CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE STUDY

The growth of aviation industry in Nigeria and the increased adoption of air transportation as one of the best means of transport have been obstructed by various weather hazards. There is a greater need for aviation weather forecasters to deliver quality forecasts (Weli & Ifediba, 2014). Despite the relatively conducive weather of Nigeria compared to other countries (such as Mauritania, Somalia, Japan etc.), there has been a marked increase in the cases of recorded flight delay, diversion and cancellation, which in most cases, are attributed to poor weather conditions such as wind shear, thunderstorm, poor visibility, fog, dust haze and line squall (National Oceanic and Atmospheric Administration (NOAA), 2004; Sasse & Hauf, 2003; Jones, 2004; Knetch, 2008; Weli & Ifediba, 2014; Musa, 2014; Enete, Ajator, & Nwoko, 2015; Onwuadiochi, Ijioma, & Ozoemene, 2020).

Wind shear which is also regarded as wind gradient is one of the weather phenomena which affect the aviation industry and aircraft operations adversely (Azad, 2011). The effects of wind shear on aircraft operations are very much, and because of this, many researchers have defined it in various ways. For instance, Azad (2011) defined wind shear as a difference in wind speed and wind direction over a relatively short distance in the earth's atmosphere. In Aviation Meteorology, Wilson, Goodrich and Carson (2005) stated that wind shear is a change in the winds which is sufficiently abrupt to affect the performance of an aircraft so significantly that it challenges the compensation capabilities of the pilot and aircraft, while Hong Kong Observatory in 2009, observed that wind shear is a sustained change in the wind direction and speed lasting more than a few seconds and resulting in a change in the headwind and tailwind encountered by an aircraft. Such a change will cause the aircraft to go below the intended flight path, if there is a decrease in the lift or it will cause the aircraft to fly above the intended flight path, if there is a positive lift.

In his assertion, Roberto (2014) opined that the analysis of wind data is fundamental in many sectors, not only, as obvious, in Meteorology and Climate, but also in Air Quality Evaluation, Architecture, Energy Production, Analysis of outdoor sport performances, Agriculture and many others.

Wind is, of course, a possible threat if not adequately considered in some specific fields. One of such fields is the designing of airport runways (Roberto, 2014). He stated that wind (crosswinds) blowing perpendicular to the runway may cause serious accidents, especially during landing and for small airplanes. In aviation, a crosswind is the component of wind that is blowing across the runway making a landing more difficult than if the wind were blowing straight down the runway. If a crosswind is strong enough it may exceed an aircraft’s crosswind limit and an attempt to land under such conditions could cause an accident (Roberto, 2014). Crosswinds can also occur when travelling on roads, especially on large bridges and highways, which can be dangerous for motorists because of possible lift forces created as well as causing the vehicle to change direction of travel. Crosswinds and tailwinds, or headwinds, are also important during some outdoor sport activities. Pezzoli et al. (2013) for example described the effects of crosswinds on the sport of rowing.

In the analysis of past accidents, Van Es, Van der Geest and Nieuwpoort (2001) have demonstrated that the probability of occurrence of an accident increases with increasing crosswind conditions. Statistical evidence, based on historic accident data, shows that the accident risk increases exponentially when operating in conditions with crosswind exceeding 20 knots, including gusts. Tailwind conditions are also important because they are often related to accidents, mainly overrun type of events during landing (Van Es & Karwal, 2001).

While there could be a vertical and horizontal wind shear, the former is critical factor in the determination of thunderstorm type and potential storm severity and airplane pilots regard the later as change in airspeed of 30 knots (15m/s) for light aircrafts, and near 45 knots (22m/s) for airliners at flight altitudes (Azad, 2011). Thus, low level wind shear can affect aircraft airspeed during takeoff and landing in disastrous ways, a condition which makes airliner pilots to be trained to avoid all microburst wind shear, that is, headwind loss in excess of 30 knots. In general, the wind shear events that present the greatest risk to aircraft are those associated with convective activity, specifically gust fronts and microburst, and such events have resulted in several major accidents involving large transport aircraft internationally (National Research Council, 1983; Azad, 2011).

The impact of wind shear on aircraft is understood through the change in the aircraft's total energy, that is, the sum of its kinetic and potential energy (Wilson, Goodrich, & Carson, 2005). Changes in the kinetic energy are related to changes in airspeed, and changes in the potential energy are related to changes in altitude. The pilot and flight control systems can influence these allocations. When an aircraft is flying only slightly above the stall speed, a change in the wind velocity or direction can lead to a loss of lift. If the loss is of sufficient magnitude so that the response is inadequate to immediately correct the energy deficiency condition, it results in an excessive rate of descent. The altitude, at which the encounter occurs, the pilot's reaction time and the aircraft's response capability, determine whether the descent can be arrested in sufficient time to prevent an accident.

Under certain conditions, the atmosphere is capable of producing dramatic shears very close to the ground. One of the atmospheric conditions capable of producing dramatic shears is the downburst from convective or cumuliform clouds (U.S. Department of Transportation, Federal Aviation Administration, 2005). A downburst is a strong downdraft which induces an outburst of highly divergent, damaging winds on or near the ground. Downburst diameters have been observed to range from as little as 0.5 mile to 10’s of miles in diameter. The specific hazard to aviation has been exclusively researched and analyzed to be related to the scale of the downburst clouds (U.S. Department of Transportation, Federal Aviation Administration, 2005). The smaller spatial scale of a small, intense downburst results in tighter wind shear gradients that are experienced in the penetrating aircraft as more rapid changes in wind vectors, perhaps well in excess of the performance capabilities of the airplane.

A microburst which is associated with wind shear is a very localized column of sinking air which produces damaging, divergent and straight line winds at the surface. The severe downward acceleration of a microburst occurs when a relatively cold parcel of air experiences negative buoyancy while sinking through a relatively warm environment (U.S. Department of Transportation, Federal Aviation Administration, 2005).

An airplane traversing a wind shear initially encounters the outflow on the front side, which increases the headwind and/or updraft component, causing the indicated airspeed to increase and/or the airplane to rise. When exercising tight control airspeed and flight path, the pilot will retard throttle and/or lower the nose in an effort to maintain or recapture the glide slope. If encountered at takeoff, the airplane may become airborne prematurely due to increased headwinds. During an approach, if downdraft exists, the pilot will be required to add power and pull the nose up to maintain glide slope. Pilot recognition and reaction times and engine “spool up” from a low-power setting may conspire to leave the airplane in a lower than desired energy state. During takeoff, the downdraft and reduced headwind will decrease climb rate, forcing the airplane into a low-energy state as it is forced to increase angle of attack in order to avoid the ground (U.S. Department of Transportation, Federal Aviation Administration, 2005).

Airplanes also encounter the back side of the microburst, the outburst, where the tailwind component can increase dramatically, causing the airplane to descend even further in response to the resultant indicated airspeed decrease. Descending on the intensity of the microburst, the airplane may also experience one or more severe horizontal vortex rings caused by the interaction of the outburst with the surrounding atmosphere and convective weather inflows. During an approach or a takeoff, the pilot may not have enough energy and/or performance capability to maintain control and avoid ground contact (U.S. Department of Transportation, Federal Aviation Administration, 2005).

Wind shear is caused by quite a number of factors, but ground surface roughness and obstacles stand out in bold relief. For example, land and sea breezes trigger wind shear. It is therefore not surprising that pilots passing across the coastlines are always very careful, because this is where the breezes predominate (Onwuadiochi et al., 2020). During the daytime when the land gets heated by the radiation faster than the sea, and cooler air above the sea tends to move towards the land due to pressure variation; the process is known as the sea breeze. The same process is reversed during the nighttime as the land cools faster than the sea and air flows from land to sea; it is known as the land breeze (Mathew, 2006).

Friction on the earth’s surface is another controlling factor which influences wind shear by offsetting the pressure gradient force. With increasing wind speed, friction between the air and the surface increases. Frictional resistance to wind provided by the surface of the earth is influenced by many variables such as: elevation, terrain roughness and topography (Abdulla, 2014).

In fact, there is a positive link between wind shear and thunderstorm activity; see for instance, Fujita (1975), cited in U.S. Department, Federal Aviation Administration (2005), Jones (2004) and Enete et al. (2015).Wind shear fuels thunderstorms and thunderstorms are one of the atmospheric phenomena that create hazardous conditions that pilots encounter. In Harding (2011), it was asserted that thunderstorm consists of thunder and lightning produced by a cumulonimbus cloud usually accompanied by rain or hail and could produce severe turbulence, low level wind shear, low ceiling and visibilities. Though thunderstorms occur anywhere on the globe, but its occurrence is most frequent in the tropics. Furthermore, its intensities are much higher in the tropics than elsewhere on the globe.

The effects of wind shear on aircraft operations are unimaginable. Sasse and Hauf (2003) and Weli and Ifediba (2014) examined various weather hazards which include wind shear, thunderstorm, fog, dust haze and line squall that affect flight operation such as flight delays, diversions and cancellations. Weather extremes have tremendous influence on flight operations. From time immemorial, flight operations like any other human endeavours, have been significantly affected in terms of takeoff, landing and even in-flight by extreme weather such as wind shear, thunderstorm, cloud cover, temperature, rainfall, pressure and visibility (Musa, 2014). Extreme weather values have long been known to be threatening to all aspects of air transportation. Each year, more than one quarter to one-half of all accidents is weather related. While the economic losses due to flight delays, diversions, cancellations, and accidents caused by weather are estimated at more than one billion per year (National Weather Service (NWS), 2008).

Wind shear has led to an escalating increase in death toll records of aircraft accidents. For example, between 1964 and 1985, wind directly contributed to 26 major civil transport aircraft accidents in the U.S. that led to 620 deaths and 200 injuries (National Aeronautics and Space Administration, 1992). Other aircraft accidents in which wind shear was implicated include Eastern Flight 66 accidents at John F. Kennedy Airport in 1975 and Continental Flight 496 at Denver’s Stapleton International Airport, Delta Airlines Flight 191 crash in 1985, U.S. Airlines Flight crash in 1994 and Sosoliso Airlines Flight 1145 crash in

2005. In Australia, there have been few aircraft accidents attributed to low level wind shear (Potts, 2003). This is largely, because, these events are small scale, and mostly affect the approach/departure flight corridor for a short period of time; the traffic density has been relatively low and air traffic control policies have been conservative. As a result, the perceived level of risk associated with low level wind shear by the aviation industry has been low. However, in the past two years, there have been two serious air safety incidents attributed to wind shear associated with convection, so demonstrating there are significant risks (Potts, 2003).

National Oceanic and Atmospheric Administration, NOAA (2004) affirmed that weather affects flight operations. They also stated that almost 500 fatalities and 200 injuries have resulted from wind shear crashes since 1964 and that since 1985; wind shear also has caused numerous near accidents in which aircraft recovered just before ground contact. Rockwell et al. (1981), Jones (2004) and National Aeronautics and Space Administration (NASA), Aviation Safety Reporting System (ASRS) (2007) attributed the thunder-associated wind shear, dust haze induced visibility conditions, fog and harmattan dust haze and the severe thunderstorm with associated electricity (lightning and thunder), hailstones, icing, low-level wind shear effect, gustiness etc., as weather related phenomena responsible for aircraft accidents globally. Turbulent weather and climate events such as wind shear, thunderstorm and squall line have constituted serious threat to global economic growth over the past few years, especially to the socio-economy of developing nations like Nigeria (Weli & Emenike, 2016).

Wind energy still remains one of the main issues due to the variability of wind speed and direction over time (Fadare, 2010; Jung & Kwa-Sur, 2013; Ozelkan, Chen, & Ustundag, 2016). Hence, accurate estimation of wind shear for aircraft operations is also directly involved with the wind patterns which explain the variability of wind behaviour (Yusof

& Zurita-Milla, 2017). For a given location, the temporal trend of wind shear across multiple heights is captured through a typical wind profile pattern. The identification of such profiles is essential for several applications (Tamura et al., 2001). For instance, these profiles are used to understand typical wind conditions at a single hub-height or within the swept rotor area of wind turbines (Wagner, Antoniou, Pedersen, Courtney, & Jørgensen, 2009). Several studies have been conducted to describe the characteristics of frequent wind distribution patterns (Damousis, Alexiadis, Theocharis, & Dokopoulos, 2004; Apt, 2007; Carta, Ramírez, & Velázquez, 2009; Krishna, 2009). However, an efficient procedure to understand wind properties in these three dimensions (spatial, temporal and height) is still lacking, due to the complexity of characterizing changeable and intermittent wind flows (Wagner, Michael, Torben, & Uwe, 2010).

Norhakim and Raul (2017) asserted that it is possible to discover wind profile patterns with large coverage of spatial representation, and one of the methods to achieving this is using spatio-temporal pattern mining to capture frequent wind patterns continuously overtime. Spatio-temporal pattern mining is a Geographical Information System technique which offers computationally efficient approaches to identify frequent spatial and temporal patterns from large databases (Aggarwal, 2014; Akbari, Samadzadegan, & Weibel, 2015).

Murtala Mohammed International Airport in Lagos State and Port Harcourt International Airport in Rivers State are very close to the Atlantic Ocean, and wind shear is heavily triggered by the south-western trade wind from the ocean. It is therefore very pertinent that this study is carried out in the study areas.

1.2 STATEMENT OF THE RESEARCH PROBLEM

In Nigeria, greater emphases by so many researchers have always been on other meteorological phenomena affecting the aircraft operations, without much research on wind shear. Murtala Muhammed International Airport and Port Harcourt International Airport are not exceptional in this regard as some researchers such as (Weli & Ifediba, 2014; Enete et al., 2015; Weli & Emenike, 2016) have worked on thunderstorm, fog, poor visibility and line squall that pose threats to aircraft operations.

In the developed countries like USA, there has been some improvement on ways of identifying the incidence of wind shear (McCarthy, Wilson, & Fujita, 1982; Fujita, 1885; Federal Aviation Administration, 1987; Sari, 2009). The rapid changes in wind, as the microburst sweeps across the airport, may lead to quick runway changes, which interferes with traffic patterns and Air Traffic Management processes. The danger of a sudden, dramatic loss in height during landing and take-off could cause a serious accident, so it is important to avoid situations that threaten the safety of aircraft. In 1985, the Federal Aviation Administration funded an initiative, the Classify, Locate, and Avoid Wind Shear (CLAWS) Project, which developed an algorithm for a Low-Level Wind Shear Alert System (LLWAS) (McCarthy and Wilson, 1985). Some other advanced tools developed for detecting wind shear in the developed countries include Doppler Weather Radar and Wind Profiler. A combination of systems provides a greater range of information on wind shear. In Nigeria, Low Level Wind Shear Alert System was introduced not quite long, to detect wind shear at the airports.

The weather and climate of the study areas are of the nature that the areas are being affected by wind shear occurrences. The closeness of Murtala Mohammed International Airport and Port Harcourt International Airport to the coast, and the wind shear that is heavily triggered by the south-western trade wind from the Atlantic Ocean, justify the reason for carrying out this study.

Wind shear, which stands as a very serious meteorological phenomenon, has over the years, been recognized to be responsible for delays, diversions and sometimes cancellations of flight schedules, and has caused quite a number of aircraft crashes, even in Nigeria. However, the extensive number of air accidents which can be attributed to wind shear is mostly seen in the tropics and underdeveloped countries. The case of Sosoliso Airlines and Belview Airlines plane disasters in Nigeria are typical examples (Edeagha, Esosa, & Idiodi, 2005). In spite of its critical impact in the aviation industry particularly in the tropics, that experiences more frequent thunderstorms than elsewhere on the globe, there is insufficient knowledge about wind shear in the country.

However, this state of affair, in which Nigerians lack knowledge of wind shear, and is currently planning to boost her aviation industry in an age of climate change and associated weather conditions, is very alarming. Obviously, this shows that the goal of ensuring safety in the aviation industry in Nigeria will still remain a mirage, if weather conditions influencing aircraft operations are not taken into serious account in any plan to expand and improve the industry.

More so, the aviation industry has not truly understood the spatio-temporal wind profile pattern in various heights. This, therefore, has contributed copiously to the problems encountered by the aviation industry, especially in Nigeria.

Despite the severity of wind shear in many parts of the world, especially the tropical region that experiences wind shear and thunderstorm than elsewhere on the globe, and the problems it has posed to the aviation industry, no much research have been conducted concerning this phenomenon. Because of this, the researcher has therefore deemed it necessary to carry out this research in the study areas. This study therefore tries to model the association between wind shear and the aircraft operations with a view to avoiding the impending devastating impacts in the aviation industry.

In view of the foregoing, the research examines the altitudinal wind shear variations as they relate to the aviation industry in the country.

1.3 AIM AND OBJECTIVES

The aim of this study is to analyze the altitudinal wind shear variations and their relationships to aircraft operations in the coastal international airports, Nigeria, while the objectives include:

i. to extrapolate wind shear at 50 meters and 100 meters above ground level using power law model.

ii. to analyze the relationships between wind shear measured at 20 meters above ground level and flight delays, cancellations and diversions.

iii. to analyze the relationships between wind shear extrapolated at 50 meters and 100 meters above ground level (using power law model) and flight delays, cancellations and diversions.

iv. to determine the temporal variations of wind shear in the selected airports.

v. to determine the relative safety at the two airports as a result of wind shear.

1.4 RESEARCH QUESTIONS

i. How does wind shear extrapolated at 50 meters and 100 meters above ground level differ from wind shear measured at 20 meters above ground level?

ii. Are the relationships between wind shear measured at 20 meters above ground level and flight delays, cancellations and diversions significantly positive or negative?

iii. Are the relationships between wind shear extrapolated at 50 meters and 100 meters above ground level and flight delays, cancellations and diversions significantly positive or negative?

iv. How is the temporal variation of wind shear in the selected airports?

v. What is the relative safety at the two airports as a result of wind shear?

1.5 RESEARCH HYPOTHESES

Ho: There is no significant relationship between wind shear measured at 20 meters above ground level and flight delays, cancellations and diversions.

H_1: There is a significant relationship between wind shear measured at 20 meters above ground level and flight delays, cancellations and diversions.

Ho: There is no significant relationship between wind shear extrapolated at 50 meters and 100 meters above ground level and flight delays, cancellations and diversions.

H_1: There is a significant relationship between wind shear extrapolated at 50 meters and 100 meters above ground level and flight delays, cancellations and diversions.

1.6 SCOPE OF THE STUDY

This study covers a period of eleven years (from January 2008 to December 2018) at Murtala Mohammed International Airport, Ikeja, Lagos State, in the South-Western part of Nigeria and Port Harcourt International Airport, Port Harcourt, Rivers State, in the South-Southern part of Nigeria. This is because the equipment used for collecting wind shear data at the airports were installed not long ago and this is a pioneering work in the study areas. Also, the period of study stopped in 2018 because the data was collected prior to COVID-19 pandemic and the analysis done. The COVID-19 stalled the defense of the work at the appropriate time.

The Murtala Mohammed and Port Harcourt International Airports were chosen, because not only that they are coastal airports, both are also international airports with almost the same traffic. The wind shear data were obtained from Nigerian Meteorological Agency while flight diversions, flight delays and flight cancellation data were obtained from Nigerian Air Space Management Agency.

1.7 SIGNIFICANCE OF THE STUDY

The research “Analytic Study of Altitudinal Wind Shear Variations and their Relationships to Aircraft Operations in the Coastal Airports, Nigeria”, has been critically selected, as its benefits are stupendous, hence, can never be over emphasized. The study will be highly needed in the Aviation Meteorology, Aeronautics, Astronautics, Wind Engineering and Atmospheric Sciences in general. It will help to expand the knowledge of the present and upcoming meteorologists on the importance of wind shear in the aviation industry; that wind shear has both positive and negative effects.

Wind shear which is defined as a change in wind speed and/or direction in a very short distance in the atmosphere has been so catastrophic to aircrafts, and has led to outrageous and detrimental air crashes, especially in the developing counties like Nigeria. As a result of the threat posed by this phenomenon, it is now very crucial that the pilots are well trained about wind shear. For air safety, crew training now requires flight training in wind shear recognition and escape maneuvers. As has been discovered in the past by researchers that there are height variations of wind shear, this research will show some elevations of wind shear variations in the study areas. It will also show the areas that will most likely have wind shear than the others, whilst discuss their degree of variations and their relationships with the aircraft operations. This, of course, will help the meteorologists, air traffic controllers and the pilots. This study will further expose the need for training and retraining of meteorologists on the use of wind shear equipment for easy observation and dissemination of wind shear information.

Air Traffic Controllers would also benefit immensely from this research, as they will utilize the information during aircraft spacing, landing and take-off. The study will also provide measures to be taken for preventing the wind shear hazard. It will as well be a source of reference to students and researchers.

CHAPTER TWO

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 THEORETICAL FRAMEWORK

2.1.1 The Concept of Atmospheric Boundary Layer (ABL)

The concept of atmospheric boundary layer provides the theoretical basis on which the present study situates. According to Garratt (1992), atmospheric boundary layer is the layer of air directly above the earth’s surface in which the effects of the surface (friction, heating and cooling) are felt directly on time scales less than a day, and in which significant fluxes of momentum, heat and matter are carried by turbulent motions on a scale of the order of the depth of the boundary layer or less. Larsen (2013) stated that the atmospheric boundary layer is the lower part of the atmosphere, where the atmospheric variables change from their free atmosphere characteristics to the surface values and this means that wind speed goes from the free wind aloft to zero at the ground, while scalars, like temperature and humidity approach their surface value. Characteristics of the atmospheric boundary layer are of direct importance for much human activity and wellbeing, because humans basically live within the atmospheric boundary layer, and most of our activities take place here. The importance stems as well from the atmospheric energy and water cycles because the fluxes of momentum, heat, and water vapour between the atmosphere and the surfaces of the earth all pass through the atmospheric boundary layer, and are being carried and modified by mixing processes here (Larsen, 2013).

In his assertion, Garratt (1994) stated that the boundary layer affects both the dynamics and thermodynamics of the atmosphere. There are a variety of dynamic effects: more than a half of the atmosphere's kinetic energy loss occurs in the atmospheric boundary layer (Palmen & Newton, 1969). Boundary layer friction produces cross-isobar flow in the lower atmosphere, whilst boundary layer interaction permits air masses to modify their vorticity. From the thermodynamic perspective, all water vapour entering the atmosphere by evaporation from the surface must enter through the atmospheric boundary layer. Even the oceans are strongly influenced by the atmospheric boundary layer, since it is through the boundary layer that they gain most of their momentum so influencing the oceanic circulation (Garratt, 1994).

In meteorology, the atmospheric boundary layer (ABL), also known as the planetary boundary layer (PBL), is the lowest part of the atmosphere. Its behaviour is directly influenced by its contact with a planetary surface. On earth, it usually responds to changes in surface radiative forcing in an hour or less. In this layer, physical quantities such as flow velocity, temperature, moisture, etc., display rapid fluctuations (turbulence) and vertical mixing is strong. Above the atmospheric boundary layer is the "free atmosphere" where the wind is approximately geostrophic (parallel to the isobars) while within the PBL the wind is affected by surface drag and turns across the isobars.

As noted by Abdulla (2014), Atmospheric Boundary Layer is part of the troposphere directly influenced by the presence of the earth’s surface, and responds to surface forcing with a timescale of about an hour or less. Typically, due to aerodynamic drag, there is a wind gradient in the wind flow just a few hundred meters above the Earth's surface – the surface layer of the planetary boundary layer. Wind speed increases with increasing height above the ground, starting from zero due to the no-slip condition (Brown, 2001; Wizelius, 2007). Flow near the surface encounters obstacles that reduce the wind speed, and introduce random vertical and horizontal velocity components at right angles to the main direction of flow (Dalgliesh & Boyd, 1962). This turbulence causes vertical mixing between the air moving horizontally at one level and the air at those levels immediately above and below it, which is important in dispersion of pollutants and in soil erosion (Hadlock, 1998; Lal, 2005).

The reduction in velocity near the surface is a function of surface roughness, so wind velocity profiles are quite different for different terrain types (Brown, 2001). Rough, irregular ground and man-made obstructions on the ground can reduce the geostrophic wind speed by 40 percent to 50 percent (Oke, 1987; Crawley, 1993). Over open water or ice, the reduction may be only 20 percent to 30 percent (Thompson, 1998; Harrison, 1999). These effects are taken into account when siting wind turbines (Lubosny, 2003; Maeda, Shuichiro, & Yoshiki, 2008).

The atmospheric boundary layer thickness varies greatly depending on external factors, and ranging from some hundreds of meters to 3 kilometers (Stull, 1987; Tangvald, 2012). Temperature in this layer varies diurnally and seasonally. This variation in temperature changes pressure, which causes the wind to fluctuate accordingly. Wind speed increases with respect to the altitude; duration of the wind which is very chaotic due to geographical surroundings (Taylor & Garratt, 1996).

Atmospheric boundary layer is vertically divided into three basic layers; the upper layer (also called the Ekman layer – 90% of the ABL) where wind direction varies with the height and rotational Coriolis force is the driving force in this layer. The second layer is particularly relevant for aircrafts operations and for wind energy applications where wind speed increases with the height due to the prevailing turbulent viscosity of air. This layer is called the constant flux layer or surface layer or Prandtl layer. Then follows the third and lowest layer where the flow is laminar and covers only a few millimeters deep. The wind speed becomes zero near the ground in the atmospheric boundary layer due to surface friction, which is a no-slip condition (Emeis, 2013).

Above the atmospheric boundary layer is the free atmosphere where atmospheric parameters, such as humidity and temperature are no longer affected by the surface environment. Equally the wind speed and direction are no longer affected by surface friction and are now considered geostrophic, which means that the Coriolis force and pressure gradient force govern them (Tangvald, 2012).

The relation between wind speed and height is called the wind profile. The wind speed increases with height. This increase depends on the friction against the surface. Over flat terrain with low friction (water), the wind is not affected so much and the increase with height is not very big. Over a surface with high roughness ‘city and farm’, the wind speed increases more significantly with height (Teneler, 2011).

There are two wind profile laws available that are used to interpolate (estimate) the wind speed vertically. The wind profile laws are power law and logarithmic law. The profile laws provide information about wind speed at different levels when only the wind data near the ground is available. These laws are strictly valid in the surface layer where the wind flow is largely affected by mechanical turbulence generated by the interaction of solid surface (Emeis, 2013).

Thermodynamics which deals with the relations between heat and other forms of energy is also experienced in the troposphere. Buoyancy and stability influence are the key factors to be considered when discussing the thermodynamics of an air parcel. The air parcel temperature varies adiabatically as it rises or sinks because it is thermally insulated from its surroundings. Hence, buoyancy force applies on an air parcel to balance the thermal energy conservation in terms of adiabatic heating and/or cooling processes while the air parcel tends to move upward or downward. Thermal stability is what makes the air particles to increase or suppress the vertical airflow. Instability condition takes place when the rising air parcel’s temperature is warmer than that of its surroundings (Department of Earth and Planetary Sciences, 2013). An air parcel is an imaginary volume of air that does not have any relation with the surroundings. The air parcel starts moving upward into the atmosphere until its temperature is higher than that of surroundings. Sinking air parcel’s temperature is always lower than that of surroundings where it condenses and becomes much denser. Sinking air circumstances are known as stable conditions, and rising air is known as unstable air (Idaho Museum of Natural History, 2002).

Environmental Lapse Rate (ELR) is one of the lapse rates to describe the thermal stability. It refers to the rate of temperature change as altitude increases and the ELR values vary as a function of time and location. A standard Environmental Lapse Rate is defined for the troposphere as 6.5°C per 1000m (Waugh, 2002).

U.S. Environmental Protection Agency public access server in 2012 opined that unstable conditions occur when air near the ground is heated by the conduction of reflected terrestrial radiation from the earth's surface, where the earth's surface becomes warmer due to solar radiation during daytime. Moreover, the warm air tends to develop vertical movement and continue to rise until it condenses where the surroundings temperature is less. Vertical mixing of air parcels creates turbulence. These conditions normally take place during the summer and spring days.

Over land in particular, the structure of atmospheric boundary layer turbulence is strongly influenced by the diurnal cycle of surface heating and cooling, by the presence of clouds and by horizontal variability in surface properties (Garratt, 1994). The unstably-stratified atmospheric boundary layer, or convective boundary layer (CBL), occurs when strong surface heating (due to the sun) produces thermal instability or convection in the form of thermals and plumes, and when upside-down convection is generated by cloud-top radiative cooling (Garratt, 1994). In strongly unstable conditions driven by surface heating, the outer region of the boundary layer in particular is dominated by convective motions and is often referred to as the mixed layer. In contrast, the stably-stratified atmospheric boundary layer occurs mostly (though not exclusively) at night, in response to surface cooling by long wave emission to space. The unstable atmospheric boundary layer is characterized by a near-surface super adiabatic layer and the stable atmospheric boundary layer by the presence of a surface inversion (Garratt, 1994).

Similarly, stable atmospheric conditions are very common during the winter and summer nights, when the earth surface is not warming up the air through conduction. It is a situation where there is no heat exchange between ground and air. Cold air tends to blow near the ground and warm air tends to blow at higher heights.

In some countries like Sweden, snow covers the earth's surface in winter time just like a blanket and keeps the temperature of air near surface minimum and warmer air at the higher altitudes. This kind of stable atmosphere suppresses the vertical motion of the air particles. Usually, these conditions happen during the winter periods and summer nights. A stable condition of atmosphere resists the vertical movement of air that is displaced vertically (U.S. Environmental Protection Agency public access server, 2012).

Neutral conditions occur when the air parcel does not tend to move upward or downward, which means there is no vertical mixing of air layers. These conditions appear during the winter when the earth's surface is covered with snow and when there are clouds to stop the heating and cooling cycle of earth's surface from occurring (U.S. Environmental Protection Agency public access server, 2012) and (Ahrens, Jackson, & Jackson, 2012). Neutral flow, in which buoyancy effects are absent, are readily produced in the wind tunnel, and may be closely approximated in the atmosphere in windy conditions with a complete cloud cover (Garratt, 1994).

2.2 LITERATURE REVIEW

2.2.1 Wind Shear as a Meteorological Phenomenon

So many researchers have defined wind shear in various ways owing to their observations and findings from their various researches. Abdulla in 2014, after studying wind analysis and estimate of the wind shear exponent of Sulaymanyiah International Airport Area, defined wind shear as the change of wind speed and direction. In his study based on wind potential variation at three measurement sites, Eppanapelli (2013) defined wind shear as any variation in wind speed and wind direction along a straight line. On the other hand, Azad (2011) studied the effect of wind shear coefficient on wind velocity at coastal sites of Bangladesh, and asserted that wind shear, also known as wind gradient, is a difference in wind speed and wind direction over a relatively short distance in the Earth’s atmosphere. Hong Kong Observatory (2009), defined wind shear as a sustained change (i.e. lasting more than a few seconds as experienced by aircraft) in the wind direction and/or speed, resulting in a change in the headwind or tailwind encountered by an aircraft. A decreased lift will cause the aircraft to go below the intended flight path. Conversely an increased lift will cause the aircraft to fly above the intended flight path.

Wind shear can be divided into vertical and horizontal shears. International Civil Aviation Organization (ICAO, 2005), defined vertical and horizontal components of wind shear as follows:

> Vertical wind shear is defined as change in wind speed or direction with change in height or altitude, as would be determined by means of two or more anemometers mounted at different heights on single mast and Horizontal wind shear is defined as change in wind speed or direction with change in lateral position for a given altitude,

as would be determined by two or more anemometers mounted at the same height along a runway.

Wind shear itself is a micro-scale meteorological phenomenon occurring over a very small distance, but it can be associated with meso-scale or synoptic scale weather features such as squall lines and cold fronts (Azad, 2011). It is commonly observed near microbursts and downbursts caused by thunderstorms, weather fronts, areas of locally higher low level winds referred to as low level jets, near mountains, radiation inversions that occur due to clear skies and calm winds, buildings, wind turbines and sailboats (Azad, 2011).

Wind shear highly depends on atmospheric stability conditions, diurnal cycle, seasonal variation and terrain type (Eppanapelli, 2013). In fact, it is proved that wind shear increases with the elevation. The wind shear character can be distinguished by studying the rate of wind speed increase with elevation (Eppanapelli, 2013). However, the wind shear is always positive since the wind speed increases with height (Gualtieria & Seccib, 2011).

Wind shear describes the fact that close to the ground, the wind is slowed down by friction and the influence of obstacles. Thus, wind speed is low close to the ground and increases with increasing height above the ground (Abdulla, 2014). The most generalized explanation of wind shear is “a change in wind speed and/or direction in space, including updrafts and downdrafts”. From this explanation, it follows that any atmospheric phenomena or any physical obstacle to the prevailing wind flow that produces a change in wind speed and/or direction, in effect, causes wind shear (Abdulla, 2014).

2.2.2 Variations of Wind Shear

Many studies of wind characteristics have been conducted in many countries worldwide. Rehman (2004) analyzed the long term diurnal wind data in terms of annual, seasonal and diurnal variations of data at Yanbo, which is located at the west coast of Saudi Arabia. The wind speed and wind direction hourly data for a period of 14 years between 1970 and 1983 was used in the analysis. It was found that the diurnal trend of wind speed of the order of 5.0m/s and reaching 8.0m/s were between 12:00 and 21:00 hours.

Roy (2012) analyzed the monthly distribution of shear coefficients of six stations in Bangladesh. It was discovered that the estimated average shear factors peaks around the months of January and November when recorded for the ten year interval.

Ajayi, Fagbenle, Katende, Aasa, and Okeniyi (2013) carried out wind profile characteristics and turbine performance analysis in Kano, north-western Nigeria. From data analysis, of 252 recorded monthly mean wind speeds, representing whole 21 years of monthly mean data measurements, the cumulative frequency of mean wind speeds from 4.0 m/s and below was only 23 and that for 5.0 m/s were prevalent in Kano. The 21 year’s monthly average wind speed variation ranged from 6.6 to 9.5 m/s.

In the study of wind speed and power characteristics at different heights for a wind data collection tower in Saudi Arabia, Alam, Shafiqur, Josua, and Luai (2011) stated that the highest wind speed was observed in June while lowest in August at all the heights of wind speed measurements. At 40m Above Ground Level (AGL), the monthly mean wind speed always remained above 5.5m/s except during August to October. They also discovered that as the height of wind measurements increases, the wind speed range decreases. At 40m AGL, the half hourly mean wind speed varied from 4.7m/s to 7.0m/s (range = 2.3m/s) while at 20m from 3.7m/s to 6.7m/s (range = 3.0m/s). At 40m AGL, the wind speed was found above 5.2m/s for most of the time except between 8pm and 12 mid nights.

Abdulla (2014) analyzed the monthly variation of mean wind speed for sites 3 and 7 of Sulaymanyiah International Airport Area. It was found that the maximum values of the mean wind speed were for June (4.82 and 4.26) m/s and the minimum values of the mean wind speed were for January (1.92 and 1.97) m/s for sites (3 and 7) respectively, while the rest of the values of mean wind speed for both sites approximately equal except for months: February, March and July. He also discovered after analyzing the monthly mean speed with the standard deviation of mean values for both sites (3 and 7), that the deviation of individual speeds from the mean values were between (0.6 to 1.85)m/s and (0.6 to 1.6)m/s respectively, which indicates the uniformity of the data set. He equally carried out the monthly mean wind speed with percentage frequency distribution of directions at 15m height for sites 3 and 7. He discovered in site 3 that the value of mean wind speed during August 3.77m/s had the highest frequency occurrence with (21.37%) in WNW direction sector during the year. Also in site 7, he discovered that the value of mean wind speed during August 3.67m/s had the highest frequency occurrence with (27.38%) in WNW direction sector during the year.

Wind roses were used by Abdulla (2014) to explain the resultant vectors of wind direction of sites (3 and 7) at Sulaymanyiah International Airport Area. He observed that for all months, the resultant vectors of wind direction were between west and north except for February and November were between north and east and March were between south and west.

The work on wind resource assessment in Saudi Arabia dates back to 1986, when Ansari et al. used hourly wind speed data to develop a Wind Atlas for Saudi Arabia, Alam et al. (2011). In Saudi Arabia, work on wind speed data analysis such as Weibull parameter determination and distribution, wind speed prediction using different methods such as auto-regression and neural network, wind power generation cost determination, and so on, have been reported in the literature. Rehman, Halawi and Husain (1994) presented the Weibull parameters for ten anemometer locations in Saudi Arabia and found that the wind speed was well represented by Weibull distribution function. They also presented the statistical characteristics of wind speed and diurnal variation. The autocorrelation coefficients were found to be matching with the actual diurnal variation of the hourly mean wind speed for most of the locations used in the study.

Alam et al. (2011) studied the wind speed and power characteristics at different heights for a wind data collection tower in Saudi Arabia. Their analysis of Weibull parameters showed that since the wind speed increases with height, the scale parameter and the shape also increase with height. This implies that as height increases, the shape of the distribution tends to be tight which implies less variation in the wind speed. The line of best fit showed high values of coefficient of determination (~ 95%). The scale parameter increases by about 0.058m/s for each meter increase in measurement height while the shape parameter increases by 0.0157 per meter. Also, their wind speed frequency distribution analysis showed that the percent frequencies of 55, 71, 78 and 82 percent at 10, 20, 30 and 40 meters above ground level, respectively, were found above 3.5m/s. An increase of 10 meters in height (from 10 to 20 meters) of the wind speed measurements resulted in an increase of about 16 percent in the availability of wind speed above 3.5m/s while further increase of 10m in height results only 7 percent increase in frequency.

Similarly, many studies of wind characteristics have been conducted in many countries at different temporal scales, such as annual and seasonal, based on the time scale of the wind data from the region. Keyhani (2010) conducted a study using statistical data from eleven years of wind speed measurements from Tehran, the capital of Iran, to determine the wind energy potential. For evaluating wind direction, it was found that the most portable wind direction for the eleven-year period is on 180 degree. Lewis (2011) studied monthly Annual Wind Data (2004 – 2010). He used an evaluation version of the Wind Rose Pro Software to determine and analyze the runway orientation of O' Hare runways. It was found that the wind blowing at O' Hare Airport has a southern directional bias only two of the eight runways meet the criteria of a northeast/southwest direction. The directions of the winds were predominantly southerly headings and wind speeds were greater than 7m/s.

Ahmed (2012) carried out a study on potential wind power generation in South Egypt. The diagrams of the measured wind data for three meteorological stations over a period of two years (wind speed, frequency and direction), wind shear coefficient, and the mean monthly and annual wind speed profile for every location were presented. A comparison of the rose diagrams showed that the wind speed was more persistent and blows over this region of Egypt in two main sectors N and NNW with long duration of frequencies from 67 to 87 percent over the year with an average wind speed in the range 6.8 – 7.9m/s at the three stations.

Wind data from the Kenya Meteorological Department for the period (2001 – 2006) was used to study the diurnal, monthly and inter – annual variability using empirical method (power law) and the wind rose analysis, revealed no marked variation in wind direction and frequency throughout the year (mean direction between 150 and 160 degrees with highest standard deviation of 33.5 degrees) Kamau, Kinyua, & Gathua, (2010). Ray, Rogers, and McGowan (2006) determined the accuracy of commonly used wind shear models and methods, especially when used with wind data from sites having hills and/or forests. They found that there was not a significant difference in the performance between the log and power laws. It was found that the one-seventh power law could not represent the wind shear for the flat sites, and generally accepted that wind shear trends are not necessarily true. The annual and seasonal wind data variations at Yanbo, analyzed by Rehman (2004) for a period of 14 years between 1970 and 1983, showed higher values of wind during the summer months and smaller values during winter months, wind speed reach 5.0m/s and more during the March – September months.

In the study conducted in Kano, north-western Nigeria, Ajayi et al. (2013) discovered that seasonally, the magnitude of mean wind speed ranged from 7.7 (dry) to 8.5 (wet), while the whole year average gave wind speed value of 8.1 m/s, respectively.

Ahmed (2006) studied six locations (stations) within Erbil Governorate, Kurdistan Region. The annual and monthly mean wind speeds were found, at 10m height the values of the annual mean wind speeds were ranging from (0.98 to 4.40)m/s and the mean monthly wind speed ranging from (0.71 to 6.29)m/s at Degala and Shaglawa stations respectively. The values of the estimated exponent power (α) were ranging from (0.32 to 0.39). Ahmed and Omer (2013) analyzed wind characteristics and estimated the wind direction for a Kalar region, located in southern Sulaimani city of the North Iraq. Specific hourly wind speeds and wind directions, based on one year (2003), were used to generate monthly, seasonal and annual wind roses charts for the studied area. The summary statistics for the seasonal and annual data for the surface wind speeds at 10 meters were presented and shown that the wind roses depend on spatial wind pattern and the prevailing wind direction between north and east.

Mirhosseini, Sharifi, and Sedaghat (2011) analyzed wind speed data that were recorded every three hours from 2003 – 2007 at 10m, 30m and 40m heights in the Semnan Province in Iran. It was discovered that prevailing wind directions were about (200 – 260) degrees for 30m height and an obvious result for 37.5m height; which was generally at Southwest direction for most of the months. In their studies of wind shear characteristics at Central Plains Tall Towers of the United States from (2001 – 2003), Schwartz and Elliott (2006) discovered that the annual alpha values for the levels used at the 13 towers range from 0.138 to 0.254. They had a suspicion that the 0.138 alpha at Kearny may be too low because of possible tower effects. Nonetheless, even accepting the 0.138 value at Kearny, 12 of the 13 stations had alpha values above 0.143 (1/7), a shear value often used to extrapolate measured data at 50m to the hub heights of modern turbines. It appears that for the Central Plains, the 1/7 shear assumption was too conservative and that the wind speed could increase with an exponent as high as 0.2 or 0.25. Their seasonal variability of alpha values at the 13 towers was grouped into two patterns. Stations in northwest Texas, Oklahoma and Kansas (nine stations), exhibited a flat seasonal pattern of alpha values. There was a slight tendency for maximum values to occur in early autumn and lowest values in late winter, but this tendency could have been due to the short periods of record at these sites. The other four towers in Central Texas, Colorado and the Dakotas showed a distinct maximum of alpha values from July to October and a minimum of shear from January through March or April.

Eppanapelli (2013) analyzed wind profile of wind speed measurements of three sites for one year and opined that wind speed increases with an increase in height due to negligible surface friction, less dense air and much stable conditions as elevation rises. It was found that the Weibull distribution is the best fit for the wind speed distribution of one-year measurements, if compared to the Rayleigh distribution. The variation in wind speed and wind direction between two nearby locations was very small (2 – 3%), and anemometers on met mast have 1percent of uncertainty due to leeward and shadow effects. The variation in wind speed and wind direction between two faraway locations was also not substantial but significant (4 – 5%). Wind speed distribution at the three locations proved that these sites belong to IEC-111 low wind sites with 6.5m/s as average wind speed at hub height (100m in this case).

Roy (2012) presented the estimated annual variation of wind shear (Ψ) over a ten year period. The variability and intermittency of wind gusts over this prolonged observation period was evident in the random variation of shear coefficients. For sector – 1 (Cox’s Bazar and Hatya), Ψ randomly fluctuates between approximate figures of 0.1 and 0.8 over the ten year period. For sector – 2 (Barisal) and sector – 3 (Saidpur, Rangpur), the derived range of variation resides in the domains of 0.1 – 0.4 and 0.1 – 0.56 respectively. Hatya in sector – 1 showed the largest degree of deviation. January was historically considered as a time of weak wind streams across the delta of the Bay of Bengal. But, when the curves were plotted for the month of September (when stronger wind flows were expected), the random pattern continued suggesting lack of suitability of annual shear variation for averaging wind shear characteristics.

The annual behavior of mean wind speed studied by Alam et al. (2011) showed that the annual mean wind at 10, 20, 30 and 40 meters above ground level (AGL) were 4.1, 4.8, 5.3 and 5.6m/s, respectively, in the year 2007 and 4.2, 4.9, 5.4 and 5.8m/s, in the year 2008. This showed an increase of about 2 percent in wind speed in the year 2008 compared to that in 2007. The maximum wind speeds observed during these two years at 10, 20, 30 and 40 meters AGL were 15.9m/s, 17.8m/s, 18.4m/s and 19.5m/s, respectively. The prevailing wind direction was found to be NNW and NW during the data collection period. The power law exponent (which is a number that characterizes the wind shear) was used to determine the Wind Shear Exponent (WSE). The WSE obtained using all the data values was 0.273 while 0.269 and 0.279 for the data of year 2007 and 2008, respectively. The higher values of WSE (~ 0.285) were observed from October to January and relatively lower (0.265) during rest of the months with lowest in September. It was also observed that higher value of WSE (~ 0.4) were from 7pm to 7am and lower (~ 0.1) from 8:30am to 4:30pm.

Abdulla (2014) in his study of seasonal and annual mean wind speed of sites 3 and 7 of the Sulaymanyiah International Airport Area, discovered that the highest seasonal mean wind speed was found to be 4.35m/s and 3.98m/s respectively in summer season, while the lowest value was in the winter season with 2.56m/s and 2.45m/s respectively, also annual mean wind speed as 3.32m/s and 3.12m/s respectively. For both sites, all seasons have maximum percentage frequencies of wind speed (≥ 4.5m/s) except the winter, which has the maximum percentage frequency of wind speeds between (1.0 – 1.5 and 1.5 – 2.0)m/s respectively. He also discovered that the seasonal prevailing wind direction was in west – northwest, the mean wind speed during the summer 4.35 and 3.98m/s had the highest frequency occurrence during the year (16.68%) and (20.56%) for sites 3 and 7 respectively, while the annual prevailing wind directions were between north – northwest with frequency occurrence (13.91%) and west – northwest with frequency occurrence (13.53%) for site 3 and west – northwest with frequency occurrence (17.31%) for site 7. Wind Rose analysis showed that for both sites 3 and 7, the resultant vector of wind direction was fairly consistent between 278 and 360 degree which was generally from the west to north for annual, seasons and most of the months.

2.2.3 Relationship between Wind Shear and Thunderstorm

A number of studies show the relationships between wind shear and thunderstorm. See for example Harding (2011), Weli and Ifediba (2014) and Musa (2014). Thunderstorms are one of the most beautiful atmospheric phenomena and one of the most hazardous conditions pilots encounter. Thunderstorm is a storm consisting of thunder and lightning produced by a cumulonimbus, usually accompanied with rain or hail. In Harding (2011), it was observed that all thunderstorms can produce severe turbulence, low level wind shear, low ceilings and visibilities, hail and lightning.

Thunderstorms have been found to be associated with wind shear. This is because the condition in which thunderstorm occurs also causes wind shear. Thunderstorms cause flight delay, diversion and cancellation. In the study of impacts of thunderstorm on flight operations in Port Harcourt International Airport, Omagwa, Rivers State, Nigeria, Enete et al. (2015) analyzed the annual trend thunderstorm frequency for the period of 15 years (1999 – 2013). The trend tends to be fluctuating, having its highest occurrence in 2005. Thunderstorm frequency recorded a total number of 291 with the highest number of diversions in July, flight delays occurred 526 times, having its highest number of delay in October, and flight cancellations recorded 218, having its number of cancellations in both April and September. The movement of thunderstorm frequency was in consonance with flight cancellations and delays. It was observed that the month of October with highest thunderstorm frequency showed a corresponding increase in the number of flight delays and cancellations.

Thunderstorms occur practically everywhere over the globe but they occur most frequently in the tropics (Ayoade, 2004). Also, the intensities of tropical thunderstorms are much higher than those of the middle and upper latitudes. They are therefore of considerable climatological importance in the tropics. In some tropical regions, thunderstorms occur year round. In mid-latitudes, they develop most frequently in spring, summer, and fall but arctic regions occasionally experience thunderstorms during summer (Pilot Outlook, 2010).

Thunderstorms are highly localized weather phenomena as their diameters are usually less than 25km. Their duration normally varies from 1 – 2 hours (Ayoade, 2004). Thunderstorms develop where there are warm and humid air masses unstable over considerable vertical layers of about 8000 meters. Most thunderstorms are convectional in origin, resulting from intense solar heating but some are caused by sea or land breezes. Orographic lifting along mountain ranges may cause thunderstorms to be distributed in bands or lines called squall lines which may again become organized into linear systems. Thunderstorm showers are sporadic, of short duration, but of very high intensities. The showers are accompanied by squally winds and of course lightning and thunder (Ayoade, 2004). All thunderstorms progress through a life cycle from their initial development through maturity and into disintegration (Ayoade, 2004).

It is a known fact that thunder occurs after lightning. This is caused by the collision of clouds, the sound is produced by resonance between high and low clouds, and by high clouds descending and colliding onto low clouds. And because of the built energy and intensity of thunderstorm, it becomes dangerous and unsafe for aircrafts wherever it is building, Enete et al. (2015). The speed in which the wind blows is usually high whenever thunderstorm takes place. It is very important that the direction is known by the pilots, for air safety.

Harding (2011) opined that thunderstorms are formed by a process called convection, defined as the transport of heat energy. Because the atmosphere is heated unevenly, an imbalance can occur which thunderstorms attempt to correct. He stated that three things are needed for convection to be a significant hazard to flight safety: moisture, lift and instability. Sufficient moisture must be present for clouds to form. Although convection occurs in the atmosphere without visible clouds, moisture not only is the source of a visible cloud, but also fuels the convection to continue. As the warm air rises, it cools, and the water vapour in the air condenses into cloud droplets. The condensation releases heat, allowing the rising air to stay buoyant and continue to move upward.

There are many ways for air to be lifted in the atmosphere. Convection or buoyancy is one method. Other meteorological methods include fronts, low pressure systems, interactions between thunderstorms, and interactions between the jet stream and the surface weather systems. Air also can be lifted by mechanical lift, such as when it is forced up and over a mountain range. Regardless of how the air is lifted, if the lift is enough to make the air warmer than the surrounding air, convection can continue (Harding, 2011).

In general, as you increase in altitude, the air temperature cools up to the top of the troposphere. Of course, around fronts, mountains and in shallow layers near the ground, this is not always the case. How fast air cools is a measure of atmospheric stability. Meteorologists refer to this vertical change in temperature as the lapse rate. Outside of extremes, the temperature generally decreases from between 2.7^{o}F – 5.4^{0}F per 1000feet. If the actual rising air cools slower than the lapse rate, the air remains relatively warm compared to the surroundings, and it continues to rise (Harding, 2011).

Three stages of thunderstorm each lasting 20 – 40 minutes can be recognized. In the developing stage (Towering Cumulus Stage), strong updraughts prevail in the thunderstorm cell (Ayoade, 2004). The building clouds are made entirely of liquid water and aviation hazards from this stage include turbulence and icing (Harding, 2011). The cumulus cloud grows rapidly upward to about 8000 meters, there is little or no precipitation and thunder hardly occurs (Ayoade, 2004). Even though the cloud is composed of all liquid, some of the liquid is “supercooled,” in other words; liquid water can exist at temperatures below the normal freezing point (Harding, 2011).

In the mature stage, the thunderstorm is at its highest intensity. It is characterized by the production of precipitation. There are some downdrafts even though the updrafts are still strong. Lightning and thunder are being produced. The mature thunderstorm contains water, supercooled water and ice. The cumulonimbus cloud may reach up to 18,000 meters and often develops an anvil head caused by upper tropospheric winds (Nieuwolt, 1977; Ayoade, 2004).

During the final stage, which is the dissipating stage, the updraft has ceased and the storm is dominated by downdrafts. Precipitation may still occur, but will decrease with time as moisture is depleted. This dissipating thunderstorm contains mostly ice (Harding, 2011). Eventually, the cloud dissolves or disintegrates into stratiform clouds (Ayoade, 2004).

You can visually estimate the potential for convection to continue by looking at the texture of the thunderstorms. If the cumulus tops are crip and well defined, often looking like a cauliflower, the storm will continue to grow. The crip texture occurs because the cloud is mostly made up of water drops with little ice (Harding, 2011). As the storm becomes more vertical, these water drops will change phase and freeze. This change will release heat, fueling the continued growth of the cloud. If the clouds appear fuzzy, it is likely because they are now composed mostly of ice crystals. As a result, the storm has much less energy available to grow significantly taller. Individual thunderstorms generally last less than one hour; however, if the storms are being continually forced by a moving front outflow boundary or from the same terrain feature and area, thunderstorms can continue for many hours. A special case of thunderstorms are known as supercell thunderstorms. Supercell thunderstorms have a structure, driven primarily by the changing wind speed and direction with height that allows the updrafts and downdrafts to remain separated. Thus, the storm can remain in the mature phase for extended periods. These supercell thunderstorms are often times associated with damaging winds, frequent lightning, large hail, severe to extreme turbulence, and low level wind shear. Thunderstorm outflow can cause extreme changes in wind speed and direction near the surface during critical phases of flight (Harding, 2011).

The time series of frequency of thunderstorm occurrence at Abuja has been on the increase since the early 1980s. The long term anomaly of thunderstorm occurrence also indicates the same increasing trend in thunderstorm occurrence, being more pronounced from 2001 upwards. Therefore, an increase in thunderstorm frequency is a good indicator of changing extreme weather events due to climate change (Nigeria Climate Review Bulletin, 2011).

2.2.4 Weather Parameters and Flight Operations in Nigeria

There has been an increasing awareness, concern and studies on weather as one of the causes of air disaster 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. 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 plus Other Causes. Nevertheless, he attributed it to outdated Aircrafts being flown everywhere in Nigeria rather than what the experts revealed. He also reported that between 1965 and 2002 (37 years) when the Nigeria Airways was in operation it recorded six crashes in which 219 persons died. Between 1965 and 1983 (18 years), Nigeria Airways recorded two air crashes while for another 18 years, 1984 to 2002, it recorded another three crashes out of which the last two, in 1996 and 2002 recorded no casualties.

Besides, between 1988 and 2005 (17 years), the private airlines recorded 12 crashes, of which only one had no casualties, while the total deaths recorded was 762. He added that the worst plane crash took place on 02/05/1955 in Calabar courtesy of West African Air System Company, seconded by the 11/07/1996 in Lagos through Aviation Dev. Corp. (ADC Airline) and that of 06/26/1991 in Sokoto, courtesy of Okada Air. He attributed all these accidents to outdated aircraft problem.

Okwusogu (1999) carried out a geographical study on the problems and prospects of aviation industry in Nigeria and identified only human and economic factors such as cost of maintenance, aircraft rental, insurance premium, spare parts and maintenance bills, salaries of expatriates engineering corps, and administrative policy as the problems of the aviation industry in Nigeria, while neglecting the weather factor. On the other hand, Bature (2002) identified two factors that generally affect the operation of the aviation industry in Nigeria to include the human and the natural factors in a study ‘‘Factors affecting international flight operations in Nigeria’’.

He reported that administrative, pilot`s competence level, ground crew, type and model of aircrafts in use and condition of fuel used are human factors, while the natural factor includes weather condition such as cloud, temperature, fog, wind shear, precipitation, among others. He emphasized that this climatic factor has for time immemorial been disrupting not only international flight operations but also every flight operation in the aviation industry. However, he concluded that the natural factor causes only little inconveniences, for the fact that there were responsive knowledgeable ways of dealing with the natural phenomena with respect to the aviation industry. This is considered an underestimation of the real fact. With the incessant plane crash, flight delay, cancellation and diversion in Nigeria and all over the world as a result of weather as one of the causative factors suggests that weather phenomena is not done with yet. The study carried out by Jerome (1999) within Kano International Airport environment in 1999 was on the assessment of the variation of climate parameters (temperature, pressure, humidity and evaporation) within the airport environment for the period 1968-1997. The study revealed that there was no significant variation in the climate of the airport environment. The objective of the study was just to assess the variation in the microclimate of the airport with no link to flight operations. Abdulazeez (2009) carried out a study on the effect of weather on air transport; a case study of Abuja International Airport. The study revealed that rainfall parameter was the most critical parameter influencing air transport services. Therefore, flight delay and cancellation becomes very frequent, serious and regular during the period of rainfall (March-October or early November) in Nigeria. Mohammad (2009), in his study ‘‘weathering the weather factor,” revealed that one of the greatest challenges in aviation safety in Nigeria is the weather-induced aviation disasters. These types of disasters usually occur as a result of wind shear, storms, and heavy rainfall. He further revealed that wind shear, which is a hazardous meteorological phenomenon caused by sudden changes in the wind speed and, or direction over a short distance and, or short period, is particularly hazardous when it occurs at lower altitudes. Low level wind shear has therefore been recognized as a potential hazard to the aircraft, especially during landing and take-off phases of aircraft. In addition, weather imposes some dangers in aviation as convective weather systems are usually very severe in nature and pose very serious threat to both life and property especially in aircraft operations. They are particularly hazardous to aircraft operations because of the down and updraft (wind systems) and lightning associated with such convective systems. In general, weather is a significant factor affecting safety in the skies as statistics indicate that weather contributes up to 30 percent of civil aviation accidents worldwide, either as a sole factor or among the causative factors (Musa, 2014).

According to Mohammad (2009), one of the strategies adopted by the Federal Government towards achieving safer skies over Nigeria is the strengthening of the operational capacity of our national weather service provider: the Nigerian Meteorological Agency (NIMET). Many stakeholders in the aviation industry have applauded this step. The Federal Government supported NIMET to embark on some safety-critical projects, which has recorded substantial accomplishments since May 2007. Some stakeholders believed that with some of the initiatives being implemented by NIMET, Nigeria’s skies would surely be among the world’s best in the next few years. Other initiatives that are being implemented by NIMET towards achieving safer skies over Nigeria include the establishment of a National Weather Forecasting and Research Centre in Abuja. In addition, the installation of new conventional meteorological instruments in the NIMET’s weather observatories nationwide to replace the obsolete ones, establishment of marine meteorological stations along the country’s coastal belt and human capacity development, particularly for the professional cadre of NIMET (Mohammad, 2009).

This study by Weli and Emenike (2016) examined turbulent weather conditions and their relationship to aircraft operations as well as the influence of dry and wet seasons on weather parameters of rainfall, thunderstorm and fog at the Port Harcourt International Airport. The aim was to identify which weather parameter affects aircraft operations namely: flight delay, cancellation and diversion. Data on turbulent weather conditions (fog, thunderstorm and rainfall) were obtained from the Nigerian meteorological agency, and data on flight operations were similarly obtained from the operators of different airline (Arik air, Dana and Aero contractors). The study revealed that for all aspects of aircraft operations, thunderstorm had significant relationship with aircraft operations, as it accounted for 90.4 percent variations in flight delays, (r = 0.951) at p>0.05, it also accounted for 89.68 percent variations in the case of flight cancellation with an r value of 0.947, thunderstorm in the case of flight diversion accounted for 88.36 percent variation with an r value of 0.940 at p>0.05. Findings indicate that thunderstorm was the only turbulent weather parameter that significantly affected aircraft operations especially cancellation of flight. The study also revealed that seasons influence weather parameters. The study therefore recommends an algorithm designed to forecast turbulence models jet stream, mountain induced turbulence, and convective induced turbulence to avert, most especially flight cancellation which creates opportunity for losses.

Dan-Okoro, Hassan and Agidi (2018) assessed 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 were cloud cover. Individual weather elements on their own do not affect flight operations, however, when they are combined, affects aviation transportation significantly.

2.2.5 Wind Shear and Flight Operations

In many parts of the world, a number of studies have been done showing the effects of wind shear on flight operations. Wind shear has for long disrupted flight operations both locally and internationally. Lankford (2001) study has shown that wind direction and speed is crucial for determining flight safeties.

Tailwind, headwind and crosswind vary in direction and influence both landing and takeoff phases of aircraft flight. Smith (1975) in his findings reported that during the summer months, the breeze often attains a mean speed of over 7.5m/s, with gusts up to 15m/s. These conditions made landing hazardous. Roberts (1971) in Smith (1975) have shown that a runway is considered unsafe when the wind component at right angles to it exceeds a certain value depending on aircraft type. Therefore, in an effort to ensure successful landing, the Pilot is provided with detailed information on wind behaviour in the last 30 meters of descent. The Air Traffic Controller usually apprises the Pilot of surface conditions about 10 minutes before touchdown. On the other hand, Keddie (1971) in Smith (1975) carried out a research that revealed that a mean speed measured over 4½ minutes period provided a reasonable estimate of speed 10 minutes later. Crossley (1966) in Smith (1975) revealed that a mean headwind of 4m/s on the trans-atlantics crossing would increase the flight time by one minute and it consequently became less profitable to deviate from great circle routes in other to seek the least-time track for fear of anticipated strong winds (jet streams). In general terms, Smith (1975) concluded that, forecast wind conditions has the most important role in determining the selection of the fastest and the most economical flight path, for the fact that favourable tailwinds can produce the most significant improvements in air speed, fuel consumption, and estimated arrival times. Griffiths (1976) supports this fact by recommending that, the routing of a flight should take full cognizance of tailwinds and headwind and optimum levels in order to obtain the most economical route. This helps to avoid areas of turbulence. It is apparent from the findings that wind is both a hazard and a resource for flight operations.

Despite the relatively conducive weather of Nigeria compared to other countries (such as Mauritania, Somalia, Japan etc.), there has been a marked increase in the cases of recorded flight delay, diversion and cancellation, which in most cases, are attributed to poor weather conditions National Oceanic and Atmospheric Administration (NOAA, 2004). Aircraft accident has not been an exception, but its occurrence, though resulting to very devastating losses, has been on a low rate compared to other defects, with its highest occurrence between 2003 and 2006. Most of the air crashes, delays and cancellations were caused by poor weather conditions such as thunderstorm occurrence, poor visibility (associated with fog, dust haze etc.), wind shear and squall (Jones 2004b; Knecht, 2008).

Moreover, though there are other factors that contribute to the disruptions in flight efficiency (such as technical, operational and human factors), weather-related factors have been proven to be the highest cause of interruptions in the efficiency of flight operations in Nigeria with more devastating losses, hence, the International Air Transport Association (IATA) stated that 71 percent of air accidents in Nigeria are due to mainly poor weather conditions with the inclusion of human errors, ageing aircraft and deficiency in safety management system (Punch, 2005).

The Nigerian aviation industry witnessed its darkest period between 2003 and 2010 when several aircraft accidents occurred, resulting in loss of lives. Aviation Safety Reporting System (ASRS, 2007) noted that out of a total of 376 air fatalities that occurred in Africa in 2005 alone, Nigeria accounted for 225 of them and concluded that Nigeria accounted for 9.3 percent of all air accidents in Africa. However, investigations revealed that the air crashes which occurred between 2003 and 2006 were traceable to bad weather and wind shear. Most crashes were associated with poor weather conditions, pilot error, mechanical failure etc. (Knecht, 2005). Generally, flight delay, cancellation, division and air craft accidents affect the Nigerian Aviation Industry as Ayoade (1988) 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'.

The study carried out by Weli and Ifediba (2014) at Murtala Mohammed International Airport Lagos showed that the majority of the delays, diversions and cancellations at the airport which are weather related are caused by squall line. It occurs in both rainy and dry season. Its occurrence in dry season is attributed to the proximity of the airport to the Atlantic Ocean. Squall is known to be the advanced level of wind shear of which both of them have caused some plane crashes as can be seen in the literature.

Onwuadiochi, Ijioma, Ezenwaji and Obikwelu (2020) carried out a study on the effects of wind shear on flight operations in Sam Mbakwe Airport, Imo State, and the study revealed that wind shear contributes to flight delays and cancellations at the Airport. It reveals a weak positive relationship between wind shear measured at 20m above ground level and flight delay. The positivity shows that as wind shear at the airport increases, the chances of flight delay also increases. The correlation between wind shear measured at 20m above ground level and flight delay is 0.195, which is less than 0.5. The R-Square (Coefficient of Determination) between wind shear measured at 20m AGL and flight delay the two variables is 51.4 percent. This shows that wind shear is responsible for 51 percent of flight delays at the airport. The relationship is significant because the P-value of the F-test is 0.0006, which is less than 0.05. A unit increase in wind shear leads to 0.148 increase in chances of flight delay.

The work also shows a weak positive relationship between wind shear measured at 20m above ground level and flight cancellation. It shows that as the wind shear increases, the chances of flight cancellation also increase. The correlation between wind shear measured at 20m above ground level and flight cancellation is 0.392 which is less than 0.5. The R-square (Coefficient of Determination) is 67.1 percent. This means that wind shear measured at 20m above ground level contributed to 67 percent of flight cancellation at the study area. The relationship is significant because the P-value of the F-test is 0.000023, which is less than 0.05. A unit increase in wind shear leads to 0.022 unit increase in flight cancellation.

The correlation between wind shear calculated at 100m above ground level and flight delay is also a weak positive correlation with the value of 0.193 which is less than 0.5.The positive nature of the relationship between the variables implies that as wind shear increases, the chances of flight delay also increase. The R-square (Coefficient of Determination) is 51.3 percent. This implies that wind shear measured at 100m above ground level contributed to 51 percent of flight delay at the study area. The P-value of the F-test is 0.0006, which is less than 0.05. This shows that the relationship is significant. It therefore reveals that a unit increase in wind shear leads to 0.118 unit increase in flight delay.

The study shows a weak positive relationship between wind shear calculated at 100m above ground level and flight cancellation. The correlation between wind shear measured at 100m above ground level and flight cancellation is 0.394 which is less than 0.5.Also, the positive nature of the relationship between the variables implies that as wind shear increases, the flight delay also increases. The R-square (Coefficient of Determination) is 67.3 percent of the flight cancellation. This means that wind shear measured at 100m above ground level contributed to 67 percent of the flight cancellation. The relationship is significant because the P-value of the T-test is 0.000022, which is less than 0.05. A unit increase in wind shear leads to 0.018 unit increase in the chances of flight cancellation.

2.2.6 Measuring and Estimating Wind Shear

A number of models and methods are available for measuring and estimating wind shear. Wagner et al (2011), Eppanapelli (2013) and Abdulla (2014) noted the two models used for estimating wind shear as power law and logarithmic law. The power law is a simple mathematical function while logarithmic law is more sophisticated. Wind shear is also measured with the aid of an instrument known as Low Level Wind Shear Alert System (LLWAS).

Nigeria is located within the equatorial region of West Africa and is therefore regularly exposed to severe tropical thunderstorm activity with the associated danger of wind shear or microburst activity, particularly dangerous to air transport around airports during landing and take-off (Musa, 2014).

Therefore, the Nigerian Meteorological Agency felt that safety of lives could not be guaranteed with the implementation of MIDAS IV AWOS without Wind Shear Alert System. After the completion of MIDAS IV AWOS installation, the low-level wind shear alert system (LLWAS) installation was implemented in 2008 at Abuja International Airport. The Low-Level Wind Shear Alert System (LLWAS) is designed to detect low-level wind shear in the terminal area. The ground-based system provides both audio and visual alarms to ATC personnel in clearly represented numerical and graphical form. In locations where Low-Level Wind shear is known to be experienced, LLWAS significantly increase the operational efficiency and safety of the airport (Aderinto & Dahunsi, 2008).

The introduction of a new automated system for Airports in Nigeria has indeed improved the quality of aeronautical information being provided to users due to availability of state of the earth weather instruments installed along the runways to take measurements at the airside as well as the algorithms used to obtain information. The conventional measurements continue to serve as backup to the automated measurements. The most delightful thing is that Nigerian Meteorological Agency has about 55 surface manual observing stations spread across the country in addition to the stations at the airports. For accurate and up-to-date weather information, which is essential for the safety of life and protection of property as well as for general welfare and well-being of people, a quality assurance group was established from the department of weather forecasting services to observe the performance of these automatic observing stations. This group periodically downloads the archived data from the weather stations' computers in all the stations. This exercise enabled the group to detect errors resulting from instrument measurements. Its observations were forwarded to the engineering and technical services department for remedial action to be effected. Based on the group report, Engineers/Technicians from this department would in turn either calibrate the malfunctioning sensor or effect a replacement as the case may be (Aderinto & Dahunsi, 2008). This is maintenance effort to keep the equipment current. NIMET (2011) also reported flight delays, cancellations and diversions due to adverse weather conditions during the year 2010. Preliminary analysis of air traffic at the Nnamdi Azikiwe International Airport Abuja shows March with the highest number of flight disruptions. Smith (1975) has shown that almost all losses of large civil jets planes directly attributable to turbulence occur in or near thunderstorms. Updraughts and downdraughts of 30m/s and above have been recorded within cumulus clouds in the United State. Flight within a well-developed cumulonimbus cloud is usually difficult if not dangerous. This is because the turbulence nature of precipitation associated with it affects aircraft and the response of the aircraft to the turbulence condition is one of the major causes of accidents. It is on this note that Powell (1981) in Abdulazeez (2009) recommended that the takeoff of an aircraft should be postponed when there is any risk of flying into the area of an active thunderstorm from cloud. Similarly, on arrival in such a condition, the approach and landing should be delayed if possible until the storm has cleared. However, Abdulazeez (2009) made it clear that not all clouds are dangerous to flight operations because there are some clouds that are very safe for flying. These include clouds of the cirrus, stratus, and even some types of the cumulus family.

2.2.7 Automated Aeronautical Meteorological Observation

Automation of Aeronautical meteorological observation was introduced in Nigeria in February 2003 with the first implementation at the Nnamdi Azikiwe International Airport Abuja, the Federal capital city of Nigeria. Before the introduction of the new system, observations were taken from the manually observed stations by the observers, and visibility measurements were visual observations. This information is then forwarded to the Traffic Services providers. With the new system in place, a fully automated METAR (routine weather message/report) including algorithms for cloud and weather and the AUTO TREND is achieved. The MIDAS IV System (Vaisala Product) deployed at the Airport is providing all the basic Authomatic Weather Observing System (AWOS) parameters with Transmissometers, Ceilometers and Present Weather Sensors for visibility measurements. At present Low Level Wind Shear Alert System (LLWAS) has been added to the System. Before the introduction of the new system, NIMET relied on manually observed stations to take in-situ measurements. From 2003 to 2005, Automatic Weather Observing Systems (AWOS) were installed in most of NIMET stations, including the four major airports (Lagos, Port Harcourt, Abuja and Kano). That was done to complement measurements from conventional instruments. These Weather Observing Systems (AWOS) produces the basic weather parameters such as Air Temperature, Relative Humidity, Pressure, Precipitation, Wind Speed, Wind Direction and Solar radiation (Aderinto & Dahunsi, 2008).

Doppler Weather Radar (DWR) is highly sophisticated weather monitoring equipment used for the detecting, tracking and monitoring convective systems such as severe storms, microburst, line squalls, wind shear, thunderstorms etc. It detects the location, severity, speed and direction of convective systems. Six Doppler Weather Radars have been located each in Abuja, Kano, Lagos, Maiduguri, Port Harcourt and Yola airports (Aderinto & Dahunsi, 2008). Another critical project embarked upon, for more accurate weather forecasts in the ongoing aviation sector transformation is the procurement and installation of Upper Air sounding equipment. With financial support from the Federal Government, the Nigerian Meteorological Agency has completed the procurement and installation of Upper Air Sounding equipment at Lagos, Maiduguri and Enugu airports (Aderinto & Dahunsi, 2008). Other initiatives include, the establishment of a National Weather Forecasting and Research Centre in Abuja; installation of new conventional meteorological instruments in the NIMET’s weather observatories nationwide to replace the obsolete ones, establishment of marine meteorological stations along the countries coastal belt; human capacity development, particularly for the professional cadre of NIMET (Aderinto & Dahunsi, 2008).

2.2.8 Aircraft Accidents/Incidents and Causative Factors

Globally, it was estimated that approximately 80 percent of all aviation accidents occur shortly before, after, or during takeoff or landing (Wikipedia online version, 2009).

A study by National Aviation Safety Data Analysis Centre (2003) revealed that, between 1994 and 2003, there were 19,562 aircraft accidents involving 19,823 aircrafts. Weather was a contributing or causal factor in 4,159 (21.3%) of these accidents, and 4,167 aircrafts were involved. These weather factors, according to NASDAC varied based on the operating rules the aircraft was flying under at the time of event, and that the operating rules were based on Title 14 Code of Federal Aviation Regulations (FAR), which are rules designed to promote safe aviation operation, protecting pilots, passengers, and the public from unnecessary risk.

This study revealed the proximate effects of turbulence, density, altitude, wind, and cloud cover (ceiling), icing and visibility in causing the 4,159 (21.3%) weather- related accidents. Wind, cloud cover and visibility were the critical of the six factors. This finds relevance in the work of Wen-Lin Guan (2010) that low clouds, fog and wind are the most hazardous factors, in which gust, wind shear and turbulence being most dangerous. In addition, the study revealed that from 1994 to 2003 the annual number of weather-related accidents has declined. However, it has remained roughly constant as a percentage of total accidents. The declined trend of the annual number of weather-related accidents revealed by the study may not be a true picture because the study did not indicate the other factors responsible for the remaining 15,303 (78.7%) accidents out of the 19,562 that occurred, as some of the factors could be weather-induced.

According to statistics of Aviation Safety Network (2006) of United States in Wen-Lin Guan (2010), from 1950-2000, there were 40 aviation accidents caused by turbulence or crosswind and 39 accidents by wind shear or downdraft (downwards airflow). ASN (2006) statistics also shows that from 1990-2000 two major accidents were caused by wind shear with over 90 fatalities while three major accidents were caused by turbulence and crosswind with over 50 fatalities. From PlaneCrashInfo.com accident database, Kebabjian (2009) compiled and presented 1,300 fatal accidents involving commercial aircraft, world-wide, from 1950 through 2008 for which a specific cause is known. Aircraft with 10 or less people aboard, military aircraft, private aircraft and helicopters were not included. The study shows that pilot error (29%), mechanical failure (22%) and weather factors (28%) were the most critical factors responsible for the accidents in the six decades. "Pilot error (weather related)" represents accidents in which pilot error was the cause but brought about by weather related phenomena. "Pilot error (mechanical related)" represents accidents in which pilot error was the cause but brought about by some type of mechanical failure. "Other human error" includes air traffic controller errors, improper loading of aircraft, fuel contamination, improper maintenance procedures and non-adherence of ground crews to the procedures of operating aircrafts. Sabotage includes explosive devices, shoot downs and hijackings. Where there were multiple causes, the most prominent cause was used (Kebabjian, 2009). An important aspect Kebabjian did not indicate is the individual parameters responsible for the accidents. This is because factors such as human error, mechanical failure and other cause can be weather induced.

Ranter (2003) revealed that in 2002 Africa was the most unsafe continent. Nearly 27 percent of all fatal airliner accidents happened in Africa, while she only accounted for approximately 3 percent of all world aircraft departures. All regions (Europe, North America, South America, and Central America) recorded a steadily decreasing accident rate in a moving 10-year average trend over the past 11 years (1992-2002) except Africa. However, the average number of accidents per year in Australia was not moving much since 1995.

In 2006, Africa was again the unsafe region, with a record of 18.5 percent of all fatal airliner accidents. The study gives a picture of the situation in Africa. However, it did not account for the factors (human, mechanical or weather) responsible for the accidents.

In the same vein, Joseph (2005) reported that Nigeria occupies position 21 on the list of world’s 25 most dangerous skies with 33 numbers of accidents and 1,070 fatalities from 1945-2005 (Military accidents, Corporate Jets, hijackings and other criminal occurrences not included). He added that while some attributed the cause of the accidents to ageing aircraft, the International Air Transport Association (IATA) said human error weather-related and human error safety management deficiencies were responsible, and accounted for 71 percent of all accidents in the continent. Africa is a big issue on safety with 25 percent accident rate, which is six times less safe than the world rate.

2.2.9 Flight Phase (departure and arrival) and Accident

Weather is responsible for the problematic nature of flight phases, and because of this, International aeronautics and meteorology society generally acknowledged that low level wind shear, among other weather parameters is a severe hazard to aircraft during takeoff, approach and landing (Wen-Lin Guan, 2010). Twenty-three out of twenty-eight accidents were in the epoch of approach and landing (Wen-Lin Guan, 2010). For instance, the Sosoliso plane crash in 2005 in Port Harcourt, Nigeria happened during approach and landing phase (Ayigbe, 2006). Ranter (2003) revealed that the year 2002 witnessed a rise in the number of approach and landing accidents, which is one of the four most pressing safety problems facing the aviation industry. It accounted for 54 percent of all accidents, compared to 38 percent in 2001.

(Wikipedia, 2009) shows that approach/landing and takeoff/climb cause the highest number of accidents, hence, the most problematic phases in aircraft. Ground flight phase caused the least number of accidents. In related development, Kebabjian (2009) in looking at the causes of fatal accidents by decade, revealed the percentage of accidents and fatalities by approach/landing and takeoff/climb phases of flight. The approach/landing phase accounted for 51 percent accidents and 18 percent of fatalities while Takeoff/climb phase accounted for 17 percent of accidents and 22 percent of fatalities. However, he did not indicate the study period.

2.2.10 Determining the Spacio-Temporal Wind Profile Pattern

Several techniques have been developed over the years to estimate the spatio-temporal pattern of the wind resource (Veronesi & Grassi, 2016). Brower (2012) opined that majority of these techniques are part of a set referred to as numerical wind flow models, which estimate the wind resource solving the physical equations that govern the motion of air in the atmosphere. These methods have varying level of complexity, derived by the type and amount of equations they include. The simplest ones are the mass-consistent models (Philips, 1979), first developed in the 1970s, which only solve the equation of conservation of mass. On the other end of the complexity spectrum are numerical weather prediction models (Brower, 2012), which solve all the computational fluid dynamics equations plus others that govern the energy exchanges between soil and atmosphere. These methods are able to estimate the long term wind resource and its time variability, even though they tend to be time-consuming and computationally expensive (Veronesi, Grassi, & Raubal, 2016).

Interestingly, another branch of research has been dedicated to the development of techniques for wind resource assessment based purely on statistical algorithms (Veronesi & Grassi, 2016). Statistical models correlate wind speed data from weather stations, with remotely sensed physical parameters, to infer the wind spatio-temporal pattern (Veronesi & Grassi, 2016). Veronesi et al. (2016) stated that statistical methods are accurate, computationally efficient, and less time-consuming than physical models. These methods have been tested in the literature for estimating both the long term pattern of the wind resource ((Veronesi et al., 2016; Aksoy, Toprak, Aytek, & Unal, 2004; Luo, Taylor, & Parker, 2008; Foresti, Tuia, Kanevski, & Pozdnoukhov, 2011; Cellura, Cirrincione, Marvuglia, & Miraoui, 2008) and for time-series estimations with models such as (Auto Regressive Moving-Average (ARMA) (Castellanos & Ramesar, 2006; Philippopoulos & Deligiorgi, 2009), Markov chain (Shamshad, Bawadi, Hussin, Majid, & Sanusi, 2005) and autoregressive models (Poggi, Muselli, Notton, Cristofari, & Louche, 2003). However, in 2012, Ohashi and Torgo stated that spatio-temporal prediction, that is, the estimation of the hourly wind speed pattern in areas where no direct observations are available, of wind speed time-series using machine learning techniques, is a recent research topic. The major problem in wind resource assessment is the large amount of uncertainty involved, which ranges from malfunctions of the weather stations to the extrapolation of the wind speed profile in complex terrains. Assessing this uncertainty is difficult with numerical wind flow models, but straightforward with statistical wind resource assessment, which can precisely account for all these sources of uncertainties (Cellura et. al., 2008).

In their study, Veronesi and Gassi (2016) presented a new generalized statistical methodology to generate the spatial distribution of wind speed time-series, using Switzerland as a case study. The research was based upon a machine learning model and demonstrated that statistical wind resource assessment can successfully be used for estimating wind speed time-series. In fact, the method was able to obtain reliable wind speed estimates and propagated all the sources of uncertainty (from the measurements to the mapping process) in an efficient way, that is minimizing computational time and load. This allows not only an accurate estimation, but the creation of precise confidence intervals to map the stochasticity of the wind resource for a particular site. The validation shows that machine learning can minimize the bias of the wind speed hourly estimates. Moreover, for each mapped location, this method delivers not only the mean wind speed, but also its confidence interval, which are crucial data for planners.

ThiThi, Boopathi, Bastin, Rangaraj, and Gomathinayagam (2017) technically studied the wind power potential at 100 m AGL (above ground level) in Myanmar by utilizing MERRA_2 (Modern-Era Retrospective analysis for Research and Applications) reanalysis datasets, Geo-informatics data sets and maps. The results show that promising wind potential areas are in Ayeyarwaddy, Yagon, Tanintharyi, Mandalay, Magway, Sagaing Regions and Rakhine States, the highest wind power density is 261 W/m^2 and installable technical wind power potential is 153 GW approximately. Based on the analysis by using industry-standard software, Annual Energy Production of 4454.88 MWh/year may be obtained with capacity factor of 25 percent. Subsequently, they determined the wind power potential in different hub heights at 50 m, 80 m and 120 m. The results can fulfill to facilitate the development of wind energy not only for utility-scale generation but also village power and other off-grid applications in Myanmar. Therefore, their study provides technical wind power potential estimation to perform future wind feasibility investigations in Myanmar.

The traditional utilization of reanalysis data is as a historical record of wind speed patterns which can be employed to correlate with actual short-term wind speed measurements from meteorological masts (ThiThi et. al., 2017). The reanalysis data can also reduce the costs and risks of wind farm development by providing a source of long-term meteorological data that is difficult or expensive to acquire through normal meteorological measurement campaigns. Moreover, the reanalysis data are gridded datasets that combine data obtained from global circulation models (GCM's) with measured data. In mapping the average wind resource over large areas, NCEP-R2 (National Centers for Environmental Prediction), ERA-Interim (European Center for Medium-Range Weather Forecasts reanalysis series), NCEP-CFSR (Climate Forecast System Reanalysis), NASA-MERRA (Modern-Era Retrospective analysis for Research and Applications) are currently freely and publicly available (Carvalho, Rocha, Gomez-Gesteira, & Santos, 2014). Among them, ThiThi et al. (2017) chose MERRA dataset for the estimation of wind power potential in their study.

ThiThi et al. (2017) stated that MERRA is a NASA (National Aeronautics and Space Administration) reanalysis product with coupled numerical modeling with large quantities of empirical data such as surface measurements and earth observation satellite data to generate a long term continuous dataset. The main advantage of MERRA data is the availability of long-term wind speed data on a global grid and the original MERRA wind is in the public domain to construct the wind power density dataset. Therefore, the MERRA dataset had been used in several studies to estimate the potential wind resource such as in UK (The Crown Estate, 2014) and also other countries (Olauson & Bergkvist, 2015; Cosseron, Schlosser, & Gunturu, 2014; Zhang et. al., 2015; Gunturu & Schlosser, 2015; Ritter, Shena, Cabrera, Odening, & Deckert, 2015). Olauson and Bergkvist (2015) investigated a model for the Swedish wind power production based on MERRA reanalysis data and noted that MERRA dataset has a relatively high temporal and spatial resolution. Cosseron, et al. (2014) also used reanalysis data from the MERRA data product and computed wind power density for the assessment of the wind power resource over Europe. In 2015, Zhang et al. compared three NWP-based wind resource assessment methods (MERRA, AnEn based on MERRA, and WIND Toolkit) across the United States. Gunturu and Schlosser (2015) used MERRA boundary layer flux data to construct wind profile at 50 m, 80 m, 100 m and 120 m turbine hub heights and estimated wind power density of each level by comparing with NREL (National Renewable Energy Laboratory) wind map. One thing was observed that MERRA could provide a more accurate dataset using the comprehensive suite of satellite based information for climate and atmospheric research". Ritter et al. (2015) applied MERRA data to obtain wind speed data at an unobserved location in Germany. Hallgren, Gunturu and Schlosser (2014) found that MERRA data provided a more robust assessment of the temporal characteristics (i.e. mean, median, availability, intermittency, etc.) of wind power than that used in other studies. In this study, MERRA_2 reanalysis dataset is used for technical wind energy potential assessment in Myanmar. It hopes to perform the starting point for future wind feasibility investigations in Myanmar.

Recently, several authors have explored the wind potential assessment all over the world (Ohunakin, 2015; Mentis, 2013; European Environment Agency Technical Report, 2009; Mentis, Siyal, Korkovelos, & Howells, 2016). ThiThi et al. (2017) technically estimated wind energy potential by using input data such as gridded reanalysis weather data, terrain elevations, land cover and socioeconomic data. The results were presented in color-coded maps by using GIS (Geographic Information Systems) analysis tools. The study prompted to support whether government needs to figure out certain policies and regulatory frameworks that are required when there is enough potential to utilize wind energy through technical wind potential in Myanmar.

2.2.11 Literature Gap

The aviation industry in Nigeria has been suffering due to inclement weather relating to wind shear. This is as a result of unavailability of wind shear monitoring equipment such as Low Level Wind Shear Alert System (LLWAS). This has also hampered research on wind shear in most parts of Nigeria, especially Murtala Mohammed International Airport in Lagos State and Port Harcourt International Airport in Rivers State. In a way to improve the meteorological services of aviation industry in Nigeria and to drastically reduce aviation accident, especially in this age of climate change situations, Low Level Wind Shear Alert Systems (LLWAS) have been installed at the airports and Murtala Mohammed International Airport and Port Harcourt International Airport were among the first airports that got the equipment.

Most of the studies done on wind in Nigeria, focused on wind energy production. As regards to that, the researcher has therefore deemed it fit to carry out a study of wind shear on aircraft operations at Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State, so as to fill this gap, and to enable researchers and students consult this study as a source of reference.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter describes the study areas, the type of data used, sources of data, and the various methods that were employed to analyze the data for this study.

3.2 THE STUDY AREAS

Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State are the two study areas of this research work.

3.2.1 LOCATION OF MURTALA MOHAMMED INTERNATIONAL AIRPORT

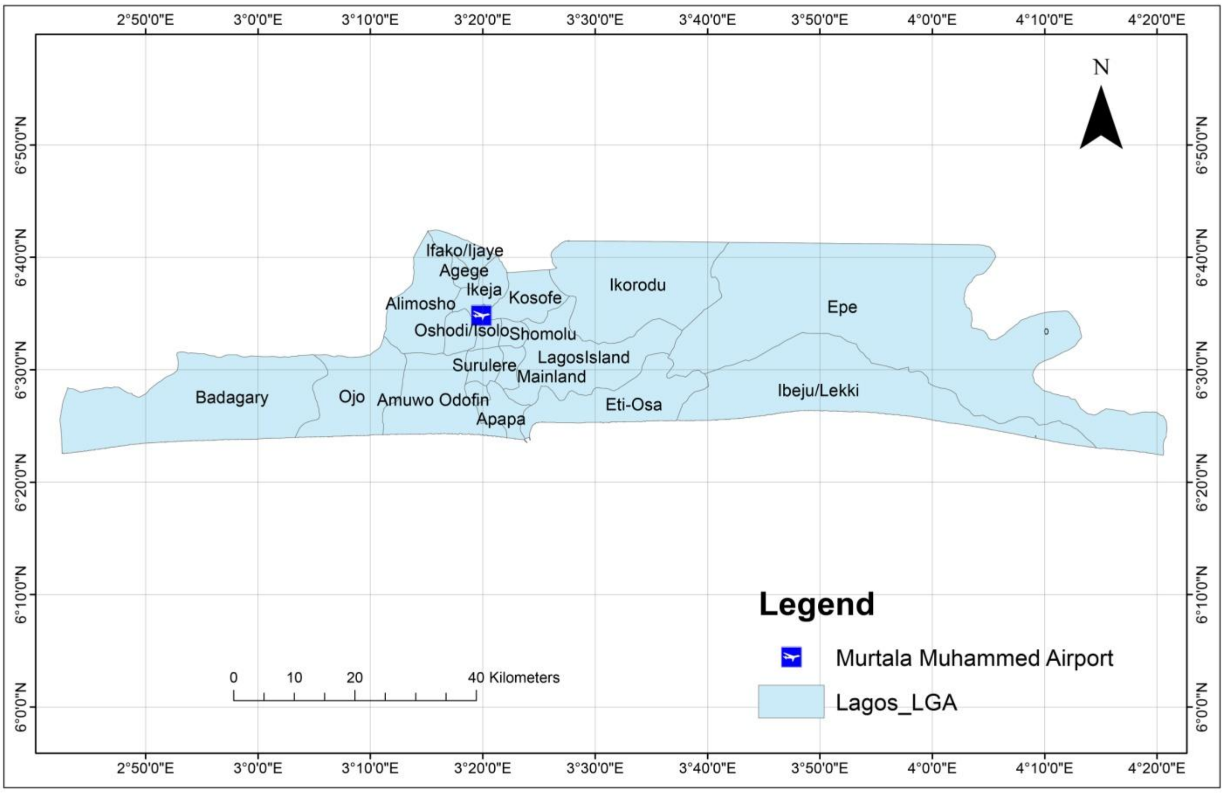
Murtala Mohammed International Airport (MMIA) (IATA: LOS, ICAO: DNMM) is an international airport located in Ikeja, Lagos State, Nigeria, and is the major airport serving the entire country (Fig. 3.3). Lagos State is located on the south-western part of Nigeria on the narrow coastal flood plain of the Bight of Benin (fig. 3.1). It lies approximately between latitude 6^0 22^1N and 6^0 42^1 N of the equator and between longitude 2^0 42^1E and 3^0 22^1E of the Greenwich Meridian (fig. 3.2). It is bounded to the North and East by Ogun State of Nigeria, to the West by the Republic of Benin, and to the South by the Atlantic Ocean. It has five administrative divisions of Ikeja, Badagry, Ikorodu, Lagos Island and Epe which were subdivided to 20 Local Government Areas (LGAs) during the creation of States and LGAs in Nigeria in 1999. Presently, there has been a creation by the State Government of 37 Local Council Development Areas (LCDA) in addition to the 20 LGAs making a total of 57 Local government administrative units. Territorially, Lagos State encompasses an area of 358,862 hectares or 3,577 km^2 (BNRCC, 2012).

The population of Lagos State by the 2006 National Census conducted by the National Population Commission was 17,552,942. Going by a population growth rate of 3.2 percent, the projected population for the State in 2015 is 23,305,971 (National Bureau of Statistics of Nigeria, 2013). Development in Lagos State is so rapid that the metropolitan area has expanded and absorbed the once rural communities. Hence, Lagos can best be described as a megacity. A megacity by definition is a continuous urbanized area with population of at least 10 million people (UNCHS, 1996). The population of the State has been above 10 million people since the 2006 National census. Some four Local Government Areas of Ogun State, adjoining Lagos State have fused into Lagos State forming Lagos Megacity Region (LMCR) (Oteri & Ayeni, 2016).

Murtala Mohammed International Airport was initially built during World War II. Originally known as Lagos International Airport, it was renamed in the mid 1970s, during construction of the new international terminal, after a former and fourth Nigerian military head of state, Murtala Mohammed. It consists of an international and a domestic terminal, located about one kilometre from each other. Both terminals share the same runways. This domestic terminal used to be the old Ikeja Airport. International operations moved to the new international airport when it was ready while domestic operations moved to the Ikeja Airport, which became the domestic airport.

Fig. 3.1: Map of Nigeria showing Lagos State

Source: Ministry of Lands and Survey



3.2: Map of Lagos State showing Murtala Mohammed International Airport

Source: Ministry of Lands and Survey

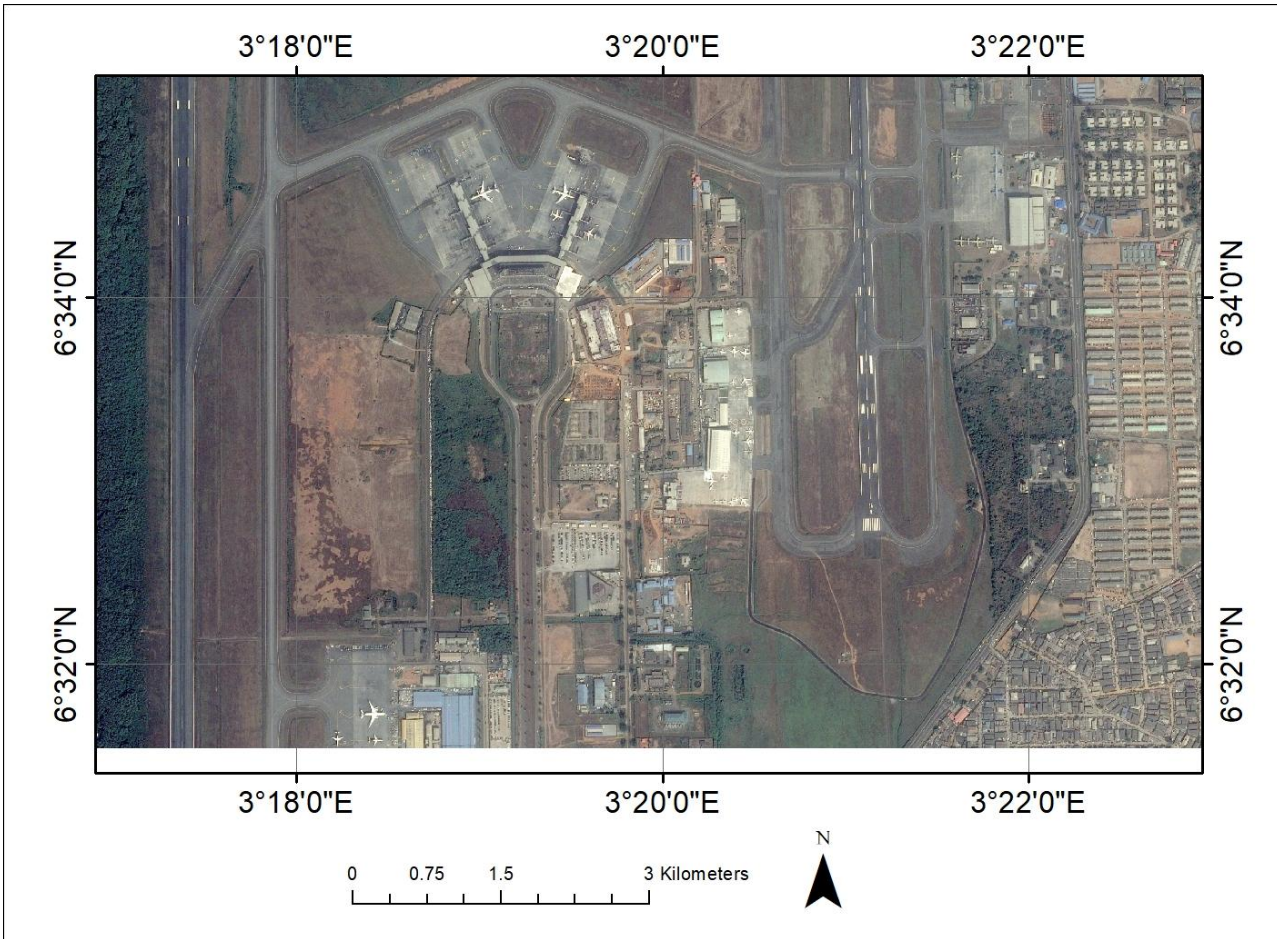


Fig. 3.3: Satellite Image of Murtala Mohammed International Airport

3.2.1.1 *Relief, Geology and Drainage*

Lagos State has a coastline of 180 km long (Oteri, 2013). Underlain by sedimentary rocks; it is on a coastal plain characterized by predominantly flat terrain, with an average elevation of less than 15m above sea level. The land slopes gently from the interior to the sea. Water bodies and wetlands cover over 40 percent of the total land area of the State with lagoons and creeks consisting 22 percent of its area. An additional 12 percent is subject to seasonal flooding. The coastal areas consist of lagoons, creeks and swamps separated from the open sea by a strip of sandy land that varies in width from two to sixteen kilometres. The entrance into Lagos Lagoon is the only major outlet through which the lagoons and creeks drain into the sea (Building Nigeria's Response to Climate Change Project (BNRCC), 2012).

The groundwater is contained in four aquifers in the sedimentary basin: the first and shallow aquifer, is the Recent Sediments along the Atlantic Sea coast and along river valleys. It is used for very small private domestic supplies through dug wells and shallow boreholes. The second and third aquifers are in the Coastal Plains Sands Formation. They are exploited through dug wells in places, shallow - and deep – boreholes (maximum depth of 300 m at the coast). These aquifers provide substantial quantities of water for private, public and industrial water supplies. This is the main aquifer exploited in Lagos megacity. The fourth aquifer is the deep and highly productive Abeokuta formation. Only a few boreholes located mainly in Ikeja industrial area, extract water from the fourth aquifer. The water from this aquifer is hot with temperatures as high as 80 °C recorded in a few of the boreholes (Coode Blizard Ltd et al., 1996). This aquifer is undergoing massive development in adjoining Ogun State in recent times where it is encountered at shallower depths of between 300 to 550 m (Oteri & Ayeni, 2016).

3.2.1.2 *Climate*

Lagos has a tropical wet and dry climate. It experiences two rainy seasons, with the heaviest rains falling from April to July and a weaker rainy season from September to November. There is a brief relatively dry spell in August and a longer dry season from December to March (Oteri & Ayeni, 2016). Rainfall varies from one location to the other in Lagos Megacity. With its high mean annual rainfall, Lagos Megacity has abundant water resources in the form of surface water (rivers, lagoons, lakes and creeks) and groundwater. The major rivers are Ogun, Yewa, Aye, Owo, Oworu and Osun (Oteri & Ayeni, 2016).

3.2.1.3 *Soil and Vegetation*

The dominant vegetation of the State is the tropical swamp forest consisting of fresh water and mangrove swamp forests both of which are influenced by the double rainfall pattern of the State, which makes the environment a wetland region, hence, the reference to Lagos as an environment of aquatic splendour. Its wetland environment is characterized by rich alluvial and terrallitic red-yellow soil, on which would be found dense luxuriant undergrowth, climbers, epiphytes and tropical hard woods (Oteri & Ayeni, 2016).

3.2.1.4 *Occupation*

Lagos megacity is the nation's economic nerve centre with over 2,000 industries (Business News, 2014). 65% of the country's commercial activities are carried out in the Lagos megacity. Two of the nation's largest seaports - Apapa and Tin-Can Ports are located in Lagos megacity. Business News (2014) stated that Lagos megacity is arguably the most economically important State in the country. According to the Punch Newspaper (2015), the GDP of Lagos megacity is estimated at $91bn. The Executive Governor of Lagos State Mr Akinwunmi Ambode, is reported to have in August 2015 declared that the GDP of Lagos State has hit US131bn, which is per capita of US$5620.87 (Ayinla, 2015).

3.2.2 LOCATION OF PORT HARCOURT INTERNATIONAL AIRPORT

The Port Harcourt International Airport lies between latitude 4^{o} 72^{1}N and 4^{o} 91^{1}N of the equator and longitude 6^{o} 88^{1}E and 7^{o} 12^{1}E of the Greenwich Meridian (fig. 3.7). Its shores form part of the West Africa Atlantic ocean coastline with two third of its landed space lying within the Niger Delta Basin (Enete et al., 2015). Port Harcourt International Airport (IATA:PHC,ICAO: DNPO) is an international airport located in Omagwa, a suburb of Port Harcourt city in Rivers State, Nigeria (Enete et al., 2015). Port Harcourt is situated at the southernmost part of Nigeria (fig. 3.4) in Rivers State (fig. 3.5), and it is located between latitude $4^{0}30^{1}$ and $4^{0}47^{1}$ north of the Equator and longitude $7^{0}00^{1}$ and $7^{0}15^{1}$ east of the Greenwich Meridian (fig. 3.6). It is the largest city of Rivers State, Nigeria (The Tide News, 2013). It lies along the Bonny River and is located in Niger Delta (The Tide News, 2013). Port Harcourt is bounded to the Eastern and Western parts by meandering creeks and to the southern part by the first dockyard creek (Bonny River) and mangrove swamps. Towards the north where there is availability of land, it is bounded by Ikwerre Local Government Area (Ajie & Dienye, 2014).

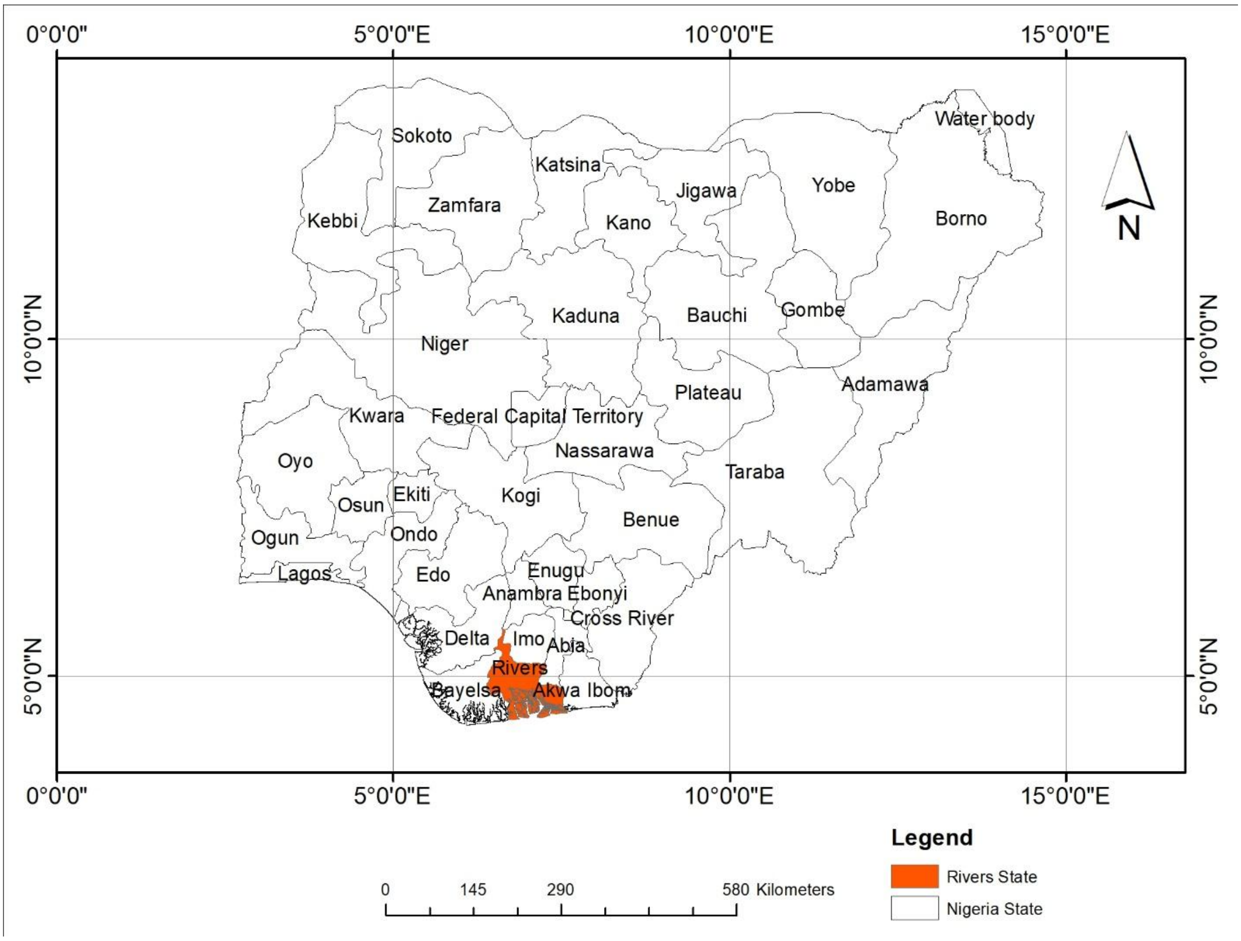


Fig. 3.4: Map of Nigeria showing Rivers State

Source: Ministry of Lands and Survey

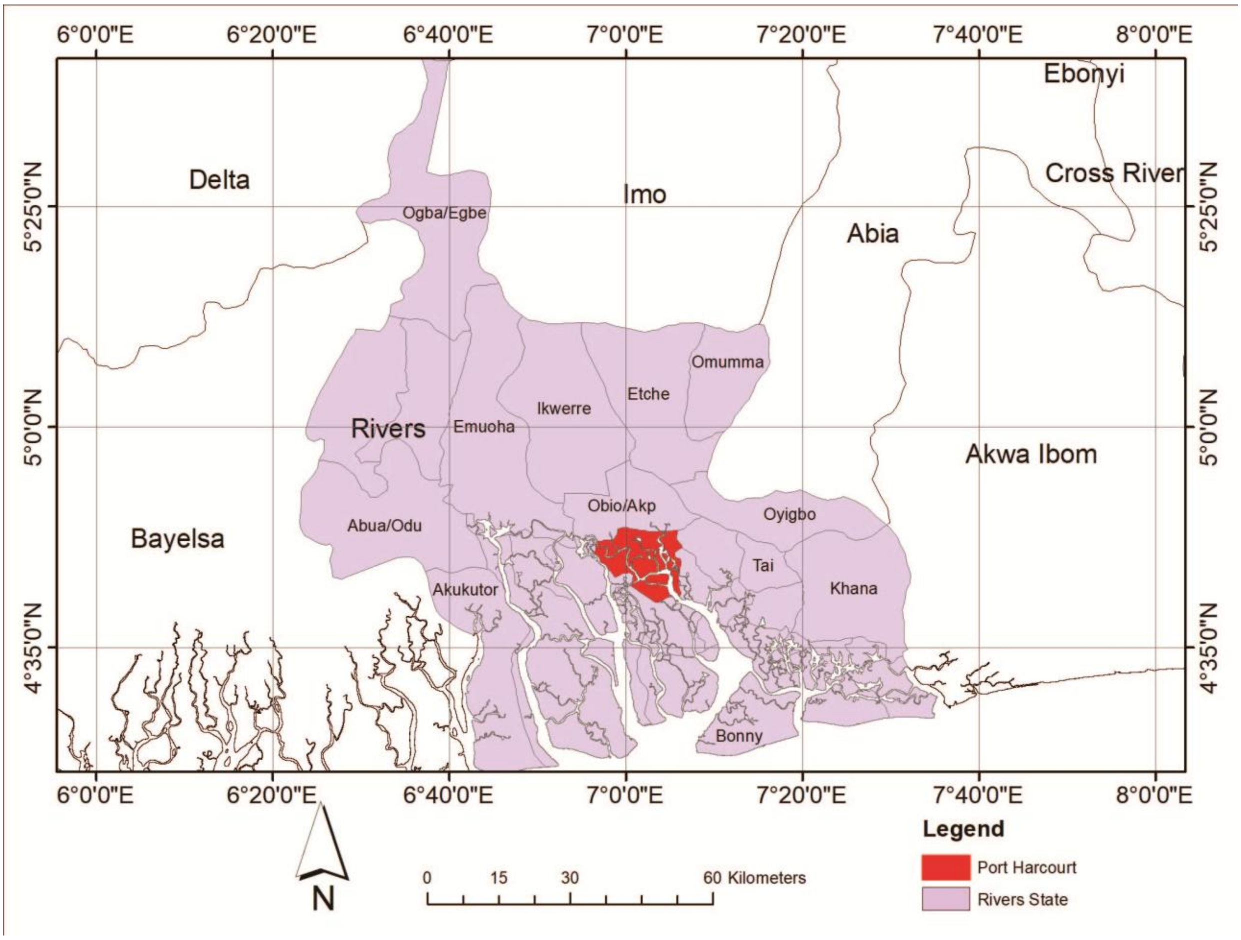


Fig. 3.5: Map of Rivers State showing Port Harcourt

Source: Ministry of Lands and Survey

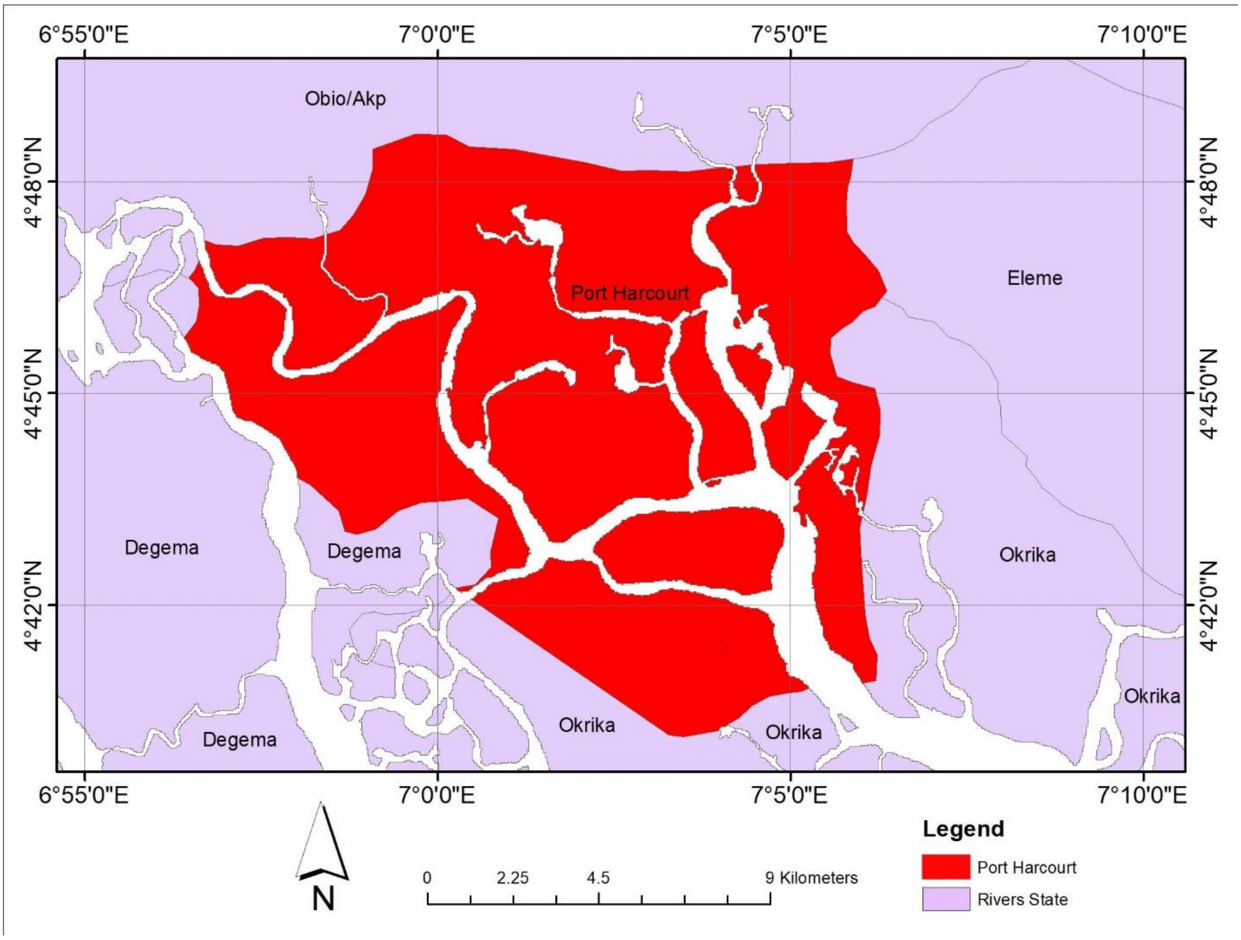


Fig. 3.6: Map of Port Harcourt

Source: Ministry of Lands and Survey

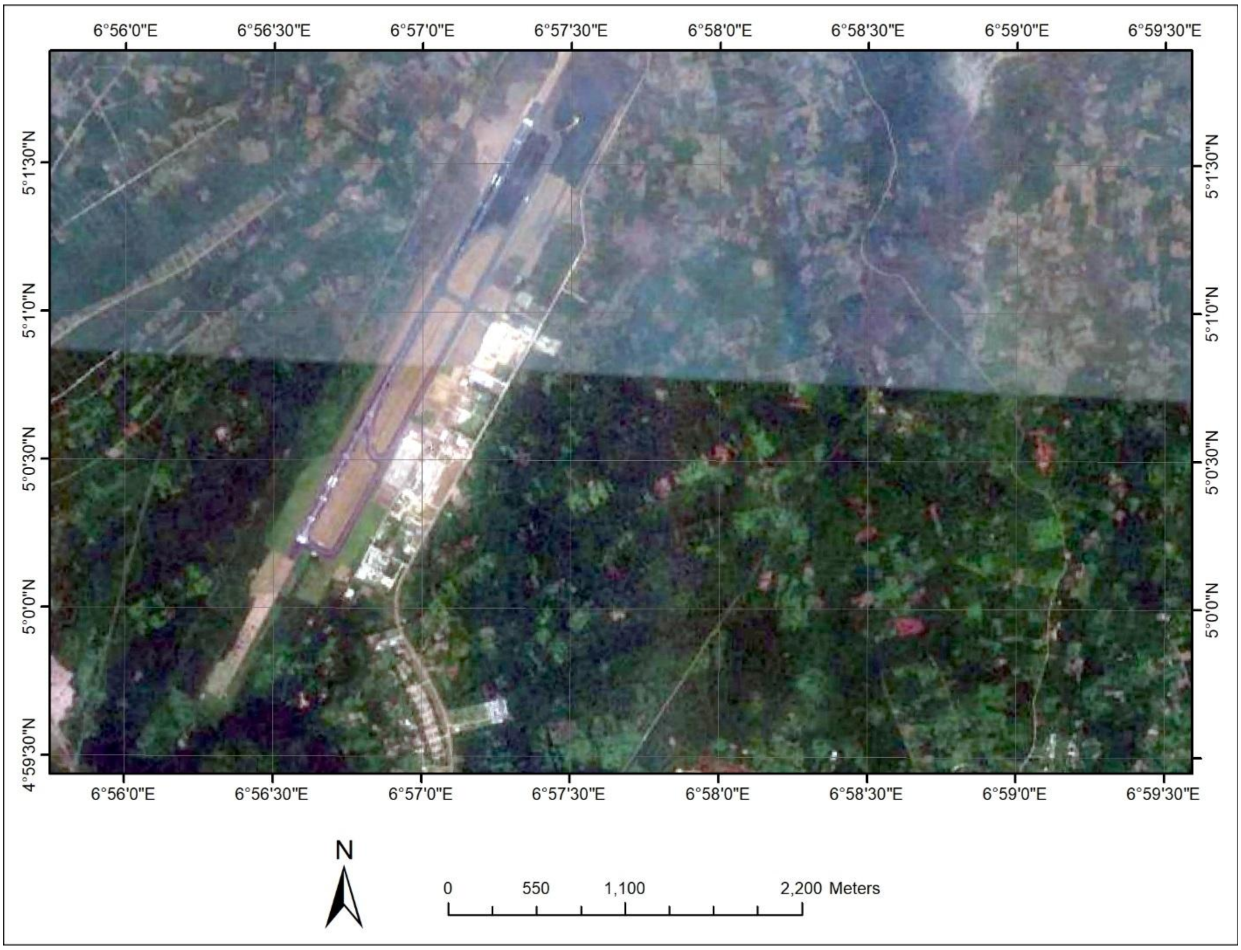


Fig. 3.7: Satellite Image of Port Harcourt International Airport

As of 2016, the Port Harcourt urban area has an estimated population of 1,865,000 inhabitants, up from 1,382,592 as of 2006 (Demographia, 2016).

The area that became Port Harcourt in 1912 was before that part of the farmlands of the Diobu village group of the Ikwerre, an Igbo sub-group (Onwuejeogwu, 1981). Port Harcourt was founded in 1912 by Frederick Lugard, governor of both the Northern Nigeria Protectorate and the Southern Nigeria Protectorate (African Affairs, 1972).The colonial administration of Nigeria created the port to export the coal that geologist Albert Ernest Kitson had discovered in Enugu in 1909 (Williams, 2008). A railway called the Eastern Line was also built by the British to link the collieries of Enugu located 243 kilometres (151 mi) north of Port Harcourt (Nigeria Chief Secretary’s Office, 1933). The colonial government caused the people of Diobu to cede their land, and in 1912 the building of a port-town was started (Njoku, 2008). Other villages that were later absorbed into the city included Oroworukwo, Mkpogua, and Rumuomasi (Wolpe, 1974; Izeogu, 1989). In the creeks to the south of the original port were the fishing camps and grounds of the Okrika-Ijaw group (Okafor, 1973).

3.2.2.1 *Relief, Geology and Drainage*

The ground surface of the area slopes from the north towards the Atlantic Ocean in the south (Nwankwoala & Walter, 2012). This gentle slope is characteristic of the entire Niger Delta area and the topographic heights rarely exceed 80 m in the area (Nwankwoala & Walter, 2012). Port Harcourt is majorly drained by Bonny River and some other creeks (Ajie & Dienye, 2014).

Geologically, Port Harcourt as well as the entire Rivers State, lies within the Niger Delta Sedimentary Basin (Nwankwoala, Abam, Ede, Teme, & Udom, 2008; Nwankwoala & Walter, 2012). Lithostratigraphically, these rocks are divided into the Oldest Akata Formation (Paleocene), the Agbada Formation (Eocene) and the Youngest Benin Formation (Miocene) (Reyment, 1965; Short & Stauble, 1967; Murat, 1970; Merki, 1970; Nwankwoala & Walter, 2012).

The major aquiferous formation in the study area is the Benin Formation (Nwankwoala & Walter, 2012). It is about 2100m thick at the centre and consists of coarse-medium grained sandstones, thick shales and gravels. The upper section of the Benin Formation is the quarternary deposits which is about 40 – 150m thick and comprises of sand and silt/clay with the later becoming increasingly more prominent seawards (Etu-Efeotor & Akpokodje, 1990). The formation consists of predominantly freshwater continental friable sands and gravels that have excellent aquifer properties with occasional intercalations of claystone/shales (Olobaniyi & Oweyemi, 2006). According to Etu-Efeotor (1981), Etu-Efeotor and

Akpokodje, (1990), Offodile (2002) and Udom, Ushie, & Esu, 2002), the Benin Formation is highly permeable, prolific, productive and most extensively tapped aquifer in the Niger Delta. The main source of recharge is through direct precipitation. The water infiltrates through the highly permeable sands of the Benin Formation to recharge the aquifers (Nwankwoala & Walter, 2012).

3.2.2.2 *Climate*

The Port Harcourt Airport features a tropical monsoon climate with lengthy and heavy rainy seasons and very short dry seasons (Enete et al., 2015; World Meteorological Organization (WMO), 2018; National Oceanic and Atmospheric Administration (NOAA), 2018). Only the months of December and January truly qualifies as dry season months in the city (WMO, 2018; NOAA, 2018). The harmattan, which climatically influences many cities in West Africa, is less pronounced in Port Harcourt. Port Harcourt's heaviest precipitation occurs during September with an average of 369 mm of rain (WMO, 2018). Rainfall is seasonal, variable and energetic (Enete et al., 2015). Generally, south of latitude 05^0N, rain occurs on the average every month of the year but with varying duration circulation over the area (Enete et al., 2015). December on average is the driest month of the year; with an average rainfall of 20 mm dry seasons (Enete et al., 2015; WMO, 2018; NOAA, 2018). Temperatures throughout the year in the city are relatively constant, showing little variation throughout the course of the year. Average temperatures are typically between 25 °C-28 °C in the city (Enete et al., 2015; WMO, 2018; NOAA, 2018).

3.2.2.3 *Vegetation*

The climate conditions of Port Harcourt have an intimate relationship with the vegetation type of the area. The high rainfall and humidity promotes thick vegetation termed tropical rainforest (Iloeje, 1979). The area also has both mangrove swamp forest and fresh water swamp forest. Mangrove swamp forest is permanently occupied by salt and tidal waters whereas fresh water swamp forests are seen in areas where fresh water dominates (Ezenwaji & Chima, 2016).

3.2.2.4 *Occupation*

Port Harcourt is widely known as a commercial city. In 1956, crude oil was discovered in commercial quantities at Oloibiri, and Port Harcourt's economy turned to petroleum when the first shipment of Nigerian crude oil was exported through the city in 1958 (Hudgens & Trillo, 2003). Port Harcourt became the center of the Nigerian oil economy and it subsequently reaped benefits of its associations with the petroleum industry by undergoing modernization and urbanization (Hudgens & Trillo, 2003; Amaechi, 2012). Port Harcourt's growth is further due to its position as the commercial center and foremost industrial city of the former Eastern Region; its position in the Niger Delta; and its importance as the center of social and economic life in Rivers State (Amaechi, 2012).

3.3 RESEARCH METHODOLOGY

3.3.1 DATA NEEDS

The data needed for this study are wind shear data measured at 20m above ground level, wind shear data extrapolated at 50m and 100m above ground level and data on flight delays, cancellations and diversions at Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State, Nigeria, for a period of eleven years (from January 2008 to December 2018). The 20m height was chosen because this is the height at which wind shear is measured at the airports, whereas 50m and 100m elevations were chosen because it is within the troposphere where aircrafts ply, especially during take-off and landing.

3.3.2 DATA SOURCES

The study predominantly relied on secondary sources. The data on wind shear for the two airports were obtained from the Nigerian Meteorological Agency (NIMET), while data on flight delays, cancellations and diversions were obtained from Nigerian Airspace Management Agency (NAMA). Other data sources include journals, textbooks, library, conference proceedings, and unpublished thesis of B.Sc., M.Sc., Ph.D. dissertations and the internet.

3.3.3 METHOD OF DATA COLLECTION

3.3.3.1 *Daily data collection*

The daily wind shear data were obtained from the daily records of Nigerian Meteorological Agency (NIMET), Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State, while the daily records of flight delays, cancellations and diversions were obtained from Nigerian Airspace Management Agency (NAMA), of the same airports.

3.3.3.2 *Monthly data collection*

The monthly wind shear data at 20m above ground level were obtained from the records of Nigerian Meteorological Agency (NIMET). Low Level Wind Shear Alert System (LLWAS) is the instrument that records wind shear. The Low-Level Wind Shear Alert System (LLWAS) was designed to detect low-level wind shear in the terminal area. The ground-based system provides both audio and visual alarms to Air Traffic Control (ATC) personnel in clearly represented numerical and graphical form. In locations where low-level wind shear is known to be experienced, LLWAS significantly increase the operational efficiency and safety of the airport. Similarly the monthly data on flight delays, diversion and cancellations were obtained from the records of the Nigerian Airspace Management Agency (NAMA), in

Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State.

3.3.4 METHOD OF DATA ANALYSIS

3.3.4.1 *Calculation of wind shear at 50m and 100m above ground level (AGL)*

There are two models used to calculate wind shear at an estimated height. These include power law and logarithmic law.

Power Law

The power law is a very simple and appropriate mathematical function that evaluates the wind shear at different heights using only one parameter (Wagner, Courtney, Gottschall, & Marsden, 2011). It is a simple but useful model of the vertical wind profile which was first proposed by Hellman in 1916, derived empirically and that represents atmospheric wind profiles under atmospheric conditions where stability is not neutral. According to the power law, the wind profile is a function of thermal stability and surface roughness. It is used to evaluate increase in wind shear along with the increase in height. Equation 3.1 presents the formula for power law.

$$\frac{V_2}{V_1} = \left(\frac{Z_2}{Z_1}\right)^{\propto} \qquad (3.1)$$

Where V_1 is the wind shear measured at certain height Z_1, V_2 is the wind shear measured at certain height Z_2, α is the wind shear exponent obtained empirically.

$$\propto = \frac{In(V_2/V_1)}{In(Z_2/Z_1)} \qquad (3.2)$$

The wind shear exponent (α) is not constant and depends on numerous factors, including atmospheric conditions, time of day, season, wind speed, nature of terrain, temperature, mechanical mixing parameters, and wind shear exponent can also differ by measurement heights (Abdulla, 2014).

Logarithmic Law

The logarithmic wind profile law is a function of fluid mechanics and the concept of atmospheric stability. The log wind profile is a mathematical relationship which is used to approximate the general logarithmic profile of wind speeds as they increase with increasing distances from the ground.

The wind speed change with elevation ($\frac{\partial U}{\partial Z}$) was introduced by Prandtl (1932) and is usually expressed as:

$$\frac{\partial U}{\partial Z} = \frac{U*}{KZ} \qquad (3.3)$$

Where U_* is the friction velocity, K is Von Karman's constant (0.4) and Z is the height.

The logarithmic wind profile equation is derived from the interaction of equation (3) over height from $z = z_o$ to any height Z.

$$\frac{U}{U*} = \frac{1}{K} In \frac{Z}{Zo} \qquad (3.4)$$

Where z_o is the roughness length of the terrain (in meters), which in principle, can only be applied under neutral stability conditions.

The effects of the atmospheric stability could be added by including an extra term into the profile:

$$\frac{U}{U*} = \frac{1}{K}\left(In \frac{Z}{Zo} - \Psi\right) \qquad (3.5)$$

Where Ψ is the stability dependent function, positive if the atmosphere is unstable and negative for stable conditions. At a special case, the wind speed from a known reference height can be used to calculate the wind speed at another height using the following logarithmic formula:

$$\frac{U_1}{U_2} = \frac{In(Z_1/Z_0)}{In(Z_2/Z_0)} \qquad (3.6)$$

Where U_2 is the predicted wind speed at height z_2, U_1 is the known wind speed at height z_1, and z_0 is the roughness length at the site of interest. This relation is valid at heights between 20m and 100m.

The logarithmic law is weak because it cannot be used to represent the wind shear for all conditions. That is, the log law is mathematically undefined for time periods where the wind speeds at two different heights are the same. The power law is often the preferred one due to simple mathematical calculations, whereas logarithmic law needs to be analyzed with complex physical and mathematical considerations.

3.3.4.2 *Determination of wind shear exponent* (α)

A wind shear exponent (α) is not constant and depends on numerous factors, including atmospheric conditions, time of day, season, wind speed, nature of terrain, temperature, mechanical mixing parameters and wind shear exponent can also differ by measurement heights (Abdulla, 2014). Early assumptions by Von Karman showed that under certain conditions, α is equal to 1/7. This value is often used in practical situations to estimate the vertical wind profile.

However, studies have shown that α can change from less than 1/7 to more than ½ for some different type of terrain (Green, 2005; Manwell, McGowan, & Rogers, 2009; Sen, Altunkaynak, & Erdik, 2012).

In addition to this, according to the 14th edition of the Wind Resource Analysis Program (WRAP) report, 7082 different wind shear exponents were calculated from the measurement performed in 39 different regions. The calculations show that 7.3 percent of wind shear exponents were distributed between 0 and 0.14, and 91.91 percent of them were above 0.14, while a 0.8 percent of wind shear exponents were calculated as negative (Minnesota Department of Commerce, 2002; Firtin, Guler, & Akdag, 2011).

A number of models have been proposed for variation of wind shear exponent (α)

3.3.4.3 *Justus and Mikhail Method*

Abdulla (2014) stated that Justus and Mikhail in 1976 used a least-square fit to observations and obtained the formula

$$\alpha = \frac{[0.37 - 0.0881 \ln V_1]}{1 - 0.0881 \ln \frac{Z_1}{10}} \qquad (3.7)$$

$$Where\ V_1(^{m}/_{sec}) is\ the\ wind\ speed\ at\ the\ reference\ height\ Z_1(m)$$

3.3.4.4 *The (1/7) Power Law Method*

Some researchers also found discrepancies with the Justus and Mikhail method and went on to suggest that α = 1/7 should be used (Ahmed, 2009).

$$\frac{V_2}{V_1} = \left(\frac{Z_2}{Z_1}\right)^{\frac{1}{7}} \qquad (3.8)$$

This 1/7 power law comes from laboratory studies and has been found to give a good approximation of the wind profile in the natural atmospheric boundary layer (Abdulla, 2014). They argue that 1/7 power law should give conservative but reasonable wind power estimates for most aero-generator sites (Abdulla, 2014).

The two methods outlined above do not incorporate the stability and roughness dependence of (α) (Abdulla, 2014).

3.3.4.5 *The Roughness Length Method*

For practical estimation of wind shear and wind structure at some places, one needs at least to know the average wind speed either climatologically or actually observed and information on its modification by the local terrain (Abdulla, 2014). There are many situations where terrain influence can be summarized by way of simple roughness parameter. The roughness is best parameterized by the roughness length Z_0 which can easily be defined from the relative change of average speed V with height Z in neutral stability at levels well above the roughness elements, so the exponent (α) of the power law profile, related to Z_0 by

$$\alpha = \left(\ln \frac{\sqrt{Z_1 Z_2}}{Z_0} \right)^{-1} \qquad (3.9)$$

Numerically, its value lies in the range of (0.1 – 0.50) (Ahmed, 2009). Table (4.1) shows typical values of wind shear exponent (α) for different types of surfaces and conditions.

Table 3.1: Wind shear exponent (α) of various terrains

A	Terrain Type
0.10	(open water), lake, ocean, sand and smooth land ground
0.13	Mown grass
0.14	Neutral stability condition. (1/7) power law
0.15	Foot high grass on level ground (smooth, level, grass covered)
0.16	Lowland, fields
0.19	High grass
0.20	Tall crops, hedges and shrubs raw crops
0.25	Wooded country with many trees
0.28	Villages and spread houses
0.30	Small town with some trees and shrubs
0.32	Suburb
0.40	City area with tall building
0.50 – 1.00	This may be found between (30 and 150) meters and in extreme case

Source: Ahmed, (2009)

3.3.4.6 *Roughness Length Z_0*

The roughness of an area is determined by the size and the distribution of the roughness elements (Abdulla, 2014). Roughness is parameterized by a simple length scale and the roughness length Z_0. This length is a mathematical factor used in the formula for logarithmic wind profile, which shows how wind speed is influenced by the terrain (Teneler, 2011).

The roughness length is defined as the height above ground Z_0 in meters at which the wind speed is theoretically equal to zero. The roughness length is not constant, but varies with wind speed (Z_0 increases rapidly with increasing speed) (Erik, Niels, Lars, Jorgen, & Helmut, 1997; Green, 2005).

Tapia (2009) showed another variable which is used to define the roughness as well, the roughness class which is defined as:

$$Roughness\ class = \left\{ \begin{matrix} 1.6998 + \dfrac{\ln Z_0}{\ln 150}\ if\ Z_0 \leq 0.03 \\ 3.9125 + \dfrac{\ln Z_0}{\ln 3.333}\ if\ Z_0 > 0.03 \end{matrix} \right\} \qquad (3.10)$$

Table 3.2: Roughness classes and the associated roughness length Z_0

Roughness class	Roughness length, Z_0 (m)	Landscape Type
0	0.0002	Water surface
0.5	0.0024	Completely open terrain with smooth surface e.g. Concrete airport runways or mowed grass
1	0.03	Open agricultural area without faces and hedgerows and very scattered buildings. Only softly rounded hills.
1.5	0.055	Agricultural land, some houses and 8m tall sheltering hedgerows with a distance of approximately 1250 meters.
2	0.1	Agricultural land, some houses and 8m tall sheltering hedgerows with a distance of approximately 500meters.
2.5	0.2	Agricultural land, many houses, shrubs and plants, or 8m tall hedgerows with a distance of approximately 250meters.
3	0.4	Villages, small towns, agricultural land with many or tall hedgerows, forests or very rough and uneven terrain.
3.5	0.8	Larger cities with tall buildings
4	1.6	Metropolitan areas with tall buildings and skyscrapers.

Source: Raghheb, (2012)

In this study, to extrapolate the wind shear at 50 meters and 100 meters above ground level, the power-law which is represented by equation (3.1) was used. This is because it is a very simple and appropriate mathematical model to evaluate the wind shear at different heights using only one parameter. The exponent (α) which is 1/7 comes from laboratory studies and has been found to give a good approximation of the wind profile in the natural atmospheric boundary layer (Abdulla, 2014).

The statistical estimation (or analytic) techniques employed in achieving the research target also include descriptive statistics (such as mean, standard deviations, and charts), and inferential statistics including Pearson's Product Moment Correlation (PPMC), Regression, and Analysis of Variance (ANOVA) with Least Significant Difference (LSD) multiple comparison approach. All inferential analyses were judged at 5% (0.05) level of significance.

3.3.4.7 ***Descriptive Statistics***

The descriptive statistical techniques were employed in describing the behaviour of the data series over the period. Particularly, the mean and standard deviation captured the centre and spread of the dataset, while the charts pictured the annual and monthly trends of the data series together with the comparative evidences.

3.3.4.8 ***Pearson's Correlation***

The Pearson's correlation analytic technique was employed in validating the extent and relationship among the study variables without suppressing the other. This statistical estimation technique was considered appropriate as the data series of the variables under investigation were all converted to a continuous data through log-transformation. Geometrically, the Pearson's correlation coefficient is generally computed as:

$$r = \frac{Cov\ (M,N)}{\sqrt{(Var\ (M))(Var\ (N))}} = \frac{\sum_{i=1}^{T}[(M-\bar{M})(N-\bar{N})]}{\sqrt{\left[\sum_{i=1}^{T}(M-\bar{M})^2\right]\left[\sum_{i=1}^{T}(N-\bar{N})^2\right]}} \qquad (3.11)$$

Where,

r is the correlation coefficient,

$Cov\ (M,N) = \sum_{i=1}^{T}[(M - \bar{M})(N - \bar{N})]$ is the covariance of M and N series,

$Var\ (M) = \sum_{i=1}^{T}(M - \bar{M})^2$ is the variance of M series,

$Var\ (N) = \sum_{i=1}^{T}(N - \bar{N})^2$ is the variance of N series

T = Total number of observations,

$\bar{M}$ and $\bar{N}$ and mean values of series of M and N values,

M and N are variables of interest.

3.3.4.9 *Analysis of Variance* (ANOVA)

The Analysis of Variance compares means of two or more groups. It is an extension of t-test which is limited to only two groups. In this study, the ANOVA technique was used to determine and compare whether a significant variation exist in the data series among the wind shear at various meters above ground level, and as well as monthly distributions. In establishing a significant variation, the study employed Least Significant Difference (LSD) multiple comparison technique to ascertain which is different from which. However, before the detailed ANOVA test was commenced, the researcher considered the basic assumptions of ANOVA test such as Homogeneity of the variances using the Levene's approach, and as well confirming normality of the data series. The Fisher's statistics for the ANOVA test is generally estimated thus:

$$\text{F} - \text{Ratio} = Ms_b / Ms_w \qquad (3.12)$$

Where, Ms_b is the between Mean Square

Ms_b is the within Mean Square

The decision to reject or accept a significant difference was based on probability value less than 0.05 (i.e., $p<0.05$).

3.3.4.10 *Regression Analysis*

The functional relationship among the selected variables was determined using the classical linear regression analysis technique. Geometrically, the relationship is represented as:

$$Number\ of\ Flight\ diversions, delays\ and\ cancellations = f(wind\ shear)$$

Such that:

$$LFDS, LFDL, LFCL = f(WS) \tag{3.13}$$

Where,

FDS = Number of flight diversions

FDL = Number of flight delays

FCL = Number of flight cancellations

L = Log-transformational operator

WS = Wind shear

Analytical packages used were Microsoft Excel, Eviews and Statistical Package for Social Sciences (SPSS) version 25.0 for windows.

CHAPTER FOUR

DATA PRESENTATION, ANALYSIS AND DISCUSSION

4.1 DATA PRESENTATION

The annual time series secondary data used for this study were sourced from Nigerian Airspace Management Agency (NAMA) at Lagos and Port Harcourt and Nigerian Meteorological Agency (NIMET). The data were compiled and presented in tables and charts for easy understanding and further analysis.

The data on monthly distribution of flight diversions, delays and cancellation at Murtala Mohammed International Airport, Lagos is presented in Table 4.1. The data sum, mean and standard deviation were also presented.

Table 4.1: Monthly Distribution of Flight Diversions, Delays and Cancellation at Murtala Mohammed International Airport, Lagos (2008-2018)

Months	No. of Flight Diversions	No. of Flight Delays	No. of Flight Cancellations
Jan.	29	19	14
Feb.	22	28	21
Mar.	31	57	33
Apr	29	57	30
May	33	73	35
June	42	66	29
July	47	59	34
Aug.	38	37	26
Sept.	26	63	39
Oct.	17	77	38
Nov.	30	31	23
Dec.	23	17	18
SUM	**367**	**584**	**340**
AVE.±Std.	**30.58±8.54**	**48.67±21.12**	**28.33±8.03**

Source: Nigerian Airspace Management Agency (NAMA), Lagos.

The data on monthly distribution of flight diversions, delays and cancellation at Port Harcourt International Airport is presented in Table 4.2. The data sum, mean and standard deviation were also presented.

Table 4.2: Monthly Distribution of Flight Diversions, Delays and Cancellation at Port Harcourt International Airport (2008-2018)

Months	No. of Flight Diversions	No. of Flight Delays	No. of Flight Cancellations
Jan.	22	21	11
Feb.	17	33	17
Mar.	32	52	21
Apr	25	55	33
May	38	74	29
June	39	61	28
July	44	57	31
Aug.	33	30	21
Sept.	21	59	37
Oct.	19	75	35
Nov.	22	29	20
Dec.	20	18	15
SUM	**332**	**564**	**298**
AVE.±Std.	**27.67±9.11**	**47±19.93**	**24.83±8.45**

Source: Nigerian Airspace Management Agency (NAMA), Port Harcourt.

The data on monthly distribution of wind shear measured at 20m above ground level at Murtala Mohammed International Airport is presented in Table 4.3. It also shows the sum, average and standard deviation of the data.

Table 4.3: Monthly Distribution of Wind Shear measured at 20m above ground level at Murtala Mohammed International Airport, Lagos (2008-2018)

M/Y	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Ave.
JAN	7.2	4.4	3.0	2.7	3.5	3.6	4.7	4.2	3.0	4.0	3.9	4.0
FEB	8.7	8.7	3.0	4.4	3.8	5.0	4.0	4.3	3.0	3.8	4.0	4.8
MAR	8.4	9.0	4.4	4.7	3.7	4.6	5.0	4.0	3.6	4.2	4.3	5.1
APR	9.0	9.8	5.0	4.5	4.2	4.8	1.2	4.0	5.0	3.4	3.7	5.0
MAY	6.1	9.8	4.0	3.9	3.6	2.7	4.0	4.0	2.9	15.6	13.0	6.3
JUN	5.9	7.7	3.4	3.7	3.0	4.3	3.9	5.0	3.0	4.0	4.0	4.4
JUL	8.7	9.8	3.6	6.0	3.8	5.7	4.8	4.2	3.1	4.0	4.4	5.3
AUG	9.7	10.5	4.6	7.5	5.4	8.0	5.2	4.7	3.0	4.3	5.0	6.2
SEP	8.0	7.6	4.0	7.3	6.0	7.0	4.0	4.0	2.0	3.3	4.1	5.2
OCT	5.5	5.7	2.7	2.6	3.9	3.6	3.4	3.0	2.0	2.8	3.0	3.5
NOV	4.1	5.9	3.1	2.6	3.5	3.7	3.5	2.7	2.0	2.7	2.9	3.3
DEC	5.0	5.0	3.2	5.1	3.1	3.9	3.7	4.0	2.3	3.3	3.4	3.8
SUM	**86.3**	**93.9**	**44**	**55**	**47.5**	**56.9**	**47.4**	**48.1**	**34.9**	**55.4**	**55.7**	**56.9**
AVE.	**7.19**	**7.83**	**3.67**	**4.58**	**3.96**	**4.74**	**3.95**	**4.01**	**2.91**	**4.62**	**4.64**	**4.74**
Std.	**1.82**	**2.11**	**0.73**	**1.68**	**0.89**	**1.52**	**1.05**	**0.63**	**0.84**	**3.50**	**2.70**	**0.98**

Source: NIMET

Table 4.4 shows the data on monthly distribution of wind shear measured at 20m above ground level at Port Harcourt International Airport. It also shows the sum, average and standard deviation of the data.

Table 4.4: Monthly Distribution of Wind Shear measured at 20m above ground level at Port Harcourt International Airport (2008-2018)

M/Y	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**Ave.**
JAN	3.3	5.3	4.0	3.8	2.4	2.4	2.4	3.0	2.4	2.1	2.0	3.0
FEB	3.8	2.3	4.0	2.8	2.4	2.5	3.2	3.1	3.2	2.4	3.0	3.0
MAR	3.2	2.3	4.0	2.9	2.5	2.5	2.7	2.4	2.7	2.7	2.1	2.7
APR	2.4	2.6	4.0	2.2	2.4	2.3	2.7	2.4	2.7	3.0	2.8	2.7
MAY	2.3	2.3	4.0	1.7	2.4	2.4	2.7	2.6	2.7	2.1	2.5	2.5
JUN	2.2	2.6	3.0	2.2	2.7	2.3	2.8	2.9	2.7	2.3	2.4	2.6
JUL	2.2	3.5	2.0	2.7	2.4	2.5	2.5	2.4	2.4	2.6	2.5	2.5
AUG	2.4	2.1	3.0	3.5	2.8	2.7	2.7	2.8	2.7	3.1	2.8	2.8
SEP	1.9	2.3	4.0	2.3	2.4	2.7	2.5	2.7	2.6	2.8	2.7	2.6
OCT	2.1	2.8	3.0	2.2	2.2	2.3	2.1	2.0	2.2	2.0	2.0	2.3
NOV	1.6	2.2	3.0	1.8	1.9	1.9	1.9	1.9	2.0	2.0	1.7	2.0
DEC	1.5	1.8	3.0	3.1	1.9	2.1	1.8	2.6	1.8	2.0	2.0	2.1
SUM	**28.9**	**32.1**	**41**	**31.2**	**28.4**	**28.6**	**30**	**30.8**	**30.1**	**29.1**	**28.5**	**30.8**
AVE.	**2.41**	**2.68**	**3.42**	**2.60**	**2.37**	**2.38**	**2.50**	**2.57**	**2.51**	**2.43**	**2.38**	**2.57**
Std.	**0.69**	**0.93**	**0.67**	**0.65**	**0.27**	**0.23**	**0.40**	**0.37**	**0.38**	**0.41**	**0.41**	**0.31**

Source: NIMET

The data on monthly distribution of wind shear extrapolated at 50m above ground level at Murtala Mohammed International Airport is presented in Table 4.5. The sum, average and standard deviation of the data are also presented in the table.

Table 4.5: Monthly Distribution of Wind Shear extrapolated at 50m above ground level at Murtala Mohammed International Airport, Lagos (2008-2018)

M/Y	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Ave.
Jan.	8.2	5.0	3.4	3.1	4.0	4.1	5.4	4.8	3.4	4.6	4.4	4.6
Feb.	9.9	9.9	3.4	5.0	4.3	5.7	4.6	4.9	3.4	4.3	4.6	5.5
Mar.	9.6	10.3	5.0	5.4	4.2	5.2	5.7	4.6	4.1	4.8	4.9	5.8
Apr.	10.3	11.2	5.7	5.1	4.8	5.5	1.4	4.6	5.7	3.9	4.2	5.7
May	7.0	11.2	4.6	4.4	4.1	3.1	4.6	4.6	3.3	17.8	14.8	7.2
Jun.	6.7	8.8	3.9	4.2	3.4	4.9	4.4	5.7	3.4	4.6	4.6	5.0
Jul.	9.9	11.2	4.1	6.8	4.3	6.5	5.5	4.8	3.5	4.6	5.0	6.0
Aug.	11.1	12.0	5.2	8.6	6.2	9.1	6.0	5.4	3.4	4.9	5.7	7.1
Sep.	9.1	8.7	4.6	8.3	6.8	8.0	4.6	4.6	2.3	3.8	4.7	6.0
Oct.	6.3	6.5	3.1	3.0	4.4	4.1	3.9	3.4	2.3	3.2	3.4	4.0
Nov.	4.7	6.7	3.5	3.0	4.0	4.2	4.0	3.1	2.3	3.1	3.3	3.8
Dec.	5.7	5.7	3.6	5.8	3.5	4.4	4.2	4.6	2.6	3.8	3.9	4.3
SUM	**98.5**	**107.2**	**50.1**	**62.7**	**54**	**64.8**	**54.3**	**55.1**	**39.7**	**63.4**	**63.5**	**64.8**
AVE.	**8.21**	**8.93**	**4.18**	**5.23**	**4.50**	**5.40**	**4.53**	**4.59**	**3.31**	**5.28**	**5.29**	**5.4**
Std.	**2.07**	**2.42**	**0.83**	**1.91**	**1.01**	**1.74**	**1.20**	**0.72**	**0.95**	**3.99**	**3.07**	**1.11**

Source: Author's Computation

The data on monthly distribution of wind shear extrapolated at 50m above ground level at Port Harcourt International Airport is presented in Table 4.6. The sum, average and standard deviation of the data are also presented in the table.

Table 4.6: Monthly Distribution of Wind Shear extrapolated at 50m above ground level at Port Harcourt International Airport (2008-2018)

M/Y	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Ave.
Jan.	3.7	6.0	4.6	4.3	2.7	2.7	2.7	3.4	2.7	2.4	2.3	3.4
Feb.	4.3	2.6	4.6	3.2	2.7	2.9	3.6	3.5	3.6	2.7	3.4	3.4
Mar.	3.6	2.6	4.6	3.3	2.9	2.9	3.1	2.7	3.1	3.1	2.4	3.1
Apr.	2.7	3.0	4.6	2.5	2.7	2.6	3.1	2.7	3.1	3.4	3.2	3.1
May	2.6	2.6	4.6	1.9	2.7	2.7	3.1	3.0	3.1	2.4	2.9	2.9
Jun.	2.5	3.0	3.4	2.5	3.1	2.6	3.2	3.3	3.1	2.6	2.7	2.9
Jul.	2.5	4.0	2.3	3.1	2.7	2.9	2.9	2.7	2.7	3.0	2.9	2.9
Aug.	2.7	2.4	3.4	4.0	3.2	3.1	3.1	3.2	3.1	3.5	3.2	3.2
Sep.	2.2	2.6	4.6	2.6	2.4	3.1	2.9	3.1	3.0	3.2	3.1	3.0
Oct.	2.4	3.2	3.4	2.5	2.5	2.6	2.4	2.3	2.5	2.3	2.3	2.6
Nov.	1.8	2.5	3.4	2.1	2.2	2.2	2.2	2.2	2.3	2.3	1.9	2.3
Dec.	1.7	2.1	3.4	3.5	2.2	2.4	2.1	3.0	2.1	2.3	2.3	2.5
SUM	**32.70**	**36.60**	**46.90**	**35.50**	**32.00**	**32.70**	**34.40**	**35.10**	**34.40**	**33.20**	**32.60**	**35.30**
AVE.	**2.73**	**3.05**	**3.91**	**2.96**	**2.67**	**2.73**	**2.87**	**2.93**	**2.87**	**2.77**	**2.72**	**2.94**
Std.	**0.78**	**1.05**	**0.78**	**0.74**	**0.31**	**0.27**	**0.44**	**0.41**	**0.42**	**0.45**	**0.47**	**0.34**

Source: Author's Computation

Table 4.7 shows the data on monthly distribution of wind shear extrapolated at 100m above ground level at Murtala Mohammed International Airport. It also shows the sum, average and standard deviation of the data.

Table 4.7: Monthly Distribution of Wind Shear extrapolated at 100m above ground level at Murtala Mohammed International Airport, Lagos (2008-2018)

M/Y	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Ave.
Jan.	9.0	5.3	3.8	3.4	4.4	4.5	5.9	5.3	3.8	5.0	4.9	5.0
Feb.	10.9	10.9	3.8	5.5	4.8	6.3	5.0	5.4	3.8	4.8	5.0	6.0
Mar.	10.5	11.3	5.5	5.9	4.6	5.8	6.3	5.0	4.5	5.3	5.4	6.4
Apr.	11.3	12.3	6.3	5.6	5.3	6.0	1.5	5.0	6.3	4.3	4.6	6.2
May	7.6	12.3	5.0	4.9	4.5	3.4	5.0	5.0	3.6	19.5	16.3	7.9
Jun.	7.4	9.6	4.3	4.6	3.8	5.4	4.9	6.3	3.8	5.0	5.0	5.5
Jul.	10.9	12.3	4.5	7.5	4.8	7.1	6.0	5.3	3.9	5.0	5.5	6.6
Aug.	12.1	13.1	5.8	9.4	6.8	10.0	6.5	5.9	3.8	5.4	6.3	7.7
Sep.	10.0	9.5	5.0	9.1	7.5	8.8	5.0	5.0	2.5	4.1	5.1	6.5
Oct.	6.9	7.1	3.4	3.3	4.9	4.5	4.3	3.8	2.5	3.5	3.8	4.4
Nov.	5.1	7.4	3.9	3.3	4.4	4.6	4.4	3.4	2.5	3.4	3.6	4.2
Dec.	6.3	6.3	4.0	6.4	3.9	4.9	4.6	5.0	2.9	4.1	4.3	4.8
SUM	**108.00**	**117.40**	**55.30**	**68.90**	**59.70**	**71.30**	**59.40**	**60.40**	**43.90**	**69.40**	**69.80**	**71.2**
AVE.	**9.00**	**9.78**	**4.61**	**5.74**	**4.98**	**5.94**	**4.95**	**5.03**	**3.66**	**5.78**	**5.82**	**5.93**
Std.	**2.27**	**2.68**	**0.91**	**2.08**	**1.11**	**1.91**	**1.31**	**0.79**	**1.06**	**4.37**	**3.38**	**1.20**

Source: Author's Computation

Table 4.8 shows the data on monthly distribution of wind shear extrapolated at 100m above ground level at Port Harcourt International Airport. It also shows the sum, average and standard deviation of the data.

Table 4.8: Monthly distribution of wind shear extrapolated at 100m above ground level at Port Harcourt International Airport (2008-2018)

M/Y	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Ave.
Jan.	4.1	6.6	5.0	4.8	3.0	3.0	3.0	3.8	3.0	2.6	2.5	3.8
Feb.	4.8	2.9	5.0	3.5	3.0	3.1	4.0	3.9	4.0	3.0	3.8	3.7
Mar.	4.0	2.9	5.0	3.6	3.1	3.1	3.4	3.0	3.4	3.4	2.6	3.4
Apr.	3.0	3.3	5.0	2.8	3.0	2.9	3.4	3.0	3.4	3.8	3.5	3.4
May	2.9	2.9	5.0	2.1	3.0	3.0	3.4	3.3	3.4	2.6	3.1	3.2
Jun.	2.8	3.3	3.8	2.8	3.4	2.9	3.5	3.6	3.4	2.9	3.0	3.2
Jul.	2.8	4.4	2.5	3.4	3.0	3.1	3.1	3.0	3.0	3.3	3.1	3.2
Aug.	3.0	2.6	3.8	4.4	3.5	3.4	3.4	3.5	3.4	3.9	3.5	3.5
Sep.	2.4	2.9	5.0	2.9	3.0	3.4	3.1	3.4	3.3	3.5	3.4	3.3
Oct.	2.6	3.5	3.8	2.8	2.8	2.9	2.6	2.5	2.8	2.5	2.5	2.8
Nov.	2.0	2.8	3.8	2.3	2.4	2.4	2.4	2.4	2.5	2.5	2.1	2.5
Dec.	1.9	2.3	3.8	3.9	2.4	2.6	2.3	3.3	2.3	2.5	2.5	2.7
SUM	**36.30**	**40.40**	**51.50**	**39.30**	**35.60**	**35.80**	**37.60**	**38.70**	**37.90**	**36.50**	**35.60**	**38.70**
AVE.	**3.03**	**3.37**	**4.29**	**3.28**	**2.97**	**2.98**	**3.13**	**3.23**	**3.16**	**3.04**	**2.97**	**3.23**
Std.	**0.87**	**1.15**	**0.82**	**0.82**	**0.33**	**0.29**	**0.50**	**0.47**	**0.46**	**0.52**	**0.53**	**0.39**

Source: Author’s Computation

4.2 DATA ANALYSIS

Data analysis for this study was categorized into descriptive and inferential evaluation. The descriptive aspect of the analysis captured the graphical presentation of the interaction among the study variables in the selected Airports. Particularly, the line graph was employed in achieving this target.

Objective One: To extrapolate wind shear at 50 meters and 100 meters above ground level using power law model.

The extrapolation of wind shear at 50m and 100m above ground level at Murtala Mohammed International Airport and Port Harcourt International Airport were done using the power law model (equation 1). From table 4.3 to 4.8, it can be observed that the values of wind shear extrapolated at 50 meters and 100 meters above ground level at the airports are higher than the values of wind shear measured at 20 meters above ground level at the two airports. This increase in wind shear at 50 meters and 100 meters above ground level is as a result of decrease in frictional resistance which is more pronounced close to the ground. This explains that wind shear increases with altitude.

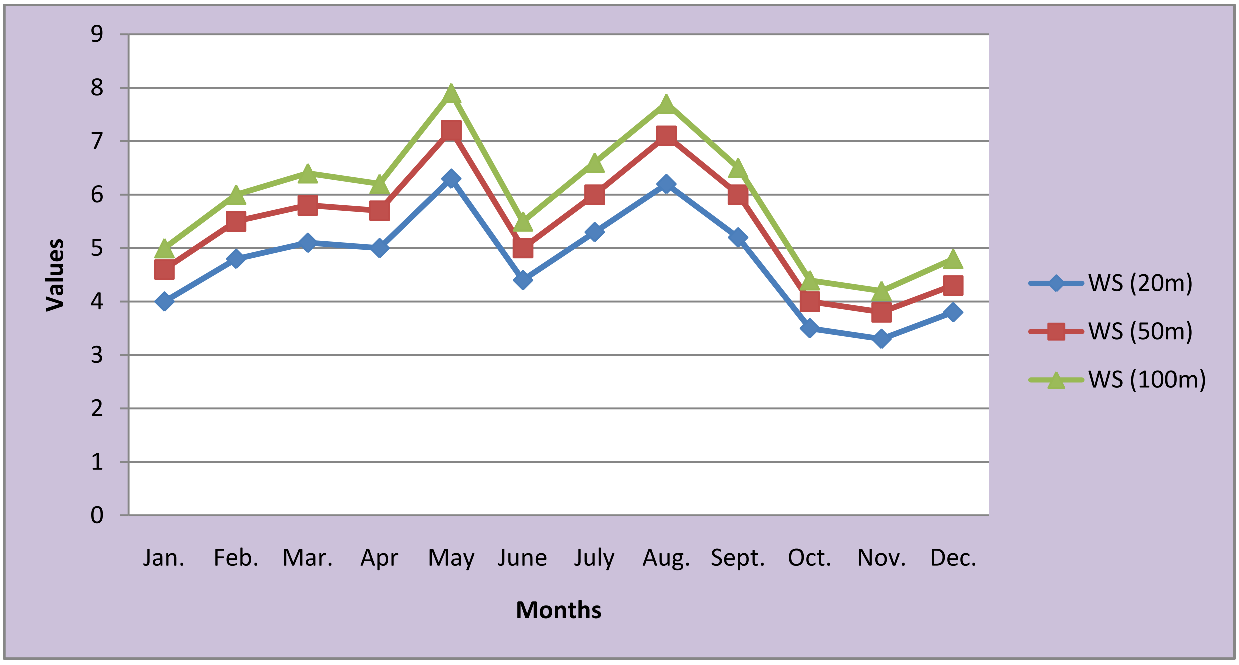


Fig. 4.1: Graphical Representation of Wind Shear at 20m, 50m and 100m above ground level at Murtala Mohammed International Airport, Lagos (2008-2018)

Source: Author's computation

As shown in figure 4.1, the distribution of wind shear at 20m, 50m, and 100m above ground level at Murtala Mohammed International Airport, Lagos from 2008-2018 follows similar pattern. In the first quarter of every year, the wind shear rises steadily and smoothly. Stepping into the first month of the second quarter, the wind shear spikes up and dropped sharply in the second month, rises again in July and August and decline steadily through to November, then with a rising attempt in December.

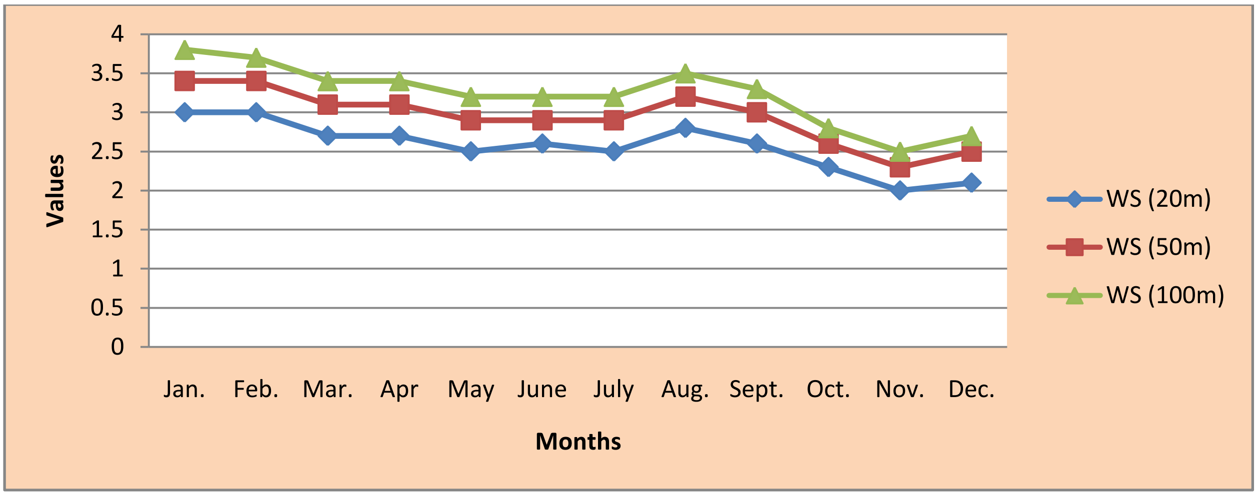


Fig. 4.2: **Graphical Representation of Wind Shear at 20m, 50m and 100m above ground level at Port Harcourt International Airport (2008-2018)**

Source: Author's computation

The result in figure 4.2 shows that the distribution of wind shear at 20m, 50m, and 100m above ground level at Port Harcourt International Airport from 2008-2018 follows similar pattern. As shown in the result, the wind shear drops smoothly from January through July for the period. Approaching the month of August, it rose and after then decline continuously through to November; and rose slightly again in December.

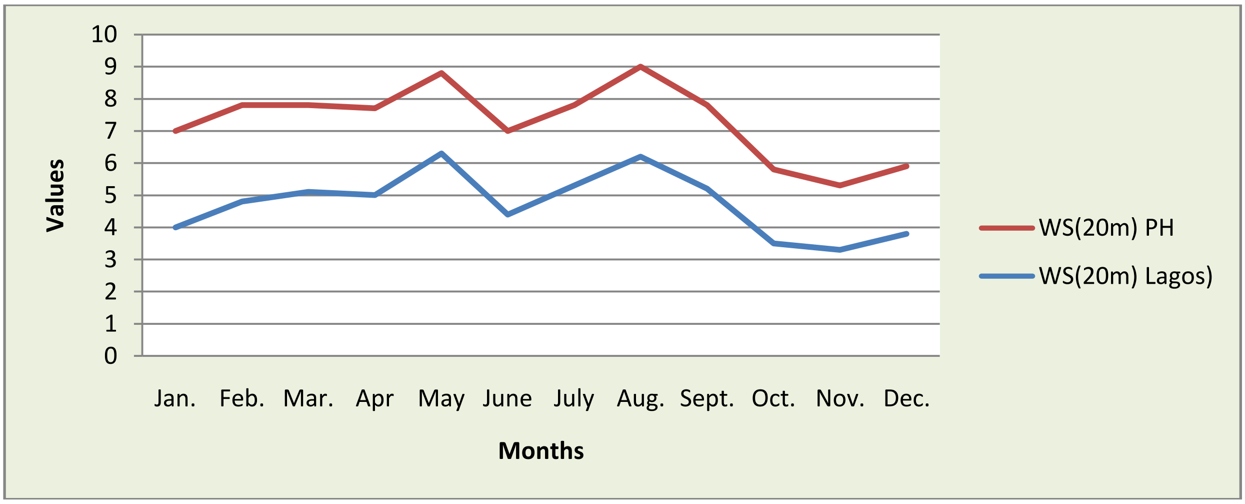


Fig. 4.3: Comparative Graphical Representation of Wind Shear measured at 20m above ground level at Murtala Mohammed International Airport, Lagos and Port Harcourt International Airport (2008-2018)

Source: Author's computation

Comparatively, as presented in figure 4.3, the pattern of wind shear measured at 20m above ground level at Murtala Mohammed International Airport, Lagos, and Port Harcourt International Airport, Port Harcourt are very similar. Though the wind shear measured at 20m are higher in Lagos compared to Port Harcourt international Airport, Nigeria.

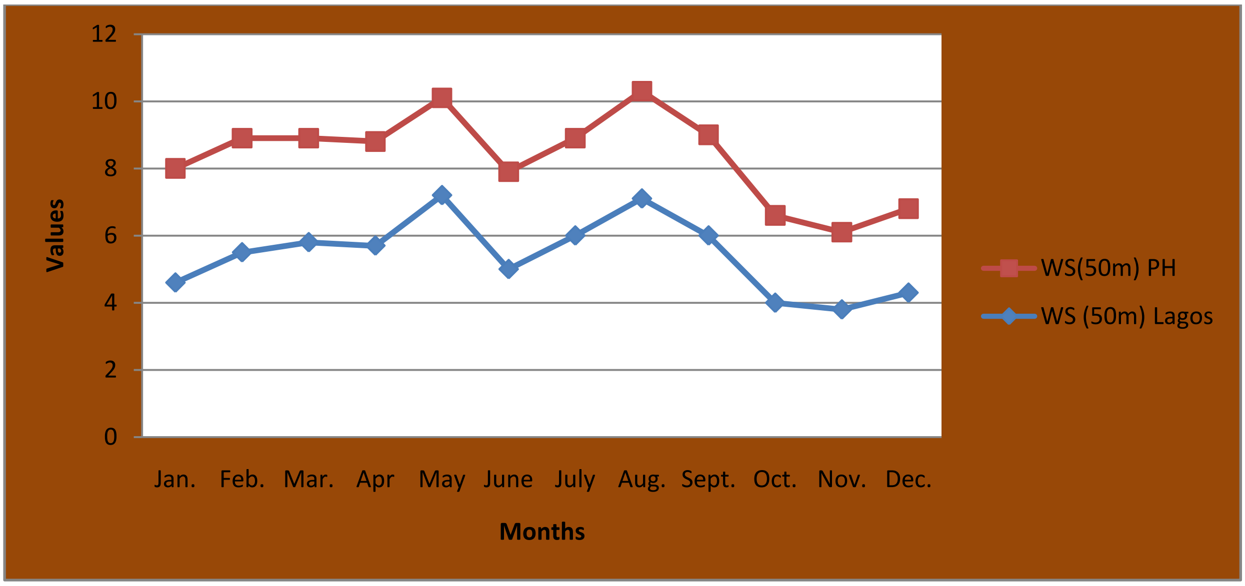


Fig. 4.4: Comparative Graphical Representation of Wind Shear extrapolated at 50m above ground level at Murtala Mohammed International Airport, Lagos and Port Harcourt International Airport (2008-2018)

Source: Author's computation

The graphical representation in figure 4.4 shows a similar pattern in distribution of wind shear extrapolated at 50m above ground level at Murtala Mohammed International Airport and Port Harcourt International Airport. From the graph, there is a smooth rise from January to March while the wind shear stood still through April. In May, it rose sparingly and dropped sharply in June. From June through August, the wind shear rose steadily and falls continuously from September to November. A little appreciation in the wind shear value was seen in December.

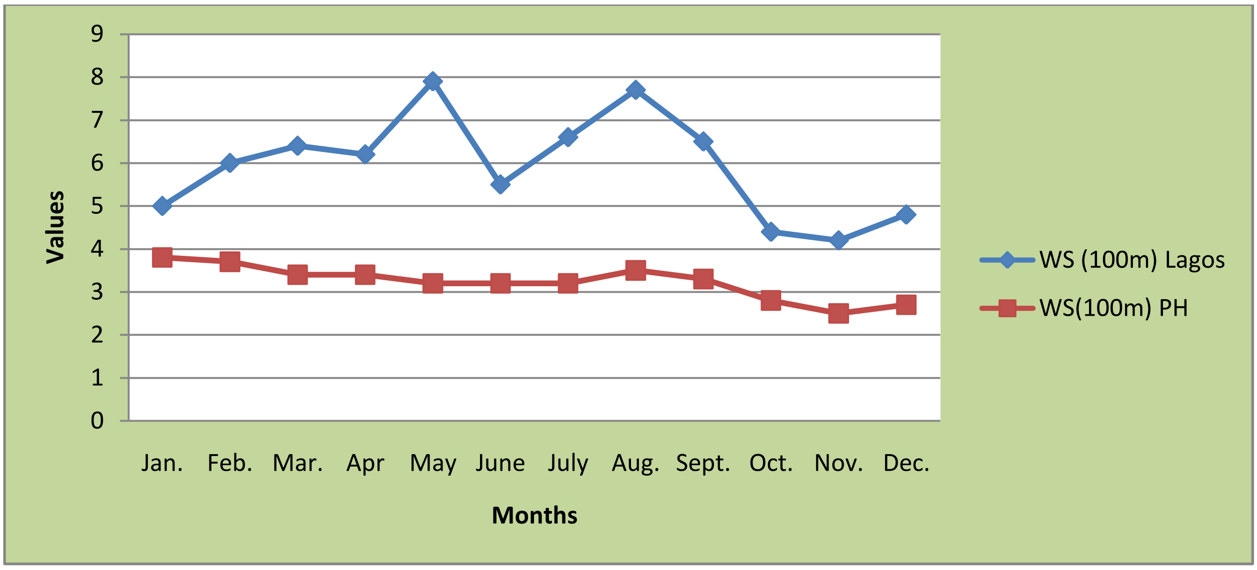


Fig. 4.5: Comparative Graphical Representation of Wind Shear extrapolated at 100m above ground level at Murtala Mohammed International Airport, Lagos and Port Harcourt International Airport (2008-2018)

Source: Author's computation

As shown in figure 4.5, there is dissimilarity in the patterns of wind shear extrapolated at 100m above ground at Murtala Mohammed International Airport and Port Harcourt International Airport for the study period. Specifically, the wind shear distribution at Murtala Mohammed International Airport follows a random (zig-zag) pattern while the distribution at Port Harcourt International Airport is smooth, and detrended over the period. In a more specific term, the wind shear at Murtala Mohammed international Airport is steadily increasing between January and April, while from May through December, the wind shear continues to exhibit rise and fall movement.

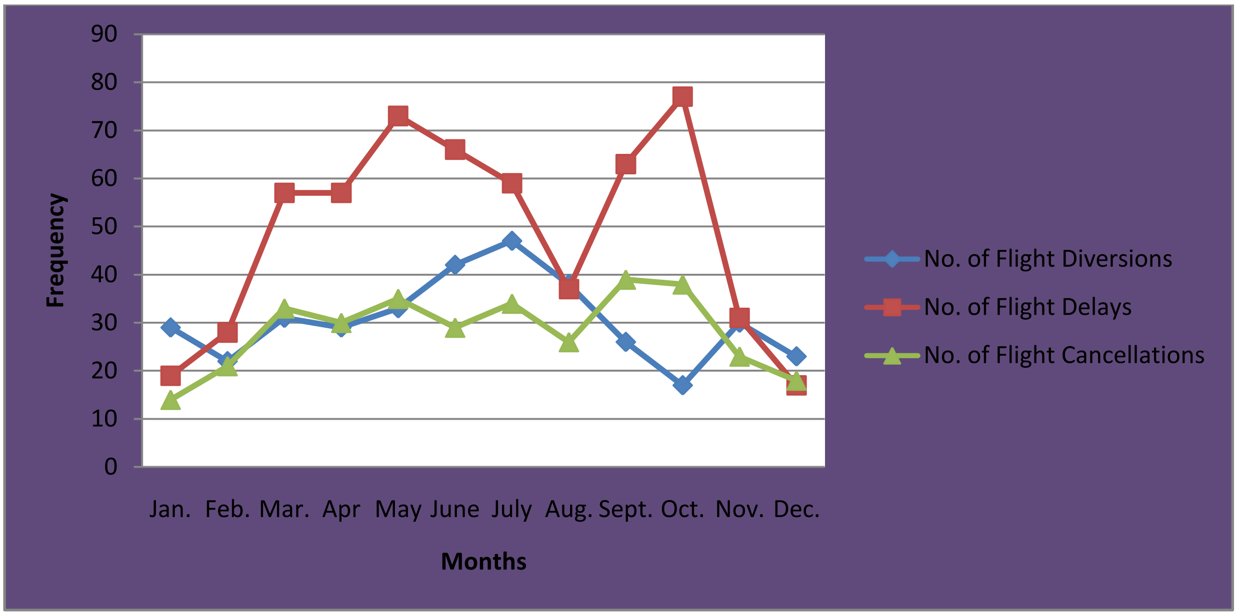


Fig. 4.6: Graphical Representation of number of Flight Delays, Cancellations and Diversions at Murtala Mohammed International Airport, Lagos (2008-2018)

Source: Author's computation

The pattern of occurrence of flight diversions, delays and cancellations at Murtala Mohammed International Airport, Lagos is random and unpredictable. Saliently, the distribution of number of flight cancellations over the period (2008-2018) shows similarity with the distribution of number of flight delays within the period. The implication is that, as the number of flight delays increases, the number of flight cancellations increases, and vice versa. This agreement as shown in figure 4.6 did not extend fully to frequency of flight diversions in the Airport; thereby indicating that flight delay or cancellation does not at all times lead to flight diversion.

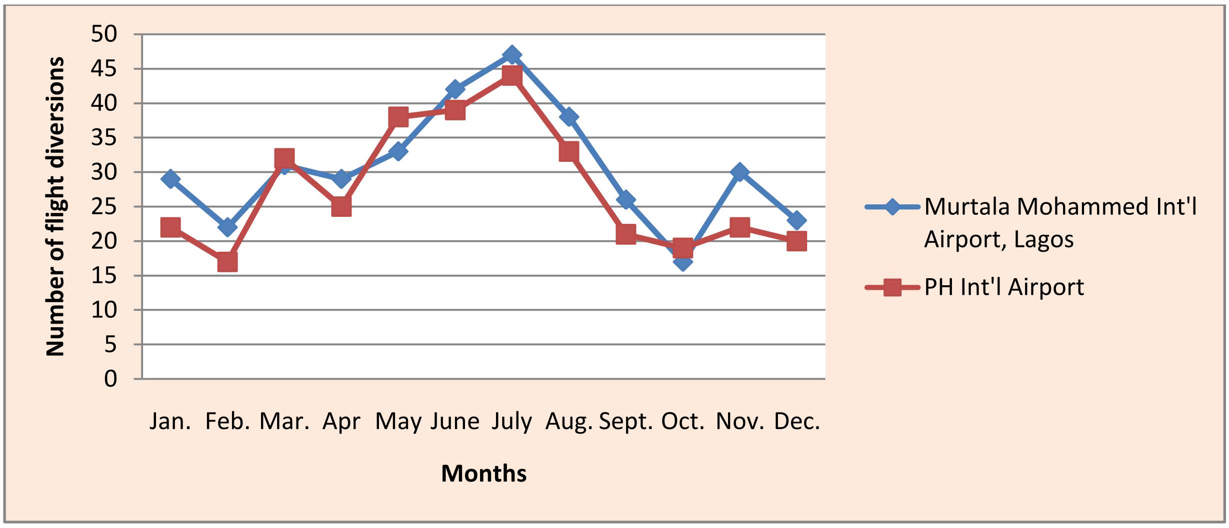


Fig. 4.7: Comparative Graphical Representation of number of Flight Diversions at Murtala Mohammed International Airport, Lagos and Port Harcourt International Airport (2008-2018)

Source: Author's computation

As shown in figure 4.7, there is a confirmed similar distribution in frequency of flight diversions at Murtala Mohammed International Airport and Port Harcourt International Airport, though with a slightly varying magnitude which is traceable to difference in location. The both exhibit a random (zig-zag) movement for the period.

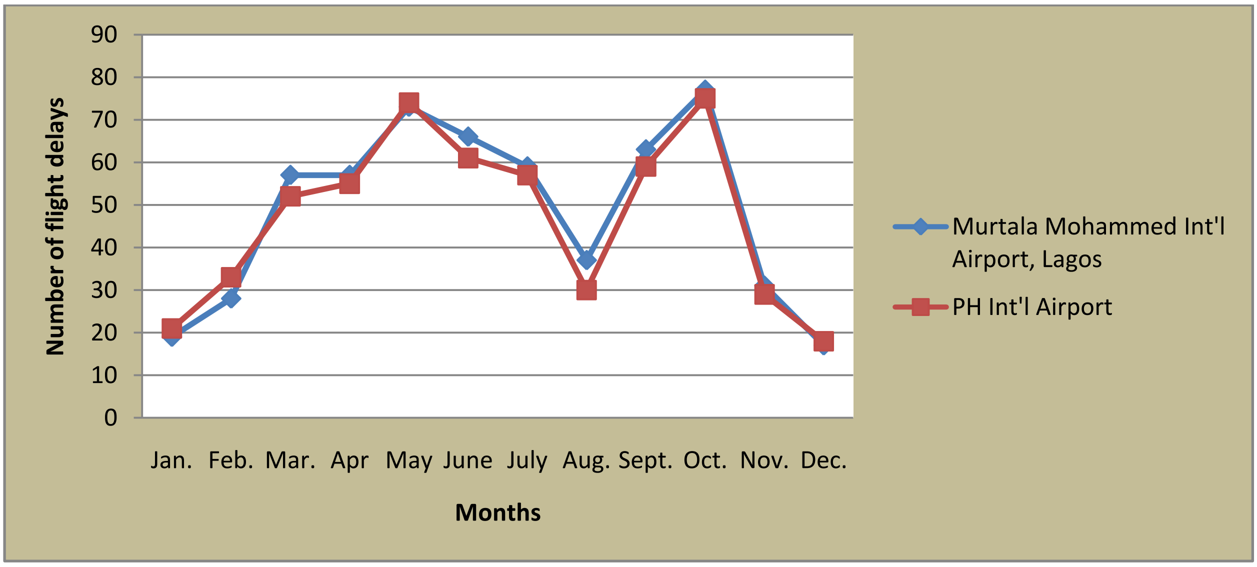


Fig. 4.8: Comparative Graphical Representation of number of Flight Delays at Murtala Mohammed International Airport, Lagos and Port Harcourt International Airport (2008-2018)

Source: Author's computation

The graphical representation in figure 4.8 exposed the close relationship in the distribution of number of flight delays at Murtala Mohammed International Airport and Port Harcourt International Airport. Evidently, there is almost a perfect relationship in frequency of flight delays in both Airports at the two locations in Nigeria.

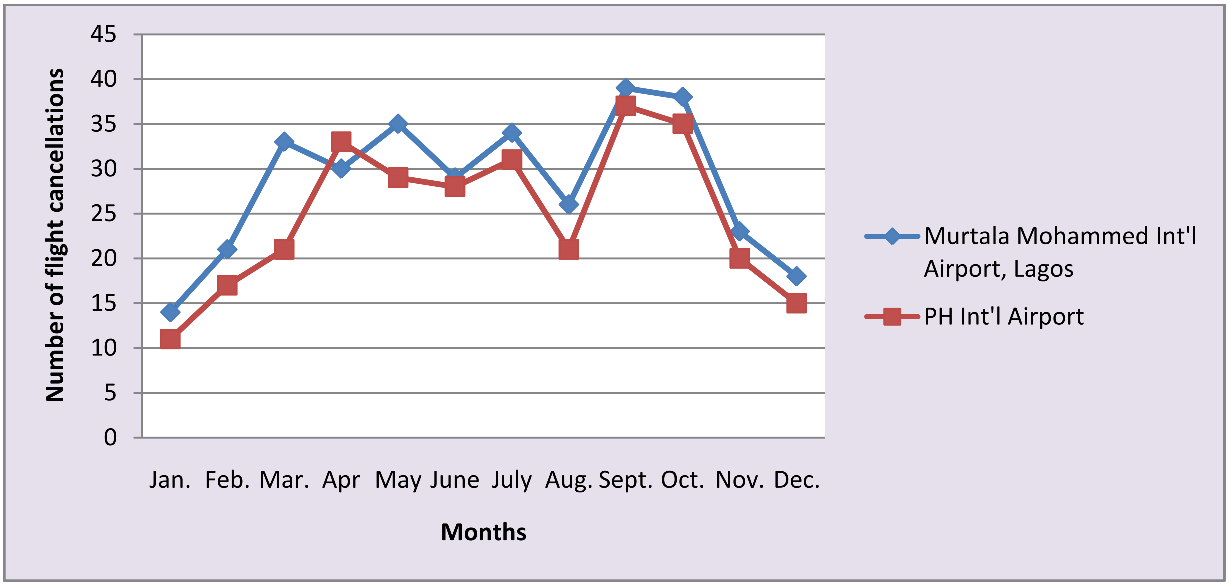


Fig. 4.9: Comparative Graphical Representation of number of Flight Cancellations at Murtala Mohammed International Airport, Lagos and Port Harcourt International Airport (2008-2018)

Source: Author's computation

The comparative graphical representation of the number of flight cancellations at Murtala Mohammed International Airport and Port Harcourt International Airport shows that at the early months of every year (January through March), the number of flight cancellation increases steadily at both Airports. In April through May, the frequency of flight cancellations at the both Airports is in counter pattern (one rises and the other falls). From June through December, the pattern of flight cancellations at both Airports aligns with each other.

4.2.1 Correlational Analysis

Relationships between the wind shear measured at 20m above ground level and flight diversions, delays, and cancellations; and relationships between the wind shear extrapolated at 50m and 100m above ground level (using power law model) and flight diversions, delays and cancellations at Murtala Mohammed International Airport, Lagos State and Port Harcourt International Airport, Rivers State (2008-2018) were estimated. More so, the functional bonds (or relationships) between wind shear and flight diversions, delays, and cancellations were equally exposed. Since wind shear data is a continuous (measurement) data and which must be correlated and regressed with discrete (count) data of number of flight diversions, delays, and cancellations, the datasets must be log-transformed before analysis so as to keep them on the same level of measurement and ensuring that they do not lose their natural power.

Objective Two: To analyze the relationships between wind shear measured at 20m above ground level and flight diversions, delays and cancellations.

Table 4.9: Correlation Matrix of the Relationships between Wind Shear measured at 20m above ground level and Flight Diversions, Delays and Cancellations at Murtala Mohammed International Airport, Lagos

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000			

LFDS	0.505668	1.000000		
	1.853494	-----		
	0.0935	-----		
LFDL	0.385092	0.197451	1.000000	
	1.319533	0.636935	-----	
	0.2164	0.5385	-----	
LFCL	0.397647	0.109155	0.946445	1.000000
	1.370481	0.347254	9.269925	-----
	0.2005	0.7356	0.0000	-----

Source: Author's Eviews Result

*** Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear measured at 20m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations.*

From the Pearson's correlation estimation as shown in Table 4.9, there is an insignificant positive relationship between wind shear measured at 20m above ground level and number of flight diversions (r_p=0.506, p=0.0935>0.05); number of flight delays (r_p=0.385,p=0.2164>0.05), and number of flight cancellations (r_p=0.398, p=0.2005>0.05). Also, there is an insignificant positive relationship between number of flight diversions and delays (r_p=0.197, p=0.5385>0.05); number of flight diversions and number of flight cancellations (r_p = 0.109, p=0.7356>0.05) and a significant positive relationship between number of flight delays and cancellations at Murtala Mohammed International Airport, Lagos

(r_p=0.946, p=0.000<0.05). The result therefore shows that, fluctuations in wind shear lead to increases in number of flight diversions, delays, and cancellations in the area. More so, increases in number of flight delays causes increases in number of flight diversions and cancellations.

The functional relationship between wind shear at 20m above ground level and number of flight diversions at Murtala Mohammed International Airport, Lagos is ***exponential*** in nature with the highest R-Square value among other estimated models **[See Appendix I]**. The relationship is such that:

LFDS = $e^{0.208WS+2.449}$ - - - - - - (4.1)

The estimate above shows that should in case the wind shear at 20m above ground level is known, the number of flight diversions can be predicted. Evidently, if for instance, the wind shear at 20m above ground level is 4.0, the number of flight diversions can be obtained by appropriate substitution into the model (4.1) above as:

LFDS = $e^{0.208WS+2.449}$ = $e^{0.208(4.0)} \times e^{2.449}$ = 2.2979 × 11.57676 = 26.62035 ≅ 27±1.641.

For flight delays and wind shear, the relationship is also ***exponential***, such that:

LFDL = $e^{0.281WS+2.427}$ - - - - - - (4.2)

In the case of equation (4.2) above, if the wind shear is known (for instance, 4.0), the number of flight delays can be obtained thus:

LFDL = $e^{0.281WS+2.427}$ = $e^{0.281(4.0)} \times e^{2.427}$ = 3.0771 × 11.3249 = 34.8477 ≅ 35±6.023.

While, for number of flight cancellations and wind shear, the relationship is ***quadratic*** in nature **[See Appendix I]**, such that:

LFCL = $4.522 - 2.277\text{WS} + 0.949WS^2$ - - - (4.3)

The model in equation (4.3) above shows that, if for instance wind shear at 20m above ground level is known (e.g., 4.0), the number of flight cancellations can be estimated as:

$$\text{LFCL} = 4.522 - 2.277(4.0) + 0.949(4.0)^2 = 4.522 - 9.108 + 15.184 = 10.598 \cong 11 \pm 1.513.$$

Table 4.10: Correlation Matrix of the Relationships between Wind Shear measured at 20m above ground level and number of Flight Diversions, Delays and Cancellations at Port Harcourt International Airport

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000			

LFDS	0.101628	1.000000		
	0.323050	-----		
	0.7533	-----		
LFDL	0.052285	0.420754	1.000000	
	0.165568	1.466686	-----	
	0.8718	0.1732	-----	
LFCL	-0.162944	0.316225	0.889905	1.000000
	-0.522255	1.054082	6.169355	-----
	0.6129	0.3166	0.0001	-----

Source: Author's Eviews Result

***Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear measured at 20m above ground level; FDL = Flight delays; FCL = Flight cancellations; FDS = Flight diversions*

From the Pearson's correlation estimation as shown in Table 4.10, there is an insignificant negative relationship between wind shear measured at 20m above ground level and number of flight cancellations ($r_p = -0.163$, p=0.6129>0.05), and insignificant positive relationship between wind shear and number of flight diversions (r_p=0.102, p=0.7533>0.05), and between wind shear measured at 20m above ground level and number of flight delays (r_p=0.052, p=0.8718>0.05) at Port Harcourt International Airport. However, the interactions between the number of flight diversions and delays (r_p=0.421, p=0.1732>0.05), and between number of flight diversions and cancellations (r_p=0.316, p=0.3166>0.05), are positive and insignificant, while there is a positive and significant relationship between the number of flight delays and cancellations (r_p=0.890, p=0.0001>0.05). The implication of the result therefore, is that increase in wind shear (at 20m above ground level) leads to higher number of flight delays and diversions, and reduction in number of flight cancellations at the area. Meanwhile, when flights are delayed, they are most likely to be cancelled.

The functional relationship between wind shear at 20m above ground level and number of flight diversions at Port Harcourt International Airport is ***cubic*** in nature with the highest R-Square value among other estimated models **[See Appendix I]**. The relationship is such that:

$$\text{LFDS} = -3.301 + 11.054\text{WS} - 4.386WS^3 \qquad - \quad - \quad - \quad - \qquad (4.4)$$

Based on the model as presented in (4.4), if the wind shear at 20m above ground level is increased by one unit, the number of flight diversions at Port Harcourt International Airport can be determined as:

$$\text{LFDS} = -3.301 + 11.054(1.0) - 4.386(1.0)^3 = -3.301 + 11.054 - 4.386 = 12.139 \cong 12.$$

For the relationship between number of flight delays and wind shear, the best model is also a ***Cubic*** model **[See Appendix I]**. Hence:

$$\text{LFDL} = -9.423 + 22.342\text{WS} - 8.995WS^3 \qquad - \quad - \quad - \quad - \qquad (4.5)$$

Such that for a wind shear value of 1.2 at 20m above ground level in the Airport, the number of flight delays can be estimated as:

$$\text{LFDL} = -9.423 + 22.342(1.2) - 8.995(1.2)^3 = -9.423 + 26.8104 - 15.5434 = 1.844 \cong 2.$$

However, for flight cancellations and wind shear at 20m above ground level, the relationship is ***cubic*** **[See Appendix I]**. Hence;

$$LFCL = -1.532 + 18.530WS^2 - 13.743WS^3 \quad - \quad - \quad - \quad - \quad (4.6)$$

Such that for a wind shear value of 1.2 at 20m above ground in the Airport, the number of flight cancellations can be estimated as:

$$LFCL = -1.532 + 18.530(1.2)^2 - 13.743(1.2)^3 = -1.532 + 26.6832 - 23.7479 = 1.403 \cong 1.$$

Table 4.11: Panel Correlation Matrix of the Relationship between Wind Shear measured at 20m above ground level and Flight Diversions, Delays and Cancellations at Port Harcourt and Murtala Mohammed International Airport, Nigeria

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 24

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000 ----- -----			
LFDS	0.320575 1.587411 0.1267	1.000000 ----- -----		
LFDL	0.146148 0.692933 0.4956	0.309002 1.523925 0.1418	1.000000 ----- -----	
LFCL	0.264355 1.285669 0.2119	0.259414 1.259889 0.2209	0.892972 9.305242 0.0000	1.000000 ----- -----

Source: Author's Eviews Result

***. Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear measured at 20m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

The panel correlation result as shown in Table 4.11 indicates that wind shear measured at 20m above ground level interact positively and insignificantly with number of flight diversions, delays, and cancellations ($r_{WS.FDS}$ = 0.321, p=0.267>0.05; $r_{WS.FDL}$ = 0.146, p=0.4956>0.05; $r_{WS.FCL}$ = 0.264, p=0.2119>0.05). In the result also, it was shown that a positive but insignificant relationship exist between number of flight diversions and delays

($r_{FDS.FDL}$ = 0.309, p=0.1418>0.05), and between number of flight diversions and cancellations ($r_{FDS.FCL}$ = 0.259, p=0.2209>0.05). Meanwhile, the relationship between number of flight delays and cancellations is positive and significant ($r_{FDL.FCL}$ = 0.893, p=0.000<0.05). By implication, the result shows that increases in number of flight delays causes increase in number of flight diversion and cancellations, and vice versa; while increases in wind shear causes increase in flight diversions, delays and cancellations.

Objective Three: To analyze the relationships between wind shear extrapolated at 50m and 100m above ground level (using power law model) and flight diversions, delays and cancellations.

Table 4.12: Correlation Matrix of the Relationships between Wind Shear extrapolated at 50m above ground level (using power law model) and Flight Diversions, Delays and Cancellations at Murtala Mohammed International Airport, Lagos

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000			

LFDS	0.504366	1.000000		
	1.847094	-----		
	0.0945	-----		
LFDL	0.372060	0.197451	1.000000	
	1.267556	0.636935	-----	
	0.2337	0.5385	-----	
LFCL	0.388725	0.109155	0.946445	1.000000
	1.334186	0.347254	9.269925	-----
	0.2117	0.7356	0.0000	-----

Source: Author's Eviews Result

***. Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear extrapolated at 50m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

The Pearson's correlation test result in Table 4.12 shows that wind shear relate positively and insignificantly with number of flight diversions, delays and cancellations at Murtala Mohammed International Airport, Lagos ($r_{WS.FDS}$ = 0.504, p=0.0945>0.05; $r_{WS.FDL}$ = 0.372, p=0.2337>0.05; $r_{WS.FCL}$ = 0.389, p=0.2117>0.05). The result also shows that a positive but insignificant relationship exist between number of flight diversions and delays ($r_{FDS.FDL}$ = 0.197, p=0.5385>0.05), and between number of flight diversions and cancellations ($r_{FDS.FCL}$ = 0.109, p=0.7356>0.05). Meanwhile, the relationship between number of flight delays and cancellations is positive and significant ($r_{FDL.FCL}$ = 0.946, p=0.000<0.05). By implication, the result shows that increases in number of flight delays causes increase in number of flight diversion and cancellations, and vice versa; while increases in wind shear causes increase in flight diversions, delays and cancellations.

The mathematical/regressional relationships between wind shear extrapolated at 50m above ground level (using power law model) and number of flight diversions, delays and cancellations are as represented in Table 4.13.

Table 4.13: Regression Models showing the Relationship between WS at 50m above ground level and FDS, FDL, and FCL at Murtala Mohammed International Airport, Lagos

Independent variable (Regressor)	Dependent variable (Regressand)	Regression line/Equation	Regression identity
Wind shear (WS)	Flight diversions (FDS)	LFDS = $e^{0.209WS+2.381}$	Exponential
Wind shear (WS)	Flight delays (FDL)	LFDL = $e^{0.273WS+2.371}$	Exponential
Wind shear (WS)	Flight cancellations (FCL)	LFCL = 5.307 – 3.081WS + 1.111WS^2	Quadratic

Source: Author's compilation [**See Appendix I**];
Note: *L stands for log-transformational operator*

Result shown in the Table 4.13 revealed that the best regressional relationship between wind shear at 50m above ground level at Murtala Mohammed International Airport, Lagos and number of flight diversions and delays are respectively exponential; while the relationship between wind shear at 50m above ground level and number of flight cancellations at the location is Quadratic.

Table 4.14: Correlation Matrix of the Relationships between Wind Shear extrapolated at 50m above ground level (using power law model) and Flight Diversions, Delays and Cancellations at Port Harcourt International Airport

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000			

LFDS	0.118524	1.000000		
	0.377465	-----		
	0.7137	-----		
LFDL	0.022242	0.420754	1.000000	
	0.070352	1.466686	-----	
	0.9453	0.1732	-----	
LFCL	-0.190346	0.316225	0.889905	1.000000
	-0.613138	1.054082	6.169355	-----
	0.5535	0.3166	0.0001	-----

Source: Author's Eviews Result
***. Correlation is significant at the 0.01 level (2-tailed); r = Pearson's Correlation; WS = Wind Shear extrapolated at 50m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

From the Pearson's correlation estimation as shown in Table 4.14, there is an insignificant positive relationship between wind shear extrapolated at 50m above ground level and number of flight diversions ($r_{LWS.LFDS}$ = 0.119, p=0.7137>0.05); and between wind shear extrapolated at 50m above ground level and number of flight delays ($r_{LWS.LFDL}$ = 0.022, p=0.9453>0.05); while negative and insignificant relationship between wind shear extrapolated at 50m above ground level and number of flight cancellations($r_{LWS.LFCL}$ = 0.190, p=0.5535>0.05) at Port Harcourt International Airport. Additionally, the number of flight diversions, delays and cancellations interact positively among themselves ($r_{LFDS.LFDL} = 0.421$, $p=0.1732>0.05$; $r_{LFDS.LFCL} = 0.316$, $p=0.3166>0.05$; $r_{LFDL.LFCL} = 0.890$, $p=0.0001<0.05$). Only the relationship between flight delays and cancellations is significant.

The mathematical/regressional relationships between wind shear extrapolated at 50m above ground level (using power law model) and number of flight diversions, delays and cancellations at Port Harcourt International Airport are as represented in Table 4.15.

Table 4.15: Regression Models showing the Relationship between WS at 50m above ground level and FDS, FDL, and FCL at Port Harcourt International Airport

Independent variable (Regressor)	Dependent variable (Regressand)	Regression line/Equation	Regression identity
Wind shear (WS)	Flight diversions (FDS)	$LFDS = -5.805 + 13.251WS - 4.025WS^3$	Cubic
Wind shear (WS)	Flight delays (FDL)	$LFDL = -4.900 + 24.891WS^2 - 15.926WS^3$	Cubic
Wind shear (WS)	Flight cancellations (FCL)	$LFCL = -3.321 + 19.360WS^2 - 12.591WS^3$	Cubic

Source: Author's compilation [**See Appendix I**];
Note: *L stands for log-transformational operator*

From the regression estimate in Table 4.15, the best operational relationship between wind shear extrapolated at 50m above ground level (using power law model) at Port Harcourt International Airport and number of flight diversions, delays and cancellations are respectively cubic.

Table 4.16: Panel Correlation Matrix of the Relationship between Wind Shear extrapolated at 50m above ground level (using power law model) and Flight Diversions, Delays and Cancellations at Murtala Mohammed and Port Harcourt International Airport, Nigeria

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Sample: 1 24
Included observations: 24

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000			

LFDS	0.322968	1.000000		
	1.600631	-----		
	0.1237	-----		
LFDL	0.136929	0.309002	1.000000	
	0.648362	1.523925	-----	
	0.5235	0.1418	-----	
LFCL	0.258579	0.259414	0.892972**	1.000000
	1.255544	1.259889	9.305242	-----
	0.2225	0.2209	0.0000	-----

Source: Author's Eviews Result

***Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear extrapolated at 50m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

The panel correlation estimate as presented in Table 4.16 shows that wind shear extrapolated at 50m above ground level (using power law model) interact positively and insignificantly with the number of flight diversions, delays, and cancellations ($r_{LWS.LFDS} = 0.323$, $p=0.1237>0.05$; $r_{LWS.LFDL} = 0.137$, $p=0.5235>0.05$; $r_{LWS.LFCL} = 0.259$, $p=0.2225>0.05$). In the result also, it was shown that a positive but insignificant relationship exist between number of flight diversions and delays ($r_{LFDS.LFDL} = 0.309$, $p=0.1418>0.05$), and between number of flight diversions and cancellations ($r_{LFDS.LFCL} = 0.259$, $p=0.2209>0.05$). Meanwhile, the relationship between number of flight delays and cancellations is positive and significant ($r_{LFDL.LFCL} = 0.893$, $p=0.000<0.05$). By implication, the result shows that increases in number of flight delays is a significant correlate of flight cancellations, while flight diversions is a weak predictor of flight delays and cancellations. Meanwhile, increase in wind shear encourages flight diversions, delays and cancellations in the selected airports.

Objective Three cont'd: Estimation of the relationship between wind shear extrapolated at 100m above ground level (using power law model) and flight diversions, delays and cancellations at Murtala Mohammed and Port Harcourt International Airport, Nigeria.

Table 4.17: Pearson's Correlation Matrix of the Relationship between Wind Shear extrapolated at 100m above ground level (using power law model) and Flight Diversions, Delays and Cancellations at Murtala Mohammed International Airport, Lagos

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000			

LFDS	0.504425	1.000000		
	1.847383	-----		
	0.0944	-----		
LFDL	0.372006	0.197451	1.000000	
	1.267343	0.636935	-----	
	0.2337	0.5385	-----	
LFCL	0.387798	0.109155	0.946445**	1.000000
	1.330440	0.347254	9.269925	-----
	0.2129	0.7356	0.0000	-----

Source: Author's Eviews Result

***Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear extrapolated at 50m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

The Pearson's correlation estimate in Table 4.17 with ($r_{LWS.LFDS}$ = 0.504, p=0.0944>0.05; $r_{LWS.LFDL}$ = 0.372, p=0.2337>0.05; $r_{LWS.LFCL}$ = 0.388, p=0.2129>0.05) shows that wind shear (LWS) extrapolated at 100m above ground level (using power law model) relate positively and insignificantly with the number of flight diversions (LFDS), delays (LFDL), and cancellations (LFCL). Also, the result shows that relationship between number of flight diversions, delays and cancellations are positive with only the relationship between number of flight delays and flight cancellations being significant ($r_{LFDS.LFDL}$ = 0.197, p=0.5385>0.05; $r_{LFDS.LFCL}$ = 0.109, p=0.7356>0.05; $r_{LFDL.LFCL}$ = 0.946, p=0.0000<0.05). The implication of the result is that increase in number of flight delays is a significant predictor of flight cancellations, while increase in number of flight diversions is a weak positive predictor of flight delays and cancellations. Meanwhile, increase in wind shear encourages flight diversions, delays and cancellations in the selected airports.

The mathematical/regressional relationships between wind shear extrapolated at 100m above ground level (using power law model) and number of flight diversions, delays and cancellations at Murtala Mohammed International Airport, Lagos are as represented in Table 4.18.

Table 4.18: Regression Models showing the Relationship between WS at 100m above ground level and FDS, FDL, and FCL at Murtala Mohammed International Airport, Lagos

Independent variable (Regressor)	**Dependent variable (Regressand)**	**Regression line/Equation**	**Regression identity**
Wind shear (WS)	Flight diversions (FDS)	LFDS = $e^{0.210WS+2.329}$	Exponential
Wind shear (WS)	Flight delays (FDL)	LFDL = $e^{0.275WS+2.304}$	Exponential
Wind shear (WS)	Flight cancellations (FCL)	LFCL = 5.534– 3.211WS + 1.089WS^2	Quadratic

Source: Author's compilation [**See Appendix I**];
Note: *L stands for log-transformational operator*

Result shown in Table 4.18 revealed that the best regressional relationship between wind shear at 100m above ground level at Murtala Mohammed International Airport, Lagos and number of flight diversions and delays are respectively exponential; while the relationship between wind shear at 100m above ground level and number of flight cancellations at the location is Quadratic.

Table 4.19: Pearson's Correlation Matrix of the Relationship between Wind Shear extrapolated at 100m above ground level (using power law model) and Flight Diversions, Delays and Cancellations at Port Harcourt International Airport

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 12

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000 ----- -----			
LFDS	0.101137 0.321472 0.7545	1.000000 ----- -----		
LFDL	0.018791 0.059433 0.9538	0.420754 1.466686 0.1732	1.000000 ----- -----	
LFCL	-0.189123 -0.609050 0.5561	0.316225 1.054082 0.3166	0.889905 6.169355 0.0001	1.000000 ----- -----

Source: Author's Eviews Result

***Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear extrapolated at 50m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

In Table 4.19, there is a positive and insignificant relationship between wind shear extrapolated at 100m above ground level and number of flight diversions and delays ($r_{LWS.LFDS}$ = 0.101, p=0.7545>0.05; $r_{LWS.LFDL}$ = 0.019, p=0.9538>0.05); while, the relationship between the wind shear extrapolated at 100m above ground level is negatively and insignificantly correlated with the number of flight cancellations ($r_{LWS.LFCL} = -0.189$, p=0.5561>0.05). The number of flight diversions, flight delays and flight cancellations interact positively among themselves ($r_{LFDS.LFDL}$ = 0.421, p=0.1732>0.05; $r_{LFDS.LFCL}$ = 0.316, p=0.3166>0.05; $r_{LFDL.LFCL}$ = 0.890, p=0.0001<0.05). The relationship between number of flight delays and cancellations is statistically significant.

The mathematical/regressional relationships between wind shear extrapolated at 50m above ground level (using power law model) and number of flight diversions, delays and cancellations at Port Harcourt International Airport are as represented in Table 4.20.

Table 4.20: Regression Models showing the Relationship between WS at 100m above ground level and FDS, FDL, and FCL at Port Harcourt International Airport

Independent variable (Regressor)	Dependent variable (Regressand)	Regression line/Equation	Regression identity
Wind shear (WS)	Flight diversions (FDS)	LFDS = −7.490+ 14.357WS $-3.663WS^3$	Cubic
Wind shear (WS)	Flight delays (FDL)	LFDL = −6.342+ $24.161WS^2 - 14.146WS^3$	Cubic
Wind shear (WS)	Flight cancellations (FCL)	LFCL = −4.367+ $18.643WS^2 - 11.081WS^3$	Cubic

Source: Author's compilation [**See Appendix I**];
Note: *L stands for log-transformational operator*

From the regression estimate in Table 4.20, the best operational relationship between wind shear extrapolated at 100m above ground level (using power law model) at Port Harcourt International Airport and number of flight diversions, delays and cancellations are respectively cubic.

Table 4.21: Panel Correlation Matrix of the Relationship between Wind Shear extrapolated at 100m above ground level (using power law model) and Flight Diversions, Delays and Cancellations at Murtala Mohammed and Port Harcourt International Airport, Nigeria

Covariance Analysis: Ordinary
Sample: Jan. 2008 – Dec. 2018
Included observations: 24

Correlation t-Statistic Probability	LWS	LFDS	LFDL	LFCL
LWS	1.000000			

LFDS	0.319700	1.000000		
	1.582580	-----		
	0.1278	-----		
LFDL	0.136093	0.309002	1.000000	
	0.644329	1.523925	-----	
	0.5260	0.1418	-----	
LFCL	0.257967	0.259414	0.892972	1.000000
	1.252362	1.259889	9.305242	-----
	0.2236	0.2209	0.0000	-----

Source: Author's Eviews Result
***Correlation is significant at the 0.01 level (2-tailed); r_p = Pearson's Correlation; WS = Wind Shear extrapolated at 100m above ground level; FDS = Flight diversions; FDL = Flight delays; FCL = Flight cancellations*

The panel correlation estimate presented in table 4.21 revealed that wind shear extrapolated at 100m above ground level is positively and insignificantly related to the number of flight diversions, delays and cancellations ($r_{LWS.LFDS}$ = 0.320, p=0.1278>0.05; $r_{LWS.LFDL}$ = 0.136, p=0.5260>0.05; $r_{LWS.LFCL}$ = 0.258, p=0.2236>0.05). The number of flight diversions, flight delays and flight cancellations interact positively among themselves ($r_{LFDS.LFDL}$ = 0.309, p=0.1418>0.05; $r_{LFDS.LFCL}$ = 0.259, p=0.2209>0.05; $r_{LFDL.LFCL}$ = 0.893, p=0.0000<0.05). The relationship between the number of flight delays and cancellations is statistically significant.

Objective Four: Analyzing the monthly temporal variations of wind shear in the selected airports, the researcher employed the analysis of variance (ANOVA) technique. The disaggregated and pooled analysis results are as shown in Table 4.22:

Table 4.22: Comparative Result of Wind Shear at 20m, 50m and 100m above ground level at Murtala Mohammed International Airport, Lagos

Levels	N	Mean	Std. Dev.	95% C. I. for Mean		Min	Max
				Lower Bound	Upper Bound		
20m	12	4.7417	.97464	4.1224	5.3609	3.30	6.30
50m	12	5.4167	1.11342	4.7092	6.1241	3.80	7.20
100m	12	5.9333	1.19646	5.1731	6.6935	4.20	7.90
Total	36	5.3639	1.17599	4.9660	5.7618	3.30	7.90

Source: Author's computation using SPSS 25.0

The respective mean values for wind shear at 20m, 50m and 100m above ground level are 4.74, 5.42, and 5.93. The standard deviations are: 0.975, 1.113 and 1.196 respectively. The minimum and maximum values are 3.30 and 6.30; 3.80 and 7.20; and 4.20 and 7.90 for the 20m, 50m and 100m respectively. The upper and lower bounds for wind shear at 20m above ground level lies between 4.12 and 5.36; for wind shear at 50m above ground level, it lies between 4.71 and 6.12; while for wind shear at 100m above ground level, it lies between 5.17 and 6.69. On the average, the wind shear at Murtala Mohammed International Airport, Lagos for the period of 2008-2018 lies between 4.97 and 5.76 with a mean±std. of 5.36±1.18. Inferential comparative (ANOVA) result is as presented in Table 4.23:

Table 4.23: ANOVA Result

Levene's statistic based on mean = 0.270; p=0.765>0.05

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	8.571	2	4.285	3.550	.040
Within Groups	39.833	33	1.207		
Total	48.403	35			

Source: Author's SPSS 25.0 output

Evidently as in Table 4.23, the Levene's test for equality of variance (with $p=0.765>0.05$) confirmed equal variances among the groups, thereby authenticating the use of ANOVA statistical technique. From the ANOVA test result, there is a significant difference in wind shear values at 20m, 50m, and 100m above ground level ($F=3.550$, $p=0.040<0.05$). That is to say, the wind shear varies significantly by meters above ground level. In order to ascertain whether those at 20m above ground level vary from those at 50m above ground level and from those at 100m above ground level, the researcher carried out a multiple comparison (Post Hoc) test, employing the Least Significant Difference (LSD) method. The result is as shown in Table 4.24.

Table 4.24: Multiple Comparison test Result

Dependent Variable: Wind shear at 20m, 50m and 100m above ground level, Lagos

					95% Confidence Interval	
(I) Level(metre)	(J) Level(metre)	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
20m	50m	-.67500	.44852	.142	-1.5875	.2375
	100m	-1.19167*	.44852	.012	-2.1042	-.2791
50m	20m	.67500	.44852	.142	-.2375	1.5875
	100m	-.51667	.44852	.258	-1.4292	.3959
100m	20m	1.19167*	.44852	.012	.2791	2.1042
	50m	.51667	.44852	.258	-.3959	1.4292

Source: Author's SPSS 25.0 output
**The mean difference is significant at the 0.05 level*

The Least Significant Difference (LSD) post Hoc analysis as shown in Table 4.24 indicates that the wind shear at 20m above ground level is negligibly lower compared to wind shear at 50m and 100m above ground level. The wind shear at 100m above ground level is higher compared to that at 50m, while the wind shear at 100m above ground is significantly higher compared to the wind shear at 20m above ground level. This explains that the low value of wind shear at 20m above ground level is as a result of frictional resistance close to the ground level. At 50m above ground level, the value is higher than the value at 20m above ground level but lower than the value at 100m above ground level. This is because there is less frictional resistance at 50m above ground level than 20m above level, and higher frictional resistance at 50m above ground level than 100m above ground level. Similarly, at 100m above ground level, the value is higher than the value at both 20m and 50m above ground level because the air is freer with least frictional resistance.

The monthly comparative result for the wind shear at 20m, 50m, and 100m above ground level is as shown in Table 4.25.

Table 4.25: Statistics Result

	N	Mean	Std. Dev.	95% C. I. for Mean		Min	Max
				Lower Bound	Upper Bound		
Jan	3	4.5333	.50332	3.2830	5.7837	4.00	5.00
Feb.	3	5.4333	.60277	3.9360	6.9307	4.80	6.00
Mar.	3	5.7667	.65064	4.1504	7.3829	5.10	6.40
Apr.	3	5.6333	.60277	4.1360	7.1307	5.00	6.20
May	3	7.1333	.80208	5.1409	9.1258	6.30	7.90
Jun.	3	4.9667	.55076	3.5985	6.3348	4.40	5.50
Jul.	3	5.9667	.65064	4.3504	7.5829	5.30	6.60
Aug.	3	7.0000	.75498	5.1245	8.8755	6.20	7.70
Sep.	3	5.9000	.65574	4.2710	7.5290	5.20	6.50
Oct.	3	3.9667	.45092	2.8465	5.0868	3.50	4.40
Nov.	3	3.7667	.45092	2.6465	4.8868	3.30	4.20
Dec.	3	4.3000	.50000	3.0579	5.5421	3.80	4.80
Total	36	5.3639	1.17599	4.9660	5.7618	3.30	7.90

Source: Author’s computation using SPSS 25.0

The descriptive statistics presented in Table 4.25 shows that monthly, the wind shear at the various meters has its highest value in May (mean=7.13) with a standard deviation of 0.80208. This is followed by August, with a mean value of 7.00 and a standard deviation of 0.75498. However, the lowest wind shear value was in November (mean=3.77) with a standard deviation of 0.45092.

Table 4.26: ANOVA Result

Levene's statistic based on mean = 0.191; p=0.997>0.05

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	39.543	11	3.595	9.738	.000
Within Groups	8.860	24	.369		
Total	48.403	35			

Source: Author's SPSS 25.0 output

The Levene's statistics for equality of variance indicates appropriateness of use of ANOVA as the variances among the series groups are equal (Lev. Stat. = 0.191; p=0.997>0.05). The Fisher's estimate emanating from the ANOVA test shows that there is a statistically significant difference in the monthly values of wind shear at 20m, 50m and 100m above ground level at Murtala Mohammed International Airport, Lagos (F=9.738, p=0.000<0.05). The multiple comparison (Post Hoc) result revealed a statistically significant variation between wind shear in January and March, April, May, July, August, and September (p<0.05); between February and May, August, October, November, and December (p<0.05); between March and May, August, October, November, and December (p<0.05); between April and May, August, October, November, and December (p<0.05); between May and June, July, September, October, November, and December (p<0.05); between June and August and November (p<0.05); between July and August, October, November, and December (p<0.05); between August and September, October, November, and December (p<0.05); and between September and October, November, and December (p<0.05) [**See Appendix II**].

Table 4.27: Comparative result of wind shear at 20m, 50m and 100m above ground level at Port Harcourt International Airport

Levels	N	Mean	Std. Dev.	95% C. I. for Mean		Min	Max
				Lower Bound	Upper Bound		
20m	12	2.5667	.31431	2.3670	2.7664	2.00	3.00
50m	12	2.9417	.33967	2.7258	3.1575	2.30	3.40
100m	12	3.2250	.39109	2.9765	3.4735	2.50	3.80
Total	36	2.9111	.43607	2.7636	3.0587	2.00	3.80

Source: Author's SPSS computation

The mean and standard deviations for the wind shear at 20m, 50m and 100m above ground level at Port Harcourt International Airport are 2.57±0.314, 2.94±0.340, and 3.23±0.391 respectively. With the standard deviations not too far from zero is an indication that the data series are not highly volatile and there is little or no suspicion of presence of outliers. The minimum and maximum values are 2.00 and 3.00; 2.30 and 3.40; and 2.50 and 3.80 for the 20m, 50m and 100m respectively. The upper and lower bounds for wind shear at 20m above ground level lies between 2.37 and 2.77; for wind shear at 50m above ground level, it lies between 2.73 and 3.16; while for wind shear at 100m above ground level, it lies between 2.98 and 3.47. On the average, the wind shear at Port Harcourt International Airport for the period of 2008-2018 lies between 2.76 and 3.06 with a mean±std. of 2.91±0.436. Inferential comparative (ANOVA) result is as presented in Table 4.28.

Table 4.28: ANOVA Result

Levene's statistic based on mean = 0.184; p=0.833>0.05

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	2.617	2	1.309	10.694	.000
Within Groups	4.038	33	.122		
Total	6.656	35			

Source: Author's SPSS 25.0 output

As shown in Table 4.28, the Levene's test for equality of variance (with p=0.833>0.05) established assumption of equal variances among the groups, thereby authenticating the use of ANOVA statistical technique. From the ANOVA test result, there is a significant difference in wind shear values at 20m, 50m, and 100m above ground level (F=10.694, p=0.000<0.05). That is to say, the wind shear varies significantly by meters above ground level. In order to ascertain whether those at 20m above ground level vary from those at 50m above ground and from those at 100m above ground level, the researcher carried out a multiple comparison (Post Hoc) test, employing the LSD method. The result is as presented in Table 4.29.

Table 4.29: Multiple Comparison test Result for wind shear at Port Harcourt International Airport

Dependent Variable: Wind shear comparison, Port Harcourt

(I) Level(metre)	(J) Level(metre)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
20m	50m	-.37500*	.14281	.013	-.6656	-.0844
	100m	-.65833*	.14281	.000	-.9489	-.3678
50m	20m	.37500*	.14281	.013	.0844	.6656
	100m	-.28333	.14281	.056	-.5739	.0072
100m	20m	.65833*	.14281	.000	.3678	.9489
	50m	.28333	.14281	.056	-.0072	.5739

Source: Author's SPSS 25.0 output

* *The mean difference is significant at the 0.05 level*

From the Least Significant Difference (LSD) test result, wind shear at 20m above ground level is significantly lower compared to those at 50m and 100m above ground level at Port Harcourt International Airport (p<0.05); while the wind shear at 50m above ground level is insignificantly lower compared to those at 100m above ground level. This is also because there is less frictional resistance at 50m above ground level than 20m above level, and higher frictional resistance at 50m above ground level than 100m above ground level. Similarly, at 100m above ground level, the value is higher than the value at both 20m and 50m above ground level because the air is freer with least frictional resistance.

The monthly comparative result for the wind shear at 20m, 50m, and 100m above ground level is as shown in Table 4.30.

Table 4.30: Statistics Result

	N	Mean	Std. Dev.	95% C. I. for Mean		Min	Max
				Lower Bound	Upper Bound		
Jan	3	3.4000	.40000	2.4063	4.3937	3.00	3.80
Feb.	3	3.3667	.35119	2.4943	4.2391	3.00	3.70
Mar.	3	3.0667	.35119	2.1943	3.9391	2.70	3.40
Apr.	3	3.0667	.35119	2.1943	3.9391	2.70	3.40
May	3	2.8667	.35119	1.9943	3.7391	2.50	3.20
Jun.	3	2.9000	.30000	2.1548	3.6452	2.60	3.20
Jul.	3	2.8667	.35119	1.9943	3.7391	2.50	3.20
Aug.	3	3.1667	.35119	2.2943	4.0391	2.80	3.50
Sep.	3	2.9667	.35119	2.0943	3.8391	2.60	3.30
Oct.	3	2.5667	.25166	1.9415	3.1918	2.30	2.80
Nov.	3	2.2667	.25166	1.6415	2.8918	2.00	2.50
Dec.	3	2.4333	.30551	1.6744	3.1922	2.10	2.70
Total	36	2.9111	.43607	2.7636	3.0587	2.00	3.80

Source: Author's computation using SPSS 25.0

The monthly descriptive comparison in the wind shear at 20m, 50m, and 100m above ground level at Port Harcourt International Airport revealed that the monthly wind shear at the various meters has its highest value in January (mean=3.40) with a standard deviation of 0.400. This is followed by February, with a mean value of 3.37 and a standard deviation of 0.351. However, the lowest wind shear value was in November (mean=2.27) with a standard deviation of 0.252. In overall, the average wind shear at Port Harcourt International Airport stood at 2.92 with a standard deviation of 0.436 for the period under review.

Table 4.31: ANOVA Result

Levene's statistic based on mean = 0.081; p=0.999>0.05

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	3.989	11	.363	3.264	.007
Within Groups	2.667	24	.111		
Total	6.656	35			

Source: Author's SPSS 25.0 output

The Levene's statistic value is 0.081 with a p-value of 0.999>0.05; which indicates that the variances in series of dataset between the months are equal. Hence, the use of ANOVA technique is appropriate. The ANOVA test result with F-stat. = 3.264, p= 0.007<0.05, shows that there is a statistically significant difference in the monthly values of wind shear at 20m, 50m and 100m above ground level at the Port Harcourt International Airport. The multiple comparison (Post Hoc) test result revealed a statistically significant variation between wind shear in January and October, November, and December (p<0.05); between February and October, November, and December (p<0.05); between March and November, and December (p<0.05); between April and November, and December (p<0.05); between May and November (p<0.05); between June and November (p<0.05); between July and November (p<0.05); between August and October, November, and December (p<0.05); and between September and November (p<0.05) [**See Appendix II**].

Objective Five: To determine the relative safety at the two airports as a result of wind shear.

Based on the wind shear movement and number of flight diversions, delays and cancellations associated with it, the Airport safer for landing was determined statistically as follows:

Table 4.32: Airport Safer for Landing

	Murtala Mohammed Int'l Airport				Port Harcourt Int'l Airport			
Parameters	WS	FDS	FDL	FCL	WS	FDS	FDL	FCL
Mean	5.36	30.58	48.67	28.33	2.91	27.67	47.00	24.83
Std. dev.	1.10	8.54	21.12	8.03	0.35	9.11	19.93	8.45
CV	20.5%	27.9%	43.4%	28.3%	12.0%	32.9%	42.4%	34.0%

CV=Coefficient of variation

Source: Author's SPSS 25.0 output

The coefficient of variation (CV) results, which is the ratio of standard deviation to the mean of the data at Murtala Mohammed and Port Harcourt International Airports, is shown in table 4.32. The coefficient of variation of wind shear at Murtala Mohammed International Airport is 0.205 (20.5%) while the coefficient of variation of wind shear at Port Harcourt International Airport is 0.120 (12.0%). From the coefficient of variation results, Port Harcourt International Airport (with overall smaller CV) is considered safer for flight landing.

CHAPTER FIVE

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY OF FINDINGS

The study shows that wind shear increases with altitude at the study areas. This is evident as the values of wind shear extrapolated at 50m and 100m above ground level at the airports are higher than the values of wind shear measured at 20m above ground level at the airports. This increase in wind shear at 50m and 100m above ground level is as a result of decrease in frictional resistance which is more pronounced closed to the ground.

A similarity in the distribution pattern of wind shear at 20m, 50m and 100m above ground level at Murtala Mohammed International Airport was revealed by the study. Likewise, at Port Harcourt International Airport, wind shear at 20m, 50m and 100m above ground level also shows a similarity in the distribution pattern. Comparatively, the distribution pattern of wind shear at 20m and 50m above ground level at the two airports are very similar, though the wind shear measured at 20m are higher in Lagos compared to Port Harcourt International Airport, Nigeria. The distribution patterns of wind shear extrapolated at 100m above ground level at the airports show some dissimilarities. The wind shear at Murtala Mohammed International Airport has a random (zig-zag) distribution whereas wind shear at Port Harcourt International Airport has smooth distribution and detrended over the period.

The study reveals that the number of flight delays increases as the number of flight cancellations increase, and vice versa. It also reveals that flight delays or cancellations do not always lead to flight diversions in the study areas.

The correlation analysis conducted at Murtala Mohammed International Airport shows a weak (insignificant) positive relationship between wind shear measured at 20m above ground level and number of flight diversions, delays and cancellations. Also, there is a weak (insignificant) positive relationship between number of flight diversions and delays; number of flight diversions and number of flight cancellations and a significant (strong) positive relationship between number of flight delays and cancellations at Murtala Mohammed International Airport, Lagos. The result therefore shows that, fluctuations in wind shear lead to increases in number of flight diversions, delays, and cancellations in the area.

At Port Harcourt International Airport, an insignificant negative relationship between wind shear measured at 20m above ground level and number of flight cancellations was discovered, while an insignificant positive relationship was discovered between wind shear and number of flight diversions, and between wind shear and number of flight delays. However, the interactions between the number of flight diversions and delays and between number of flight diversions and cancellations are positive and insignificant, while there is a positive and significant relationship between number of flight delays and cancellations. This implies that increase in wind shear (at 20m above ground level) leads to higher number of flight delays and diversions, and reduction in number of flight cancellations at the area. Meanwhile, when flights are delayed, they are most likely to be cancelled.

Considering the wind shear extrapolated at 50m above ground level, the study shows that wind shear relate positively and insignificantly with number of flight diversions, delays and cancellations at Murtala Mohammed International Airport, Lagos. The result also shows that a positive but insignificant relationship exist between the number of flight diversions and delays, and between the number of flight diversions and cancellations, whereas the relationship between the number of flight delays and cancellations is positive and significant. By implication, the result shows that increases in the number of flight delays cause increases in number of flight diversions and cancellations, and vice versa; while increases in wind shear cause increases in flight diversions, delays and cancellations.

The Pearson’s correlation estimation reveals an insignificant positive relationship between wind shear extrapolated at 50m above ground level and number of flight diversions; and between wind shear extrapolated at 50m above ground level and number of flight delays; while a negative and insignificant relationship was shown between wind shear extrapolated at 50m above ground level and number of flight cancellations at Port Harcourt International Airport. Additionally, the number of flight diversions, delays and cancellations interact positively among themselves. Only the relationship between flight delays and cancellations is significant.

It was shown that wind shear extrapolated at 100m above ground level (using power law model) relate positively and insignificantly with the number of flight diversions, delays and cancellations at Murtala Mohammed International Airport. The result also shows that the relationship between the number of flight diversions, delays and cancellations are positive with only the relationship between the number of flight delays and flight cancellations being significant. The implication of the result is that increase in the number of flight delays is a significant predictor of flight cancellations, while increase in number of flight diversions is a weak positive predictor of flight delays and cancellations. Meanwhile, increase in wind shear encourages flight diversions, delays and cancellations in the selected airports.

At Port Harcourt International Airport, the study shows a positive and insignificant relationship between wind shear extrapolated at 100m above ground level and number of flight diversions and delays; while the relationship between the wind shear extrapolated at 100m above ground level is negatively and insignificantly correlated with the number of flight cancellations. The number of flight diversions, flight delays and flight cancellations interact positively among themselves. The relationship between the number of flight delays and cancellation is statistically significant.

Evidently, the study reveals some temporal variations in the mean and standard deviation of wind shear in the study areas. The respective mean values for wind shear at 20m, 50m and 100m above ground level are 4.74, 5.42, and 5.93. The standard deviations are: 0.975, 1.113 and 1.196 respectively. On the average, the wind shear at Murtala Mohammed International Airport, Lagos for the period of 2008-2018 lies between 4.97 and 5.76 with a mean±std. of 5.36±1.18. The study reveals from the ANOVA test result that at Murtala Mohammed International Airport, there exists a significant difference in wind shear values at 20m, 50m, and 100m above ground level. This means that wind shear varies significantly by meters above ground level. The study confirmed using the Least Significant Difference (LSD) post Hoc method that the wind shear at 20m above ground level is negligibly lower compared to wind shear at 50m and 100m above ground level. The wind shear at 100m above ground level is higher compared to that at 50m, while the wind shear at 100m above ground is significantly higher compared to the wind shear at 20m above ground level. The descriptive statistics shows that monthly, the wind shear at the various meters has its highest value in May (mean=7.13) with a standard deviation of 0.80208. This is followed by August, with a mean value of 7.00 and a standard deviation of 0.75498. However, the lowest wind shear value was in November (mean=3.77) with a standard deviation of 0.45092.

The mean and standard deviations for the wind shear at 20m, 50m and 100m above ground level at Port Harcourt International Airport are 2.57±0.314, 2.94±0.340, and 3.23±0.391 respectively. On the average, the wind shear at Port Harcourt International Airport for the period of 2008-2018 lies between 2.76 and 3.06 with a mean±std. of 2.91±0.436. The study reveals from the ANOVA test result that at Port Harcourt International Airport, there exists a significant difference in wind shear values at 20m, 50m, and 100m above ground level. By implication, this means that wind shear varies significantly by meters above ground level. The study confirmed using the Least Significant Difference (LSD) post Hoc method that the wind shear at 20m above ground level is significantly lower compared to those at 50m and 100m above ground level at Port Harcourt International Airport; while the wind shear at 50m above ground level is insignificantly lower compared to those at 100m above ground level. The study also shows the monthly descriptive comparison in the wind shear at 20m, 50m, and 100m above ground level at Port Harcourt International Airport. It was shown that the monthly wind shear at the various meters has its highest value in January (mean=3.40) with a standard deviation of 0.400. This is followed by February, with a mean value of 3.37 and a standard deviation of 0.351. Also, it shows that the lowest wind shear value was in November (mean=2.27) with a standard deviation of 0.252. In overall, the average wind shear at Port Harcourt International Airport stood at 2.92 with a standard deviation of 0.436 for the period under study.

The study also reveals based on the effects of wind shear and its resultant flight delays, diversions and cancellations that Port Harcourt International Airport with overall higher coefficient of variation (CV) is considered safer for flight landing.

5.2 CONCLUSION

Virtually all forms of transport (air, water, road and rail) are strongly influenced by climate and weather. The aviation industry is a major consumer of climate information. Cole in 1975 stated that the rapidly expanding aviation community has become the single largest most demanding consumer for America’s weather service, and this has risen tremendously in the recent especially in Africa like Nigeria. Added to this increase is the fact that so many individuals now own their private aircrafts.

In Nigeria, Nigerian Meteorological Agency (NIMET) which was formerly a department in Federal Airports Authority of Nigeria (FAAN) is now a separate Agency. This is because of the importance of weather in aviation and other human endeavours. It has been known that many aspects of air transportation and flight operations, are affected by weather phenomena especially wind shear; including accidents, flight delays, diversions, cancellations, routing and fuel economy. Weather exerts a strong influence on air earners, general aviation operations and the air traffic control system.

Wind shear has been identified as one of the major hazards which the flights encounter. This can be seen during aircraft taking off, landing or as they ply their routes. Poor knowledge of micro-meteorological characteristics (including wind shear) of an aircraft has exacerbated the consequences of weather hazards on aviation industry.

From the study, there is crystal clear evidence that the Atmospheric Boundary Layer (ABL) within 20m above ground level (AGL) of the troposphere, at Murtala Mohammed International Airport and Port Harcourt International Airport is influenced by the presence of the earth’s surface. At 50m and 100m AGL, there were increased wind shear values. This shows that wind shear increased with increasing height above ground level at the study areas.

The work also shows that wind shear contributed to the delays, cancellations and diversions of flight schedules at Murtala Mohammed International Airport and Port Harcourt International Airport. This is because the correlation between measured and extrapolated wind shear and flight delays, cancellations and diversions were positive.

5.3 RECOMMENDATIONS

The study, based on the findings, proposed the following recommendations:

1. For efficient and smooth running of the aviation industry, the models that are provided in the study should be used to forecast for the effects of wind shear on flight operations. By so doing, the passengers will be provided with the information beforehand, and this will

help to minimize or prevent unnecessary flight diversions, flight delays and flight cancellations which the passengers encounter at the airports.

2. There is need for Government to install Low Level Wind Shear Alert System in every airport in the country for efficient monitoring of wind shear.
3. There should be training and retraining of Meteorologists, Air Traffic Controllers and Engineers who are staff of Nigerian Meteorological Agency and Nigerian Airspace Management Agency, so as to update their knowledge on the effects of wind shear in the aviation industry in the country. The same should also be done in the agencies involved in the observation, forecasting and dissemination of weather information in other countries.
4. Pilots should always be well trained and retrained, so that they can have good knowledge of wind shear and other hazardous weather phenomena.
5. The research, from its findings, has also shown the months with high rate of wind shear in the study areas, and the knowledge of this can help the Meteorologists and Pilots in the forecast and piloting duties respectively.
6. The work also recommends that more studies should be carried out by the students and researchers on wind shear. This is to help the aviation industry especially in the developing countries, like Nigeria, grow to full maturity, and to curb accidents caused by wind shear.

5.4 SUGGESTIONS FOR FURTHER RESEARCH

1. Similar studies can be conducted in the other airports within the coastal environment of Nigeria, and should be compared with the present work.
2. Similar studies can also be conducted at the airports in the northern or other parts of Nigeria.
3. Since wind shear disturbances are not limited to the tropics, similar studies can be conducted at the airports in other countries, especially by some postgraduate students and

academics that travel abroad for studies, and comparing the studies in other countries and home conducted researches, some hidden facts about wind shear may be exposed.

4. A study may be carried out to calculate the wind shear exponent of Murtala Mohammed International Airport and Port Harcourt International Airport, or other airports, using various models.
5. This study may provide information for developing wind energy in the study areas, and the work may be continued in the future including the power generation by the wind turbine.

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APPENDIX I

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT, LAGOS

Model Description

Model Name		MOD_1
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.256	3.435	1	10	.094	2.331	.685		
Logarithmic	.255	3.420	1	10	.094	2.953	1.025		
Quadratic	.256	1.547	2	9	.265	2.133	.952	-.088	
Cubic	.256	1.548	2	9	.264	2.158	.860	.000	-.025
Exponential	.263	3.561	1	10	.088	2.449	.208		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT, LAGOS

Model Description

Model Name		MOD_2
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.148	1.741	1	10	.216	2.289	.966		
Logarithmic	.143	1.673	1	10	.225	3.175	1.423		
Quadratic	.152	.809	2	9	.475	4.164	-1.548	.828	
Cubic	.151	.801	2	9	.479	3.140	.000	.140	.078
Exponential	.159	1.892	1	10	.199	2.427	.281		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT CANCELLATIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT, LAGOS

Model Description

Model Name		MOD_3
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.158	1.878	1	10	.201	2.374	.603		
Logarithmic	.150	1.761	1	10	.214	2.931	.879		
Quadratic	.173	.940	2	9	.426	4.522	-2.277	.949	
Cubic	.169	.915	2	9	.435	3.602	-.635	.000	.177
Exponential	.162	1.927	1	10	.195	2.443	.193		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_4
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.010	.104	1	10	.753	3.032	.257		
Logarithmic	.020	.206	1	10	.659	3.296	.319		
Quadratic	.372	2.661	2	9	.124	-6.292	21.400	-11.749	
Cubic	.386	2.826	2	9	.112	-3.301	11.054	.000	-4.386
Exponential	.010	.100	1	10	.758	3.033	.076		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_5
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.003	.027	1	10	.872	3.562	.201		
Logarithmic	.012	.124	1	10	.733	3.780	.377		
Quadratic	.683	9.692	2	9	.006	-15.919	44.378	-24.549	
Cubic	.684	9.725	2	9	.006	-9.423	22.342	.000	-8.995
Exponential	.005	.052	1	10	.824	3.460	.077		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 20M ABOVE GROUND LEVEL AND FLIGHT CANCELLATIONS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_6
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear 20m
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.027	.273	1	10	.613	3.605	-.485		
Logarithmic	.011	.112	1	10	.745	3.131	-.276		
Quadratic	.700	10.488	2	9	.004	-11.352	33.432	-18.848	
Cubic	.712	11.125	2	9	.004	-1.532	.000	18.530	-13.743
Exponential	.032	.326	1	10	.581	3.687	-.175		

The independent variable is Wind shear 20m.

RELATIONSHIP BETWEEN WIND SHEAR AT 50M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_1
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.254	3.412	1	10	.094	2.240	.686		
Logarithmic	.256	3.448	1	10	.093	2.817	1.126		
Quadratic	.257	1.558	2	9	.262	1.250	1.901	-.367	
Cubic	.257	1.559	2	9	.262	1.567	1.307	.000	-.075
Exponential	.262	3.556	1	10	.089	2.381	.209		

The independent variable is Wind shear at 50m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 50M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_2
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.138	1.607	1	10	.234	2.212	.937		
Logarithmic	.133	1.535	1	10	.244	3.017	1.502		
Quadratic	.146	.772	2	9	.490	5.342	-2.905	1.162	
Cubic	.144	.759	2	9	.496	4.004	-.718	.000	.200
Exponential	.149	1.751	1	10	.215	2.371	.273		

The independent variable is Wind shear at 50m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 50M ABOVE GROUND LEVEL AND FLIGHT CANCELLATIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_3
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.151	1.780	1	10	.212	2.314	.592		
Logarithmic	.143	1.666	1	10	.226	2.827	.941		
Quadratic	.171	.929	2	9	.430	5.307	-3.081	1.111	
Cubic	.167	.900	2	9	.440	4.069	-1.028	.000	.196
Exponential	.154	1.825	1	10	.207	2.397	.189		

The independent variable is Wind shear at 50m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 50M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_4
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.014	.142	1	10	.714	2.940	.311		
Logarithmic	.023	.235	1	10	.639	3.249	.405		
Quadratic	.350	2.418	2	9	.144	-9.886	25.567	-12.257	
Cubic	.364	2.577	2	9	.130	-5.805	13.251	.000	-4.025
Exponential	.014	.139	1	10	.717	2.950	.093		

The independent variable is Wind shear at 50m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 50M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_5
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.000	.005	1	10	.945	3.656	.089		
Logarithmic	.004	.045	1	10	.837	3.735	.272		
Quadratic	.572	6.019	2	9	.022	-21.840	50.292	-24.364	
Cubic	.587	6.400	2	9	.019	-4.900	.000	24.891	-15.926
Exponential	.002	.017	1	10	.900	3.544	.045		

The independent variable is Wind shear at 50m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 50M ABOVE GROUND LEVEL AND FLIGHT CANCELLATIONS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_6
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.036	.376	1	10	.553	3.778	-.587		
Logarithmic	.021	.213	1	10	.655	3.178	-.453		
Quadratic	.647	8.241	2	9	.009	-16.556	39.452	-19.431	
Cubic	.672	9.211	2	9	.007	-3.321	.000	19.360	-12.591
Exponential	.042	.439	1	10	.523	3.914	-.210		

The independent variable is Wind shear at 50m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 100M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT, LAGOS

Model Description

Model Name		MOD_7
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.254	3.413	1	10	.094	2.167	.691		
Logarithmic	.256	3.436	1	10	.093	2.714	1.198		
Quadratic	.256	1.550	2	9	.264	1.276	1.724	-.296	
Cubic	.256	1.551	2	9	.264	1.552	1.228	.000	-.058
Exponential	.262	3.552	1	10	.089	2.329	.210		

The independent variable is Wind shear at 100m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 100M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_8
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.138	1.606	1	10	.234	2.113	.943		
Logarithmic	.134	1.541	1	10	.243	2.877	1.602		
Quadratic	.146	.768	2	9	.492	5.523	-3.014	1.133	
Cubic	.144	.757	2	9	.497	4.079	-.772	.000	.186
Exponential	.149	1.750	1	10	.215	2.304	.275		

The independent variable is Wind shear at 100m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 100M ABOVE GROUND LEVEL AND FLIGHT CANCELLATIONS AT MURTALA MOHAMMED INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_9
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.150	1.770	1	10	.213	2.254	.595		
Logarithmic	.143	1.667	1	10	.226	2.740	1.002		
Quadratic	.169	.916	2	9	.434	5.534	-3.211	1.089	
Cubic	.165	.891	2	9	.444	4.190	-1.093	.000	.183
Exponential	.154	1.817	1	10	.207	2.351	.190		

The independent variable is Wind shear at 100m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 100M ABOVE GROUND LEVEL AND FLIGHT DIVERSIONS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_10
Dependent Variable	1	Flight diversions
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight diversions

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.010	.103	1	10	.754	2.965	.264		
Logarithmic	.018	.179	1	10	.681	3.216	.387		
Quadratic	.361	2.544	2	9	.133	-12.426	27.882	-12.243	
Cubic	.374	2.691	2	9	.121	-7.490	14.357	.000	-3.663
Exponential	.010	.100	1	10	.758	2.972	.079		

The independent variable is Wind shear at 50m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 100M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_11
Dependent Variable	1	Flight delays
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight delays

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.000	.004	1	10	.954	3.664	.075		
Logarithmic	.004	.036	1	10	.852	3.712	.268		
Quadratic	.570	5.966	2	9	.022	-26.195	53.656	-23.753	
Cubic	.583	6.285	2	9	.020	-6.342	.000	24.161	-14.146
Exponential	.001	.014	1	10	.908	3.546	.041		

The independent variable is Wind shear at 100m above ground level.

RELATIONSHIP BETWEEN WIND SHEAR AT 100M ABOVE GROUND LEVEL AND FLIGHT DELAYS AT PORT HARCOURT INTERNATIONAL AIRPORT

Model Description

Model Name		MOD_12
Dependent Variable	1	Flight cancellations
Equation	1	Linear
	2	Logarithmic
	3	Quadratic
	4	Cubic
	5	Exponential[a]
Independent Variable		Wind shear at 50m above ground level
Constant		Included
Variable Whose Values Label Observations in Plots		Unspecified
Tolerance for Entering Terms in Equations		.0001

a. The model requires all non-missing values to be positive.

Model Summary and Parameter Estimates

Dependent Variable: Flight cancellations

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	.036	.371	1	10	.556	3.827	-.581		
Logarithmic	.022	.220	1	10	.649	3.225	-.503		
Quadratic	.632	7.720	2	9	.011	-19.742	41.712	-18.749	
Cubic	.654	8.492	2	9	.008	-4.367	.000	18.643	-11.081
Exponential	.042	.436	1	10	.524	3.987	-.208		

The independent variable is Wind shear at 100m above ground level.

APPENDIX II: MULTIPLE COMPARISON TEST RESULTS

Multiple Comparisons

Dependent Variable: Wind shear comparison, Lagos

LSD

(I) Group (Months)	(J) Group (Months)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Jan	Feb.	-.90000	.49610	.082	-1.9239	.1239
	Mar.	-1.23333*	.49610	.020	-2.2572	-.2094
	Apr.	-1.10000*	.49610	.036	-2.1239	-.0761
	May	-2.60000*	.49610	.000	-3.6239	-1.5761
	Jun.	-.43333	.49610	.391	-1.4572	.5906
	Jul.	-1.43333*	.49610	.008	-2.4572	-.4094
	Aug.	-2.46667*	.49610	.000	-3.4906	-1.4428
	Sep.	-1.36667*	.49610	.011	-2.3906	-.3428
	Oct.	.56667	.49610	.265	-.4572	1.5906
	Nov.	.76667	.49610	.135	-.2572	1.7906
	Dec.	.23333	.49610	.642	-.7906	1.2572
Feb.	Jan	.90000	.49610	.082	-.1239	1.9239
	Mar.	-.33333	.49610	.508	-1.3572	.6906
	Apr.	-.20000	.49610	.690	-1.2239	.8239
	May	-1.70000*	.49610	.002	-2.7239	-.6761
	Jun.	.46667	.49610	.356	-.5572	1.4906
	Jul.	-.53333	.49610	.293	-1.5572	.4906
	Aug.	-1.56667*	.49610	.004	-2.5906	-.5428
	Sep.	-.46667	.49610	.356	-1.4906	.5572
	Oct.	1.46667*	.49610	.007	.4428	2.4906
	Nov.	1.66667*	.49610	.003	.6428	2.6906
	Dec.	1.13333*	.49610	.031	.1094	2.1572
Mar.	Jan	1.23333*	.49610	.020	.2094	2.2572
	Feb.	.33333	.49610	.508	-.6906	1.3572
	Apr.	.13333	.49610	.790	-.8906	1.1572
	May	-1.36667*	.49610	.011	-2.3906	-.3428
	Jun.	.80000	.49610	.120	-.2239	1.8239
	Jul.	-.20000	.49610	.690	-1.2239	.8239
	Aug.	-1.23333*	.49610	.020	-2.2572	-.2094
	Sep.	-.13333	.49610	.790	-1.1572	.8906
	Oct.	1.80000*	.49610	.001	.7761	2.8239
	Nov.	2.00000*	.49610	.000	.9761	3.0239
	Dec.	1.46667*	.49610	.007	.4428	2.4906
Apr.	Jan	1.10000*	.49610	.036	.0761	2.1239

	Feb.	.20000	.49610	.690	-.8239	1.2239
	Mar.	-.13333	.49610	.790	-1.1572	.8906
	May	-1.50000*	.49610	.006	-2.5239	-.4761
	Jun.	.66667	.49610	.192	-.3572	1.6906
	Jul.	-.33333	.49610	.508	-1.3572	.6906
	Aug.	-1.36667*	.49610	.011	-2.3906	-.3428
	Sep.	-.26667	.49610	.596	-1.2906	.7572
	Oct.	1.66667*	.49610	.003	.6428	2.6906
	Nov.	1.86667*	.49610	.001	.8428	2.8906
	Dec.	1.33333*	.49610	.013	.3094	2.3572
May	Jan	2.60000*	.49610	.000	1.5761	3.6239
	Feb.	1.70000*	.49610	.002	.6761	2.7239
	Mar.	1.36667*	.49610	.011	.3428	2.3906
	Apr.	1.50000*	.49610	.006	.4761	2.5239
	Jun.	2.16667*	.49610	.000	1.1428	3.1906
	Jul.	1.16667*	.49610	.027	.1428	2.1906
	Aug.	.13333	.49610	.790	-.8906	1.1572
	Sep.	1.23333*	.49610	.020	.2094	2.2572
	Oct.	3.16667*	.49610	.000	2.1428	4.1906
	Nov.	3.36667*	.49610	.000	2.3428	4.3906
	Dec.	2.83333*	.49610	.000	1.8094	3.8572
Jun.	Jan	.43333	.49610	.391	-.5906	1.4572
	Feb.	-.46667	.49610	.356	-1.4906	.5572
	Mar.	-.80000	.49610	.120	-1.8239	.2239
	Apr.	-.66667	.49610	.192	-1.6906	.3572
	May	-2.16667*	.49610	.000	-3.1906	-1.1428
	Jul.	-1.00000	.49610	.055	-2.0239	.0239
	Aug.	-2.03333*	.49610	.000	-3.0572	-1.0094
	Sep.	-.93333	.49610	.072	-1.9572	.0906
	Oct.	1.00000	.49610	.055	-.0239	2.0239
	Nov.	1.20000*	.49610	.024	.1761	2.2239
	Dec.	.66667	.49610	.192	-.3572	1.6906
Jul.	Jan	1.43333*	.49610	.008	.4094	2.4572
	Feb.	.53333	.49610	.293	-.4906	1.5572
	Mar.	.20000	.49610	.690	-.8239	1.2239
	Apr.	.33333	.49610	.508	-.6906	1.3572
	May	-1.16667*	.49610	.027	-2.1906	-.1428
	Jun.	1.00000	.49610	.055	-.0239	2.0239
	Aug.	-1.03333*	.49610	.048	-2.0572	-.0094
	Sep.	.06667	.49610	.894	-.9572	1.0906
	Oct.	2.00000*	.49610	.000	.9761	3.0239

	Nov.	2.20000*	.49610	.000	1.1761	3.2239
	Dec.	1.66667*	.49610	.003	.6428	2.6906
Aug.	Jan	2.46667*	.49610	.000	1.4428	3.4906
	Feb.	1.56667*	.49610	.004	.5428	2.5906
	Mar.	1.23333*	.49610	.020	.2094	2.2572
	Apr.	1.36667*	.49610	.011	.3428	2.3906
	May	-.13333	.49610	.790	-1.1572	.8906
	Jun.	2.03333*	.49610	.000	1.0094	3.0572
	Jul.	1.03333*	.49610	.048	.0094	2.0572
	Sep.	1.10000*	.49610	.036	.0761	2.1239
	Oct.	3.03333*	.49610	.000	2.0094	4.0572
	Nov.	3.23333*	.49610	.000	2.2094	4.2572
	Dec.	2.70000*	.49610	.000	1.6761	3.7239
Sep.	Jan	1.36667*	.49610	.011	.3428	2.3906
	Feb.	.46667	.49610	.356	-.5572	1.4906
	Mar.	.13333	.49610	.790	-.8906	1.1572
	Apr.	.26667	.49610	.596	-.7572	1.2906
	May	-1.23333*	.49610	.020	-2.2572	-.2094
	Jun.	.93333	.49610	.072	-.0906	1.9572
	Jul.	-.06667	.49610	.894	-1.0906	.9572
	Aug.	-1.10000*	.49610	.036	-2.1239	-.0761
	Oct.	1.93333*	.49610	.001	.9094	2.9572
	Nov.	2.13333*	.49610	.000	1.1094	3.1572
	Dec.	1.60000*	.49610	.004	.5761	2.6239
Oct.	Jan	-.56667	.49610	.265	-1.5906	.4572
	Feb.	-1.46667*	.49610	.007	-2.4906	-.4428
	Mar.	-1.80000*	.49610	.001	-2.8239	-.7761
	Apr.	-1.66667*	.49610	.003	-2.6906	-.6428
	May	-3.16667*	.49610	.000	-4.1906	-2.1428
	Jun.	-1.00000	.49610	.055	-2.0239	.0239
	Jul.	-2.00000*	.49610	.000	-3.0239	-.9761
	Aug.	-3.03333*	.49610	.000	-4.0572	-2.0094
	Sep.	-1.93333*	.49610	.001	-2.9572	-.9094
	Nov.	.20000	.49610	.690	-.8239	1.2239
	Dec.	-.33333	.49610	.508	-1.3572	.6906
Nov.	Jan	-.76667	.49610	.135	-1.7906	.2572
	Feb.	-1.66667*	.49610	.003	-2.6906	-.6428
	Mar.	-2.00000*	.49610	.000	-3.0239	-.9761
	Apr.	-1.86667*	.49610	.001	-2.8906	-.8428
	May	-3.36667*	.49610	.000	-4.3906	-2.3428
	Jun.	-1.20000*	.49610	.024	-2.2239	-.1761

	Jul.	-2.20000*	.49610	.000	-3.2239	-1.1761
	Aug.	-3.23333*	.49610	.000	-4.2572	-2.2094
	Sep.	-2.13333*	.49610	.000	-3.1572	-1.1094
	Oct.	-.20000	.49610	.690	-1.2239	.8239
	Dec.	-.53333	.49610	.293	-1.5572	.4906
Dec.	Jan	-.23333	.49610	.642	-1.2572	.7906
	Feb.	-1.13333*	.49610	.031	-2.1572	-.1094
	Mar.	-1.46667*	.49610	.007	-2.4906	-.4428
	Apr.	-1.33333*	.49610	.013	-2.3572	-.3094
	May	-2.83333*	.49610	.000	-3.8572	-1.8094
	Jun.	-.66667	.49610	.192	-1.6906	.3572
	Jul.	-1.66667*	.49610	.003	-2.6906	-.6428
	Aug.	-2.70000*	.49610	.000	-3.7239	-1.6761
	Sep.	-1.60000*	.49610	.004	-2.6239	-.5761
	Oct.	.33333	.49610	.508	-.6906	1.3572
	Nov.	.53333	.49610	.293	-.4906	1.5572

*. The mean difference is significant at the 0.05 level.

Multiple Comparisons

Dependent Variable: Wind shear comparison, Port Harcourt

LSD

		Mean Difference			95% Confidence Interval	
(I) Group (Months)	(J) Group (Months)	(I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Jan	Feb.	.03333	.27217	.904	-.5284	.5951
	Mar.	.33333	.27217	.233	-.2284	.8951
	Apr.	.33333	.27217	.233	-.2284	.8951
	May	.53333	.27217	.062	-.0284	1.0951
	Jun.	.50000	.27217	.079	-.0617	1.0617
	Jul.	.53333	.27217	.062	-.0284	1.0951
	Aug.	.23333	.27217	.400	-.3284	.7951
	Sep.	.43333	.27217	.124	-.1284	.9951
	Oct.	.83333*	.27217	.005	.2716	1.3951
	Nov.	1.13333*	.27217	.000	.5716	1.6951
	Dec.	.96667*	.27217	.002	.4049	1.5284
Feb.	Jan	-.03333	.27217	.904	-.5951	.5284
	Mar.	.30000	.27217	.281	-.2617	.8617
	Apr.	.30000	.27217	.281	-.2617	.8617
	May	.50000	.27217	.079	-.0617	1.0617
	Jun.	.46667	.27217	.099	-.0951	1.0284
	Jul.	.50000	.27217	.079	-.0617	1.0617
	Aug.	.20000	.27217	.470	-.3617	.7617
	Sep.	.40000	.27217	.155	-.1617	.9617
	Oct.	.80000*	.27217	.007	.2383	1.3617
	Nov.	1.10000*	.27217	.000	.5383	1.6617
	Dec.	.93333*	.27217	.002	.3716	1.4951
Mar.	Jan	-.33333	.27217	.233	-.8951	.2284
	Feb.	-.30000	.27217	.281	-.8617	.2617
	Apr.	.00000	.27217	1.000	-.5617	.5617
	May	.20000	.27217	.470	-.3617	.7617
	Jun.	.16667	.27217	.546	-.3951	.7284
	Jul.	.20000	.27217	.470	-.3617	.7617
	Aug.	-.10000	.27217	.717	-.6617	.4617
	Sep.	.10000	.27217	.717	-.4617	.6617
	Oct.	.50000	.27217	.079	-.0617	1.0617
	Nov.	.80000*	.27217	.007	.2383	1.3617
	Dec.	.63333*	.27217	.029	.0716	1.1951
Apr.	Jan	-.33333	.27217	.233	-.8951	.2284
	Feb.	-.30000	.27217	.281	-.8617	.2617

	Mar.	.00000	.27217	1.000	-.5617	.5617
	May	.20000	.27217	.470	-.3617	.7617
	Jun.	.16667	.27217	.546	-.3951	.7284
	Jul.	.20000	.27217	.470	-.3617	.7617
	Aug.	-.10000	.27217	.717	-.6617	.4617
	Sep.	.10000	.27217	.717	-.4617	.6617
	Oct.	.50000	.27217	.079	-.0617	1.0617
	Nov.	.80000*	.27217	.007	.2383	1.3617
	Dec.	.63333*	.27217	.029	.0716	1.1951
May	Jan	-.53333	.27217	.062	-1.0951	.0284
	Feb.	-.50000	.27217	.079	-1.0617	.0617
	Mar.	-.20000	.27217	.470	-.7617	.3617
	Apr.	-.20000	.27217	.470	-.7617	.3617
	Jun.	-.03333	.27217	.904	-.5951	.5284
	Jul.	.00000	.27217	1.000	-.5617	.5617
	Aug.	-.30000	.27217	.281	-.8617	.2617
	Sep.	-.10000	.27217	.717	-.6617	.4617
	Oct.	.30000	.27217	.281	-.2617	.8617
	Nov.	.60000*	.27217	.037	.0383	1.1617
	Dec.	.43333	.27217	.124	-.1284	.9951
Jun.	Jan	-.50000	.27217	.079	-1.0617	.0617
	Feb.	-.46667	.27217	.099	-1.0284	.0951
	Mar.	-.16667	.27217	.546	-.7284	.3951
	Apr.	-.16667	.27217	.546	-.7284	.3951
	May	.03333	.27217	.904	-.5284	.5951
	Jul.	.03333	.27217	.904	-.5284	.5951
	Aug.	-.26667	.27217	.337	-.8284	.2951
	Sep.	-.06667	.27217	.809	-.6284	.4951
	Oct.	.33333	.27217	.233	-.2284	.8951
	Nov.	.63333*	.27217	.029	.0716	1.1951
	Dec.	.46667	.27217	.099	-.0951	1.0284
Jul.	Jan	-.53333	.27217	.062	-1.0951	.0284
	Feb.	-.50000	.27217	.079	-1.0617	.0617
	Mar.	-.20000	.27217	.470	-.7617	.3617
	Apr.	-.20000	.27217	.470	-.7617	.3617
	May	.00000	.27217	1.000	-.5617	.5617
	Jun.	-.03333	.27217	.904	-.5951	.5284
	Aug.	-.30000	.27217	.281	-.8617	.2617
	Sep.	-.10000	.27217	.717	-.6617	.4617
	Oct.	.30000	.27217	.281	-.2617	.8617
	Nov.	.60000*	.27217	.037	.0383	1.1617

	Dec.	.43333	.27217	.124	-.1284	.9951
Aug.	Jan	-.23333	.27217	.400	-.7951	.3284
	Feb.	-.20000	.27217	.470	-.7617	.3617
	Mar.	.10000	.27217	.717	-.4617	.6617
	Apr.	.10000	.27217	.717	-.4617	.6617
	May	.30000	.27217	.281	-.2617	.8617
	Jun.	.26667	.27217	.337	-.2951	.8284
	Jul.	.30000	.27217	.281	-.2617	.8617
	Sep.	.20000	.27217	.470	-.3617	.7617
	Oct.	.60000*	.27217	.037	.0383	1.1617
	Nov.	.90000*	.27217	.003	.3383	1.4617
	Dec.	.73333*	.27217	.013	.1716	1.2951
Sep.	Jan	-.43333	.27217	.124	-.9951	.1284
	Feb.	-.40000	.27217	.155	-.9617	.1617
	Mar.	-.10000	.27217	.717	-.6617	.4617
	Apr.	-.10000	.27217	.717	-.6617	.4617
	May	.10000	.27217	.717	-.4617	.6617
	Jun.	.06667	.27217	.809	-.4951	.6284
	Jul.	.10000	.27217	.717	-.4617	.6617
	Aug.	-.20000	.27217	.470	-.7617	.3617
	Oct.	.40000	.27217	.155	-.1617	.9617
	Nov.	.70000*	.27217	.017	.1383	1.2617
	Dec.	.53333	.27217	.062	-.0284	1.0951
Oct.	Jan	-.83333*	.27217	.005	-1.3951	-.2716
	Feb.	-.80000*	.27217	.007	-1.3617	-.2383
	Mar.	-.50000	.27217	.079	-1.0617	.0617
	Apr.	-.50000	.27217	.079	-1.0617	.0617
	May	-.30000	.27217	.281	-.8617	.2617
	Jun.	-.33333	.27217	.233	-.8951	.2284
	Jul.	-.30000	.27217	.281	-.8617	.2617
	Aug.	-.60000*	.27217	.037	-1.1617	-.0383
	Sep.	-.40000	.27217	.155	-.9617	.1617
	Nov.	.30000	.27217	.281	-.2617	.8617
	Dec.	.13333	.27217	.629	-.4284	.6951
Nov.	Jan	-1.13333*	.27217	.000	-1.6951	-.5716
	Feb.	-1.10000*	.27217	.000	-1.6617	-.5383
	Mar.	-.80000*	.27217	.007	-1.3617	-.2383
	Apr.	-.80000*	.27217	.007	-1.3617	-.2383
	May	-.60000*	.27217	.037	-1.1617	-.0383
	Jun.	-.63333*	.27217	.029	-1.1951	-.0716
	Jul.	-.60000*	.27217	.037	-1.1617	-.0383

	Aug.	-.90000*	.27217	.003	-1.4617	-.3383
	Sep.	-.70000*	.27217	.017	-1.2617	-.1383
	Oct.	-.30000	.27217	.281	-.8617	.2617
	Dec.	-.16667	.27217	.546	-.7284	.3951
Dec.	Jan	-.96667*	.27217	.002	-1.5284	-.4049
	Feb.	-.93333*	.27217	.002	-1.4951	-.3716
	Mar.	-.63333*	.27217	.029	-1.1951	-.0716
	Apr.	-.63333*	.27217	.029	-1.1951	-.0716
	May	-.43333	.27217	.124	-.9951	.1284
	Jun.	-.46667	.27217	.099	-1.0284	.0951
	Jul.	-.43333	.27217	.124	-.9951	.1284
	Aug.	-.73333*	.27217	.013	-1.2951	-.1716
	Sep.	-.53333	.27217	.062	-1.0951	.0284
	Oct.	-.13333	.27217	.629	-.6951	.4284
	Nov.	.16667	.27217	.546	-.3951	.7284

*. The mean difference is significant at the 0.05 level.