Original Research Article

SEASONAL EFFECTS OF WEATHER ELEMENTS ON FLIGHT OPERATIONS AT NNAMDI AZIKIWE INTERNATIONAL AIRPORT ABUJA, NIGERIA

Abstract

The purpose of the study was to assess the significance of weather conditions on aviation transport at Nnamdi Azikiwe International Airport, Abuja. Records on visibility, rainfall, cloud cover, wind speed and direction to cloud cover, and two aspects of flight operations (flight delays and cancellations) for 15 years (2000-2014) were collected from the secondary source. The Spearman rank correlation coefficient, the coefficient of determination, t-test, and multiple linear correlations were used to ascertain relationships between weather elements and flight operations (flight delays and cancellations). Findings of this study show that wind speed has no effect on flight delays since the test of significance value of 1.63 was less than the critical value 1.77. The major weather elements that influenced flight operations was cloud cover. Individual weather elements on their own do not affect flight operations, however, when they are combined, affects aviation transportation significantly.

Keywords: rainy season, weather elements, flight delay, flight cancellation, correlation.

Background to study

Aviation transport is significantly affected by weather. From thunderstorms to the wind, fog, rainfall, and wind speed, every phase of flight have the potential to be impacted by weather. Kulesa (2000), stated that weather is responsible for 70% of all delays, while also being an important contributing factor in 23% all aviation accidents. Mizra et al., (2009), in their work, discovered that weather phenomenon that may affect one flight might have no relevance to a flight that follows ten minutes later, but may affect a different flight which it may encounter the weather phenomenon during the same period.

According to statistics of the Aviation Safety Network (ASN, 2006) of the United States, in the World Aviation study by Eads *et al*., (2002), shows that poor visibility in the summer months and rain storm in winter months lead to substantial delays and a lot of flight cancellations.

"Ranter (2003)", opined that Africa was the most unsafe continent for air travel. In 2002, Africa accounted for 27% of fatal airline accidents, while she is only responsible for 3% of all worlds' aircraft departures. All regions including Europe, North America, South America and Central America recorded a steadily decreasing accident rate over the past 11 years of (1992-2002), except Africa.

Quantitative studies on the impact of weather on the efficiency of air travel, are, however, still limited to case studies, and are confined to either certain aspects of the problem or specific countries, "Theusner and Röhner (2006)". Most of these studies are accomplished in the U.S., but in the past 5 years, some case studies have also been done in Europe. "Theusner and Röhner (2006)", investigated aviation weather hazards, aviation weather impact areas and evaluation methods in the framework of the European Integrated Project FLYSAFE. Most findings collected here are based on their report. Critical weather phenomena having an impact on efficiency and safety of air traffic are:

I. Thunderstorms and lightning

II. Low visibility, associated with clouds, mist, fog, snow, or sandstorms

III. In-flight icing, ground icing

IV. Wind gusts, and wind shear

V. Heavy precipitation, including snow and ice, as well as surface contamination (standing water, ice, or snow on take-off, landing and aircraft maneuver surfaces)

VI. Turbulence (in clouds or clear air)

VII. Volcanic ash

VIII. Sandstorms

IX. Aircraft wake vortices.

"Hauf (2002)", explains that the main reasons for this are methodological problems. These are, as he explains, related mainly to the multiple causes of the delays and difficulty in attributing them to a single cause, and that the relative weight of one factor with respect to others is difficult or impossible to assess. Another problem he points out is that information about delays, and their causes are only partially determined and often lost. The methods to assess the weather impact on aviation are included in "Theusner and Röhner, (2006)".

The analysis of weather-related accidents and incidents are affected by:

I. Type and strength of weather hazard

II. Geographical and seasonal distribution

III. Type of aircraft affected

IV. Typical conditions of occurrence.

V. A climatology of weather hazards as part of risk analysis, with the latter defined by observed occurrence, for example, cloudburst

VI. Necessary and sufficient conditions for the existence of the hazard, or

VII. Issued warnings.

Two different procedures are in use for reporting visibility, and these vary from one country to another:

I. Minimum visibility (This is the lowest visibility measured in any direction).

II. Prevailing visibility (This is the visibility that prevails over at least half of the horizon.)

Flight crews (e.g. Pilots, Co-pilots, flight engineers) are concerned with the range at which they can see objects. The visibility of an object depends not only on the transparency of the atmosphere, but also on factors as such as the nature of the object and its visible background, the size of the object, and its illumination. Outside of clouds, fog and precipitation, it usually is good except in dust, smoke or haze. It may vary with altitude (in the horizontal direction) due to the unequal distribution of obscuring particles. Normal meteorological measurements are made horizontally at the ground level. They give little information about the visibility from points above the ground. On approach and landing, the slant visibility (from aircraft down to the ground) is required. The air-to-ground visibility may be much greater than the horizontal visibility at ground level if a shallow layer of fog or haze is present.

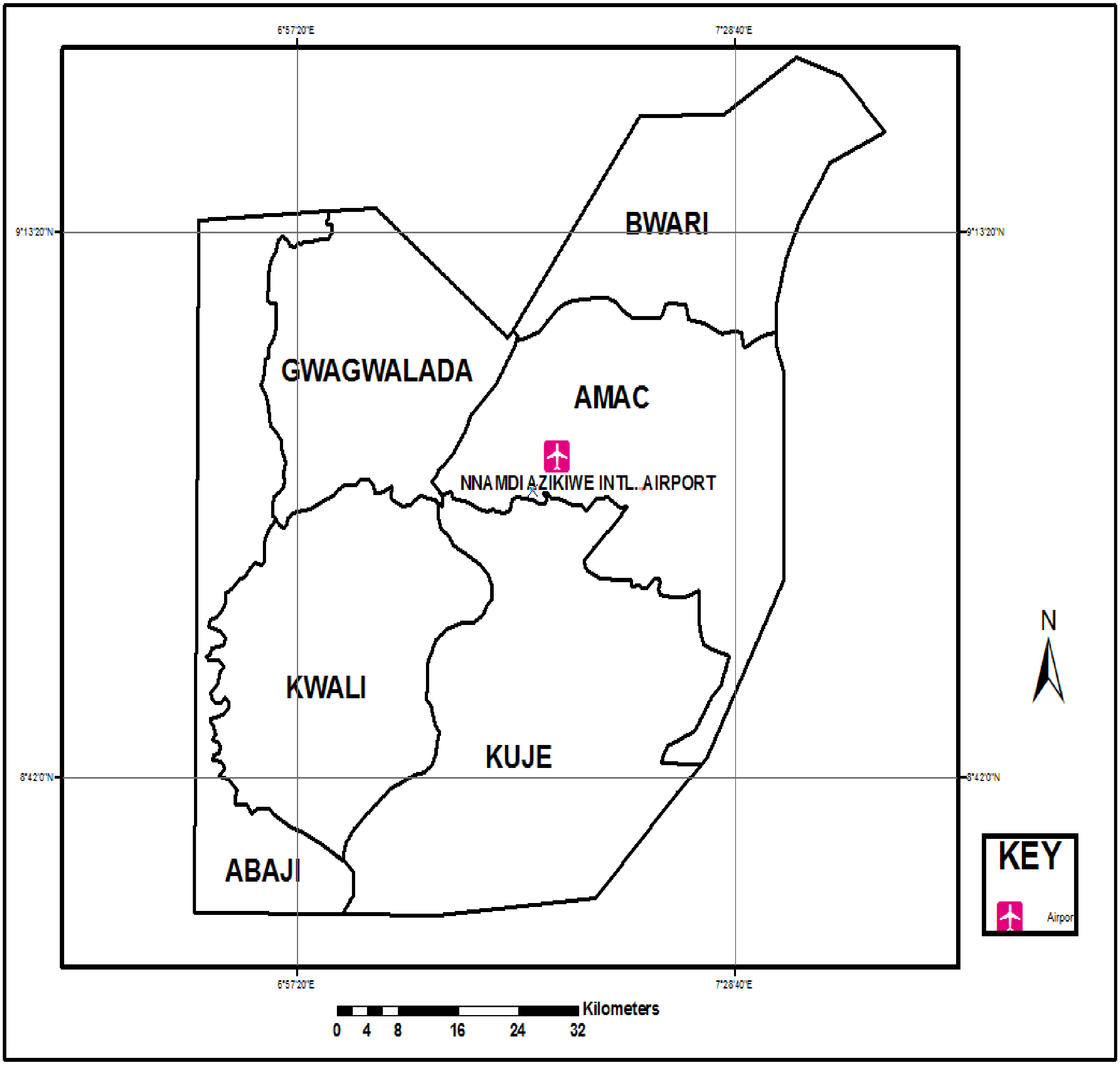
Weather phenomena are tied to two seasons in Nigeria. During the rainy seasons there are delays and diversions of flights as a result of thunderstorm occurrences, and in the dry season, there is the dust haze that reduces visibility. During the period of poor visibility, flights can be diverted to alternate airports when it is difficult to land at their original destination due to poor weather conditions. All of these conditions pose a great risk to passengers, and increased the cost of flight operations; this has been experienced at the Nnamdi Azikiwe International Airport, Abuja. This study, therefore, is an attempt to fill the gap in knowledge by examining the importance of weather conditions in aviation transport between 2000 to 2014 at Nnamdi Azikiwe International Airport, Abuja. This study will show the proximate effect between weather elements and aviation transportation

Study Area

Nnamdi Azikiwe International Airport is located in the Federal Capital Territory (FCT), Abuja. It is about 45km south of the city. The airport has both international areas which serves domestic and international flights and the private area that is used for charter flights. The elevation of the airport is 1,123ft / 342m above mean sea level. It has two runway directions namely 04/22, and the runway length is 3600m/11,842 ft (Nigerian Aeronautical Information Publication [NAIP], 2013).

Abuja International Airport provides flight services both to domestic and

International destinations. It is a public airport operated by the Federal Airports Authority of



Nigeria.

Source: Federal Capital Development Authority (FCDA) 2017

The climate of the Study Area

The climate is generally tropical (Abomeh, 2013). The climate if FCT is largely governed by the Inter-Tropical Convergence Zone (ITCZ). This zone of convergence is normally defined by both the moisture-laden south-west winds and the north-east dry, continental winds. Rain normally occurs south of ITCZ when the ITCZ passes northwards through the FCT between the middle of March and June, and it heralds the beginning of the rainy season. On its return southwards about the middle of October, it heralds the onset of the dry season. Consequently, there is a distinct rainy season that starts in April and ends in October, and a dry, cold season that begins in November and ends in March (Ujoh *et al.,* 2010).

The mean annual rainfall total ranges from 1,145mm to 1,631.7mm (Ujoh *et al.,* 2010). This reflects a situation that results from the FCT's location on the windward side of the Jos plateau. This gives rise to frequent rainfalls and a noticeable increase in the mean annual total from the south to the north (Balogun, 2001).

The FCT records its highest temperatures and greatest diurnal ranges during the dry season when the maximum temperature ranges between 30.40^{0}C and 35.1^{0}C. During the rainy season, the maximum temperature ranges between 25.8^{0}C and 30.2^{0}C. Also, the diurnal range is much reduced. Two main factors strongly influence temperature patterns in the FCT. These are cloud cover and elevation, these, therefore, accounts for the relatively higher temperatures in some parts of the FCT (Ujoh *et al.,* 2010).

Abuja is easily the best place to situate a business because of its strategic location and market structure. Abuja officially became Nigeria's capital in December 1991, following relocation from the former capital Lagos. It is one of Africa's few purposes built cities (Jibril, 2006; Adama, 2007). The City was designed to serve as a model to other Nigerian cities in the way utilities and services are managed. It has been reported that the population in some areas in Abuja is growing by as much as 20-30% per annum Jibril (2006).

METHODOLOGY

Mode of Data Collection

The study adopted a retrospective survey design, which involved the use of historical/archival data of weather parameters and records of flight operations from Nnamdi Azikiwe International Airport, Abuja. Weather and flight cancellation data for 15 years were collected from Nigeria Meteorological Agency (NIMET) and the Nigerian Air Space Management Agency (NAMA) both located at the Abuja International Airport respectively. The weather parameters collected from Nigerian Metrological Agency (NIMET) includes:

i. Rainfall data from 2000 -2014 (15 years) for Nnamdi Azikiwe International Airport
ii. Records of low horizontal visibility from 2000-2014 (15 years) for Nnamdi Azikiwe International Airport.
iii. Records of wind speed (WNSPD) on runway 04/22 for Nnamdi Azikiwe International Airport.
iv. Records of cloud cover from 2000-2014 (15 years) for Nnamdi Azikiwe International Airport.

While The Airport Operational Data which include **flight delays**, **cancellations,** and **diversions** were collected for the same period.

Data Analysis

Multivariate analysis such as Spearman Rank Correlation Coefficient, the coefficient of determination, t-test analysis and multiple correlations will be used to demonstrate the relationship.

Spearman Rank Correlation Coefficient: It is used widely in assessing the level of association between two variables when the raw data are not in absolute values but only ranked in form. In this study it will be used to assess the relationship between rainfall and flight operations (cancellation, delay and diversion), visibility and flight operations (cancellation, delay and diversion), wind speed and flight operations (cancellation, delay and diversion), and cloud cover and flight operations (cancellation, delay and diversion). It has the formula thus:

$$rs = \frac{1-6\sum d^2}{n(n^2-1)}$$

Where

rs= Spearman rank correlation coefficient

n= the number of pairs of occurrences being considered

d= the difference between the pairs of ranked values

d^2= summation of the squares of the difference

Multiple regression analysis was adopted for the analysis to show the extent of the relationship between weather elements and flight cancellations and delays. This is because it gives a better relationship of causative factors. Every value of independent variable x is associated with a value of the dependent variable y.

$$R = \sqrt{\frac{r^2_{yx_1} + r^2_{yx_2} - 2r_{yx_1} \cdot r_{yx_2} \cdot r_{x_1x_2}}{1 - r^2_{x_1x_2}}}$$

Where:

R= correlation coefficient (overall)

r_{yx1} = correlation coefficient for y and x1

r_{yx2} = correlation coefficient for y and x2

r_{x1x2} = correlation coefficient for x1 and x2.

The coefficient of determination (R^2) is also determined, it is calculated as the square of the correlation coefficient (R) between the sample and predicted data.

The significance level for a given hypothesis test is a value for which a P-value less than or equal to is considered statistically significant. When a calculated value is greater than a table value the null hypothesis will be rejected and vice versa.

RESULTS AND DISCUSSION

The relationship between Flight Cancellation and Weather Elements

Table 1 shows the relationship between flight cancellation and visibility, rainfall, cloud cover and wind speed. The annual and monthly relationship between flight cancellation and weather elements in the space of (15 years) is as shown in Table 1. The Spearman rank correlation analysis and test for significance are presented.

Table 1: Relationship between Weather Elements and Flight Cancellation

Annual Relationship Between Weather Elements and Cancellation						
	Correlation Analysis			**Test for significance**		
	Correlation coefficient	**Coefficient-of determination**	**Remark,**	**Calculated value**	**Critical value**	**Remark**
Flight cancellation and visibility	-0.64	0.41	Fairly-strong negative relationship	3	1.77	Rejected
Flight cancellation and rainfall	0.33	0.11	Positively weak relationship	1.27	1.77	Accepted

Flight cancellation and cloud cover	0.7	0.49	Fairly-strong positive relationship	3.56	1.77	Rejected
Flight cancellation and wind speed	-0.52	0.27	Fairly-strong negative relationship	2.21	1.77	Rejected

Source: Data Analysis (2017)

Table 2: Monthly Relationship Between Weather Elements and Cancellation

	Correlation coefficient	Coefficient of determination	Remarks	Calculated value	Critical Value	Remarks
Fights Cancellation and Visibility	0.32	0.10	Positively weak relationship	1.06	1.18	Accepted
Flight Cancellation and Rainfall	-0.84	0.71	Fairly strong negative relationship	4.91	1.18	Rejected
Flight Cancellation and Cloud Cover	-0.25	0.06	Negatively weak relationship	0.81	1.18	Accepted
Flight cancellation and wind speed	-0.04	0.00	No relationship	0.13	1.18	Accepted

Source: Data Analysis (2017)

The annual correlation analysis as presented in Table 1 shows that flight cancellation and visibility has a correlation coefficient of -0.64, with 0.41 coefficient of determination. The test for significance indicates that the postulated null hypothesis is rejected since the calculated value (3) is greater than the critical value (1.77). This further indicates that at 0.05%, the correlation coefficient is significant. These findings agree with the study by Ayoade (2004), who revealed that poor visibility is the single most important weather hazard to all forms of transportation, especially air transportation. Poor visibility can be caused by thick fog, snow, rain, dust haze, mist, smoke, low ceilings and smog among others.

The correlation coefficient between annual flight cancellations and rainfall stood at 0.33, with 0.11 coefficient of determination. The coefficient of determination (0.11 or 11%) implies that 89% of the variations in flight cancellations as correlated with rainfall amount are determined by other unforeseen factors. The test for significance shows that at 0.05%, the correlation coefficient is not significant, since the calculated value (1.27) is less than the critical value (1.77).

Results of correlation between annual flight cancellations records and cloud cover within the study period show a correlation coefficient of 0.7, with a coefficient of determination of 0.49. This implies a fairly strong positive relationship between both variables. The coefficient of determination (0.49 or 49%) indicates that 51% of the variations in flight cancellation as correlated with cloud cover are determined by other unforeseen related factors. The test for significance indicates that the postulated null hypothesis is rejected since the calculated value (3.56) is greater than the table value (1.77).

The annual flight cancellation and wind speed correlated stood at -0.52, with a coefficient of determination of 0.27. This indicates a fairly strong negative relationship between flight cancellations and wind speed. The estimated coefficient of determination (0.27 or 27%) indicates that 73% of the variations in flight cancellations, as correlated with wind speed are determined by other related factors. The test for significance indicates that the postulated null hypothesis is rejected since the calculated value (2.21) is greater than the table value (1.77). This further indicates that at 0.05%, the correlation coefficient is significant

The result of the correlation between monthly flight cancellations and visibility, rainfall, cloud cover, and wind speed is shown in Table 2. The monthly flight cancellations and visibility correlation coefficient stood at 0.32, with a coefficient of determination at 0.10. This indicates a weak positive relationship. The coefficient of determination (0.10 or 10%) indicates that the undetermined proportions of variation (90%) are due to other factors. The significant test shows that at 0.05%, the correlation coefficient is not significant, since the calculated value (1.06) is less than the critical value (1.81). This find relevance in the work of Miner (2002), who reported that there is a relationship between weather parameters and flight operations, but that the relationship was insignificant due to weather modification.

Furthermore, the monthly flight cancellation and rainfall analysis show that the correlation coefficient of both variables stood at –0.84, with a coefficient of determination of 0.71. This indicates a fairly strong negative relationship between rainfall effects and flight cancellation. The coefficient of determination (0.71 or 71%) indicates that the undetermined proportions of variation (29%) are due to other related factors. The significance test shows that at 0.05%, the correlation coefficient is significant as proved by the calculated value (4.91) compare to the critical value (1.81). Enete, *et al.,* (2015) revealed that rainfall accounted for 32% of flight cancellations with 218 occurrences from 2008-2013 in Port-Harcourt. Rainfall has a greater influence on the number of flight cancellations and delays than on diversions.

The monthly data set of flight cancellation and cloud cover has a correlation coefficient of -0.25, and a coefficient of determination of 0.06. This implies a negatively weak relationship. The coefficient of determination (0.06 or 6%) implies that 94% of the variation in the monthly flight cancellations and cloud cover relationship is due to other factors. The test for significance shows that at 0.05%, the correlation coefficient is not significant, since the calculated value (0.81) is less than the critical value (1.81). Cloud cover has a negative impact on flight operations at Nnamdi Azikiwe International Airport. This is in agreement with the findings of Christopher (2013) that noted a positive relationship between cloud cover and flight cancellation in Abuja, and Kano International Airport between 1986 and 2005.

In contrast with the annual results, the monthly data set of flight cancellations and wind speed has a correlation coefficient of 0.04, and a coefficient of determination of 0.00. This indicates that there is no relationship between monthly flight records and wind speed. The coefficient of determination (0.00 or 0%) implies that 100% of the monthly flight cancellations are not due to wind speed. The test for significance shows that at 0.05%, the correlation coefficient is not significant, since the calculated value (0.13) is less than the critical value (1.81). This implies that the annual relationships of these weather elements have more of an effect on flight cancellations than the monthly relationships of these weather elements except in the case where the monthly rainfall has more of an effect on flight cancellations than the annual rainfall. From Table 4, which shows the annual relationship of the weather element, cloud cover has the strongest relationship with flight cancellations followed by visibility and wind speed while in the monthly relationship of weather elements rainfall has the strongest relationship with flight cancellation. Enete *et al.,* (2015) concurs with the fact that wind speed is the climatic element with least affects air transportation in Nigeria.

Flight Delay and Weather Elements

The relationship between the data set of flight delays and visibility, rainfall, cloud cover and wind speed, as weather elements, are presented in Table 3.

Table 3: Relationship between Weather Elements and Flight Delays

Annual Relationship Between Weather Elements and Flight Delay						
	Correlation Analysis			**Test for significance**		
	Correlation coefficient	**Coefficient of determination**	**Remark**	**Calculated value**	**Critical value**	**Remark**
Flight delay and visibility	-0.46	0.21	Negative weak relationship	1.87	1.77	Rejected
Flight delay and rainfall	0.44	0.19	Positively weak	1.77	1.77	Accepted

			relationship			
Flight delay and cloud cover	0.65	0.42	Fairly strong positive relationship	3.09	1.77	Rejected
Flight delay and wind speed	-0.41	0.17	negative weak relationship	1.63	1.77	Accepted

Source: Data Analysis (2017).

Table 4: Monthly Relationship between Weather Elements and Flight Delays

Flight delay and visibility	0.27	0.07	Positively weak relationship	0.89	1.81	Accepted
Flight delay and rainfall	-0.77	0.59	Fairly weak negative relationship	3.80	1.81	Rejected
Flight delay and cloud cover	0.24	0.06	Positively weak relationship	0.78	1.81	Accepted
Flight delay and wind speed	-0.20	0.04	Very weak negative relationship	0.64	181	Accepted

Source: Data Analysis (2017).

Table 3 shows the correlation between flight delays and visibility, rainfall, cloud cover and wind speed. The results show that the relationship between flight delays and visibility and wind speed has small negative correlation, hence weak relationship. While the correlation of flight delays on rainfall and wind speed shows a positive but weak relationship.

Table 4 shows the correlation of the same elements (weather/climate) with flight delay on a monthly basis, and the results show that rainfall and wind speed have a very weak (negative) relationship with a flight delays. That implies that they have almost no influence on flight delays. While visibility and cloud cover have a fairly positive relationship with flight delay, implying there is a little influence, on a monthly, basis of these elements on flight delays.

Multiple Correlations of Flight Cancellation and Weather Elements

Table 5 shows the influence of weather elements (visibility, rainfall, cloud cover and wind speed) on annual and monthly flight cancellations and flight delays respectively.

Table 5: Multiple Relationship Between Visibility, Rainfall, Cloud Cover, Wind speed and Flight Cancellations.

	Multiple Correlation	Coefficient of Multiple Determination
Annual Correlation	0.94	0.88
Monthly Correlation	0.94	0.88

Source: Data Analysis (2017).

Table 6: Multiple Relationship between Visibility, Rainfall, Cloud Cover, Wind speed and Flight Delays

Multiple Relationship Between Visibility, Rainfall, Cloud Cover, Wind speed and Flight Delays		
	Multiple Correlation	Coefficient of Multiple Determination
Annual Correlation	0.93	0.86
Monthly Correlation	0.79	0.63

Source: Data Analysis (2017).

Multiple correlation analysis between the various weather elements and flight cancellations shows that both the annual and monthly flight cancellation records were influenced by weather variables. The coefficient of the multiple determinations (0.88) implies that 88% of flight cancellations are determined by the combined variation of the various weather elements (visibility, rainfall, cloud cover, and wind speed). This finding is contrary to that of Christopher (2013), in that the effects of weather parameters on flight operations are insignificant, hence not solely responsible for flight cancellation in Nigeria in recent years. In another vein, Enete, *et al.,* (2015), revealed that rainfall accounted for 32% of flight cancellations with 218 occurrences, 0.2% of diversion with 291 occurrences, and 24% of delays, with 526 occurrences at the airport in Port Harcourt from 2008-2013. Rainfall has a greater influence on the number of flight cancellations and delays than on diversions based on the correlations.

The multiple correlation analysis of annual and monthly flight delay records, and the various weather elements (rainfall, cloud cover, visibility, and wind speed), showed a high degree of association. However, their degree of the relationship varies, as indicated by the coefficient of multiple determinations. The annual records have a multiple determination coefficient of 0.86 (86%). This indicates that 86% of the variations in annual flight delay are due to the combined variation of weather elements (rainfall, cloud cover, visibility and wind speed). Likewise, the monthly correlation of flight delay and weather elements has multiple determination coefficients of 0.63 (63%). This indicates that 63% of the variation in monthly flight delays is due to the combined variation of weather elements (rainfall, cloud cover, visibility and wind speed). This implies that individual elements on their own do not significantly impact flight operations. However, the combined effects of these weather elements affect aviation transportation significantly.

Emmanuel *et al.,* (2013) noted that visibility, rainfall, cloud cover and wind speed have contributed to many flight delays and aircraft accidents in the world. Visibility, rainfall, cloud cover and wind speed all restrict visibility and can result in flight delays. Adverse weather conditions causing widespread low ceilings and visibilities can restrict flying operations for days.

This finding is consistent Allan *et al.,* (2001), conducted on weather related flight delays at Newyork 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.,* (2001) found that 68% of the cumulative flights' 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.

Conclusion

Four weather elements, namely visibility, rainfall, cloud cover and wind speed along with records of flight operations (flight delays and cancellations) were collected from the Nigerian Airspace Management Agency and the Nigerian Metrological Agency. In this study, the weather elements were correlated with the records of flight operations. Weather elements have a great influence on air transportation, especially when they are combined. However, the statistical analysis clearly shows that wind speed has no strong degree of association or influence on flight cancellations and flight delays. This indicates that wind speed has no negative effect on air transportation due to the general absence of strong gust and stormy weather, e.g., line squalls in the vicinity of the airport.

RECOMMENDATION

1. Critical examination of weather parameters should be conducted on a regular basis.
2. 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.
3. 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.
4. More accurate ways of weather information should be emphasized through the training and retraining of aviation personnel.

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