JADS

Journal of African Development Studies
Volume 11, No. 2, December 2024
ISSN: 2079-0155 (Print); 2710-0022 (Online)

BUILDING CAPACITIES IN THE CIVIL SERVICE

Ethiopian Civil Service University
Addis Ababa. Ethiopia
P.O. Box. 5648

Cool Harmattan Episodes in the Northwestern Region of Nigeria (1961 – 2020), by Alex Folorunsho [1]*, Adewale Francis Olatunde [2], Samuel Ibbi Ibrahim [3], Nokshuwan Emmanuel Jidauna [4]

Abstract

This study examined cool harmattan episodes in the Northwestern Region of Nigeria from 1961 to 2020. Over a period of 60 years, monthly minimum temperatures of the harmattan seasons (November to February) were collected and analyzed for five (5) selected stations: Kaduna, Kano, Gusau, Katsina, and Sokoto. The study concentrated on evaluating sub-periods occurrences of cool harmattan events in the study area. Specifically, the analysis encompassed the 1961-1990 and 1991-2020 sub-periods, respectively. A Standard Anomaly Index (SAI) was employed in this study to assess cool harmattan episodes (CHEs) during the harmattan seasons. The categorization of the index was adapted from a similar study conducted in the same geographic region, which established SAI thresholds for various levels of harmattan intensity. However, that study specifically concentrated on severe cold harmattan events, whereas the present study extends the application of the SAI to examine cool harmattan episodes (CHEs). Findings revealed that stations such as Kano, Katsina and Sokoto experienced an increase in CHEs during the most recent sub-period (1991-2020) compared to the earlier sub-period (1961-1990). In contrast, stions like Kaduna and Gusau saw a decline in CHEs during the latter sub-period (1991-2020) compared to the former or first sub-period (1961-1990). The cause of the decline in CHEs in these stations (Kaduna & Gusau) may be associated with the issue of climate change. The study recommends that further research is needed to better understand the underlying factors influencing the regional differences and to inform targeted climate adaptation measures.

Keywords: Northwestern Nigeria, Cool Harmattan, Minimum Temperature, Standard Anomaly Index, Harmattan Season, Sub-Period.

[1, 2, 3 & 4]Department of Geography, Faculty of Social Sciences, Federal University Lokoja, Nigeria.

*Corresponding author's email: folorunsho.alex66@gmail.com Tel: +2349060212109

JADS Vol. 11, No. 2, DOI: https://doi.org/10.56302/jads.v11i2.11209

Introduction

Human-induced climate change is increasing climate variability and the frequency of severe, extreme, and rare events during cold seasons worldwide (National Aeronautics and Space Administration [NASA], 2023; European Commission, 2023; Folorunsho et al., 2024). Human activities such as burning fossil fuels, deforestation, and industrialization are eliciting discernible signatures in the atmosphere, thereby exerting a progressive (and pronounced) influence on the global climate. This climate change can also cause opposite conditions in the climate elements of a particular area, different from neighboring environments (Hoegh-Guldberg et al., 2007; National Weather Service, 2019; European Commission, 2023).

The impact of climate change around the world have been leading to decline in the occurrences of cool (moderate, temperate or fair) events during winters and cold seasons (such as the harmattan season) in favour of the escalation of rare and harsh episodes, especially during the most recent sub-period (1991-2020) (Luedeling et al., 2009; Twardosz & Kossowska-Cezak, 2015; Johnson et al., 2018; Templer & Reinmann, 2018; Trenberth, 2018; Abolo, 2023; Van der Walt & Fitchett, 2021). Nigeria, particularly the Northwestern region, is not exempted from regions that have been witnessing a decline in cool harmattan episodes (CHEs) within the cold season (harmattan), especially in the most recent sub-period (1991-2020). This has been very disturbing and has been attributed to the negative impact of climate change (Adunwoke, 2018; Ogbaje, 2018; Bello, 2020; Mfonobong, 2020; Chime, 2022). For instance, the study of Folorunsho et al. (2023) on decadal variations of minimum temperature during harmattan seasons in this region revealed that recent decades such as the 1991-2000, 2001-2010 and 2011-2020 were getting warmer compared to earlier decades such as the 1961 to 1970 decade for most of the study stations. This, therefore, is likely to reduce the occurrence of cool harmattan episodes in the region. Another study conducted by the same authors at the beginning of 2024 also indicated that other intensities, such as severe harmattan events, were escalating in the same region.

Yet, scientists have associated cool episodes occurring within cold seasons with better and clear human thoughts, reduction of inflammations, improve sleep quality, and beneficial for skin health because it constricts blood vessels. It also lowers some disease risks such as malaria and dengue fever (Baum 2018; Abbott, 2022). In contrast, researchers have documented unfavourable situations during the events of severe and extreme cold seasons (Sommer et al., 2020; Hubbart, 2022; Grandoni, 2023). It has been noted that there is rise in some health risk such as asthma, catarrh, tonsillitis, influenza, pneumonia, bronchitis, sickle cell, rheumatism, arthritis, death from hypothermia, and at times even cerebrospinal meningitis during unusual or very cold harmattan conditions (Meade *et al*., 2010; Okeahialam, 2016; Akpunonu & Onyenucheya, 2019).

The harmattan is a season that occurs in West Africa from November to February. The season is notable for its wintry weather; however, dust haze is another trait associated with the season. Yet, cool conditions are notable during the harmattan periods (Folorunsho et al., 2023). The impact of climate change has been noted to have caused decline in the episodes of cool conditions during the seasons of harmattan and have escalated the occurrences of severe events in the last sub-period (1991-2020) compared to earlier sub-periods (such as the 1961-1990 period) (Templer & Reinmann, 2018). This situation has become worrisome because there have been several indications about the decline in the Northwestern region of Nigeria in the most recent sub-period (1991-2020) (Adunwoke, 2018; Ogbaje, 2018; Bello, 2020; Mfonobong, 2020; Chime, 2022). Due to its proximity to the Sahara Desert, this region is one of the coldest in Nigeria during the harmattan season. Nonetheless, scientific studies indicated a warming decadal harmattan seasons in this region and an increase in the frequency of unusual harmattan events, deviating from the typical, stable conditions experienced in the past (Folorunsho et al., 2023; Folorunsho et al., 2024). This has necessitated an investigation into the varying intensities of harmattan in the region, particularly the cooler intensity, which has potential health benefits for the local population. The implication of the decline in cool harmattan episodes is that the people living in this region will be exposed to other spectrums (intensities) of the harmattan seasons such as severe and unusual events/episodes which may put their health at risks of illnesses associated with the events (Folorunsho et al., 2024). It is therefore necessary to examine cool harmattan episodes (CHEs) in the Northwestern region of Nigeria, between the two most recent sub-periods (1961-1990 & 1991-2020). The understanding of the CHEs over time (sub-periods) and space (region) will inform targeted climate adaptation measures and contribute to the broader knowledge of climate dynamics in the Northwestern region of Nigeria.

There exists a paucity of scholarly investigations concerning cool harmattan episodes (CHEs), denoting moderate cold harmattan (MCH) events within scientific discourse. The implications of the decline in the occurrences of moderate temperature events have not been given special attention as the occurrences of weird and unusual episodes, despite the interconnectedness of these events. A number of studies majorly on winter seasons have examined topics related to declining cool temperature events during the cold seasons. For instance, Kreyling (2010) examined winter climate change in some temperate areas. In the study, it was revealed that there has been decline in cold winters in some parts of the temperate region, in the most recent sub-period (1991-2020) compared to some earlier periods. The work of Dahl et al. (2023) on warmer winters resulting in reshaping of the European beech forest soil microbiome also showed declines in cool and cold events in recent years. In line with these studies, Collins et al. (2024) noted that the impact of climate change may demonstrate global interconnectedness in occurrences, in some areas of the world. Pratolongo and Plater (2019) associated the decline in cool episodes in some parts of temperate coastal wetlands with the increased human population in this area and the influence of their activities on the local climate.

The work of Shabbar and Bonsal (2003) on the assessment of changes in winter cold and warm spells over Canada showed distinct increases in cold spells during the study period in the eastern part and a decline in the western region. However, an earlier study of Bonsal et al.

(2001) on the characteristics of daily and extreme temperatures over Canada had also noted increased cooling episodes in northeast of the country in the most recent sub-period (1991-2020) compared to some previous sub-periods. Similarly, a recent report by the World Meteorological Organization [WMO] (2021) revealed cooler winters in Texas (USA) in the later part of the last sub-period (1991-2020). In China, Fu, and Ding (2020) carried out a study on changing characteristics of the winter temperature. It was demonstrated that there was an overall upward trend of winter temperature in sixty years (two sub-periods). This means that there was a slight decline in cool and moderate events in favour of warmer winters during the study period.

In Africa, the study of Fernandez et al. (2023) on climate change impacts on winter chill in Mediterranean temperate fruit orchards revealed a decline in cool episodes in some parts of northern African. Conversely, Fihlani and Booty (2023) in an article on cold snaps in South Africa showed that there have been upsurges in cool events during the cold season in some parts of Johannesburg, in the later part of the last sub-period (1991-2020). Over West Africa, Quaicoe (2023), have observed that the harmattan season in Ghana has become increasingly unpredictable, with many regions experiencing abrupt shifts in atmospheric conditions. These changes, attributed to the impacts of climate change, have led to periods of milder harmattan temperatures as well as instances of more extreme weather events. The World Health Organization [WHO] (2023) also noted that climate change is directly contributing to a range of humanitarian emergencies, including heatwaves and the occurrence of extreme events in different regions such as in West Africa, all of which are increasing in scale, frequency, and intensity. This broader climatic impact may also disrupt or influence the harmattan seasons and may cause a noticeable decline in cooler episodes.

In Nigeria, the work of Balarabe (2018) on the thirty years trend analysis of harmattan season visibility and temperature in Sahel Zone of Nigeria revealed that climate anomalies have created short-duration climatic change and variability as against the normal cycle, thereby causing the harmattan temperature to rise during the study period. The study noted that this issue has posed, and continues to pose, a significant threat to lives and property in Nigeria. Specifically in the Northwestern region of the country, there have been indications about the decline of cool harmattan episodes (CHEs), and this may be associated with warming harmattan seasons in recent times (Folorunsho et al., 2023).

Most research works that have been carried out on the harmattan seasons in the Northwestern region of Nigeria focused on dust haze and poor visibility during the season due to the region's vulnerability to severe dust storms, which can significantly impact air quality and health (McTainsh 1980; Aweda et al. 2017; Danlami et al. (2018). However, regarding harmattan intensity, the study of researchers like Abaje and Oladipo (2019) on recent changes in temperature in some areas of the Northwestern region and that of Folorunsho et al. (2023) as was mentioned earlier showed a warming harmattan in this region. These events have potential to contribute to a decline in favorable events, such as cool harmattan episodes. This, therefore, necessitates the assessment of CHEs in the region. Knowledge of the long-term climatic occurrences of cool harmattan episodes (CHEs) of the harmattan seasons will be provided by sub-periods assessment of the events. This will offer an opportunity to understand the occurrences of the events in two sub-periods. Therefore, the objective of this study is to examine the sub-periods occurrences of CHEs during the harmattan seasons in the Northwestern region of Nigeria from 1961 to 2020.

Study Area

The Northwestern region of Nigeria constitutes one of the six geopolitical zones within the country, encompassing approximately 26% of the total landmass, equivalent to 216,065 km². This geopolitical zone comprises seven states out of the 36 in Nigeria, namely Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara. Geographically, it shares borders with Niger Republic to the North, Benin Republic to the West, and it is adjoining the Northeastern and North Central geopolitical zones of Nigeria to the East and South, respectively (Africa Portal, 2020). The study area is situated between latitudes 9^{O} to 13^{O} 28‘N of the Equator and longitudes 3^{O} 28′ E to 10^{O} 37′ E of the Greenwich Meridian (Folorunsho et al., 2023) (Fig 1).

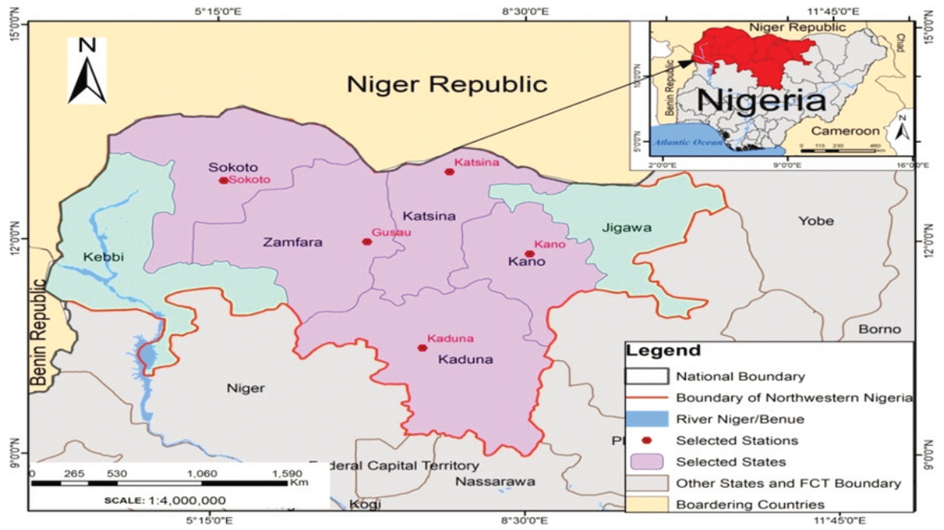

Figure 1: The Study Area
Adapted from: Folorunsho et al. (2023).

The study area has a tropical wet and dry climate, under the influence of the Inter-tropical Convergence Zone (ITCZ) movement. This area is known for its year-round elevated temperature, with a mean annual temperature fluctuating from approximately 28^{O}C in Sokoto to around 25^{O}C in Kaduna State. Specifically, Sokoto has a mean annual temperature of 28°C, with monthly averages ranging from 25°C in January to 35°C in May, one of the hottest months of the year. Gusau also has a mean of 28°C, with temperatures between 22°C in January and 33°C in May. Kano experiences a mean annual temperature of 30°C, with temperature fluctuating between 21°C in January and 34°C in May. Katsina has a mean of 31°C, with monthly temperatures from 22°C in January to 33°C in May. Kaduna's mean annual temperature is 25°C, with a range from 26°C in January to 28°C in May (Weather Spark, 2024).

Annual precipitation levels within the study area range from 500 mm in the extreme northern part to approximately 1000 mm in the southern part (Folorunsho et al., 2024). Sokoto receives an average annual rainfall of 632 mm (53 mm/month), while Gusau receives 547 mm (45 mm/month). Kano is 800 mm annually (67 mm/month), and Katsina receives 623 mm (52 mm/month). Kaduna, the wettest, receives 1,156 mm annually (96 mm/month) (Ismail & Oke, 2012; Salisu et al., 2017; Aldrees et al., 2024; Weather Spark, 2024).

Regarding the harmattan, the sun is usually directly overhead at the Tropic of Capricorn between the months of November and February, which causes the wind system and pressure belt to travel southward. This period corresponds to the occurrence of the harmattan season in the Northwestern region of Nigeria (Folorunsho et al., 2024).

The vegetation of the study area is characterized as Savanna. The northern part of the study region falls within the Sudan Savanna belt, characterized by grasslands featuring sparse and stunted trees (Karkana, & Mohammed, 2018). In contrast, the southern segment of the area is situated in the Guinea Savanna belt, typified by woodlands and tall grasses (Karkana, & Mohammed, 2018). Approximately 80% of the populace engages in agricultural activities in varying capacities, with cattle rearing prominently predominant (Folorunsho et al., 2024). Agricultural practices in this region are mostly reliant on rainfall. Despite being the most

densely populated area in Nigeria, with an estimated population of approximately 45,510,234 (Nwaerema & Edokpa, 2019), the Northwestern region concurrently exhibits the highest prevalence of individuals lacking formal education and experiencing poverty (Folorunsho et al., 2024). Poverty and low education in this region can hinder adaptive strategies to climate change, making communities more vulnerable to the effects of declining cool harmattan episodes.

Materials and Methods

This study was conducted using the mean monthly minimum temperature of the harmattan seasons (November and February) from 1961 to 2020. Data were sourced from the World Bank Group, the Climate Change Knowledge Portal, and past researchers including Olatunde et al. (2019) and Folorunsho et al. (2023), across five selected meteorological stations in the study area. These stations included Kaduna, Kano, Gusau, Katsina, and Sokoto, and were selected based on data availability. Two stations were left out from the study (Jigawa & Zamfara) because they have ample years of incomplete and missing data. The exclusion of the two climatic stations may slightly reduce the spatial coverage of the study and the representativeness. Nevertheless, the remaining stations provide sufficient data to capture regional trends, ensuring that the findings remain valid and relevant for the broader context. A Standard Anomaly Index (SAI) was used to determine the cool harmattan episodes (CHEs) for all of the harmattan months (November, December, January, and February). The formulation for the SAI is given below:

$$x_i = \frac{\mathbf{r} - \mathbf{r_i}}{\sigma} \quad \ldots\ldots\ldots (1)$$

Where 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 (Folorunsho et al., 2024).

In scientific research, this index (SAI) is employed for both temperature and precipitation anomalies, as indicated in the studies of Dilip et al. (2012), Koudahe et al. (2017), Marelign (2020) and European Union (2020). However, the categorization of the index for this study was adapted from a similar study conducted in the same geographic region, which established SAI thresholds for various levels of harmattan intensity (Table 1). However, that study specifically concentrated on severe cold harmattan events (Folorunsho et al., 2024), whereas the present study extends the application of the SAI to examine cool harmattan episodes (CHEs) (Table 1).

The categorization of harmattan intensities based on SAI is outlined in Table 1. However, the current study specifically concentrated on cool harmattan episodes (CHEs), also referred to as moderate cold harmattan (MCH) events in the study. Consequently, solely the SAI minimum temperature range of ─ 0.85 to ─ 1.28 was employed in the course of data analysis. Similarly, the harmattan months with the SAI range of ─ 0.85 to ─ 1.28 were months in which cool harmattan episodes (CHEs) had occurred. Analyzing cool harmattan episodes allows for a better understanding of the changing dynamics of the intensity among sub-periods and their broader climatic implications. In the study, the reference to cool harmattan episodes (CHEs) corresponds with the occurrences of moderate cold harmattans (MCH) due to the inherently temperate (middle/modest) nature of these events (i.e., cool, and moderate). Similarly, the terminologies 'episodes' and 'events' are used interchangeably in this study. They are used in reference to the occurrences of climatic happenings or phenomena such as cool/moderate harmattans.

Table 1: SAI Yardstick for Investigating the Intensities of 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 (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: Folorunsho et al. (2024).

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

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

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

Results and Discussion

Frequency of Cool Harmattan Episodes (CHEs) in Each Station

Kaduna Station:
In Kaduna, CHEs occurred 37 times in 60 years. This represented 20.32% of the total occurrences across all stations (Table 2). Specifically, majority of these events occurred in December (24 times & 26.37%), followed by January (10 times & 12.5%). These findings support the study of Folorunsho et al. (2023), who remarked that December and January constitute the zenith of the harmattan season in Northern Nigeria. On the other hand, CHEs only occurred three times (50%) in November, and were completely absent in February (Table 2). Regarding sub-periods occurrences, results showed that the first sub-period (1961-1990) witnessed the highest frequency of CHEs when compared to the most recent sub-period (1991-2020) (Table 3). In the first sub-period, CHEs occurred twenty times in 30 years. This represented 54.05% of the total occurrences of the events for the harmattan seasons (60 years) in this station. Conversely, CHEs occurred seventeen times in the span of 30 years in the second sub-period (1991-2020). This constituted 45.94% of the total occurrences of the events for the harmattan seasons (60 years) in this station (Table 3). Table 3 showed that the majority of CHEs occurred in December, in the first sub-period, and were not experienced in February, in the two sub-periods.

Findings of this station support the studies of Kreyling (2010), Fu and Ding (2020), Dehl et al. (2023) and Fernandez et al. (2023), all of whom have noted declines of cool episodes during cold seasons in the most recent sub-period (1991-2020) compared to some earlier periods in parts of the temperate region, China, Europe and extreme North Africa, respectively. Contrarily, findings of the Kaduna station are different from the research works carried out by Shabbar and Bonsal (2003), WMO (2021) and Fihlani & Booty (2023), all of whom have noted upsurges in the frequencies of cool episodes during cold seasons in the last sub-period (1991-2020) compared to some previous sub-periods in eastern Canada, Texas (USA) and parts of Johannesburg (South Africa) respectively. Yet, the National Weather Service (2019) and

European Commission (2023) have noted that the impact of climate change may manifest differently around the world.

Findings also agree with the study of Folorunsho et al. (2023) who revealed that recent decades during the harmattan seasons were getting warmer compared to some earlier decades in the Northwestern region. This may have caused the decline in CHEs in this station.

Table 2: Summary of the Occurrences of Cool Harmattan Episodes (CHEs) in Northwestern Nigeria throughout the Study Period (1961-2020).

	Frequency and Percentage of Occurrence of CHEs in Particular Month								Total Occurrence for the Study Period	
Stations	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
Kaduna	3	50	24	26.37	10	12.5	-	-	37	20.32
Kano	-	-	17	18.68	20	25	-	-	37	20.32
Gusau	3	50	23	25.27	12	15	-	-	38	20.87
Katsina	-	-	13	14.28	22	27.5	2	40	37	20.32
Sokoto	-	-	14	15.38	16	20	3	60	33	18.13
Total	6	100	91	100	80	100	5	100	182	100

Source: Analysis of Data, (2022).

Table 3: Sub-Periods Occurrences of Cool Harmattan Episodes (CHEs) in Kaduna (1961-2020).

Kaduna station	Frequency and Percentage of Occurrence of CHEs in Particular Month								Total Occurrence for the Season	
Sub-Periods	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
1961-1990	2	66.66	15	62.5	3	30	-	-	20	54.05
1991-2020	1	33.33	9	37.5	7	70	-	-	17	45.94
Total	3	100	24	100	10	100	-	-	37	100

Source: Analysis of Data, (2022).

Kano Station:
In this station, the events of CHEs have been witnessed 37 times in 60 years. This constituted 20.32% of the total occurrences across all stations (Table 2). Specifically, for the harmattan seasons, January recorded the highest frequency of CHEs in Kano. These events occurred twenty times (18.68%) in 60 years, followed by December, when the events were witnessed 17 (18.68%). The CHEs were completely absent in November and February (Table 2). These findings are in accord with the study of Folorunsho et al. (2023), who noted that December and January were the peak of the harmattan season in Northern Nigeria.

The sub-periods frequency for this station showed an upsurge of CHEs events in the most recent sub-period (1991-2020) compared to the first sub-period (1961-1990) (Table 4). These events occurred twenty-two times (59.45%) in 30 years in the most recent sub-period (1991-2020) and fifteen times (40.54% in 30 years) in the first sub-period (1961-1990). Table 4 showed that the majority of CHEs occurred in December, in the second sub-period, and were not observed in November and February, in the two sub-periods. Findings are in concord with the studies of Shabbar and Bonsal (2003), WMO (2021) and Fihlani & Booty (2023), all of whom noted upsurges in the frequencies of cool episodes during cold seasons in the last sub-period (1991-2020) compared to some previous sub-periods in eastern Canada, Texas (USA) and parts of Johannesburg (South Africa) respectively. These according to Collins et al. (2024) may demonstrate the global interconnectedness of climate events. However, results differ from that of Kreyling (2010), Fu and Ding (2020), Dehl et al. (2023), Fernandez et al. (2023) and

Folorunsho et al. (2023), who have noted declines of cool episodes during cold seasons in the most recent sub-period (1991-2020) compared to some earlier periods in some parts of the temperate region, China, parts of Europe, extreme North Africa and the Northwestern region of Nigeria respectively.

Table 4: Sub-Periods Occurrences of Cool Harmattan Episodes (CHEs) in Kano (1961-2020).

Kano station	Frequency and Percentage of Occurrence of CHEs in Particular Month								Total Occurrence for the Season	
Sub-Periods	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
1961-1990	-	-	4	23.52	11	55	-	-	15	40.54
1991-2020	-	-	13	76.47	9	45	-	-	22	59.45
Total	-	-	17	100	20	100	-	-	37	100

Source: Analysis of Data, (2022).

Gusau Station:
This station witnessed CHEs 38 times (20.87%) in 60 years (Table 2). December experienced the highest frequency of these events in 60 years (23 times & 25.27%) more than any other harmattan month in this station. This was followed by January (12 times & 15%), then November (3 times & 50%) (Table 2). Majority of the events happened in December and January, which support the study of Folorunsho et al. (2023), who remarked that these months constitute the zenith of the harmattan season in Northern Nigeria. Regarding sub-periods, Table 5 revealed that the highest frequency of CHEs occurred in December, in the second sub-period, and CHEs were completely absent in February. Similarly, in relation to sub-periods, CHEs witnessed a decline in the most recent sub-period (1991-2020) (Table 5). In this sub-period (1991-2020), the events occurred seventeen times (44.73%) in 30 years compared to the first sub-period (1961-2020), where the events occurred twenty-one times (55.26%). Findings agree with the study of Folorunsho et al. (2023) who revealed that recent decades during the harmattan seasons were getting warmer compared to some earlier decades in the Northwestern region. This warming trend may have contributed to the decline in CHEs observed at this station. Likewise, results are in consonance with the studies of Kreyling (2010), Fu and Ding (2020), Dehl et al. (2023) and Fernandez et al. (2023), all of whom have noted declines of cool episodes during cold seasons in the most recent sub-period (1991-2020) compared to some earlier periods in some parts of the temperate region, China, Europe and extreme North Africa respectively. As earlier mentioned, the impact of climate change may demonstrate global interconnectedness in occurrences, in some areas of the world (Collins et al., 2024).

Table 5: Sub-Periods Occurrences of Cool Harmattan Episodes (CHEs) in Gusau (1961-2020).

Gusau station	Frequency and Percentage of Occurrence of CHEs in Particular Month								Total Occurrence for the Season	
Sub-Periods	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
1961-1990	2	66.66	10	43.47	9	75	-	-	21	55.26
1991-2020	1	33.33	13	56.52	3	25	-	-	17	44.73
Total	3	100	23	100	12	100	-	-	38	100

Source: Analysis of Data, (2022).

Conversely, findings of this station are in discordance with that of Shabbar and Bonsal (2003), WMO (2021) and Fihlani & Booty (2023), who have noted upsurges in the frequencies of cool episodes during cold seasons in the last sub-period (1991-2020) compared to some previous sub-periods in eastern Canada, Texas (USA) and parts of Johannesburg (South Africa) respectively.

Katsina Station:
In this station, CHEs events have occurred thirty-seven times in 60 years. This represented 20.32% of the total occurrences across all stations (Table 2). Unlike Kaduna, Kano and Gusau, January recorded the highest frequency of CHEs in Katsina for the harmattan seasons (Table 2). These events happened twenty-two times (27.5%) in 60 years in this month (January), followed by December, where the events were witnessed 13 (14.28%). These events only occurred two times (40%) in February and were completely absent in November (Table 2).

Table 6: Sub-Periods Occurrences of Cool Harmattan Episodes (CHEs) EVENTS in Katsina (1961-2020).

Katsina station	Frequency and Percentage of Occurrence of CHEs in Particular Month								Total Occurrence for the Season	
Sub-Periods	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
1961-1990	-	-	4	30.76	11	50	2	100	17	45.94
1991-2020	-	-	9	69.23	11	50	-	-	20	54.05
Total	-	-	13	100	22	100	2	100	37	100

By sub-periods frequency, this station experienced an upsurge of CHEs events in the most recent sub-period (1991-2020) compared to the first sub-period (1961-1990) (Table 6). The events occurred twenty times (54.05%) in 30 years in the most recent sub-period (1991-2020) and seventeen times (45.94%) in the first sub-period (1961-1990). Findings agree with the studies carried out by Shabbar and Bonsal (2003), WMO (2021) and Fihlani & Booty (2023), all of whom have noted upsurges in the frequencies of cool episodes during cold seasons in the last sub-period (1991-2020) compared to some previous sub-periods in their various study areas. However, results are different from the studies of Kreyling (2010), Fu and Ding (2020), Dehl et al. (2023) and Fernandez et al. (2023), who have noted declines of cool episodes during cold seasons in the most recent sub-period (1991-2020) compared to some earlier periods in some parts of the temperate region, China, parts of Europe and extreme North Africa respectively.

Sokoto Station:
In the Sokoto station, CHEs occurred thirty-three times in 60 years. This comprised 18.13% of the total occurrences recorded across all stations (Table 2). Particularly for the harmattan seasons, January exhibited the highest frequency of CHEs in this station. These events occurred sixteen times (20%) in 60 years, followed by December and February, where the events were experienced 14 (15.38%) and three times (60%) respectively. However, CHEs were absent in November (Table 2).

Table 7: Sub-Periods Occurrences of Cool Harmattan Episodes (CHEs) in Sokoto (1961-2020).

Sokoto station	Frequency and Percentage of Occurrence of CHEs in Particular Month								Total Occurrence for the Season	
Sub-Periods	Nov	%	Dec	%	Jan	%	Feb	%	Total	%
1961-1990	-	-	8	57.14	7	43.75	1	33.33	16	48.48
1991-2020	-	-	6	42.85	9	56.25	2	66.66	17	51.51
Total	-	-	14	100	16	100	3	100	33	100

Source: Analysis of Data, (2022).

The sub-periods frequency exhibited little increase in the occurrences of CHEs during the latest sub-period (1991-2020) compared to the first sub-period (1961-1990), as depicted in Table 7. In the last sub-period (1991-2020), these events occurred seventeen times (51.51%) in 30 years compared to the first sub-period (1961-1990), where the events occurred sixteen times (48.48%). Table 7 thereby revealed that January witnessed the highest occurrence of CHEs in the second sub-period, and the events were totally absent in November. Findings are consistent

with the studies conducted by Shabbar and Bonsal (2003), WMO (2021) and Fihlani & Booty (2023), who have noted upsurges in the frequencies of cool episodes during cold seasons in the last sub-period (1991-2020) compared to some previous sub-periods in eastern Canada, Texas (USA) and parts of Johannesburg (South Africa) respectively. However, results differ from the research works carried out by Kreyling (2010), Fu and Ding (2020), Dehl et al. (2023), Fernandez et al. (2023) and Folorunsho et al. (2023), who have noted declines of cool episodes during cold seasons in the most recent sub-period (1991-2020) compared to some earlier periods in some parts of the temperate region, China, parts of Europe, extreme North Africa and the Northwestern region of Nigeria respectively.

The Region
The outcomes delineated in Table 2 pertaining to the study area showed that CHEs have been witnessed 182 times in 60 years across stations, throughout the harmattan seasons. Notably for the harmattan seasons in the study area, CHEs occurred ninety-one times in December, 80 times in January, 6 times in November and 5 times in February (Table 2). These findings which revealed that December and January witnessed the highest frequency of CHEs in the study area are consistent with the study of Folorunsho et al. (2023), who remarked that these months constitute the peak of the harmattan season in Northern Nigeria.

Over the study period, findings showed that the Gusau station exhibited the greatest frequency of CHEs (38 times) throughout the harmattan seasons. This was closely followed by Kaduna, Kano, and Katsina stations, each with a tally of 37 CHEs, respectively. In the study area, Sokoto witnessed the lowest events of cool harmattan throughout the study period. These events occurred thirty-three times in the station. This is because this station had been noted to have witnessed more severe cold harmattans (over the recent 60 years period) than any other station in the Northwestern region of Nigeria (Folorunsho et al., 2023).

Table 8: SAI Sub-Periods Summary of CHEs in Northwestern Region of Nigeria.

Sub-Periodic Frequency	Stations and Percentage of Occurrence of CHEs											
(1961-1990)	Kd	%	Kn	%	Gu	%	Kt	%	Sk	%	Total	%
Season Frequency	20	22.47	15	16.85	21	23.59	17	19.10	16	17.97	89	100
(1991-2020)												
Sub-Periodic Frequency	17	18.27	22	23.65	17	18.27	20	21.50	17	18.27	93	100

*Kd: Kaduna, Kn: Kano, Gu: Gusau, Kt: Katsina, Sk: Sokoto.

Source: Analysis of Data, (2022).

Regarding sub-periods occurrence of CHEs in the study area, results revealed that the second sub-period (1991-2020) witnessed more CHEs than the first sub-period (1961-1990). The events occurred ninety-three times (in 30 years) in the second sub-period and eighty-nine times (in 30 years) in the first sub-period across the stations. However, the marginal difference in occurrence between the two sub-periods is minimal (Table 8). These findings are different from that of Kreyling (2010), Pratolongo & Plater (2019), Fu & Ding (2020), and Dahl et al. (2023) in their various study areas where cool winters have been noted to have witnessed a decline in the last sub-period (1991-2020) compared to some earlier sub-periods. However, the sub-periods results of the study area are similar to those of the World Meteorological Organization [WMO] (2021) in Texas (USA), where cooler winters were noted to have increased in the later part of the last sub-period (1991-2020), compared to some earlier periods.

Lastly, results showed that Gusau witnessed the highest occurrence of CHEs in the first sub-period (21 times) while Kano experienced the lowest (15 times) (Table 8). Conversely, the Kano station recorded the highest occurrence of CHEs in the second sub-period (22 times) while stations like Kaduna, Gusau and Sokoto experienced the lowest occurrences of the events (17 times each) (Table 8).

Conclusion

In the study, the harmattan months with the SAI range of ─ 0.85 to ─ 1.28 are months in which cool harmattan episodes (CHEs) had occurred. Findings in this study revealed that CHEs occurred in all stations in the study area. The events have occurred 182 times in all stations throughout the study period. Across the geographical stations, the findings showed that CHEs had the highest frequency in Gusau (38 times) and lowest in Sokoto (33 times) throughout the study period. Other stations such as Kaduna, Kano and Katsina had the same frequency (37 times each).

In relation to sub-periods occurrence of CHEs in the study area, results revealed that the second sub-period (1991-2020) witnessed more CHEs (93 times in 30 years) than the first sub-period (1961-1990), where the events occurred 89 times across the stations. Overall, the findings revealed a regional disparity in CHEs across stations in the study area. While Kano, Katsina, and Sokoto saw an increase in CHEs in 1991-2020 compared to 1961-1990, Kaduna and Gusau experienced a decline. Yet, scientists have associated cool episodes occurring within cold seasons with better and clear human thoughts, reduction of inflammations, improve sleep quality, beneficial for skin health, as it constricts blood vessels (Baum 2018; Abbott, 2022). These contrasting trends may suggest the complex impact of climate change on CHEs, with varying regional occurrences. Therefore, investigation is needed to better understand and unravel the underlying factors influencing the regional differences and to inform targeted climate adaptation measures.

References

Abaje, I. B., & Oladipo, E. O. (2019). Recent changes in the temperature and rainfall conditions over Kaduna State, Nigeria. *Ghana Journal of Geography, 11*(2): 127-157.

Abbott, D. (2022). *Top 10 Health Benefits of Cold Weather.* https://www.linkedin.com/pulse/top-10-health-benefits-cold-weather-daniel-abbott

Abolo, G. (2023). South Africa's Cold Weather Has Arrived – Some Tips on how to Stay Warm and Safe. *The Oasis Reporters.* https://www.theoasisreporters.com/south-africas-cold-weather-has-arrived-some-tips-on-how-to-stay-warm-and-safe/

Adunwoke, P. (2018). *Staying Healthy during Harmattan.* https://guardian.ng/features/staying-healthy-during-harmattan/

Akpunonu, S., & Onyenucheya, A. (2019). *Coping with harmattan–related diseases.* https://guardian.ng/features/coping-with-harmattan-related-diseases/

Aldrees, A., Mohammed, A., Dan' azumi, S., & Abba, S. I. (2024). Frequency-Based Flood Risk Assessment and Mapping of a Densely Populated Kano City in Sub-Saharan Africa Using MOVE Framework. *Water,16*: 2-16.

Aweda, F.O., Falaiye, O. A., & Babatunde, G. J. (2017). Elemental concentration of Harmattan dust sample in Iwo and Oyo Town, southwest Nigeria. *Journal of Applied Sciences and Environmental Management, 21*(7), 23-37. https://doi.org/10.4314/jasem. v21i7.16

Balarabe, M. (2018). The Thirty Years Trend Analysis of Harmattan Season Visibility and Temperature in Sahel Zone of Nigeria. *Journal of Theoretical and Applied Physics, 1*(18): 15-21.

Baum, I. (2018). 10 Surprising Health Benefits of Cold Weather. *Business Insider.* https://www.businessinsider.com/10-surprising-health-benefits-of-cold-weather-2018-2?r=US&IR=T

Bello, M. N. (2020). *Harmattan: Sokoto Govt. Distributes 300 Cardigans, Blankets to Almajiri Schools.* https://nnn.ng/harmattan-sokoto-govt-distributes-300-cardigans- blankets-to-almajiri-schools/

Bonsal, B. R., Zhang, X., Vincent, L. A., & Hogg, W. D. (2001). Characteristics of daily and Extreme Temperatures over Canada. *Journal of Climate, 14*(9), 1959–1976.

Chime, V. (2022). *Climate Watch: NiMet warns of temperature rise in harmattan season*. https://www.thecable.ng/climate-watch-nimet-warns-temperature- rise-in-harmattan-

Collins, M., Thompson, V., & Hegerl, G. C. (2024). Earth's Interconnected Climate: Understanding our changing world. *Frontiers.* https://kids.frontiersin.org/articles/10.3389/frym.2024.1433392#:~:text=We%20now%20know%20that%2C%20due, area%20rippling%20across%20the%20globe.

Dahl, M. B., Kreyling, J., Petters, S., & Wang, H. (2023). Warmer winters result in reshaping the European beech forest microbiome (bacteria, archaea, and fungi)—with potential implications for ecosystem functioning. *Environmental Microbiology 25*(6), 1-18.

Danlami, D., Suleiman, S., Adamu, A. B., & Gwari, M. (2018). Temporal and spatial variations of ground surface visibility during Harmattan season in North-Eastern Nigeria. *Ceylon Journal of Science, 47*(4), 337. https://doi.org/ 10.4038/cjs. v47i4.7551

Dilip, N. C., & Dimacha, M. D. (2012). A Study on Temporal Variation and Trends of Temperature in Kokrajhar Assam, India. *Journal of Environmental Research and Development, 7*(2A), 1100-1113.

European Commission. (2023). *Causes of climate change.* https://climate.ec.europa.eu/climate-change/causesclimatechange_en: ~:text=Burning%20fossil%20fuels%2C%20cutting%20down, greenhouse%20effect%20and%20global%20warming.

European Union (2020). *Calculating Climatologies and Anomalies*. https://cds.climate.copernicus.eu/toolbox/doc/howto/13_how_to_calculate_climatologies_and_anomalies/13_how_to_calculate_climatologies_and_anomalies.html

Fernandez, E., Mojahid, H., Fadon, E., Rodrigo, J., Ruiz, D., Egea, J. A., Mimoun, M. B., Kodad, O., El Yaacoubi, A. Ghrab, M., Egea, J. Benmoussa, H., Borgini, N., Elloumi, O. & Luedeling, E. (2023). Climate change impacts on winter chill in Mediterranean temperate fruit orchards. Regional Environmental Change, 23(7), 25-39.

Fihlani, P., & Booty, N. (2023). South Africans marvel at snow and sleet in Johannesburg during cold snap. *BBC.* https://www.bbc.com/news/world-africa-66155057

Folorunsho, A., Olatunde, A. F., & Ibrahim, S. I. (2023). Analysis of Decadal Variations of Minimum Temperature during Harmattan Seasons in Northwestern Nigeria. *FUDMA International Journal of Social Sciences, 3*(2): 166-178.

Folorunsho, A., Olatunde, A. F., & Ibrahim, S. I. (2024). Severe Cold Harmattan Events in the Northwestern Region of Nigeria from 1961 to 2020. *Ghana Journal of Geography, 16*(1): 59-90.

Fu, D., & Ding, Y. (2020). The study of changing characteristics of the winter temperature and extreme cold events in China over the past six decades. *International Journal of Climatology, 14*(4), 2480-2494

Grandoni, D. (2023). How a 'totally insane' warm spell is upending winter around the world. *The Washington Post*. https://www.washingtonpost.com/climate-environment/2023/01/05/warm-winter-effects-europe-us/

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., & Hatziolos, M. E. (2007). Coral Reefs under rapid Climate Change and Ocean Acidification. *Science 318*, 1737-1742.

Hubbart, S. (2022). *Warmer Winters and Your Health: Five Ways That Climate Change Impacts You. Neefusa.* https:

Ismail, A., & Oke, I. A. (2012). Statistical and trend analyses of rainfall in Sokoto. *International Research Journal of Engineering Science, Technology, and Innovation (IRJESTI), 1*(6): 161-174.

Johnson, N. C., Xie, S., Kosaka, Y., & Li, X. (2018). Increasing occurrence of cold and warm extremes during the recent global warming slowdown. *Nature Communications, 9*: 1724. https://doi.org/10.1038/s41467-018-04040-y.

Karkana, M. Z., & Mohammed, S. (2018). Vegetation density and diversity in the dryland of Northwestern Nigeria. *Dutse Journal of Pure and Applied Sciences (DUJOPAS), 4*(1): 195-208.

Koudahe, K., Kayode, A.J., Samson, A. O., Adebola, A. A., & Djaman, K. (2017). Trend Analysis in Standardized Precipitation Index and Standardized Anomaly Index in the Context of Climate Change in Southern Togo. *Atmospheric and Climate Sciences, 7*(4), 401-423. doi: 10.4236/acs.2017.74030.

Kreyling, J. (2010). Winter climate change: A critical factor for temperate vegetation performance. *Ecology 91*(7):1939-48.

Luedeling, E., Zhang, M., & Girvert, E. H. (2009). Climatic changes lead to declining winter chill for fruit and nut trees in California during 1950-2099. *Plos One, 4*(7), 19-28.

Marelign, A. (2020). Variability and Time Series Trend Analysis of Climate and Small Holder Farmers Perception: The Case of Janamora Woreda, Northwestern Ethiopia. *Ethiopian Journal of Environmental Studies & Management, 13*(6): 719 – 730, 2020. doi: https://ejesm.org/doi/v13i6.6

McTainsh, G. (1980). Harmattan dust deposition in Northern Nigeria. *Nature, 286*, 587–588.

Meade, M. S., & Emch, M. (2010). *Medical Geography.* (3rd Ed). New York: Guilford Press New York.

Mfonobong, D. (2020). *Top 10 Coldest States in Nigeria During Harmattan*. https://nigerianinfopedia.com.ng/coldest-states-in-nigeria/

National Aeronautics and Space Administration. (2023). *Extreme Weather and Climate Change.* https://science.nasa.gov/climate-change/extreme-weather/

National Weather Service. (2019). *Climate Variability.* https://www.weather.gov/mrx/climatevariability

Nwaerema, P., & Edokpa, D. (2019). Regional Assessment of Population and Warming of a Tropical Country, Nigeria, from 2006 to 2036. *Environmental and Earth Sciences Research Journal, 6*(1): 1-7.

Ogbaje, S. (2018). North will Experience Severe, Longer Harmattan Season, says N i M e t . *EnviroNews*. https://www.environewsnigeria.com/north-will-experience-severe-longer-harmattan-season-says-nimet/

Okeahialam, B. N (2016). The Cold Dusty Harmattan: A Season of Anguish for Cardiologists and Patients. *Journal of Environmental Health Insight*, 10, 143-146. https://doi:10.4137/ehi.538350

Olatunde, A. (2019). Decadal and Sub-Periods Assessment of Temperature Influenced Outdoor Thermal Discomfort from 1950 to 2015 in Cities of North-Western Nigeria. Savanna Journal, 25(1), 52-66.

Pratolongo, P., & Plater, A. (2019). Temperate Coastal Wetlands. *Science Direct.* https://www.sciencedirect.com/topics/earth-and-planetary-sciences/temperate-climate

Quaicoe, E. B. (2023). *The Changing Climate: Whether harmattan or air pollution, why must we be concerned.* https://www.myjoyonline.com/the-changing-climate-whether-harmattan-or-air-pollution-why-must-we-be-concerned/

Salisu, U. S., Kudi, C. A., Bale, J. O. O., Babashani, M., Kaltungo, B. Y., Saidu, S. N. A., Asambe, A., & Baba, A. Y. (2017). Seroprevalence of Brucella antibodies in camels in Katsina State, Nigeria. *Tropical Animal Health Production, 45*(6): 12-26.

Shabbar, A., & Bonsal, B. (2003). An Assessment of Changes in Winter Cold and Warm Spells over Canada. *Natural Hazards Journal, 29*, 173–188.

Sommer, L., Buchehe, M., Samuel, M., Wight, P., Sakas, M.E., & Mayer, A. (2020). *How Warming Winters Are Affecting Everything.* https://www.npr.org/2020/02/18/803125282/how-warming-winters-are-affecting-everything

Templer, P., & Reinmann, A. (2018). *Warmer Winters Are Harming Northeast Forests.* Boston University. https://www.bu.edu/articles/2018/climate-change-warmer-winter-harming-forests-in-northeast/

Trenberth, K. E. (2018). Climate change caused by human activities is happening and it already has major consequences. *Journal of Energy & Natural Resources Law, 36*(4), 463-481. https://doi.org/ 10.1080/02646811.2018.1450895

Twardosz, R., & Kossowska-Cezak, U. (2015). Exceptionally Cold and Mild Winters in Europe (1951–2010). *Theoretical and Applied Climatology, 125*, 399–411 https://doi.org/10.1007/s00704-015-1524-9

Van der Walt, A. J., & Fitchett, J. M. (2021). Extreme Temperature Events (ETEs) in South Africa: a review. *South African Geographic Journal, 104*(1), 1-20. https://doi.org/10.1080/03736245.2021.1907219

Weather Spark (2024). *Climate and Average Weather Year-Round in Nigeria.* https://weatherspark.com/y/53014/Average-Weather-in-Gusau-Nigeria-Year-Round#:~:text=Over%20the%20course%20of%20the, or%20above%20105%C2%B0F.

World Health Organization [WHO] (2023). *Climate change*. https://www.who.int/news-room/factsheets/detail/climate-change-and-health

World Meteorological Organization [WMO], (2021). *Extreme weather hits the USA and Europe.* https://public.wmo.int/en/media/news/extreme-weather-hits-usa-europe

Acknowledgments

First, I sincerely thank Dr. Olatunde A. F. and Prof. Ibrahim S. I. for their invaluable guidance and support throughout the study. I am also grateful to the institutions, researchers, and individuals who provided essential data and resources, including the World Bank Group, Climate Change Knowledge Portal, Olatunde A. F., Folorunsho A., and Jidauna N. E.

Special thanks go to my family and friends for their unwavering encouragement and understanding during this work. Finally, I appreciate the efforts of everyone who directly or indirectly contributed to the successful completion of this project.

I affirm that there is no conflict of interest concerning this article.

Author Continuations

This research was primarily conducted by the corresponding author. However, Dr. Olatunde A. F, Prof. Ibrahim S. I. and Jidauna N. E. provided valuable input by reviewing the work and offering advice on the methodology used in the study. Their constructive feedback was instrumental in refining the approach and analysis.