%) occurred in the month of January, while 5 (20%) occurred in the month of December in the study area. Severe cold harmattan did not occur in November and February throughout the study period. By decadal frequency, SCH events occurred in all the decades except the fifth decade (2001-2010) (Table 6). In the decades where these events occurred, the first decade (1961-1970) had the highest frequency (5 times) in 10 years. This represented 33.33% of the total occurrences for the season, followed by the second decade (1971-1980) with 4 occurrences (26.66%). The results are similar to the findings of Twardosz et al. (2015), who found that the highest frequency of exceptionally cold winters in Europe occurred in the first decade (1961-1970). Other decades like the third, fourth and sixth recorded the same frequencies, which was 2 occurrences each (13.33%) in 10 years. The

findings mean that the third decade down to the last decade had fewer SCH events compared to the first two decades.

The findings support the studies of New et al. (2006), Grab et al. (2009), Bednorz (2011) and Van der Walt et al. (2021a), who have noted that negative extreme events of cold winters were becoming less frequent in West Africa, Lesotho, Central Spitsbergen (Norway) and South Africa respectively. In these studies, the events were noted to have reduced significantly compared to earlier decades and periods in the regions. The findings also align with the issues of global warming, which have resulted in a decline in the frequency of severe and extreme weather events in some places around the world. In relation to this, Twardosz et al. (2015) have noted a reduction in the frequency of cold winter events (Cold Winter Months) after the first decade (1961-1970) in Europe. However, the findings are in contrast with those of Zhang et al. (2012), which showed increased frequencies of striking cold weather events between 1991 to 2010.

Table 6: Decadal Occurrence of Severe Cold Harmattan (SCH) Events in Kano (1961-2020).

| Kano station | Frequency and Percentage of Occurrence of SCH Events in Particular Month | | | | | | | | Total Occurrence for the Season | |
|---|---|---|---|---|---|---|---|---|---|---|
| Decades | Nov | % | Dec | % | Jan | % | Feb | % | Total | % |
| 1961-1970 | - | - | 3 | 60 | 2 | 20 | - | - | 5 | 33.33 |
| 1971-1980 | - | - | 1 | 20 | 3 | 30 | - | - | 4 | 26.66 |
| 1981-1990 | - | - | - | - | 2 | 20 | - | - | 2 | 13.33 |
| 1991-2000 | - | - | - | - | 2 | 20 | - | - | 2 | 13.33 |
| 2001-2010 | - | - | - | - | - | - | - | - | 0 | 0 |
| 2011-2020 | - | - | 1 | 20 | 1 | 10 | - | - | 2 | 13.33 |
| Total | - | - | 5 | 100 | 10 | 100 | - | - | 15 | 100 |

Source: Analysis of Data, (2022).

*Gusau Station:*

In Gusau, SCH episodes have happened 6 times (10.91%) in the past 60 years, 2 (8%) of which occurred in December, and 4 (13.33) happened in January in the study area (Table 4). Over the whole research period, SCH was completely absent in the months of November and February. This is because harmattan gradually begins in November and its intensity progressively fades in the month of February. Regarding decadal occurrences, SCH events were completely absent in the fifth decade (2001-2010) (Table 7). This finding is in dissonance with that of Zhang et al. (2012), who indicated that the highest frequency of striking cold weather events in Eurasia was recorded in this decade (2001-2010) and in the 2000s. The work of Bhatla et al. (2016) also showed that the highest frequency of severe cold wave events in Kheri, India, occurred in the decade 2001-2010.

For other decades in Gusau, SCH events occurred 1 times each (16.66%), starting from the first decade down to the fourth decade. However, these events occurred two times (33.33%) in the most recent decade (2011-2020). This means that for this station, SCH had the highest frequency in the last decade. This is tallied with a study by Stanford University (cited in Jordan, 2016) in which striking cold winter events in the Eastern United States were noted to have increased in the last decade (2011-2020) compared to some previous decades. This also agreed with the findings of Mgboh et al. (2020) in regard to the uncommon cold events that were experienced in Northern Nigeria in the most recent decade (2011-2020).

Table 7: Decadal Occurrence of Severe Cold Harmattan (SCH) Events in Gusau (1961-2020).

| Gusau station | Frequency and Percentage of Occurrence of SCH Events in Particular Month | | | | | | | | Total Occurrence for the Season | |
|---|---|---|---|---|---|---|---|---|---|---|
| Decades | Nov | % | Dec | % | Jan | % | Feb | % | Total | % |
| 1961-1970 | - | - | 1 | 50 | - | - | - | - | 1 | 16.66 |
| 1971-1980 | - | - | - | - | 1 | 25 | - | - | 1 | 16.66 |
| 1981-1990 | - | - | - | - | 1 | 25 | - | - | 1 | 16.66 |
| 1991-2000 | - | - | - | - | 1 | 25 | - | - | 1 | 16.66 |
| 2001-2010 | - | - | - | - | - | - | - | - | 0 | 0 |
| 2011-2020 | - | - | 1 | 50 | 1 | 25 | - | - | 2 | 33.33 |
| Total | - | - | 2 | 100 | 4 | 100 | - | - | 6 | 100 |

Source: Analysis of Data, (2022).

*Katsina Station:*

For Katsina station, severe cold harmattan (SCH) events occurred 15 times (27.27%) in 60 years. This is illustrated in Table 4. Out of the total occurrences (15 times) of these events, 9 (36%) occurred in the month of December while 6 (20%) occurred in January. In this station, SCH did not occur in the months of November and February throughout the study period. Regarding decades, the occurrence of SCH events in this station is very irregular (Table 8). For the harmattan seasons, it occurred 2 times (13.33%) in the first decade, 4 times (26.66%) in the second, 2 times (13.33%) in the third, 1 time (6.66%) in the fourth, 2 (13.33%) in the firth decade and 4 (26.66%) in the last decade. The highest frequencies were experienced in the second and last decade, respectively. This may mean that there has been a return of previous severe frequency from an early decade (second decade) to the most recent decade. This

irregularity may be associated with climate change and global warming issues. Yet, this situation is likely to continue in this station, as WMO has warned of an expected rise in the frequency and intensity of severe weather and climate in in Northern Nigeria in the years to come (Falaju, 2022).

For the highest frequency of SCH events (4 times) that was also witnessed in the last decade (2011-2020) in Katsina station (see Table 8), the findings are in concord with the work of Stanford University (cited in Jordan, 2016) in which striking cold winter events were noted to have increased significantly in the last decade (2011-2020) compared to some previous decades in the Eastern United States. Nonetheless, results that revealed that the least events of SCH occurred in Katsina station in the 1991-2000 decade (Table 8) is in discordance with the study of Zhang et al. (2012), who showed that the highest frequency of striking cold events in Eurasia occurred in the 1990s (and 2000s). However, the findings well matched the report of the World Meteorological Organization [WMO] (2013) that the 1900s (together with the 2000s) were the warmest in history for both the North and South hemispheres.

Table 8: Decadal Occurrence of Severe Cold Harmattan (SCH) Events in Katsina (1961-2020).

| Katsina station | Frequency and Percentage of Occurrence of SCH Events in Particular Month | | | | | | | | Total Occurrence for the Season | |
|---|---|---|---|---|---|---|---|---|---|---|
| Decades | Nov | % | Dec | % | Jan | % | Feb | % | Total | % |
| 1961-1970 | - | - | 2 | 22.22 | - | - | - | - | 2 | 13.33 |
| 1971-1980 | - | - | 2 | 22.22 | 2 | 33.33 | - | - | 4 | 26.66 |
| 1981-1990 | - | - | - | - | 2 | 33.33 | - | - | 2 | 13.33 |
| 1991-2000 | - | - | 1 | 11.11 | - | 25 | - | - | 1 | 6.66 |
| 2001-2010 | - | - | 1 | 11.11 | 1 | 16.66 | - | - | 2 | 13.33 |
| 2011-2020 | - | - | 3 | 33.33 | 1 | 16.66 | - | - | 4 | 26.66 |
| Total | - | - | 9 | 100 | 6 | 100 | - | - | 15 | 100 |

Source: Analysis of Data, (2022).

*Sokoto Station:*

In Sokoto, severe cold harmattan (SCH) events occurred 16 times (29.09%) in 60 years, 7 (28%) of these events happened in the month of December, while 9 (30%) occurred in January (Table 4). This event did not occur at all in the months of November and February throughout the study period. Based on decadal frequency, SCH events occurred in all six decades, with the second decade having the highest frequency of occurrence (5 times in 10 years). This was followed by the first decade, which had 4 events (25%) of SCH. In the third and fourth decades, SCH events occurred 1 time each (6.25%), while the fifth decade had 2 (12.5%) occurrences. Findings also showed that SCH events occurred 3 times in the last decade (Table 9). Generally, for this station, results are in contrast with the study of Johnson et al. (2018), who noted that the highest occurrence of striking cold winter events happened between 2002 and 2014. Results are also different from the study of Van der Walt et al. (2021a) which showed that the occurrence of severe and extreme cold winter events has reduced significantly in South Africa compared to earlier decades — but findings in Sokoto station revealed that the occurrences of SCH events increased from 1 time of occurrence in the third decade (1981-1990) to 3 times of occurrence in the last decade (2011-2020) (Table 9). The marginal rise in the occurrence of SCH events in the last decade is in harmony with the work of Bello (2020), who noted that the increase in these events in Sokoto state (in the last decade) prompted the state government to distribute protective cloths to school students to tackle the situation.

Table 9: Decadal Occurrence of Severe Cold Harmattan (SCH) Events in Sokoto (1961-2020).

| Sokoto station | Frequency and Percentage of Occurrence of SCH Events in Particular Month | | | | | | | | Total Occurrence for the Season | |
|---|---|---|---|---|---|---|---|---|---|---|
| Decades | Nov | % | Dec | % | Jan | % | Feb | % | Total | % |
| 1961-1970 | - | - | 3 | 42.85 | 1 | 11.11 | - | - | 4 | 25 |
| 1971-1980 | - | - | 2 | 28.57 | 3 | 33.33 | - | - | 5 | 31.25 |
| 1981-1990 | - | - | - | - | 1 | 11.11 | - | - | 1 | 6.25 |
| 1991-2000 | - | - | 1 | 14.28 | - | - | - | - | 1 | 6.25 |
| 2001-2010 | - | - | 1 | 14.28 | 1 | 11.11 | - | - | 2 | 12.5 |
| 2011-2020 | - | - | - | - | 3 | 33.33 | - | - | 3 | 18.75 |
| Total | - | - | 7 | 100 | 9 | 100 | - | - | 16 | 100 |

Source: Analysis of Data, (2022).

*The Region*

In Northwestern Nigeria, all the selected stations did not experience SCH in the month of November and February; however, these events occurred in all stations (Table 4). Throughout the study time frame, SCH happened 55 times in the study area, which represents 100% of the total occurrences ─ 30 occurred in the month of January, while 25 were witnessed in the month of December. This represents 55% and 45%, respectively, during the study period. The months in which SCH events were experienced are the peak months of harmattan in the study area (Folorunsho et al., 2023). In the month of December, the Katsina station experienced the most SCH events (36% of total occurrence), followed by Sokoto (28%) and Kano (20%), with Kaduna and Gusau having the same (8%) occurrence (Table 4). In the month of January during the period of study, Kano station experienced the most SCH events with 33.33%, followed by Sokoto (30%), Katsina (20%), Gusau (13.33), with Kaduna having the least (3.33%).

Regarding the geographical spread of SCH events for the entire harmattan seasons (November, December, January, and February), Sokoto witnessed the most events (29.09%) than any other station; however, this was closely followed by Kano and Katsina, which had the same frequency (27.27%). Stations like Kaduna had the lowest frequency of SCH, this happened 3 times (5.45%) in 60 years, followed by Gusau, with a total of 6 SCH events (10.91%) (Table 4). The Kaduna station, which had the lowest frequency of SCH events, corresponds with its location in relation to the onset of the harmattan wind that comes from the north east, as this station is the farthest geographical station in the study area in relation to this wind (Folorunsho et al., 2023). Stations like Sokoto, Kano and Katsina, which are in the same latitude as Gusau in relation to the onset of this wind, witnessed more SCH than Gusau. This may be triggered by factors such as elevation, land-use and relief of this station and other anthropogenic activities.

In the first decade (1961-1970), out of the total occurrences of SCH events, Kano station witnessed the most (5 times in 10 years or 41.66%), followed by Sokoto (4 times or 33.33%), Katsina (2 times or 16.66%) and Gusau (1 time or 8.33%). This event (SCH) did not occur in Kaduna in this decade (Table 10). In the second decade (1971-1980), Sokoto experienced the highest SCH events (33.33%), followed by Kano and Katsina, with the same occurrence (26.66%). The lowest SCH events were experienced in Kaduna and Gusau with the same frequency (6.66%). This decade (1971-1980) had the highest occurrence of SCH events among all the decades (Table 11). In the next decade (1981-1990), Kano and Katsina experienced the highest SCH events, with the same occurrence (28.57%), followed by Kaduna, Gusau and Sokoto, all with the same frequency (14.28%) (Table 10). In the following decade (1991-2000), Kano experienced the highest SCH events (40%), followed by Gusau, Katsina and Sokoto, all with the same occurrence (20%). This event (SCH) did not occur in Kaduna in this decade. In

the fifth decade (2001-2010), SCH events only occurred in Katsina and Sokoto, with the same frequency (50%) out of the total occurrence for this decade. In the last decade (2011-2020), Katsina witnessed the highest SCH events (33.33%), followed by Sokoto (25%), Kano and Gusau had the same occurrence (16.66%). The lowest SCH events were experienced in Kaduna (8.33%) (Table 10). Results of the last decade are in line with Abu (2019), Bello (2020) and Mgboh et al. (2020), which noted periods of SCH events, especially in states such as Kano, Katsina and Sokoto.

Table 10: SAI Decadal Summary of SCH in Northwestern Nigeria.

| Decades and Seasonal Frequency (1961-1970) | Stations and Percentage of Occurrence of Severe Cold Harmattan (SCH) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ka | % | Kn | % | Gu | % | Kt | % | So | % | Total | % |
| Season Frequency | - | - | 5 | 41.66 | 1 | 8.33 | 2 | 16.66 | 4 | 33.33 | 12 | 100 |
| (1971-1980) | | | | | | | | | | | | |
| Season Frequency | 1 | 6.66 | 4 | 26.66 | 1 | 6.66 | 4 | 26.66 | 5 | 33.33 | 15 | 100 |
| (1981-1990) | | | | | | | | | | | | |
| Season Frequency | 1 | 14.28 | 2 | 28.57 | 1 | 14.28 | 2 | 28.57 | 1 | 14.28 | 7 | 100 |
| (1991-2000) | | | | | | | | | | | | |
| Season Frequency | - | - | 2 | 40 | 1 | 20 | 1 | 20 | 1 | 20 | 5 | 100 |
| (2001-2010) | | | | | | | | | | | | |
| Season Frequency | - | - | - | - | - | - | 2 | 50 | 2 | 50 | 4 | 100 |
| (2011-2020) | | | | | | | | | | | | |
| Season Frequency | 1 | 8.33 | 2 | 16.66 | 2 | 16.66 | 4 | 33.33 | 3 | 25 | 12 | 100 |

*Ka: Kaduna, Kn: Kano, Gu: Gusau, Kt: Katsina, So: Sokoto. Source: Analysis of Data, (2022).

Amongst decades in the study area, the second decade (1971-1980) witnessed the most SCH events (27.27%), followed by the first (1961-1970) and last decades (2011-2020) with the same percentage (21.81%). On the other hand, the fifth decade (2001-2010) witnessed the lowest SCH events (7.27%), followed by the fourth decade (9.09%) and the third decade (12.72%) (Table 11). Results are in contrast with the findings of Twardosz et al. (2015), who revealed that the highest frequency of exceptionally cold winter events in Europe occurred in the first decade (1961-1970). Results are also different from the work of Zhang et al. (2012), who established that the 1990s and 2000s witnessed the highest occurrence of striking cold winter events in Eurasia. However, the findings support the study of WMO (2013), in which the 1900s and 2000s were noted to be the warmest decades in history for both the North and South hemispheres, periods that saw unprecedented melting of glaciers. The findings of the most recent decade, which ranked second (with the first decade) in the occurrence of SCH events in consonance with Adunwoke (2018), Abu (2019), Bello (2020), Mfonobong (2020), Mgboh et al. (2020) and Chime (2022) who showed several events of SCH in this decade (2011-2020).

Overall, the factors that may be responsible for the occurrences of severe harmattan events (SCH) in each station may be related to the impacts of human activities on the local climate, such as various land-use actions, deforestation and the use of black energy. These are the key drivers of modern climate change and the producers of anomalous events. Similarly, the variations of these events (SCH) over time and space proportions in the study area may also be linked to differences in anthropogenic actions, as this has been noted by several scientists in different geographical environments (Trenberth, 2018; Kretschmer, 2021; Climate Reality Projects, 2022; National Geographic Society, 2022; Folorunsho et al., 2023).

Table 11: Frequency and Percentage of SCH among Decades in Northwestern Nigeria

| Decades | Total Frequency of Occurrence in Each Decade for the Study Area | Percentage (%) |
|---|---|---|
| (1961-1970) | 12 | 21.81 |
| (1971-1980) | 15 | 27.27 |
| (1981-1990) | 7 | 12.72 |
| (1991-2000) | 5 | 9.09 |
| (2001-2010) | 4 | 7.27 |
| (2011-2020) | 12 | 21.81 |
| Total | 55 | 100 |

Source: Analysis of Data, (2022).

***Coping Strategies to Severe Cold Harmattan (SCH) Events in the Study Area***

The residents of Northwestern Nigeria have endeavored to devise survival strategies during episodes of severe harmattan. One of the most common strategies adopted is the avoidance of unnecessary outdoor exposures (Adunwoke, 2018; Mgboh et al., 2020). This method has proven to be very effective in limiting the negative impact of severe events in the study area (Afolabi, 2022). However, this, on the other hand, affects socio-economic activities, as shops and business premises are sometimes delayed in opening, and social gatherings are also reduced (Mgboh et al., 2020).

During severe events (SCH), it is common to see the locals (people living in Northwestern Nigeria) wearing warm clothes. Most of the cloths are made of wool or fleecy synthetic fibres. Some others wear cloths made with cotton. Similarly, blankets, duvets, socks and head warmers are also important household items used by the Northwestern people during periods of severe

cold harmattan (Bello, 2020; Afolabi, 2022). This has also proven to be helpful in keeping warm and reducing the risks of severe cold-related ailments (Mgboh et al., 2020; Afolabi, 2022). Furthermore, the consumption of warm beverages by people during SCH events in order to keep warm is also very common. While at night, it is traditional to see outdoor vendors and night guards gather in cycles around fire stoked by firewood, warming up their hands and legs (Mgboh et al., 2020; Afolabi, 2022). Similarly, windows and doors of houses are usually closed and protected against cold penetration. These methods have also been very helpful in reducing the impacts of cold-related ailments such as pneumonia and hypothermia on the residents (Adesanya, 2017; Adunwoke, 2018). However, modern interventions (such as the provision of house heaters, amongst others) and governmental supports (such as the provision of shelters and cold protective cloths) are very necessary for reducing the impacts of SCH, especially on poor residents.

## Conclusion

The harmattan months of the SAI range of −1.29 and −1.65 are months in which severely cold harmattan events occurred. Findings in this study have revealed that this event (SCH) has occurred in all stations in the study area. Overall, this event has occurred 55 times in 60 years. Across the geographical stations, the findings showed that SCH had the highest frequency of occurrence in stations that lay directly to the onset of the harmattan wind (Sokoto-15 times or 29.09%; Kano-15 times or 27.27% and Katsina-15 times/27.27%), with the exception of Gusau (6 times or 10.91%), which as earlier mentioned may be attributed to factors such as topography, relief, land-use and or global warming problem. Kaduna station had the lowest frequency of occurrence of SCH in the study area throughout the entire period. It only happened 3 times

(5.45%). This may be because it is the farthest station in the study area to the onset of the wind. Among decades, findings revealed that the second decade (1971-1980) had the highest occurrences of SCH in the study area (15 times in 10 years or 27.27%), with Sokoto witnessing the highest of this event and both Kaduna and Gusau witnessing the lowest. The most recent decade (with the first decade) ranked second in regard to the total frequency of SCH events, but the Katsina station experienced the highest of this event (SCH) in this decade, while Kaduna had the lowest. However, SCH occurred in all the stations in the most recent decade (2011-2020).

There is evidence from previous studies that the occurrence of severe cold events, such as during the harmattan seasons, will jeopardize the health of people and may likely put the health of residents of the Northwestern region of Nigeria at great risk of harmattan related health outcomes such as pneumonia, sore throat, asthma, severe breaking of lips and foot, bronchitis, unusual tiredness, dehydration and even death. This was the case in the Northwestern states of Kano and Sokoto in the most recent decade (2011-2020), where several people were hospitalized because of the severe harmattan cold. Based on the findings, it is recommended that the Federal Government of Nigeria, as well as the state governments in the Northwestern region, should put adequate measures in place that focus on climate change abatement strategies such as conventional mitigation, reduction in negative emissions, and stopping of negative land use practices. This is because the occurrences of unusual weather events such as SCH have been associated with the negative impact of climate change caused by man activities.

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