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STATISTICAL ANALYSIS OF WEATHER PARAMETERS FOR SUSTAINABLE FLIGHT OPERATION IN NIGERIA

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Abstract

The recent complications in the weather system, which oftentimes lead to flight cancellation, delay and diversion have become a critical issue in Nigeria. This study however considers the weather related parameters and their impacts on flight disruption in the country. Weather data (on thunderstorm, wind speed and direction, visibility and cloud cover) and flight data (delay, cancellation and diversion) were collected from Murtala International Airport, Ikeja-Lagos, Nigeria. The data covered the period between 2005 and 2020. However, Regional Climate Models (RCMs) were also used to run climate data projections between year 2020 and 2035 in the study region. The study employed Statistical Package for Social Sciences (SPSS) software for the descriptive and inferential analysis. Time series analysis, Pearson Moment Correlation for interrelationship among the weather parameters and the flight disruption data, and multiple linear regression analysis were applied to determine the influence of weather parameters on flight disruption data. Results show that cloud cover and high visibility are negatively correlated. Wind speed has positive relationship with wind direction; and an inverse relationship between visibility, thunderstorm, and fog. Direct relationship exists between highest visibility and thick dust, wind speed and cloud cover. Thick dust, wind speed and cloud cover indicate increased visibility level in the study area. Flight delay is prominent over flight diversion and cancellation, which indicates their relevance in air traffic of the study area. The prediction model indicates high degree of cloud cover at the beginning of every year and later declines sharply in 2035, the visibility flattens out by the year 2025, and low pattern of thick dust was calculated in the same pattern in 2011, 2016 and 2027. Based on this conclusion, the study recommends accurate weather reporting and strict compliance to safety regulations, and attention should be paid to changing pattern of weather parameters in order to minimize fight related disasters.

Keywords: weather parameters, air traffic, flight delay, flight diversion, flight cancellation

INTRODUCTION

Weather is extremely changeable because the atmosphere that constitute it is never static. Consequently, it is crucial to understand the mechanism of this variation to mitigate the negative effects on the society. The general public and the aviation industry in particular have become aware of this variability, and feel its negative impacts where they live. There has been an increasing awareness, concern and studies on weather parameters as one of the causes of air disasters over the years. The importance of such studies cannot be overemphasized if air safety must be achieved. However, there is still low level of recognition and research attention on some weather parameters in Nigeria.

Aviation is one of the critical parts of any national economy. It provides fastest means of moving people and goods among the world's nations for enabling economic growth (Waitz et al., 2004). The volume of air transportation is increasing rapidly; though the safety of aviation becomes an important problem over many countries. As noted by McFadden and Hosmane (2001), accident of an aircraft usually leads to human injury and loss of life. As noted by Nwaogbe et al. (2013), air transportation is a major industry in its own right and it also provides important inputs into wider economic, political, and social processes. The demand for its services, as with most transport, is a derived one that is driven by the needs and desires to attain some other final objective. Lack of air transport, as with any other input into the economic system, can prevent efficient growth.

The Nigerian aviation industry witnessed its darkest period between 2003 and 2010, when several aircraft accidents occurred, resulting in loss of lives. It was however observed that air crashes occurred between 2003 and 2006 mostly as a result of weather and wind shear anomalies. Knecht (2008) confirmed that most of the plane crashes could be associated with poor conditions of weather and some other factors. Similarly, flight delay, cancellation, diversion and air craft accidents affect the Nigerian Aviation Industry as Ayoade (2004) has earlier noted that "the vagaries of weather with references of the various meteorological parameters act malevolently against most of man's socio-economic activities". Consequently, flight delay, flight cancellation, and flight diversion were adopted as control measure of avoiding aircraft accidents.

Weather, which is defined as the snapshot of atmospheric conditions and a technical status report of the earth atmosphere heat energy budget or simply defined as an everyday experience (Stringer, 1989), can evolve at a rapid rate over a wide spatial extent when compared with other factors that may affect the safe conduct of flight. Thus, the spectrum of weather information is an important component for flight safety and the efficient management of air transport in future (Mirza et al., 2009).

In some cases, weather is completely neglected. For instance, Arizona-Ogwu (2008), in a study on safety of air transport in Nigeria reported that experts attributed the causes of air disaster to pilot error (human related), pilot error (weather related), pilot error (mechanical related), other human error, weather, mechanical failure, sabotage etc. Nevertheless, he attributed it to out-dated air crafts being flown everywhere in Nigeria rather than what the experts revealed. He also reported that between 1988 and 2005 (in 17 years), the private airlines recorded 12 crashes, of which only one had no casualties, while the total deaths recorded was 762. There are three major weather phenomena, which pose severe threat to air transportation under the two distinct seasons observed in Nigeria. Thunderstorms occur within the wet/rainy season, while fog and dust haze (harmattan) are typical in the dry period of the year. This implies that the phenomenon of plane crash is tied to these two major seasons in Nigeria.

Thus, assessment of relevant weather parameters that include temperature, humidity, wind, cloud cover, visibility, fogs, thunderstorms, and dust haze is critical for aviation activities. This is more so considering aviation as one of the earliest industries involved in using weather as the basis for its operational decision making. Good knowledge of flight operation vis-à-vis operational weather situation is a precondition for passengers' safety and protection of goods. Riehl (1965) has shown that low ceilings and visibilities cause the major traffic disruptions at airport terminals, and the problem is said to remain unchanged over the years. In addition, Smith (1975) reports that despite increasing sophistication of automatic landing equipment, poor visibility from layer of fog, mist or thick haze and low cloud ceilings is probably the major impediment to airport operations throughout the world. The major challenges facing the aviation industry has been to adapt to the vigorous of an extreme and variable weather environment. In prospect of this fact, it becomes highly desirable to ascertain the nature of weather parameters in an area. This is because the safety of modern air communication is closely tied to accurate weather reports from the meteorological stations, and weather conditions influence the performance and durability of aircraft engines. More so, wind affects the degree of smoothness of the air and brings about changes in weather, which makes a difference between safe flight and disaster. The apprehension is that, the incessant flight cancellation, re-routing, delay, diversion of recent, mostly because of this natural factors (bad and inclement weather) may remain or even increase with the present concept of climate change and its resultant global warming if something is not done to mitigate the situation.

The focus of this study is on the statistical analysis of weather parameters for flight operation in Lagos, Ikeja, Nigeria; aiming to describe various parameters influencing flight operation, and relationship among weather parameters for supporting sustainable flight planning. Evaluating the effects of cloud cover, thunderstorm, visibility, wind speed and direction on flight operation and how weather conditions could be managed for sustainable flight operation in Murtala Mohammed International Airport is the prime focus of this study.

STUDY AREA

The Murtala Mohammed International Airport owned and operated by the Federal Airport Authority of Nigerian (FAAN) is situated in the suburb of Ikeja, 22 km northwest of Lagos. The coordinate of the airport is 06°34'39''N and 03°19'16''E (Fig. 1).

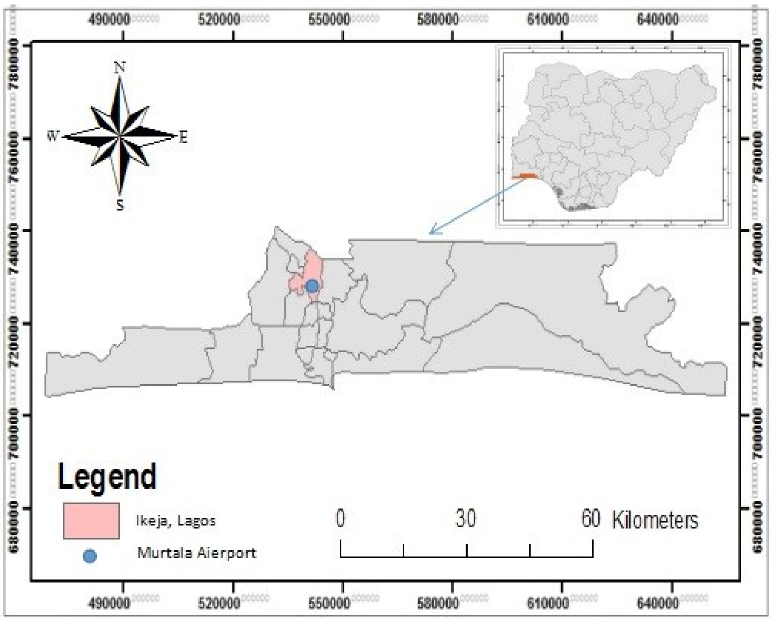

Fig. 1 Map of Lagos State showing study area at the Murtala Mohammed International Airport (source: Ministry of Lands and Housing, Ikeja, 2020)

Lagos experiences tropical wet and dry Savannah climate AW according to the Köppen climate classification. The heavy rainy season is between April and June, and the milder rainy season occurs between October and November. A very brief dry season is in August and September, whereas a long dry period occurs from December to March. The average rainfall between May and July is over 300 mm, while it is only 75 mm to 100 mm in August and September. In January, the average rainfall is only 35 mm (Fig. 2). The long dry season is followed by dry wind coming from the Sahara Desert, which is the most intense during the months from December to February (Pospichal, et al., 2010).

Temperature in Lagos does not vary greatly. March is generally the hottest month, with an average temperature reaching 29°C (Fig. 3). July is usually the coolest month, averaging 25°C. The average temperature in January is 27°C. Temperature in Lagos rarely gets colder than 20°C and rarely gets hotter than 30°C. The month with the highest average low temperature is March (23.8°C). The coldest month (with the lowest average low temperature) is August (21.7°C).

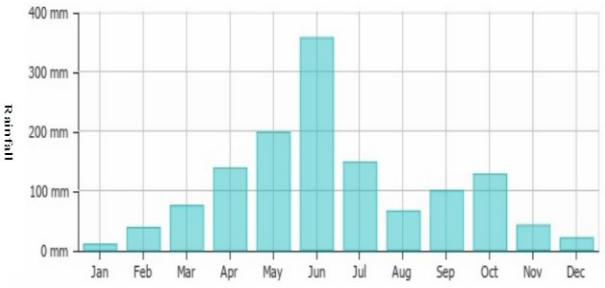

Fig. 2 Average monthly rainfall (mm) in Lagos (source: weather-and-climate.com)

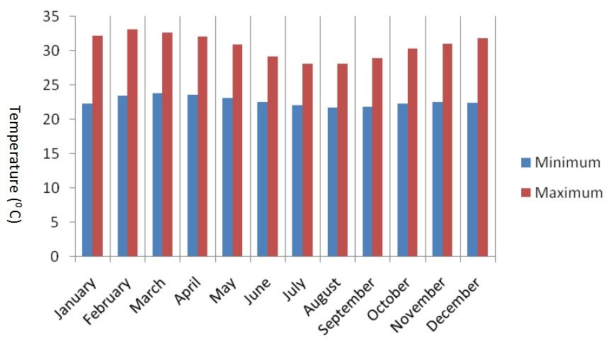

Fig. 3 Lagos average monthly temperature in Lagos (source: weather-and-climate.com)

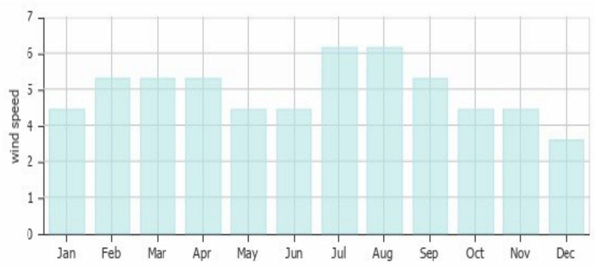

Fig. 4 Average wind speed (m/s) in Lagos (source: weather-and-Climate.com)

Furthermore, Lagos state is under the influence of the south west trade wind at most times of the year, and this account for its moderate temperature throughout the year. The highest average wind speed recorded was between July and August, which is above 6 m/s (Fig. 4).

METHODS

In this study monthly mean temperature, wind, visibility, cloud cover, thunderstorm, fog, and dust data were used for the period of 2005–2020. These parameters were selected because they were available from ground measurements. The possibilities of these parameters are noticed in reduction of visibility, creation of turbulence, and general poor aircraft performance. The focus was on analysing wind speed and direction (knot), cloud cover (okta), thunderstorm, fog (mm), dust, visibility (mi) as they affect flight delay, cancellation, and diversion in the study area. The monthly data were obtained from the Nigerian Meteorological Agency (NIMET), and monthly flight disruption data on flight diversion, delay and cancellation were collected from Nigerian Civil Aviation Authority (NCAA), Oshodi, Lagos State, Nigeria. Regional Climate Models (RCMs) were used to run climate data projections between year 2020 and 2035 within the study region.

The study employed Statistical Package for Social Sciences (SPSS) software for the descriptive and inferential statistics that include, time series for trend analysis, Pearson Moment Correlation for interrelationship among the weather parameters and the flight disruption data, and multiple linear regression analysis to determine the influence of weather parameters on flight disruption data. The correlation was tested at 5% level of significance with Pearson Product Moment Correlation. The rational for the choice of the statistics is due to the fact that all the weather variables are metric. The OFD is a simple device suitable for the detection of fog and cloud. Calculations show that the OFD responds to visibility reductions by droplets in the size range of 2–20 mm. Fog is large density of small water droplets that are small enough to "float" in the air. The size of fog particles is typically 5–50 µm (0.005–0.05 mm). The dust measuring device PCE-MPC 20 was used to measure the particles in the atmosphere. The measurable particle sizes in the particle collector are 0.3, 2.5 and 10 µm.

RESULTS AND DISCUSSIONS

Relationship among weather parameters in the study area

Table 1 shows the correlation between all studied weather elements in the study area. The results of the analysis indicate that all the tested weather parameters have correlation coefficients that are far from the value of 1.0. However, there is an inverse relationship between highest visibility and visibility, thunderstorm, fog, and wind direction; while direct relationship exists between highest visibility and thick dust, wind speed and cloud cover.

Also, the correlation matrix (Table 1) indicates negative relationship between the highest visibility and thunderstorms, thick dust, fog, cloud cover and wind

Table 1 Correlation matrix of weather parameters in the study area.

Weather parameters	Highest visibility	Visibility	Thunder-storm	Thick dust	Fog	Wind speed	Cloud cover	Wind direction
Highest visibility	1.000							
Visibility	- 0.077	1.000						
Thunderstorm	-0.058	-0.108	1.000					
Thick dust	-0.076	-0.000	-0.031	1.000				
Fog	-0.117	0.016	-0.142	-0.004	1.000			
Wind speed	0.133	0.003	-0.157	0.028	-0.052	1.000		
Cloud cover	-0.029	-0.144	-0.109	0.073	0.027	0.058	1.000	
Wind direction	-0.072	0.085	-0.125	0.122	0.135	0.470	0.095	1.000

direction with -0,077, -0.58, -0.076, -0.117, -0.029 and - 0.072 respectively. This simply explained by the influence of these parameter on visibility. It is worthy to note that dust, wind speed and cloud cover could indicate increased visibility level as an environmental factor in the study area. However, wind speed has positive relationship with recorded highest visibility of the study area. Thunderstorm has negative relationship with highest visibility, visibility, dust, winds, fog and cloud cover. Further, it was established that cloud cover and highest visibility are positively correlated. This shows that the highest visibility experience in the study area depends on the level at which cloud cover is perceived. Wind direction (0.470) has positive relationship with wind speed.

There is negative relationship between thick dust and fog (r=0.00, p>0.05). However, all other weather elements show positive association with thick dust. The association is, also, not significant. There is no relationship between fog (r=0.00, p>0.05) and thick dust, whereas, wind speed (r=0.03, p>0.05), cloud cover (r=0.07, p>0.05), and wind direction (r=0.12, p>0.05) show direct correlation with thick dust but the relationships are not significant.

The relationship between fog and wind speed (r=-0.05, p>0.05) is negative; while cloud cover (r=0.03, P>0.05) and wind speed (r=0.14, p>0.05) show positive relationship with fog, although, the correlation is not significant in any of the cases. Both cloud cover (r=0.06, p>0.05) and wind direction (r=0.5, p<0.05) show positive relationship with wind speed but not significant. There is a significant moderate relationship between wind speed and wind direction. It is evident, that strong vertical wind shear is important to severe thunderstorm development. Wind shear influences a storm in potentially several ways of significant increase of wind speed with height will tilt a storm's updraft, strong upper tropospheric winds evacuates mass from the top of the updraft, directional shear in the lower troposphere helps initiate the development of a rotating updraft, and the shear environment important in determining the thunderstorm type. This relationship could mean that wind speed is propelled by the direction of increased wind pressure. The relationship between cloud cover and wind speed (r=0.01, p>0.05) is positive but weak and not significant.

Impact of weather parameters on flight disruption in the study area

The effect of weather elements on flight operations in the study area was presented in Table 2 with multiple linear regression output. Three approaches were designed to test the impacts of weather elements on flight disruption data. Flight disruptions were measured by numerically capturing number of flight delay, number of flight diversion, and number of flight cancellation over time. Table 2 presents statistics of recorded flight disruption parameters in the study area. It was revealed that flight delay has the mean of 44.06, flight diversion has 22.13, and flight cancellation has 19.19. Considering these calculated means, it is obvious that flight delay is prominent among other parameters of flight disruption in the study area. However, the results of mean on flight diversion and cancellation are not too far apart, which indicates their relevance in air traffic. To this, Rodenhuis (2004) submitted that critical weather phenomenon reduces the operational capacity of regions entire airspace through delays, diversion and flight cancellations.

In Table 3, the multiple linear regression model presents highest visibility, thunderstorm and dust, cloud

Table 2 Recorded annual flight disruptions between 2005 and 2020

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Diversion	16	11.00	40.00	22.1250	8.77021
Delay	16	16.00	70.00	44.0625	17.22196
Cancellation	16	3.00	30.00	19.1875	6.77465

Table 3 Regression analysis of the effect of weather parameters on flight disruption in the study area

	Coefficient	p-value	Beta coefficient
Delay			
Highest Visibility	4.619	0.000	0.511
Visibility	-0.009	0.207	-0.159
Thunderstorm	3.328	0.001	0.434
Thick dust	0.876	0.616	0.051
Fog	-2.755	0.345	-0.118
Wind speed	-1.535	0.323	-0.140
Cloud cover	2.377	0.636	0.053
Wind direction	0.125	0.108	0.183
Constant	-243.132	0.577	
Diversion			
Highest Visibility	-0.067	0.936	-0.016
Visibility	-0.005	0.373	-0.178
Thunderstorm	0.339	0.640	0.093
Thick dust	0.957	0.471	0.125
Fog	-1.711	0.439	-0.154
Wind speed	-0.242	0.837	-0.046
Cloud cover	3.529	0.619	0.089
Wind direction	0.059	0.313	0.181
Constant	-152.595	0.645	
Cancellation			
Highest Visibility	0.567	0.156	0.155
Visibility	-0.001	0.760	-0.033
Thunderstorm	1.709	0.000	0.550
Thick dust	-0.965	0.125	-0.148
Fog	-0.854	0.409	-0.090
Wind speed	2.201	0.000	0.491
Cloud cover	-3.466	0.875	-0.015
Wind direction	0.033	0.223	0.120
Constant	6.774	0.965	

cover and wind direction with positive beta values of 0.511, 0.434, 0.051, 0.053, and 0.183 respectively. This result indicates that climate data (Coeff=4.62, $p<0.05$) and thunderstorm (Coeff=3.33, $p<0.05$) are significant predictor of flight delay relating to diversion indicates cloud cover with (Coeff=3.53, $p<0.05$). The beta coefficient has positive values on high visibility, thunderstorm, tick dust, cloud cover and wind. This indicates that for every 1-unit increase in the weather parameters that were positive, the delay in flight will increase by the beta coefficient values. However, the negative values explained 1-unit reduction by the beta coefficient values.

Further, it was indicated in Table 3 that cloud cover has significant impact on flight diversion. It was also revealed that thunderstorm (Coeff=1.71, $p<0.05$) and wind speed (Coeff=2.20, $p<0.05$) have significant influence on flight cancellation. The thunderstorm has highest beta coefficient being the prominent predictor of flight cancellation. It was observed that the faster the wind speed coupled with high degree of thunderstorm, more flight cancellations are usually recorded. The study of Weli and Ifediba (2014) confirmed that various weather hazards which include thunderstorm, fog, dust haze and line squall affect flight operation such as flight delays, diversion and cancellation. Also, the current study supports the findings of Schaefer and Millner (2001) who opined that weather is the single largest contributor to delays in the efficiency of flight operation. It is becoming the dominant cause of delay in Nigeria. Flights can incur delays while airborne or on the ground, for example, a late arrival of one flight may cause a late departure of the next flight on the itinerary of the aircraft.

Projection of weather parameters from 2005 to 2035

This study revealed how the studied weather parameters have contributed, and will contribute to disruption of aircraft operation between years 2005 and 2019 with projection from 2020 to 2035. The annual mean wind speed and direction, annual average of flight disruptions, horizontal visibility, annual total cloud cover, and annual average of fog, haze and thunderstorm were major parameters under consideration.

The highest visibility occurred as seasonal phenomenon from the year 2006 to the peak of year 2020 (Fig. 5). However, the highest visibility declines sharply with a rise in 2025. It was further observed that the visibility will flatten out beyond year 2025.

Thunderstorm shows a seasonal trend throughout 2005 to 2006 after which it reached its peak in 2020 with sharp upward increase in 2026, 2030 and 2034 (Fig. 6).

The thick dust had a very low abundance in 2005 and ceased to exist shortly after until 2008 when it peaked to its first highest point. It declined to zero level in 2011 till 2015 and peaks upward in 2019 (Fig. 7). This low pattern of thick dust was observed in the same configuration in 2011, 2016 and 2027.

Figure 8 shows that the trend of fog increases in 2015 and 2030 with possible sharp decline in 2035. Trend shows a regular short period of peak for fog. Almost every year is devoid of long period of fog. Fog continued to exist in short period from 2005 to 2013, however, it ceased to exist from 2015 to 2020. The observed trend further indicates visible pattern of fog between 2023 and 2028, which may not have regular trend until 2035.

In Figure 9, the trend of wind speed shows somewhat smooth directional pattern starting at a high level in 2005 and keeps declining gradually in each successive year till 2011. Later in 2013, the trend peaked to reach its highest point with downward trend till 2035.

The trend in Figure 10 shows high degree of cloud cover at the beginning of every year and later declines sharply. However, the trend further shows declining pattern in 2035. Figure 10 further indicates consistent declining pattern of cloud cover in 2035. However, the lowest downward trend would be observed in 2031. Cloud cover shows a seasonal pattern throughout the reviewed period and it is forecast that the trend will continue till 2034.

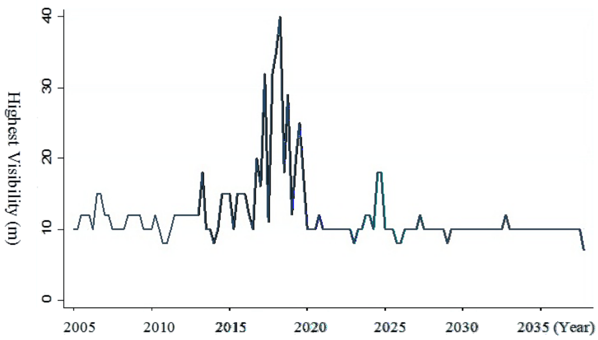

Fig. 5 Projected trend of the highest visibility from 2005 to 2035

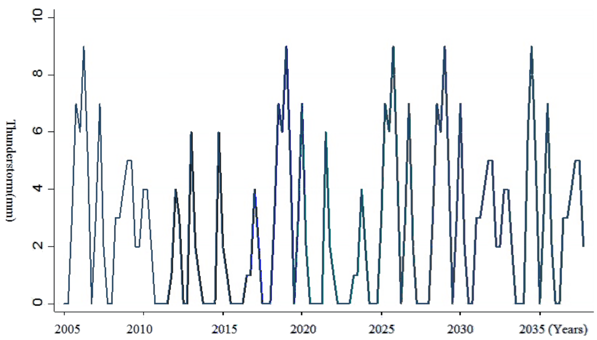

Fig. 6 Projected trend of thunderstorms from 2005 to 2035

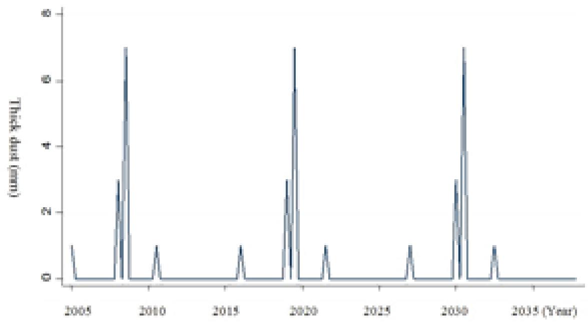

Fig. 7 Projected trend of thick dust from 2005 to 2035

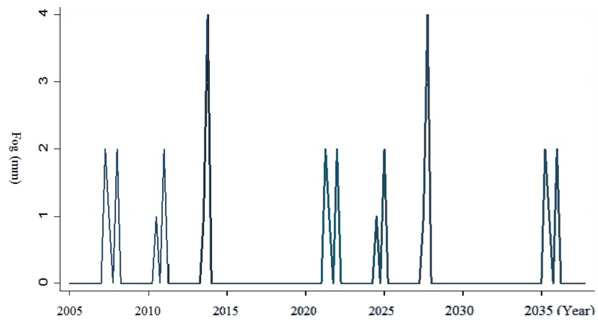

Fig. 8 Projected trend of fog from 2005 to 2035.

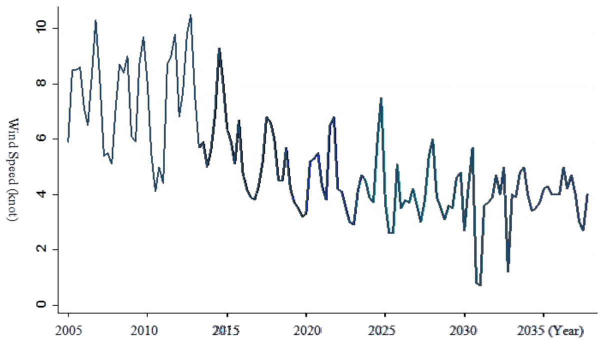

Fig. 9 Projected trend of wind speed from 2005 to 2035

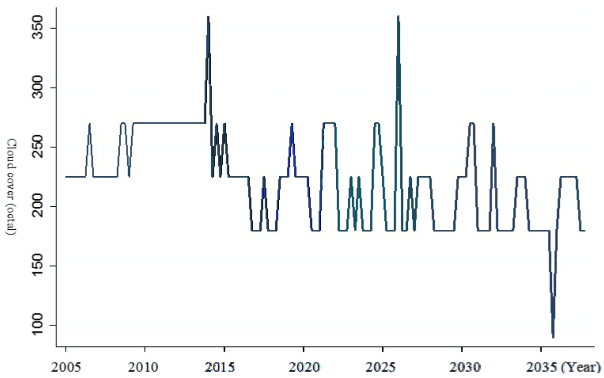

Fig. 10 Projected trend of cloud cover from 2005 to 2035

CONCLUSION

This study has analysed weather parameters along with identified cases of flight disruptions in Nigeria. It was established that cloud cover and highest visibility are negatively correlated. This shows that the highest visibility experienced in the study area depends on the level at which cloud cover is perceived. Wind direction has positive relationship with wind direction. It was established that there is an inverse relationship between visibility, thunderstorm, fog, and wind direction; while direct relationship exists between highest visibility and thick dust, wind speed and cloud cover. It is worth to note that dust, wind speed and cloud cover could indicate increased visibility level as an environmental factor in the study area.

Considering the calculated means for flight disruption parameters, it is obvious that flight delay is prominent over flight diversion and cancellation. However, the results of the mean on flight diversion and cancellation are not too far apart, which indicates their relevance in air traffic. The prediction model indicates; high degree of cloud cover at the beginning of every year and later declines sharply in 2035, regular short period of peak for fog, that the visibility will flatten out by the year 2025, and that low pattern of thick dust was observed in the same pattern in 2011, 2016 and 2027. Based on this conclusion, the study recommends accurate weather reporting and strict compliance to safety regulations, and attention should be paid to changing pattern of weather parameters in order to minimize fight related disaster.

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