



The Decadal Conditions of Thunderstorm Occurrences in Nnamdi Azikiwe International Airport, Abuja, Nigeria

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Abstract: This study evaluates the impact of thunderstorm on flight operations at Nnamdi Azikiwe International Airport, Abuja Nigeria from 1991-2020. This study focused on decadal conditions of thunderstorm occurrences trend and its influence on flight operations. This research employed secondary data of thunderstorm occurrences from Nigerian Meteorological Agency (NIMET), and flight operations data from Nigerian Airspace Management Agency (NAMA) both at Nnamdi Azikiwe International Airport, Abuja. The statistical analyses employed were descriptive statistics, Pearson's Product Moment Correlation and simple linear regression. Skewness and Kurtosis Analysis were also used to determine the degree and direction of skew. It was observed that the first decadal from 1991-2000 shows a negative slope (-0.8242) suggests a decreasing trend in thunderstorm occurrence over the years. The Second Decadal Trend of Thunderstorms from 2001-2010 show a positive slope (2.703) suggests an increasing trend in thunderstorm occurrence the increasing trend in thunderstorm activity is more pronounced in this decade as indicated compare to the first decade. The Third Decadal Trend of Thunderstorm occurrences from (2011-2020) show a negative slope (-2.7818) suggests a decreasing trend, which is lower compared to the second decade, however, the decreasing trend in thunderstorm occurrences continues. The results showed that there is a relationship between the three decades of thunderstorm occurrences at 95% confidence level, although the relationship is not statistically significant ($p > 0.05$). However, the degree of the relationship is not significant. This implies that the effects of decadal conditions of thunderstorm occurrences have on flight operations is insignificant, hence not solely responsible for plane accidents recorded in Nigeria in recent years. Therefore, flight operations could possibly be more affected by human, economic and mechanical factors. Emanating from the study, recommendations and suggestions were made. Future studies should integrate additional data variables such as wind speed, rainfall, and other climatic parameters.

Key Words: Aviation industry, Decadal trend, Nnamdi Azikiwe International Airport, Thunderstorms occurrences, climatic parameters.

1 Introduction

Quest for air transport system enable transformation of nations, cities and towns as weather events or activities such as thunderstorms amongst others bring a lot of concern to the aviation industry. For instance, Abass, Ojo, & Igbru, (2012) and Idoko et al, (2025) stated that several airlines have been moribund, while some offer partial services as a result of extreme weather events. Aviation, probably more than any other mode of transportation, is greatly affected by weather, from thunderstorms and snow storms, to wind and fog, thick-dust haze as well as temperature and pressure extreme (Hosea, 2019).

According to Krider (2022), thunderstorms are meteorological events that bring heavy rains, strong winds, hail, lightning, and tornadoes. Thunderstorms are generated by atmospheric imbalance and turbulence caused by a combination of several conditions, including unstable, warm air arising rapidly in to the atmosphere, sufficient moisture to form clouds and rain, and upward lift of air currents caused by colliding weather fronts (cold and warm), sea breezes, or mountains (Krider, 2022; UCAR, 2022). A thunderstorm is classified as severe if its winds reach or exceed 58 mph, it produces tornado, or it drops surface hail at least 1 in. (quarter-sized) in diameter (UCAR, 2022). Thunderstorms may occur singly, in clusters, or in lines (Stull, 2017). Thus, it is possible for several thunderstorms to affect location in the course of a few hours. Lightning is a major secondary threat associated with thunderstorms (Mohamood, 2021).

Thunderstorms continue to play a significant role in number of aviation accident and incident, adverse weather events (thunderstorm) seem to be the main factor of plane crash and other accident in aviation industry, for example Russian passenger plane crashed in heavy storms and exploded in flames after slamming down short of the run way, killing 44 and critically injured 8 people (Sani, 2010). Also For instance the Tenerife airport disaster was a fatal runway collision between two Boeing 747s at Los Rodeos Airport on the Spanish islands due to poor weather hazard (thunderstorm), again the crash was caused by poor weather conditions (thunderstorm, fog), which killed 583 people, making it the deadliest accident in aviation history Result of a recent research from the United State of America shows that, the total thunderstorm impact is an estimated national cost of about \$3billion for injuries, delays and unexpected operating cost (Kulesa *et al*, 2013). In the United States, between 75 and 100 Americans are hit and killed by lightning each year (UCAR, 2022).

In Africa, Victor (2007), observed that the pattern of thunderstorm occurrences is significance to airline operations. When Aircraft passes through the updraft to a strong downward of cloud, there is a danger of structural damage of flight. In the same way Hauf & Sasse, (2022) noted that, dust storm is strong turbulent wind carrying large cloud of dust. In a large storm clouds, fine dust may raise to heights of over 10,000ft and carry it for hundreds or thousands of kilometer, for example lose deposited in North-West China from Sahara Desert.

In Nigeria, the statistics of air mishaps in Nigeria are mainly due to thunderstorm hazards with the inclusion of human errors ageing aircraft, and deficiency in safety management system, (Welli & Emenike, 2016). Also in Nigeria Sosoliso Airlines flight 1145 crash landed on the runway at Port Harcourt International Airport on 10 December 2005. Deaths were 108 people on board, including 61 secondary school students, the cause of the crash is believed to be weather related (thunderstorm), (Macarthur, 2005). Again, investigation by Edegbe, (2006) in to the crash of Belleview, ADC airline, DHL airline in 2006 in Nigeria, revealed that Abuja, Lagos and Port

Harcourt airport was host to a couple of these accidents which occurred between take-off and landing and is caused by thunderstorm. The crashes of ADC airline, Sosoliso airline, DHL airline and Belview aircraft among others has safely placed Nigeria as one country with worst safety record in the preceding years, and this has resulted in Nigeria been ranked number four (4) in the world coming after Congo, Uganda, and Tanzania in air traffic disaster. Therefore the Nigerian Meteorological Agency (NIMET), were advice to improve on weather and climate forecast for safe operations of aircraft. The problem being envisaged in finding solutions to the rampant air disaster in Nigerian Airspace by the aviation authority is the negligence in addressing the weather factors identified among the causative factors. This is because when air disasters occur blames are being apportion to the human and economic factors, with little or nothing been said about the weather (Natural) factors, such as thunderstorm, visibility, and fog (Igbokwe, 2005).

Studies carried out in related theme; aim at addressing the decadal conditions of thunderstorm on flight operations (Welli & Emenike 2014; Kulesa *et al* 2013 and Enete *et al*, 2015). These studies however tend to consider the air space for smooth flight operations particularly when landing and take-off, that is why Hauf & Sasse, (2022) stressed that most of the air crashes were caused by severe thunderstorm. Based on the forgoing this study aim to examine the influence of the decadal conditions of thunderstorm frequently on flight operations in Nnamdi Azikiwe International airport, Abuja Nigeria, From 1991-2020.

2. Literature Review

There is a large body of literatures devoted to the decadal conditions of thunderstorm on flight operations. The importance of determining the role of thunderstorm on aviation industry cannot be understated. In Africa, thunderstorm is one of the major climatic factors which affect flight operations in the aviation industry (Idoko et al., 2025). Thunderstorms continue to play a significant role in number of aviation accident and incident, adverse weather events (thunderstorm) seems to be the main factor of plane crash and other accident in aviation industry.

2.1 Thunderstorm

The Intergovernmental Panel on Climate Change (IPCC, 2014) report released on extremes weather particularly thunderstorms, heavy down pours and hurricanes which are extreme weather disaster affecting flight operations there is the need to ensure safety of flight operations through the provision of accurate weather report from meteorological stations. According to Krider, (2022) thunderstorm is a heavy rain accompanied by lightning, thunder, wind, and sometimes hails. Thunderstorms occur when moist air near the ground becomes heated, especially in the summer, and rises, forming cumulonimbus clouds that produce precipitation (Krider, 2022). Electrical charges accumulate at the bases of the clouds until lightning is discharged (UCAR, 2022). Air in the path of the lightning expands as a result of being heated, causing thunder. Worldwide there are about 40,000-50,000 thunderstorms daily (National Oceanic Atmospheric Administration (NOAA), 2010).

2.2 Thunderstorms and Flight Operations

Thunderstorm, Fog, mist, haze and smog are all phenomena that can lead to a reduction in visibility at the airport (Onwuadiochi, Ijioma & Mage, 2021). Both advection and radiation fog occurs at Nnamdi Azikwe International Airport, (Hosea, 2019; SAWS, 2012). Thunderstorm is one of the most important weather hazard to all forms of transportation especially air transportation (Ayoade,

2004 & Shadere, 2005), reports that thunderstorm is perhaps a greater danger to safe plane landing because the control over it is more difficult than flooding on the runway. Poor visibility can be caused by thick fog, snow, rain, thunderstorm, harmattan dust, mist, volcanic ash or smoke, urban smoke, low ceilings and even smog. Klein et al, (2009) has shown that even with the increasing sophistication of automatic landing equipment thunderstorm is still the major impediment to flight operations throughout the world. Ehigiator, (2007) reported thunderstorm disrupted flight operations from Lagos to Owerri. While some airlines delayed flights to the northern part of the country for some hours, others cancelled their flights outright because the thunderstorm was worse (Ehigiator, 2007). Ehigiator, & Orakpo, (2010) reported that thunderstorm resulted in the cancellation of flights from Lagos to Benin, Owerri and the Northern part of the country. NIMET (2011) reported that year 2010 witnessed a few instances of disruptions due to severe weather conditions (thunderstorm).

However, the month of August recorded severe thunderstorm occurrences at the range of 25,000 to 45,000 feet but occasionally extend above 65,000 feet which caused many disruptions in flight operations across the country (Stull, 2017). These disruption affected flight operations in Abuja, Lagos, Minna, kaduna, Enugu, Owerri, Port Harcourt, and Calabar airports (Abdulazeez, 2009; Sani, 2010; Enete *et. al*, 2015; Okoro *et. al*, 2018). There were also cases of outright cancellations (Ehigiator, 2007). In July to September, thunderstorm rainfall increases northwards and it was reported that in Lagos, Abuja, and Port Harcourt which reduced horizontal visibility to between 200m-800m (Abdulazeez, 2009; Enete *et. al*, 2015; Okoro *et. al*, 2018). This resulted in flight delays at these airports (Ehigiator, 2007). In addition, thousands of Europe-bound Nigerians were stranded at the Murtala Mohammed International Airport Lagos, as heavy snow storm pounded European airports in December (Onwuadiochi *et.al*, 2021).

Preliminary analysis of air traffic at the Nnamdi Azikiwe International Airport Abuja shows August with the highest number of flight cancellations is largely due to thunderstorm frequency (Akanni *et. al*, 2016). In addition, flight disruptions were reported during the wet season mainly due to heavy down pours, severe thunderstorms and squally weather (Hosea, 2019). Hardy, (2011; Krider, 2022) attributed that thunderstorm conditions associated with electricity (lightning and thunder), hailstones, icing, low-level wind shear effect, gustiness etc. as weather related phenomena responsible for air craft accidents globally.

2.3 Thunderstorms Characteristics Trend and Patterns

Nearly all parts of the planet are known to have thunderstorms, though they are uncommon in the Polar Regions and seldom in latitudes higher 50⁰ N and 50⁰ S (Krider, 2022; Seneviratne, Nicholls & Easterling 2012). However, thunderstorms are most common in tropical and temperate regions of the earth (Krider, 2022). The characteristics are used to categorize or classify them, and these characteristics are heavily influenced by the meteorological environment in which the storms develop (Stull, 2017). There are various types of thunderstorms (Idoko et al., 2025). When moisture is available at low and intermediate levels of the atmosphere that is, from close to the ground's surface up to about 10,000 meters in altitude and when there are mild winds that do not fluctuate significantly with height, isolated thunderstorm are more likely to develop (Stull, 2017). These storms are sometimes known as local thunderstorms or air masses (Bureau of Meteorology, 2022). They often do not cause violent weather near the ground, are largely vertical in structure, and have limited lifespan (Krider, 2022; Bureau of Meteorology, 2012). Storms with organized

Multiple cells, Squall lines, or Super cells are typical what cause violent weather on the ground, and they are known as Multiple cell thunderstorms (Rafferty, 2011; Doswell, 2022).

Thunderstorms can occasionally form over a region with a diameter of hundreds of kilometers as a result of the formation of a mesoscale meteorological disturbance (Doswell, 2022). These disturbances include frontal wave cyclones, which are low pressure systems formed by waves on fronts separating warm and cool air masses, and low-pressure troughs at higher altitudes (Krider, 2022). Mesoscale convective systems (MCS) are the name for the storm pattern that results from this (Krider, 2022). MCSs are usually connected with powerful Multiple cell and super cell thunderstorms (Stull, 2017). Rainfall from strati-form clouds (cloud layers with a large horizontal extent) and convective clouds are frequently produced by these systems (Krider, 2022). When environmental winds are favorable, storm`s updraft and down draft organize, twist around, and reinforce each other (Stull, 2017). Associated As a result, a long-lived supper cell storm form (Stull, 2017, Doswell, 2022). These thunderstorms are the most powerful kind (Stull, 2017; Krider, 2022). Anvil-shaped updraft rises, turn counter clockwise, and exists to the east (Brown, 2005). Super-cells have a two-to-six-hour lifespan (Krider, 2022). They were of the view that storms are most likely to cause noticeable wind and hail damage as well as strong tornadoes (Wurman, Kosiba & White, 2021). A thunderstorm is a very significant climatic element that affects flight operations at Nnamdi Azikiwe International Airport, Abuja. (Enete *et.al*, 2015).

The conceptual scope of the study

The conceptual frame work of this research is hinged on Environmental determinism, also known as climatic determinism in this case is the view that the physical (climate) environment sets limits on human social development (Dikshit, 2007). A twenty first century approach to the study of geography which argued that the general laws sought by human geographers could be found in the physical sciences (Doyle, 2011). Geography therefore became focused on the study of how physical environment affected, or even caused, human culture and activities (Laura, 2003). For example, tropical climates were said to cause laziness, relaxed attitudes and promiscuity, while the frequent variability in the weather of the middle latitude led to determined and driven work ethics (Singh, 2007). As a result of environmental determinism (Waylon & Philippe, 2016) Opined that thunderstorm is one of the major climatic factors which affect aviation industry, it is the most obvious weather events that affects aircraft operations.

The conceptual scope is also centered and limited to turbulent weather event (thunderstorms) on flight operations. The concept covers aspect of thunderstorm which is meteorology that is the formation, structure, and the distribution and frequency of thunderstorm occurrences in Nnamdi Azikiwe International Airport, Abuja, Nigeria was chosen based on the fact that the facility is influenced by extreme weather conditions due to its location in the tropical region, and is one of the busiest airports in Nigeria. It provides flight services to both domestic and international destinations and it is a public airport operated by the Federal Airport Authority of Nigeria. The study area covers (30) thirty years (1991-2020). These periods were chosen so as to fill in the knowledge gap in the work of Abdulazzez (2009) by providing data on thunderstorm occurrences and characteristics and their analysis monthly, yearly and in decades.

Empirical Review

Ochei, *et. al*, (2015) examined that using (decadal) a 10-year daily data thunderstorm and dry thunder (thunder without precipitation) that spans from 1991-2000, the spatial, seasonal and inter-seasonal variations of thunderstorm frequency have been investigated with results which include the production of seasonal and inter-seasonal maps of dry thunder (thunder without precipitation) and thunderstorm frequencies. Results showed that there exists a latitudinal belt of reduced thunderstorm activity between 8° and 10° N. Also, due to absence of little dry season (LDS) over the south-eastern part of the country, they do not experience double maxima of thunderstorm activity. Hence, the weather over the country has been observed as not following the latitudinal divides. Also, the thunderstorm activities over the country have been observed as not following the coast, but gradually decrease towards the inland with anomaly over Ilorin and Yola. Though, several authors have carried out series of researches on the thunderstorm activities but none have been able to look at the seasonal and inter-seasonal variations of thunderstorm frequency over Nigeria.

2. 5: Gap in Literature

From the literature, there is dearth of empirical analysis of the influence of thunderstorm on flight operations which is decadal occurrences in the air ports in Nigeria. Also, there is a gap in flight operations data (1991-1996) because of insufficient data on other parameters such as flight delay, flight cancellations and flight diversion due to inadequate record keeping. However, available data for this study were from 1997-2020. To examined the nature of occurrences and variability of the frequency of thunderstorms in relation to its effects on flight operations Aremu (2014) discussed the influence of Jos Plateau on the occurrence of thunderstorm activity in Jos, Zaria, and Kaduna in his work on temporal and comparative analysis of thunderstorms and related phenomena (hail, squall and Lightning). Adefolalu, 2010; Akinsala & Ogunjobi, 2014; Weli & Emenike, 2016; Adelekan, 2018; Hosea, 2019; Onwuadiochi, 2021 were other notable contributions from Nigeria. Outside Nigeria, scholars have also worked on thunderstorm activity (Raffety, 2011; Seneviratne *et. al*, 2012; Doswell, 2015; Stull, 2017; Wurman *et.al*, 2021; Krider, 2022; Hauf & Sasse, 2022.

Despite the contributions no real attempt has been made to study thunderstorm in its entire aspect diurnal, seasonal, annual, and decadal trend in a single study. This study seeks to carry out a detailed analysis of thunderstorm over Abuja Airport because of its importance in Nigeria. This study therefore is an attempt to investigate temporal trend and to fill the gap in knowledge by examining the influence of decadal conditions of thunderstorm on flight operations between 1991-2020 at Nnamdi Azikiwe International Airport, Abuja.

3. Materials and Methods

3.1 The study area (Nnamdi Azikiwe International Airport, Nigeria)

The study area covers the confines of Nnamdi Azikiwe International Airport, in the Federal Capital Territory (FCT), Abuja, Nigeria. Established and commissioned on September 29, 1982, named after Nigeria's first president, Dr. Nnamdi Azikiwe. The airport was built in 2000 and opened in 2002. It consists of international and a domestic terminal, both terminals share the same runway. It is about 49 kilometers south of the city, the airport covers an area of about $1,476\text{km}^2$ and lies between latitude $8^{\circ} 59' 0''$ and $9^{\circ} 1' 30''$ N and longitude $7^{\circ} 14' 30''$ E and $7^{\circ} 17' 0''$ E with altitude of 314.98m. The airport type is public, the elevation (AMSL) is 1, 123ft/342m above mean sea

level (AMSL), run way direction is 04/22 and length is 3,610m/11,844ft (Nigerian Airspace Management Agency, 2013).

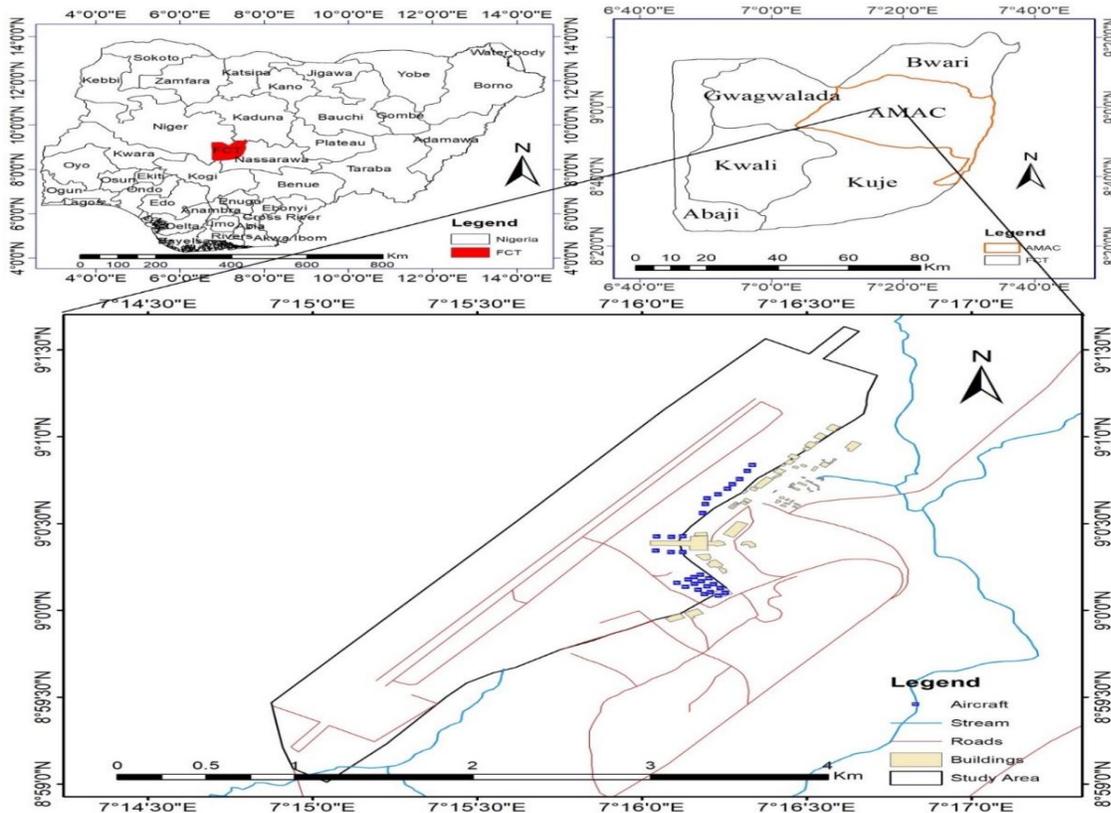


Figure 1: Abuja showing the Study Area.

Source: GIS Lab. Federal University Lokoja, 2023

Climate of the Study Area

The climate of the study area is generally (wet and dry climate) tropical [Idoko *et al*, 2025]. This includes a warm, humid rainy season and a blistering dry season. The month of April mark out onset of the wet, this runs through to October yearly. The dry season begins from November to March of the following year. Abuja experiences AW or Tropical Climate [Idoko *et al*, 2025] The month of April mark out onset of the wet, this runs through to October yearly. The dry season begins from November to March of the following year (GEO-UNESCO, 2011). The AW climate is characterized by six months of dry season (November to April) and six months of rainy season (May to October). Nnamdi Azikiwe International Airport, Abuja experiences average monthly maximum temperature between 28.87°C in August and 37.73°C in March (Idoko *et.al*, 2025). *The* day time diurnal range of temperature during the wet season is between 2°C to 3°C with night time diurnal range of temperature ranging between 1°C and 2°C. In dry season, average day time temperature can ascend as high as 38°C while the night time temperature can drop as low as 18°C (Idoko *et al*, 2025). Two main factors strongly influence temperature patterns in the study area are

cloud cover and elevation. These therefore, accounts for the relatively higher temperatures in some parts of the Federal Capital Territory (FCT) (Idoko *et al*, 2025).

3.2 Research Method

For this study, a quantitative research designs were employed to determine the monthly and annual thunderstorm occurrences, also to analyze the decadal conditions of thunderstorm occurrences in the study area. Thunderstorms which define the number of thunders in each month of the specified years and the flight information data for the period of 30 years (1991-2020). In Nnamdi Azikiwe International Airport, Abuja flight operations data were collected for the period of 23 years (1997-2020) because no available data on flight operations at Nnamdi Azikiwe International Airport, Abuja. There is a gap in flight operations data (1991-1996). However, available data for this study were from 1997-2020.

The study utilized secondary sources of data on thunderstorm, which were sourced from Nigerian Meteorological Agency (NIMET) and data on flight operations were sourced from Nigerian Airspace Management Agency (NAMA). The data on thunderstorms frequency from 1991-2020 were collected from the Nigerian Meteorological Agency (NIMET) Headquarters in Abuja, while the data on flight cancellations, delays and diversions from 1997-2020 were collected from the Nigerian Airspace Management Agency (NAMA) in Nnamdi Azikiwe International Airport, Abuja, Nigeria. Data presentation includes decadal conditions of thunderstorm occurrences from 1991- 2020, relationship between thunderstorms and years of study. In analyzing the required data, simple statistical technique such as means and graphs were employed.

3.2.1 Data Analysis

The statistical analyses employed were descriptive statistics which was used to determine the decadal conditions of thunderstorm occurrences and Simple linear regression was used to establish the decadal conditions of thunderstorm trends values for the study area. Multivariate analysis such as correlation co-efficient, the co-efficient of determination, skewness and kurtosis and simple regression was used to demonstrate the relationship between the decadal frequency of thunderstorm occurrences and the number of year in this case the three decades of thunderstorms.

3.2.2 Correlation Analysis

Pearson Product Moment Correlation Analysis were utilized to establish the degree of relationship between decadal frequency of thunderstorm occurrences and Flight operations in the study area. The correlation coefficient looks at the relationship between the dependent variable flight operations and the independent variable frequency of thunderstorm occurrences which were measured by product moment correlation coefficient r which is described as

$$r = \frac{[\Sigma xy - \Sigma x \Sigma y/n]}{[\sqrt{[n - 1][(s. d. x)(s. d. y)]}]}$$
 (Onwuadiochi, *et. al*, 2022).

Where

r = correlation coefficient of (Standard deviation of x) (Standard deviation of y)

n= total number of samples of decadal thunderstorm occurrences

s.d of x = standard deviation of x, (Frequency of decdal thunderstorm occurrences)

s.d of y = standard deviation of y (Flight Cancellations, Flight delays and Flight diversions)

r can take any value between -1 and +1

When r = +1, it shows that there is perfect relationship between x and y with increase in x (thunderstorm) leading to constant increase in y (flight operations). (Onwuadiochi, *et.al*, 2022).

Line graph were drawn to determine the correlation between X (independent variable in this case, frequency of thunderstorm occurrences) and Y (dependent variable in this case, flight operations). This means that the number of flight operations is positively associated with the number of thunderstorm occurrences. In other words, there is a general tendency for an increase in thunderstorm frequency to cause a greater number of flight operations in the study area.

3.2.3 Skewness and Kurtosis Analysis

In addressing the normality of the collected thunderstorm frequency data, the Skewness and Kurtosis analysis was used. The Skewness of the thunderstorm frequency data were analyzed using the model

$$\text{Skewness} = \frac{(y_i - \bar{y})^3}{(n-1)^3} \dots\dots\dots 1, 2, 3 \text{ (1)}$$

Where

y_i = mean sample of thunderstorm occurrences

y = the sample of thunderstorm occurrences

n = total sample number

The Kurtosis Model is presented thus;

$$K = \sum_{i=1}^n \frac{(x_i - \bar{x})^4}{(n-1)s^4} \dots\dots\dots 1, 2, 3, 4 \text{ (2)}$$

X₁ = mean samples of thunderstorm occurrences

x = the samples of thunderstorm occurrences

n = total sample number

s = standard deviation of all the samples

k = samples kurtosis

3.2.4 Decadal Thunderstorm Frequency and Trend Analysis (Regression)

Simple linear regression was used to establish the decadal frequency of thunderstorm values for the study area. The decadal thunderstorm frequency trend analysis is given by the following formula below. Y = a+bx

Where y = dependent variable (decadal thunderstorm frequency)

$$a = y - bx$$

$$b = \frac{\sum(x-x)(y-y)}{\sum(x-x)^2} \quad (\text{Onwuadiochi, et. al, 2022}).$$

x = independent variable (number of years)

X = mean of independent variable (number of years)

Y = mean of dependent variable (decadal of thunderstorm frequency)

The regression line of best fit shows the relationship of the variables.

4. Results and Discussion

The findings of the decadal conditions of thunderstorms frequency in Nnamdi Azikiwe International Airport, Abuja, Nigeria are presented below

4.0 The Decadal Conditions of Thunderstorm Occurrences and the sub-periods in Nnamdi Azikiwe International Airport, Abuja, from 1991- 2020

In terms of the decadal insights, the 1990s showed thunderstorm occurrences were relatively stable in the 1990s with slight fluctuations, which remained predominantly lower than 110. Also, the early 2000s saw some decline in the number of thunderstorms, but the latter half of the decade marked an upward trend, reaching a peak in 2007. (Figure 4.1) In the 2010s, the thunderstorm occurrences was slightly decreasing, reaching a high in 2012, then followed by a downward trend until 2018, and a slight recovery towards the end of the decade. The occurrences of thunderstorms have shown variability over the three decades, with certain years or periods having increased or decreased frequencies. The second decade (2001-2010) showed a clear increasing trend in thunderstorm occurrences, as indicated by the positive slope and a relatively high R^2 value. On the other hand, the first and third Decades (1991-2000 and 2011-2020) indicated weak decreasing trends especially in the first Decade (Figure 4.1). This variability might have been influenced by changes in local weather dynamics, or other environmental factors such as temperature, rainfall, relative humidity, visibility, wind speed, atmospheric instability, cloud cover, sea level and pressure. The result of this study agrees with that conducted by Akinsanola and Ogunjobi (2014) in which long time trends and decadal trends further suggest a sequence of alternately decreasing and increasing decadal thunderstorm frequency in the study area.

Sub-periods

The average occurrence showed that the sum of the occurrences in first sub-period (1991-2005) is 1631, so the average is 108.6 thunderstorms per year. The highest occurrence was revealed in 2005 with 128 thunderstorms, while the lowest occurred in 2000 having 94 thunderstorms. In terms of the characteristics, this sub-period (1991-2005) starts and ends with numbers around the lower 110s (Figure 4.1). The occurrences fluctuate without any distinct rising or declining trend throughout the sub-periods. This sub-period generally experienced a slight increase in thunderstorm occurrences especially in 1991, 1997 and 2005 particularly stands out as a sub-periods with notably high occurrences.

In this sub-period, the total thunderstorm occurrences was 1694, resulting in an average of 113 thunderstorms per year. The maximum peak occurred in the year 2012 with 137 thunderstorms. In 2017 and 2018 both the lowest occurrences in this sub-period showed 88 thunderstorms each (figure 4.1). This sub-periods is characterized with the highest (2012) and lowest (2017 and 2018) occurrences in the entire 30 years life span. While the sub-periods started with high occurrences, there was a noticeable dip in the latter half of this sub-period, particularly in 2017 and 2018.

The sub-period (2006-2020) experienced a slightly higher average of thunderstorm occurrences compared to the sub-periods (1991-2005). However, the sub-periods (2006-2020) saw an average closer to that of the sub-periods (1991-2005). It is worth noting the variability within each sub-period, with particularly high peaks and lows in the sub-periods (2006-2020). The 2007 with (130) occurrences and 2012 with (137) occurrences stand out with notably high thunderstorm occurrences. While 2017 with (88) and 2018 with (88) experienced the lowest thunderstorm occurrences over the 30-year period, (Figure 4.1). This sub-periods (2006-2020) analysis offers a broad view of the characteristics of thunderstorm occurrences, showing that while there are annual fluctuations, no distinct long-term trend can be deduced from the results. Over the 30 year period, while there have been years of increased thunderstorm activity, there have also been significant lows. The frequencies of thunderstorm showed a consistent upward or downward trend over the entire period but does display periods of increase and decrease which can be deduced from the result. The result showed clear inter-annual variability without any consistent upward or downward trend throughout the entire 30-year periods. Also this result is at variance with the findings of Enete *et al*, (2015) in Port-Harcourt International Airport Omagwa, Rivers State, which showed that thunderstorm occurrence was fluctuating without either a decreasing or increasing trend. This difference in result of Enete *et al*, (2015) with this study could be due to the difference in the location and the period of the study. The finding is in agreement with the result of Maxwell (2008), which observed that the monsoon period of the year is the worst for bad weather delays due to resultant convective weather activities

4.1.1 The Decadal Conditions of Thunderstorms Frequency in Nnamdi Azikiwe International Airport, Abuja

4.1.2 The First Decadal Trend of Thunderstorms in the Study Area (1991-2000)

The negative slope (-0.8242) suggests a decreasing trend in thunderstorm occurrence over the years. However, the low R^2 value (0.155) indicates that the linear model does not fit the data well. The model may not capture the true complexity of thunderstorm occurrences during this decade. The decreasing trend suggested decline in thunderstorm activity during this period, but the low R^2 indicates a weak correlation (Figure 1). Other factors such as temperature, rainfall, relative humidity, visibility, wind speed, atmospheric instability, cloud cover, sea level and pressure that may influence thunderstorm occurrences were held constant in this study.

The skewness value of -1.472 means that the distribution of thunderstorm occurrences is skewed to the left implies that there is a tendency for more extreme values (higher thunderstorm occurrences) on the lower side of the distribution. The kurtosis value of 1.711 means that the distribution of thunderstorm occurrences has relatively heavy tails compared to a normal distribution. Thus, there is an increased probability of extreme values, indicating that thunderstorm occurrences have periods of higher intensity or concentration. Based on the skewness and kurtosis values the thunderstorm occurrences exhibit a leftward skewness indicate that, there is a tendency

for more extreme values on the lower side of the distribution. The positive kurtosis indicates or implies a greater likelihood of extreme thunderstorm occurrences.

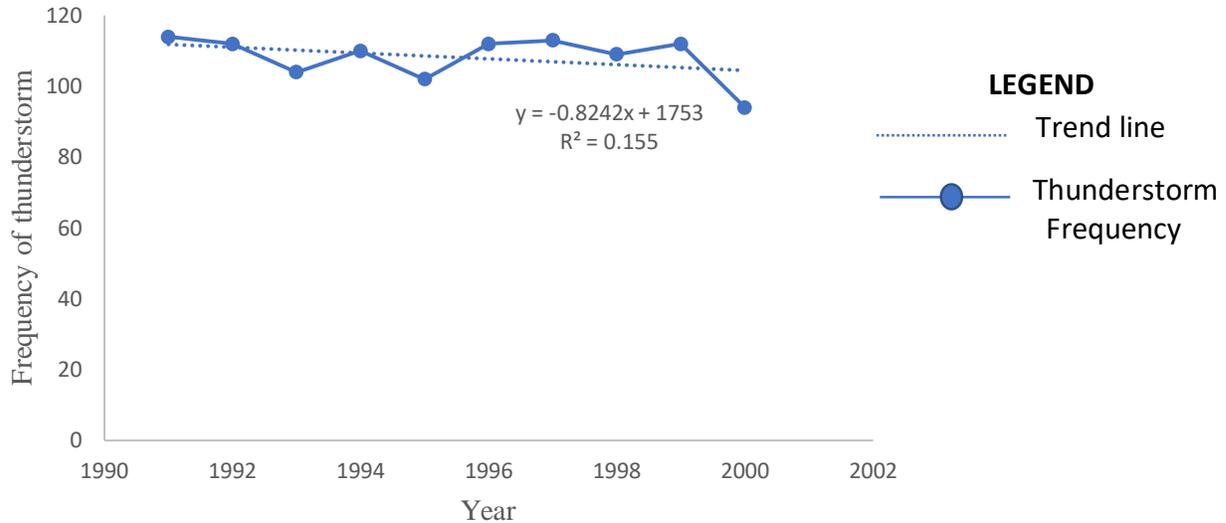


Figure 1: First Decadal Trend of Thunderstorm Frequency (1990-2000)
 Source: Author`s work 2024

4.1.3 The Second Decadal Trend of Thunderstorms in the Study Area (2001-2010)

As depicts in figure 2 the positive slope (2.703) suggests an increasing trend in thunderstorm occurrence. The higher R² value (0.571) indicates a better fit compared to the first decade, suggesting that the linear model captures more of the variability in the results. The increasing trend in thunderstorm activity is more pronounced in this decade as indicated by the positive slope and a relatively high R² value. The higher R² value suggests that the linear model is a better representation of the relationship between the year and thunderstorm occurrences during this period. The mean represents the average thunderstorm occurrences over the given years. The mean for second decades is 117, indicating that, on average, there were 117 thunderstorm occurrences.

The standard deviation for second decades is 11. This suggests a moderate amount of variability in thunderstorm occurrences around the mean. The kurtosis value of -1.312 means the distribution has slightly lighter tails compared to a normal distribution. There is a decreased probability of extreme values, indicating that thunderstorm occurrences may be more concentrated around the mean. The skewness value of -0.423 suggest that the distribution is slightly skewed to the left. There is a tendency for more extreme values on the lower side of the distribution, although the skewness is not highly pronounced.

The minimum value (99) represents the lowest recorded thunderstorm occurrences in second decades while the maximum value (130) represents the highest recorded occurrences also in the second decades during the specified period. The average thunderstorm occurrence in second decades is 117. There is a moderate amount of variability around the mean, as indicated by the

standard deviation. The distribution has slightly lighter tails (negative kurtosis), suggesting that thunderstorm occurrences may be more concentrated around the mean. The distribution is slightly skewed to the left (negative skewness), indicating a tendency for more extreme values on the lower side of the distribution.

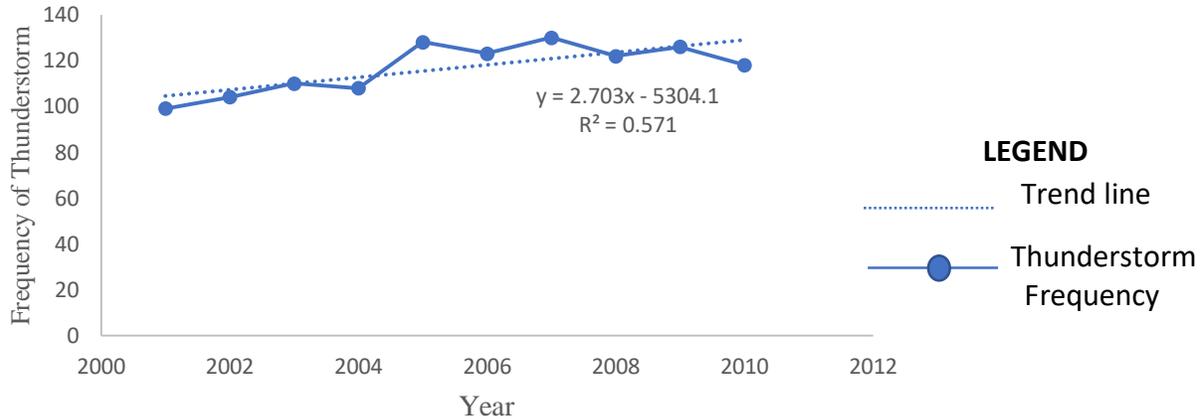


Figure 2: Second Decadal Trend of Thunderstorm (2001-2010)

Source: Author`s work, 2024

4.1.4 The Third Decadal Trend of Thunderstorm occurrences in the study area (2011-2020)

The negative slope (-2.7818) suggests a decreasing trend, and the R² value (0.2955) is lower compared to the second decade (Figure 3). The model may not capture all the variability in the data, however, the decreasing trend in thunderstorm occurrences continues, but the lower R² indicates that the linear model is less reliable in explaining the variability. Other factors such as temperature, rainfall, relative humidity, visibility, wind speed, atmospheric instability, cloud cover, sea level and pressure, not considered in this model may be influencing thunderstorm occurrences during this decade.

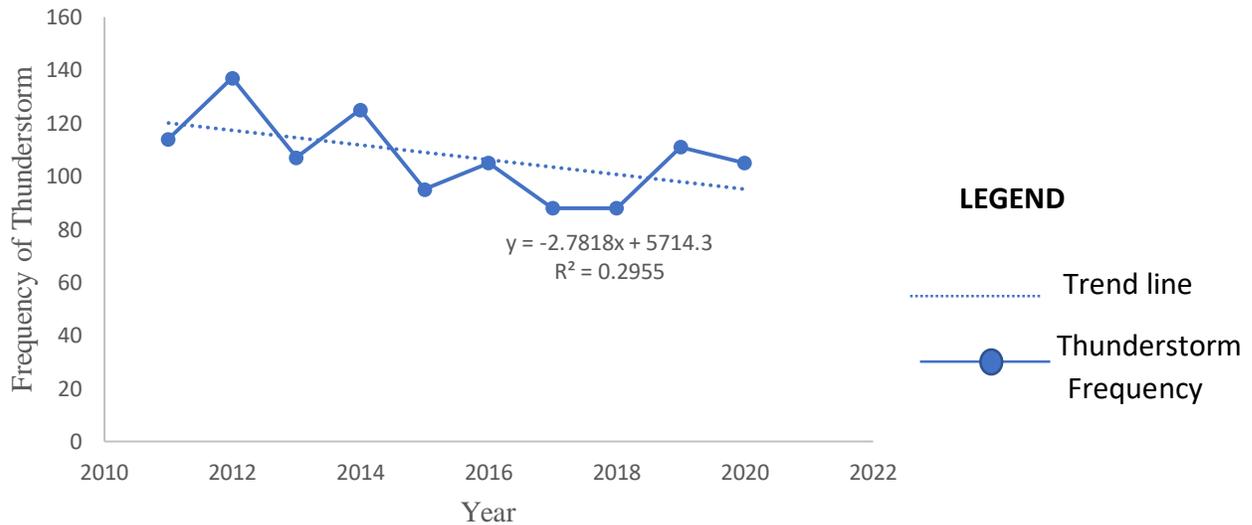


Figure 3: Third Decadal Trend of Thunderstorm Frequency (2011-2020)

Source: Author's work, 2024

4.4 Comparison of the Three Decadal Trend of Thunderstorm in the Study Area (1991-2020)

The second decade (2001-2010) shows a clear increasing trend in thunderstorm occurrences, as indicated by the positive slope and a relatively high R^2 value. The first and third Decades 1991-2000 and 2011-2020 that both suggest decreasing trends, but the strength of the correlation is weaker, especially in the first Decade. The implication of the results is that thunderstorm occurrences are subject to changes over time, and linear models may not fully capture the complexity of the underlying factors influencing these changes. It is important to consider other variables and factors such as climate patterns, land use changes, or atmospheric conditions that could impact thunderstorm activity. The mean for the third decades was 108, indicating that, on average, there were 108 thunderstorm occurrences. The standard deviation for third decades is 16, suggesting a relatively higher variability in thunderstorm occurrences around the mean compared to the previous decades.

The kurtosis value at 0.080 suggests that the distribution has tails similar to a normal distribution. There was neither a heavy-tailed nor a light-tailed pattern in the results. The skewness value at 0.543 suggests that the distribution was slightly skewed to the right. There was a tendency for more extreme values on the higher side of the distribution, although the skewness is not highly pronounced. The minimum value (88) represents the lowest recorded thunderstorm occurrences in the third decades, while the maximum value (137) represents the highest recorded occurrences in third decades during the specified period.

The average thunderstorm occurrence in third decades was 108. There was a relatively higher variability around the mean, as indicated by the standard deviation compared to the previous decades. The distribution has tails similar to a normal distribution (kurtosis value close to zero). The distribution was slightly skewed to the right (positive skewness), indicating a tendency for more extreme values on the higher side of the distribution.

The result of this study agrees with that conducted by Akinsanola and ogunjobi (2014) in which long time trends and decadal trends further suggest a sequence of alternately decreasing and increasing decadal thunderstorm frequency in the study area. This result was again in agreement with the work of Eludoyin *et al.* (2009) in which the studied trend of decadal thunderstorm distribution in Abuja Airport between 1985- 2004 noticed the increasing trend in thunderstorm activity that was more pronounced in the second decade. Furthermore, the result was also in agreement with the findings of (Idoko *et al.*, 2025) that investigated the decadal trend of thunderstorm variability at Nnamdi Azikiwe International Airport, Abuja and concluded that decadal trend of thunderstorm variability continues to be on the increase.

4.4.2 Relationship Amongst Annual Frequency of Thunderstorm and Flight Diversions, Delays and Cancellations for the entire Study period (1997-2020)

The result of flights Cancellation, Delay and Diversion from 1997 to 2020, a total of 24 years period, there were a total of 5104 flight cancellations. The annual cancellations fluctuated, with the highest number in 2020 (241 cancellations) and the lowest in 1997 (187 cancellations) reasons

were due to convective weather factors thunderstorms, visibility, wind shear, squall line, operations and mechanical. In terms of flight delays, there were a total of 3588 flight delays within 1997-2020. The annual delays ranged from a maximum of 177 in 2007 to a minimum of 121 in 1997 reasons were due to convective weather factors thunderstorms and operations while a total of 3648 flights were diverted in this period. The highest annual diversions were 174 in 2010, while the lowest was 109 in 1999 reasons were due to convective weather factors thunderstorms, operations and mechanical. Moreover, thunderstorms occurred 2671 times within 1997-2020. The frequency ranged from 137 in 2012 to 88 in both 2017 and 2018. Hence, flight cancellations happened at a rate of 41.4% of the thunderstorm frequency which implies that within 1997-2020, flight cancellations occurred almost twice as frequently as thunderstorms. Flight delays happened at a rate of 29%, meaning they were 34.3% more frequent than thunderstorms over the period; and flight diversions happened at a rate of 29.6%, meaning they were 36.6% more frequent than thunderstorms over the same period. It is noted that flight cancellations over the period (5104) were notably higher than both flight delays (3588) and flight diversions (3648). Even though the data provides the annual frequency of thunderstorms, there is no direct evidence to assert that thunderstorms are the sole reason for the flight disruptions (Table 4.3). It is possible however, that they are other factors such as climate patterns (weather), land use changes, or atmospheric conditions. It is noteworthy that 2020 had the highest number of flight cancellations. While this results does not specify the reasons, one could hypothesize that global events, like the corona virus pandemic, might have influenced this number.

How ever, the Pearson Correlation between Thunderstorm and Flight Cancellation had a value of -0.013. This correlation coefficient is very close to 0, which suggests that there is a negligible or no linear relationship between thunderstorm occurrences and flight cancellations. The negative sign indicates that when thunderstorms increase, flight cancellations slightly decrease, but this is almost non-existent given the value is proximity to 0. Significance Level of 0.953 a common threshold for determining significance is 0.05. Since 0.953 is much higher than this threshold, it can be concluded that the correlation between thunderstorms and flight cancellations is not statistically significant. In other words, any observed relationship between the two could easily be due to chance (Table 1).

Correlation between Thunderstorm and Flight Delay had a value of 0.033. This value again is very close to 0. This means that the linear relationship between thunderstorms and flight delays is very weak. The positive sign indicates that as thunderstorms increase, flight delays might increase slightly, but the correlation is almost negligible. With a probability Level of 0.880, that is again well above the 0.05 threshold, it means weak correlation between thunderstorms and flight delays is not statistically significant (Table 4.6).

Correlation between Thunderstorm and Flight Diversion had a value of 0.121. This suggests a weak positive relationship between thunderstorm occurrences and flight diversions. Although it indicates that flight diversions might increase somewhat with more thunderstorms, the correlation is still considered weak. With a significance Level of 0.572, that again is above the 0.05 threshold. Thus, the correlation between thunderstorms and flight diversions is not statistically significant (Table 1). Based on the result above, thunderstorms had a very weak or negligible effect on flight cancellations, delays, and diversions. The p-value, was above 0.05 significance level, further suggests that any observed relationships between thunderstorm occurrences and the three flight operations are not statistically significant.

Table 1 Correlations/relationship between Thunderstorm and Flight Operations in the Study Area

Observations		Flight	Flight Delay	Flight Diversion	Thunderstorm
Flight Cancellation	Pearson Correlation	1 Cancellation	.245	.097	-.013
	Sig. (2-tailed)		.248	.653	.953
	Sum of Squares and Cross-products	4383.333	1022.000	478.000	-52.667s
	Covariance	190.580	44.435	20.783	-2.290
	N	24	24	24	24
Flight Delay	Pearson Correlation	.245	1	.227	.033
	Sig. (2-tailed)	.248		.287	.880
	Sum of Squares and Cross-products	1022.000	3968.000	1066.000	129.500
	Covariance	44.435	172.522	46.348	5.630
	N	24	24	24	24
Flight Diversion	Pearson Correlation	.097	.227	1	.121
	Sig. (2-tailed)	.653	.287		.572
	Sum of Squares and Cross-products	478.000	1066.000	5576.000	571.000
	Covariance	20.783	46.348	242.435	24.826
	N	24	24	24	24
Thunderstorm	Pearson Correlation	-.013	.033	.121	1
	Sig. (2-tailed)	.953	.880	.572	
	Sum of Squares and Cross-products	-52.667	129.500	571.000	3970.958
	Covariance	-2.290	5.630	24.826	172.650
	N	24	24	24	24

Source: Author`s Fieldwork, 2024

4.3.3 Decadal Trend of Flight Cancellations, Flight Delays and Flight Diversions in the Study Area (1997-2020)

The first decade (1997-2006) saw an increased and decreased in trend of flight cancellation, which revealed that cancelled flight in this decade have fluctuated over the years. The lowest cancellations occurred in 1997 with 187, while the highest was in 2005 with 231. Notably, there was a surge in cancellations from 1997 to 2006, peaking at 231. The second decade (2007-2020) experienced a higher trend of flight cancellations compared to the first decade followed by some variability, the minimum cancelled flight in this decade occurred in 2010 (194) and the maximum was in 2020 (241). This suggests that there are factors such as climate patterns (weather), land use changes, or atmospheric conditions. Others factors are temperature, rainfall, relative humidity, visibility, wind speed, atmospheric instability, cloud cover, sea level, pressure, human, economic and mechanical in the aviation environment or related operational challenges that led to an increased propensity to cancel flights over the years, especially in the second decade. (Table 4.3)

The first decade (1997-2006) recorded the highest number of delayed flight in 2003 (173) and the lowest was in 1997 with 121 flight delayed.

While the second decade (2007-2020) trend of flight delayed peaked in 2007 (177) and the lowest flight delayed was in 1997 (121) the second decade experienced a higher trend of flight delayed compared to the first decade, but have generally remained within a consistent range throughout the period, usually between 130 to 160. There is not a pronounced upward or downward trend; rather, the delayed appear to fluctuate in a relatively stable range, indicating consistent operational or environmental factors such as climate patterns (weather), land use changes, or atmospheric conditions, others factors are temperature, rainfall, relative humidity, visibility, wind speed, atmospheric instability, cloud cover, sea level, pressure, human, economic and mechanical affecting delays. While there are fluctuations in the number of delays, it appears the airline operations (or environmental factors)

The first decade (1997-2006) of flight diversions ranged from a low of 109 in 1999 to a high of 168 in 2002. The second decade (2007-2020) saw a general upward tendency, the lowest trend of flight diversion was recorded in 2008 with 140 and the highest trend of flight diversion was 174 in 2010 the diversions, like cancellations seem to be on an upward trajectory, although there are years with dips. The reason for increased diversions could be multifaceted - from environmental conditions, airspace congestion, to safety concerns. The result is not in agreement with the work of Allan et al, (2002), conducted on annual frequencies of thunderstorm and flight operations at New York International Airport, located in the heart of the congested northeast corridor of the United States. It is an airport with a significant number of delays. Allan et al, (2002), found that 68% of the cumulative flights' cancellations, diversions and delays on days during this period, averaging more than 15, minutes, are caused by convective weather, either within, or at considerable distances from, the New York Terminal Area

Table 2: Annual and Decadal Frequency of Thunderstorm and Flight Diversions, Delays and Cancellation (1997-2020)

Year	Flight Cancellations	Flight Delays	Flight Diversions	Thunderstorms frequency
1997	187	121	154	113
1998	200	149	160	109
1999	205	128	109	112
2000	208	140	124	94
2001	198	156	140	99
2002	198	137	168	104
2003	217	173	135	110
2004	213	152	147	108
2005	231	139	149	128
2006	218	158	158	123
2007	200	177	149	130
2008	219	147	140	122
2009	221	142	149	126
2010	194	150	174	118

2011	208	133	147	114
2012	202	157	155	137
2013	206	150	168	107
2014	235	152	172	125
2015	226	140	141	95
2016	211	151	164	105
2017	214	161	157	88
2018	222	159	155	88
2019	230	153	172	111
2020	241	163	161	105
Total	5104	3588	3648	2671
Total (%)	41.4	29	29.6	100

Source: NAMA and NIMET, 2024

5 Conclusion and Recommendations

Results derived from the study showed that the second decade (2001-2010) shows a clear increasing trend in thunderstorm occurrences, as indicated by the positive slope and a relatively high R^2 value. The first and third Decades 1991-2000 and 2011-2020 respectively suggest decreasing trends, but the strength of the correlation is weaker, especially in the first Decade. This also coincides with the period of flight cancellation, delay and diversion. Similarly, the study revealed that the relationship between flight, operations and decadal conditions of thunderstorm occurrences is not statistically significant in Nnamdi Azikiwe International Airport, Abuja. Thunderstorm is a predictor variable for flight cancellation, diversion and delays.

The following recommendations are proposed in order to provide a more holistic understanding of weather's related impact on air travel/aviation.

- a) This study is limited to one climatic parameter (thunderstorms occurrences) because of insufficient data on other parameters such as flight delay, flight cancellations and flight diversion due to inadequate record keeping. Therefore, there is need for all aviation organizations concerned to develop grass roots information data base and keep proper records of every flight operations activities.
- b) Additional data variables such as wind speed, rainfall and other climatic parameters that would integrate direct and indirect impacts of thunderstorms on flight operations.
- c) A study focusing on diversions due to thunderstorms would be beneficial. This would shed light on the financial strain on the aviation industry.
- d) A longer-term study that will consider climate change effects on weather patterns extending beyond 50 years is needed, thus will provide insights into more extended patterns and their impacts on aviation.
- e) Critical examination of weather parameters should be conducted on a regular basis.
- f) Flight takeoff time should be planned based on the prevailing weather condition in order to prevent delays, cancellations and to minimize accidents associated with air transport.

- g) Reliable and well equipped weather stations with the precise prediction of weather stations should be established not only in airports but also in strategic locations across the country (Nigeria) to enable the spatial analysis of weather records across air routes.
- h) More accurate ways of weather information should be emphasized through the training and retraining of aviation personnel.

The Study Declarations

Conflict of Interest: The authors declares no conflicts of interest that could have influenced the conduct, analysis, or reporting of this study. However, the article is not in consideration elsewhere for publication.

Ethics Approval: This study was based on secondary data sources and did not involve direct human subjects. Ethical principles of transparency, integrity, and responsible scholarship were strictly observed. Therefore, ethics approval was not required.

Data Availability: Data supporting the findings of this study are available with or without request.

References

- Abass, I. I., Ojo, K. J. & Igbru, P. A. (2012). *The Impacts of Extreme Weather and climate Eventson Aviation. Environment, Ecology and Management* 1(1), 12.
- Abdulazeez, H. O. (2009). *Effects of Weather on Air Transport. Case Study of NnamdiAzikiwe International Airport, Abuja.* Unpublished Bachelor's thesis, Ahmadu Bello University Zaria. Zaria.
- Akanni, C. O., Hassan, A. M., & Osuji, T. C. (2016). Empirical Analysis of Extreme Weather Conditions and Aviation Safety in Nigeria. *Ethiopian Journal of Environmental Studies and Management*, 9(6), 680-690.
- Akinsala, I., & Ogunjobi, A. (2014). Impact of Thunderstorms on Flight Operations
- Ayigbe, F. (2006, October 20). Federal Government Releases Sosoliso Plane crash Report New Nigerian Newspaper
- Brown, R. A. (2005). Thunderstorms Encyclopedia of World Climatology. Encyclopedia of Earth Sciences Series. Springer: Dordrecht. Pp. 719- 724.
- Bureau of Meteorology (2022). Hazardous Weather Phenomena: Thunderstorms [Internet][cited 2022Sep.6]. Available from: <http://www.bom.gov.au/aviation/data/education/thunderstorm>
- Doswell, C. (2022). Mesoscale Meteorology: Severe Storms [internet]. Encyclopedia of Atmospheric Sciences (Second Edition) [cited 2022 Sep.6]. Available from: <https://www.Sciencedirect.com/tropics/earth-and-planetary-sciences/thunderstorm>
- Ehigiator, K. (2007). Nigeria, Bad Weather Disrupts Flight Operations.
- Ehigiator, K., & Orakpo, E. (2010). Nigeria, Weather Haze Forces Flight Cancellation.
- Enete, I. C., Ajator, U., & Nwoko, K. C. (2015). Impact of thunderstorms on Flight Operations in Port Harcourt International airport omagwa, Rivers State *International Journal of Weather, Climate Change and Conservation Research*, 1(1).1-10.
- Hardy, K. (2011). Thunderstorm Formation and Aviation Hazards. NOAA'S National Weather Service.

- Hauf, I. & Sasse, M. (2022). The Impact of Thunderstorms on landing traffic at Frankfurt Airport (Germany)- A case study.10th Conference on Aviation, Range, and Aerospace Meteorology: Institute of Meteorology and Climatology.
- Hosea, M. (2019). Effect of climate Change on flight operations at Nnamdi Azikiwe International Airport, Abuja, Nigeria. *Sciences World Journal* 14(2), 33-41.
- Idoko, F.N, Ishaya, S, Okosun, S.E, Okodudu, E.E Ehigiator I.R, Jegede, J., Daniel, A, Kingsley U.K, Ugochukwu, U.O, Aladelokun, O.A, Ipinmoroti, S.A, Abraham S.S, David, O.J (2025): Air travel as Catalysts for Urban Development: Examining Thunderstorm Occurrence on Flight Operations in Nnamdi Azikiwe International Airport, Nigeria. Theme; Capacity Building for Inclusive Sustainable Development. Pp 356-369. *A conference Paper of Adventist University of Central Africa held in Kigali, Rwanda 26-28th August 2025*. Published by True Scholar Research Limited, London. ISBN: 734-0341-9240-045
- Igbokwe, C. (2005). "Financial Hostage in the Air" *Punch Newspaper*.
- Inter-governmental Panel on Climate Change IPCC (2014). *Climate Change The Scientific Basis*.
- Klein, A., Kavoussi, S., & Lee, R. S. (2009). *Weather Forecast Accuracy: Study of impact on Airport capacity and estimation of avoidable costs*.
- Knecht, W.R. (2008). *Use of Weather Information by General Aviation Pilots, Part II, Qualitative: Exploring Factors Involved in Weather-Related Decision Making*. (Technical Report DOT/FAA/AM08/7). Washington, DC: Federal Aviation Administration, Office of Aerospace Medicine.
- Krider, E. P. (2022). *Thunderstorm Encyclopedia Britannica* [Internet][cited 2022 Sep. 4] Available from: <https://www.britannica.com/science/thunderstorm>.
- Kulesa, G, Brodus, R., Jackson, D, & Pelton, F. (2013) *Weather and Aviation, Transportation And Climate Change*. California Centre for the study of Energy Market (CSEM) U.S.A
- Macarthus, J. (2005) *Sosoliso Airlines Plane Crash*. En.Wikipedia././Sosoliso Airlines.
- National Oceanic Atmospheric Administration NOAA (2010). *Research-Forecast Systems Laboratory (NOAA/RSL). Service assessment: Intense Space Weather storms*.
- Nigerian Meteorological Agency (2011). *Nigeria Climate Review Bulletin 2010 Abuja*, Page 29-31.
- Ochei, M.C., Orisakwe, I.C & Oluleye A. (2015) *Spatital Seasonal and Inter-Seasonal Variations of Thunderstorm Frequency over Nigeria: African Journal of Environmental Science and Technology* DOI: 10.5897.
- Okoro, R. D, Hassan S. M, & Agidi V. A. (2018) "Trends of Weather Elements Induced Flights Cancellation in Nnamdi Azikiwe International Airport, Abuja Nigeria". *Journal of Safety Engineering* 2018, 7(1): 23-31 DOI:10.5923/j.safety.2018071.02.
- Onwuadiochi, I. Ijioma, M & Mage, J. (2021). *Comparative analysis of the Measured and Extrapolated Wind Shear distributions Murtala Muhammed Airport, Lagos and Port Harcourt International Airport, Nigeria*. *Journal of Environment and Earth Science*. 11(5), 63-78
- Qualley, W.L. (2013) *Impact of weather on the use of weather information by Commercial Airlines, Texas U.S.A*.

- Rafferty, J. (2011). *Dynamic earth: Storms violent winds and earth`s atmosphere*. Britannica Educational Publishing: New York.
- Sani, M. A. (2010). *Effect of Visibility on Aircraft Operation, a case study of Mallam Aminu Kano International Airport*, Department of Geography A.B.U Zaria.
- Seneviratne, S. Nicholls, N & Easterling, D. (2012) *Change in Climate extreme and the impacts on the Natural Physical Environment*.
- Stull, R. (2017). *Practical Meteorology: Algebra- based Survey of Atmospheric Science*. Sundog Publishing, LLC: USA.
- University Corporation for Atmospheric Research (UCAR) (2022). *Center for Science Education* [Internet]. Available from: <https://www.britannica.com/science/thunderstorm>.
- Victor, R. S (2007): *Physics, Mechanics and Process of Dust Storms* Longman Publisher Company London.
- Wurman, J. Kosiba, K & White, T. (2021). *Super-cell tornadoes are much stronger and wider than damage-based ratings indicate PNAS*. 118(14).