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DUST HAZE AND IMPLICATIONS ON AVIATION AND HUMAN HEALTH OVER NORTHERN NIGERIA

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ABSTRACT

Dust haze is a recurring environmental phenomenon known to cause serious meteorological hazards, affecting the entire environment and, more specifically, the aviation industry and human health in northern Nigeria. This region experiences thick dust haze due to its proximity to the Sahara Desert, the primary source of the dust. This review was conducted to identify the most likely implications of thick dust haze on the aviation industry and human health. Data were retrieved from PubMed/MEDLINE, Web of Science, and Scopus to identify studies reporting the effects of thick dust haze on both sectors. Findings revealed that flight incidents and fatal accidents have occurred in dust-laden air due to reduced visibility, strong gusty winds, and wind shear. Additionally, atmospheric dust has both long- and short-term effects on flight operations, including corrosion and abrasion of aircraft surfaces as well as molten ingress deterioration of engine hot components. These combined impacts can increase operating and maintenance costs, ultimately raising the overall expenses for air lines. Furthermore, most studies reported significant public health risks associated with thick dust haze, including allergic reactions, respiratory illnesses, and cardiovascular diseases. Given the severe implications of this natural catastrophe on both the aviation industry and human health, this study recommends that greater attention be given to preparing for, responding to, and mitigating these hazardous events. Implementing appropriate measures can help reduce their negative impacts on aviation operations and public health.

Key Words: Dust haze, implications, Aviation, Human Health, Northern Nigeria.

1.1 Introduction

The atmosphere contains various types of particles known as aerosols. Sunnu (2006) asserted that aerosols occur in different forms, such as dust, fume, smoke, or pollen sprays. According to Friedlander (1977), “Particle size, besides concentration and chemical composition, is ranked as the most important factor determining such effects.” The term "dust haze" refers to a light cloud of fine particles that reduces visibility. The extent of visibility loss depends on the type and quantity of particles in the air, as well as the thickness of the dust haze. Dust hazes are natural hazards and are among the most common sources of natural airborne particles, including very fine materials, potential allergens, and pollutants (Goudie & Middleton, 2006). Depending on the dust's source, these materials and substances may include quartz, silicon dioxide, oxides of magnesium, calcium, iron, aluminum, organic matter, anthropogenic pollutants, and salts. Dust haze carries millions of tons of soil into the air each year, often traveling thousands of kilometers. It can last from a few hours to several days, distributing a significant number of fine particles into the atmosphere, increasing their concentration above permissible thresholds, and negatively affecting flight operations, human health, and the broader environment (Grineski et al., 2019).

On a global scale, the largest dust sources are found in Northern Africa, the Middle East, Central and Eastern Asia, Central Australia, the west coasts of Southern Africa and South America, and the south western United States (Ginoux et al, 2012). Dust events in other regions, including higher latitudes, are increasingly gaining attention due to the growing impact of climate change (Vukovic & Vimic, 2021; Meinander et al., 2022; UNCCD, 2022). While the impact of dust on aviation is most severe near major dust source regions, such as Northern Nigeria, significant problems can also arise in distant areas due to long-range transport (dust traveling thousands of kilometers) and indirect atmospheric effects.

Crooks et al. (2016) noted that dust haze is becoming more frequent in desert and arid regions worldwide, causing substantial damage and emergencies each year. Consequently, dust haze has garnered increasing attention in recent studies on PM 2.5 (particles with an aerodynamic diameter <2.5 µm), as their levels often exceed the World Health Organization's recommended thresholds. Studies conducted separately by Akhlaq et al. (2012) and Habnenberger & Nicoll (2012) found that particles in dust haze impact weather conditions, the aviation industry, human health, agricultural production, and ecosystems. In addition to threatening the ecosystem, dust haze significantly affects the aviation industry and public health (Goudie & Middleton, 2006). Similarly, Corfidi (2013) asserted that dust haze is not entirely a natural phenomenon and warrants attention for several reasons, particularly its impacts on human health. For instance, researchers at New York University Medical Center found that acid droplets in dust haze are hazardous to lung tissues and breathing passages. A comprehensive understanding of dust's impact on aviation and human health is crucial for minimizing associated safety risks, addressing health challenges, and mitigating economic losses.

Barbara et al. (2025) stated that dust haze storms are among the most abundant aerosols on a global scale, yet their impact management remains under recognized in the aviation community. Several air traffic incidents and accidents have been attributed to mineral sand and dust emitted from hyper-arid, arid, and semi-arid regions (Middleton, 2017; Nickovic et al., 2021). A historical analysis of air traffic incidents in Australia revealed a declining trend in sand- and dust-related incidents between 1969 and 2010, attributed to technological advancements (Baddock et al., 2013). However, aviation safety in dust-laden air is still compromised by reduced visibility, strong gusty winds, and wind shear (Middleton et al., 2019; Cuevas et al., 2021; Monteiro et al., 2022).

For instance, in May 2002, 14 people were killed in an aircraft accident in Tunisia due to a severe dust storm and poor visibility conditions (Tunisia Republic, 2004). Similar accidents occurred in India in May, 2011 (with 10 fatalities) and Sudan in August, 2012 (with 31 fatalities) (Middleton, 2017). Dust-induced icing also contributed to two fatal aviation accidents in 2009 and 2014 (Nickovic et al., 2021). Apart from civil aviation accidents, dust haze storms have severely impacted air ambulance services in Australia (Holyoak et al., 2011) and military operations in the Middle East (Henderson, 2014). To prevent dust-related aviation accidents, aircraft are often grounded or rerouted during severe dust storms. However, flight cancellations, delays, and rerouting lead to substantial economic losses for the aviation industry (Williams & Young, 1999; Tozer & Leys, 2013; Cuevas et al., 2021; Monteiro et al., 2022) and cause inconvenience for passengers.

Dust haze in northern Nigeria is a phenomenon that occurs when fine opalescence dust particles are lifted and laid in suspension in the air for weeks or even months by wind of low speed. According to Alozie (2002) dust haze weather is brought about by the dry, continental air mass that enters the country form the north east after a passage over the Sahara desert during dry season. He further maintained that between January and March each year ‘bouts’ of harmattan dust haze in low visibility affects flight operations in Nigeria, as the impairment makes it difficult to see the runway. He asserted that visibility normally follows known trends and as a result, flight control measures are scheduled in order to suit these periods, thereby causing a lot of flight delays, cancellations and airport congestions. This is therefore the crux of the work and it is very imperative to review the negative thick dust haze impacts affecting different phases of flight operations as well as that of human health.

Dust haze usually obscured visibility. Visibility that is a measure of the distance at which an object can be seen is one of the major meteorological hazards that affect flight operations especially in a tropical environment like Nigeria. Ayoade (1993) explained that visibility is assessed according to how far the observer can see into the distance”**.** He further highlighted that usually markers are installed at known distances from the point of observation so that the distance away of the farthest marker the observer can see at a given time will indicate the degree of visibility at that time**.** Visibility therefore, is dependent upon the transmission of light through the atmosphere and the ability of the eye to distinguish an object because it contrasts with the background.

The effect of poor visibility on air transportation has been revealed in two ways. When there is short term poor visibility at the airport, take- offs and landings are delayed until the condition improves. On the other hand, when the poor visibility persists, flight schedules are cancelled while arriving aircraft are diverted to a nearby unaffected airport so as to land safely.

Olatunde (2012) explained that since harmattan dust haze occurs at the surface of the atmosphere it is primarily a hazard during landing and take-off of aircraft. He also noted that Nigeria is not the potential source of this phenomena, it is only adverted to Nigeria through West Africa in the north eastern Sahara along the alluvial plain of Bulma Faya Largeau. Dust haze is derived from the action of wind erosion of soil and it is characterized by fine dust particles of microscopic nature, high wind and low precipitation which bring about visibility reduction. Visibility less than 800 meters and severe dust spell has been reported as having adverse effects on flight operations such as landing and take-off of aircraft. When visibility is brought to a minimum level, this immensely affects flight operations. This automatically leads to delays, cancellations of already scheduled flights and even accidents.

Olatunde (2012) further highlighted that when the climatic condition is not favourable, the passengers will not be assured of their safety, they will be in the state of despair. Any complication developed by the aircraft, even when it is not going to result in a crash could have caused passengers to have fainted, developed heart attack or even risen their blood pressure due to the insecurity they already have. All these could make a journey which is supposed to be pleasurable, a frustrating experience.

Studies again, have revealed that the effect of harmattan dust haze on pilot’s visibility is such that when the sky is not clear, the pilot will find it difficult to see where he/she is heading to. When light rays that should reach a focus in the eyes of the pilot has been scattered by harmattan haze particles, definitely the visibility of such a pilot will be reduced. For example, studies have revealed that on January 23, 2001, a terrible plane crash was recorded in Maiduguri at about 2020 GMT as a result of reduction in visibility to about 150 meters due to harmattan dust haze.

The extent of the obscured visibility that affects flight operations vary from one aircraft to another and also depends on the location and topography of a particular airport. For example, weather approach minimal manual for Aminu Kano International airport shows that this ranges from 1000 meters with aircraft category A (Small aircraft) to 2400 meters with 747, 8080.This implies that if the landmark or light beyond the distance of 1000 meters cannot be seen, aircraft is not supposed to land or take off. However, any aircraft that insist on landing or taking off is likely to crash.

Thus, dust haze storm can cause flight

delays, cancellations and diversions or flight incidents and even accidents when there is obscured visibility, wind shears and gusty winds that can led to flight incidents and accidents. However, as rightly observed by Williams and Young (1999); Tozer and Leys, (2013); Cuevas et al 2021) flight cancellations, delays or rerouting cause a significant loss for the aviation industry.

Essienimo, Momoh and Akpootu (2016) asserted that the winter (dry) season in north western Nigeria, which usually covers a period of about five months has for years been associated with the presence of large volumes of dust haze particles over the atmosphere. They added that in West Africa, and northern Nigeria in particular, dust haze dominates during the dry season from November to March, conveying dust across West Africa to the Atlantic Ocean and the wind system is associated with the ejection and transportation of dust haze from the Sahara Desert periodically to some areas in West Africa is known as the harmattan. They further observed and noted that the dust that affects a greater part of West Africa in winter south of latitude 15 ^{0}N particularly the Nigerian zone comes mainly from North eastern Sahara, usually along the alluvian plain of Bilma (18 ^{0}N, 12 ^{0}E) in the Southern Niger and Faya Largeau (18 ^{0}N, 19 ^{0}E) Chad of the western slope of Tibesti massive. Similarly, in the Nigerian context, the harmattan dust haze is a climatic condition of dry, dust-bearing desert breeze blowing from the northeast over West Africa, usually between late November and early March. This climatic condition of dust, smoke and other particles obscure the clarity of the sky and this usually forms a terrible atmosphere for man to live and operate effectively, most especially in the aviation industry of flight operations ranging from flight stake- off, landing, aircraft movement on the runway and even the flight process.

Thus, between January and March each year ‘bouts’ of harmattan dust haze in low visibility affects flight operations most especially in northern Nigeria, as the impairment makes it difficult to see the runway. However, the visibility normally follows known trends and as a result, flight control measures are scheduled in order to suit these periods, thereby causing a lot of flight delays and airport congestions. During the harmattan period too, the entire environment and to be precise, human health is equally been threaten as the thick dust haze usually poses and aggravate aliments and diseases among patients who are around where there is severity of this meteorological hazard.

1.2TheoreticalFramework

The Aerosol-Climate Interaction Theory, propounded by Charlson, Schwartz, Hales, Cess, Coakley, Hansen, and Hofmann in 1992, provides a suitable theoretical framework for understanding the implications of dust haze on aviation and human health over Northern Nigeria. This theory explains how aerosols, including dust particles, interact with radiation and clouds, influencing climate, weather conditions, and air quality. The principles of the theory highlight that aerosols affect atmospheric radiation balance by scattering and absorbing sunlight, modifying cloud properties, and altering precipitation patterns. Additionally, the theory emphasizes that the concentration, size, and composition of aerosols determine their impact on visibility, weather, and health. Applied to the present study, this theory helps explain how dust haze in Northern Nigeria reduces visibility, leading to flight disruptions, accidents, and increased operational risks in aviation. Furthermore, it accounts for the negative health effects of dust haze, such as respiratory diseases and cardiovascular issues, due to the inhalation of fine particulate matter (PM 2.5). The theory underscores the necessity for improved dust forecasting models, mitigation strategies for aviation safety, and public health interventions to minimize exposure to hazardous aerosols.

1.3 Methodology

1.3 The Study Area

1.3.1 Location

Anuforom (2007) has classified the climatic zones which comprises of northern Nigeria as whose ones lying between latitudes 9 ^{0} 11$^{'}$ N to 11^{0}14$^{'}$ N as northern- Central and Sahel climatic zones respectively.Figure1is the climatic map of northern Nigeria, showing the location of synoptic stations in the study area.

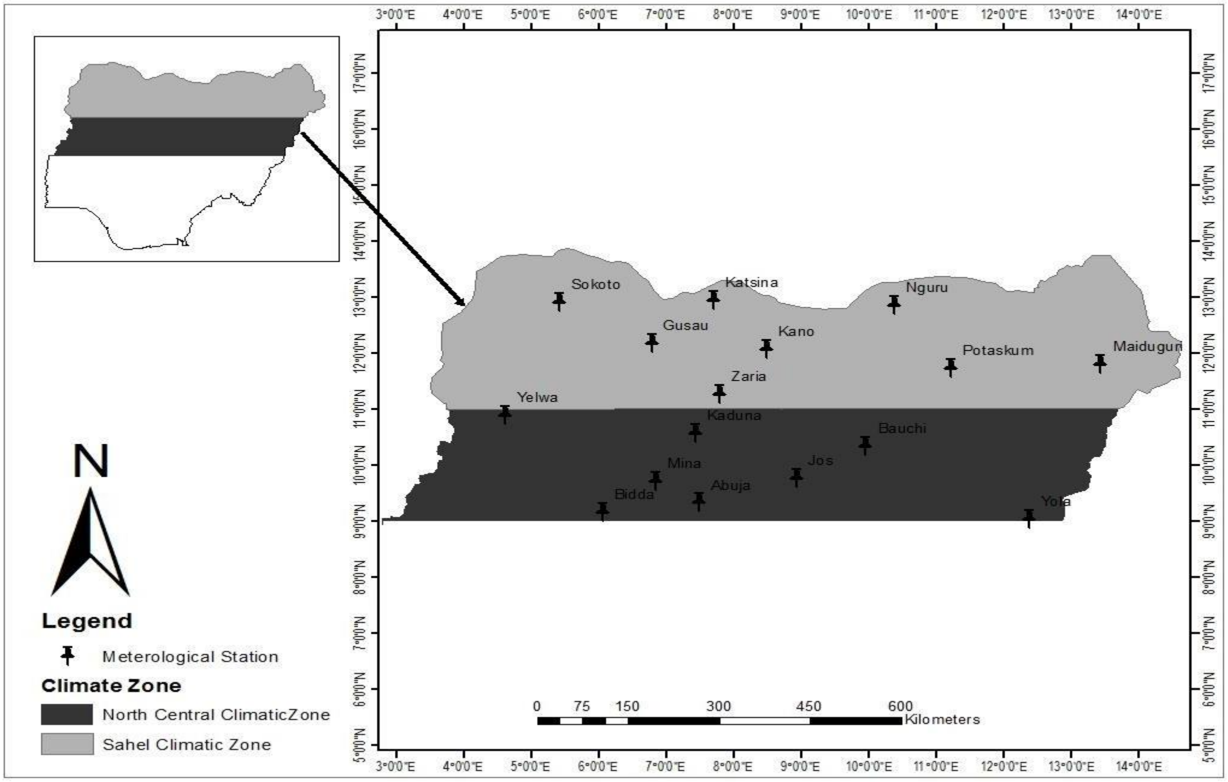

Figure1: The Location of the study area: Northern Nigeria showing the distribution of meteorological stations. Source: Anuforom (2007)

2.3.2 Materials and Methods

The study was designed to investigate dust haze and its implications on aviation and human health over northern Nigeria. The nature of the data generated includes information on the causes of dust haze, intensity of dust haze, and the effects of dust haze on aviation and human health. The source of data collection was basically from secondary sources of relevant scientific resources identified articles that were related to dust haze of both the aviation industry and human health. The empirical information which was obtained from PubMed, EMBASE, Scopus and ISI WoS (Web of Science) databases was searched and obtained to help review this meteorological hazard and its implication on aviation and human health over northern Nigeria.

3.0 Impact of Dust Haze over Northern Nigeria

3.1 Impact of Dust Haze on Aviation

The following sections review the negative thick dust haze impacts affecting different phases of flight operations. A detailed understanding of the impact of dust on aviation is important to minimize associated safety risks as well as economic loss. This is, therefore, the crux of the work, and it is imperative to review the negative thick dust haze affecting different phases of flight operations. Figure 2 summarizes most of these impacts on aircraft and runways for readers who are not familiar with the aviation-specific nomenclature.

According to Barbara et al. (2025) the impacts of dust hazards on civil aviation are diverse, but they can broadly be split into the different air traffic management phases (see Fig.2): (i) strategic

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planning, which consists of forecasting and capacity planning, route optimization, and airspace design; (ii) pre-tactical planning (i.e., 24 hours before the departure) and tactical operations, which are affected by the immediate hazard [i.e., if an intense sand and dust storm (SDS) approaches an airport and limits airport operations]; and (iii) post operation, which is essential for stakeholders who undertake Maintenance Repair and Overhaul (MRO), to deal with long-term effects of dust exposure on aircraft and engine performance (e.g., Ryder et al. 2024).

Thus, to relate this to the study area, Nigerian Civil Aviation Authority (NCAA) are in charge of prescribing special conditions for flights that require specific safety measures, while the meteorological conditions(e.g. visibility, wind speed and direction) for each airport are published as observed by the Nigerian Meteorological Agency (NiMet) or forecasted by the aerodrome meteorological office. To reduce the risk for aviation, Nigerian Airspace Management Agency (NAMA) Air Traffic Controls typically limit or suspend operational services during thick dust haze, reduced visibility, and high wind speeds. Service limitations can range from lowering the rate of operations (e.g., number of landings or takeoffs) to total airport closure if the conditions caused by thick dust haze are deemed unsafe (e.g. visibility is below a safe threshold). This has implications for airside operations, which include aircraft landing/takeoff and navigation, airport traffic management, runway management, and ground handling safety (ICAO 1986). Flights can therefore delayed, rerouted, or canceled disrupting the airport and airline operations and passenger travel. Passenger operations (e.g., check- in, baggage handling, and boarding) and landside operations (e.g., passenger pickup and drop-off curb areas of the airport, parking facilities, and other forms of transportation) can be affected as well.

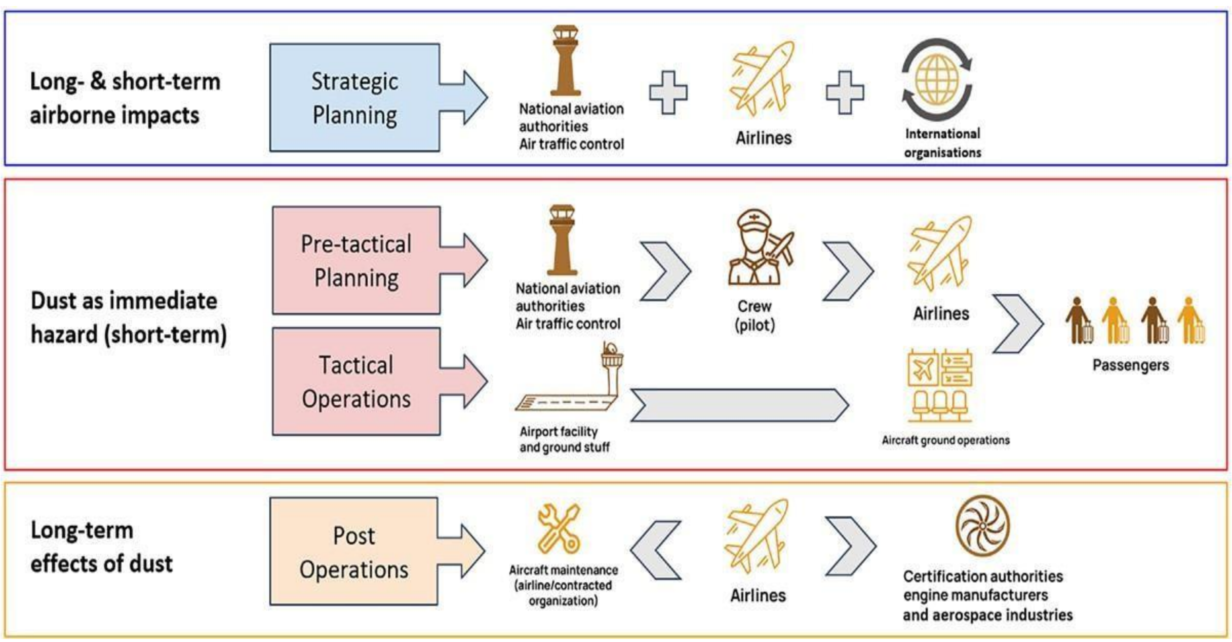

Fig.2:Impacts of dust haze on different ATM phases and affected stakeholders (After Barbara et al)

For example, studies which were conducted by the Nigerian Meteorological Agency (NiMet) (2011) showed the visibility reduction of 100–900 meters in the north and 600 – 800 meters in the south respectively, during the peak of these hazy conditions over most of the years under investigation. This is attributable to the dust haze phenomenon that originates at the Sahara desert of North Africa. Again, studies have shown that the signal of climate change in Nigeria has become visible as observed in other parts of the world. These include: the general increase in mean temperature, short rainfall duration and unusual patterns, increasing storm frequency, shift in onset/ cessation and duration of August break or dry spell and most importantly, increasing heat waves in the extreme north, which its eminent effects on flight operations is quite glaring..

3.1.1 Airport operations*:* As can be seen from the aircraft diagram below on figure 3, thick dust haze can significantly affect the activities at International airports of Abuja, the capital city of Nigeria, and others like Kano Yola, Kaduna, Maiduguri, Sokoto and so on, that are located in northern Nigeria. During very severe thick dust haze with high wind speed sand significantly reduced visibility, as a preventive measure, passengers and personnel need to stay inside the buildings. This helps prevent people from being Injured by flying debris and minimizes potential health effects from dust exposure (WHO 2021). All vulnerable parts of the grounded aircraft shall be covered to avoid intrusion and possible mechanical damage due to airborne aerosols. This includes nose cones, windscreens, wheel assemblies, engine cowlings, and pressure instruments that provide airspeed and altitude information(e.g. pitot tubes and static ports),which need to be protected against possible blockage due to dust sedimentation (e.g., Jackson 2015; EASA 2021) and subsequently incorrect measurements (e.g., AAIB 2022). Water-soluble minerals, contained in the dust, can cause metal corrosion to the airframe. To prevent this, dust deposits should be removed within an adequate time span (i.e., usually before the next flight). Since the contamination of the runway can adversely affect takeoff and landing performance, runway cleaning might be required after the event (ICAO 2002a, 2018a).

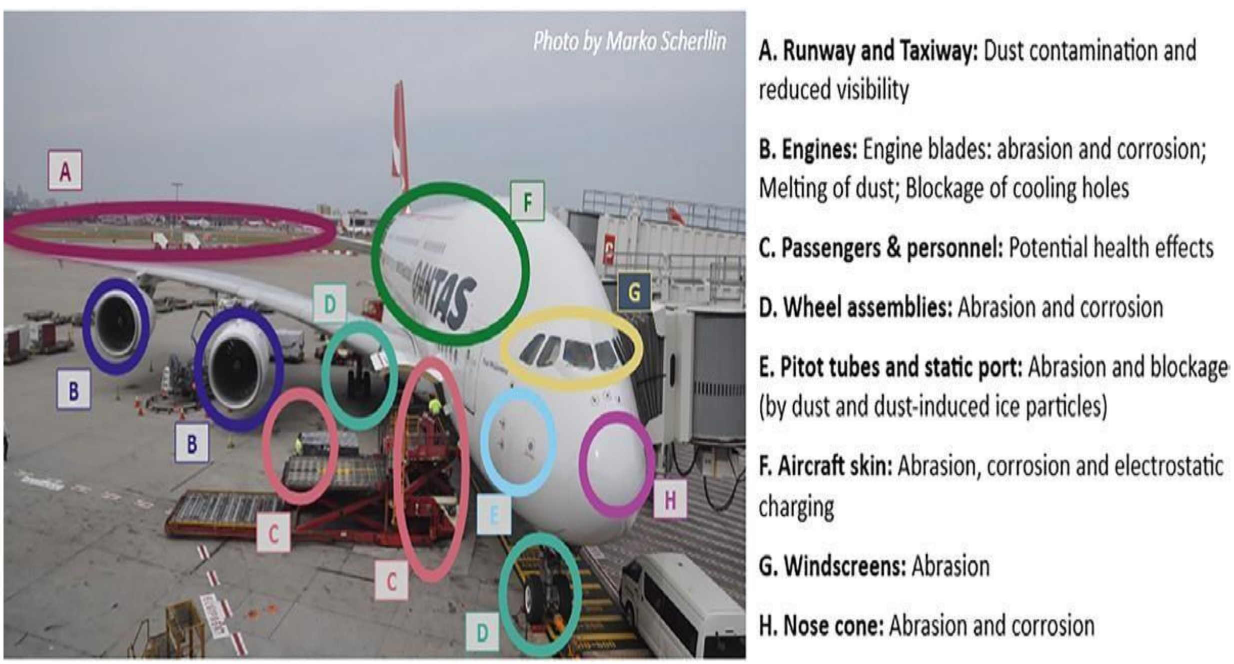

Fig.3: Aircraft and some airport-related impacts of mineral dust (After Barbara et al)

Reduced visibility is the major and most common problem of in-flight and ground traffic in dusty conditions, which typically requires reactive measures. During thick dust haze visibility can be reduced to near zero which makes any movement during the event difficult, dangerous, or even impossible (see Fig. 3). Visibility depends on the humidity (e.g., Häneland Zank, 1979; Zieger et al. 2013) and concentration of particles suspended in the air as well as aerosol optical properties (e.g., Waggoner and Charlson 1977). The literature shows large uncertainties in the estimation of the effects of aerosols on visibility in desert regions in North America (Chepil and Woodruff 1957; Patterson et al. 1976), Australia (Baddock et al. 2013), Asia (Shao and Wang 2003; Wang et al. 2008), and West Africa (d'Almeida1986; Ben Mohamed et al.1992; Camino et al. 2015). These large uncertainties can partly be explained by using particulate matter of different sizes as a proxy for dust and by different distances to the dust source region (optical obfuscation properties vary with size, dust size population decreases with the distance from the source because large particles drop out, and size and dust size population decreases with the distance from the source because large particles drop out and the remaining particles are finer sized far away from the source region).

`ECAC (1988) and ICAO (2013, 2016a) cited In Barbara et al highlighted that, if operations in low visibility conditions are permitted at an airport, the air traffic, meteorological and aeronautical information services provide relevant information, well defined and articulated procedures for operations in reduced visibility situations facilitate decision-making processes in aerodrome traffic management, including surface movement guidance and control.

3.1.2 Impact during takeoff and landing and at low flight levels:

Studies done by Barbara et al (2025) revealed that on dry dusty surfaces, flight operations of both small and giant aircrafts operating near the ground can generate dust concentration levels of several 100mg-3 which is usually referred to as brownout conditions. Several helicopter accidents were caused by brownout conditions which obscure the pilot's vision of the terrain and are therefore a significant safety threat, primarily affecting military operations in desert environments. In the lower atmosphere, dust can also reach very high concentration of up to 2-3 km above ground during major thick dust haze as has been indicated in the works of Cuevas, et al; 2021; Moniteiro et al, 2022, which affect the critical phases of flights, such as takeoff, climb, descent, holding patterns, and landing, as it is cited by Ryder, et al in Barbara, et al.

Typical examples of flight incidents and fatalities because of the Saharan thick dust haze can be seen as follows: At Aminu Kano International Airport, Nigeria, in the morning of 22nd January, 1973, poor visibility of only 300 meters, resulted to the loss of lives 183 people in a plane crash of a Jordanian airliner, (Adedokun et al., 1989). Again, in December, 1985, a B-747 aircraft belonging to the Nigerian government made a missed approach landing at the Murtala Mohammed International Airport in Lagos, recording a loss of nine lives due to the thickness of the harmattan dust haze. On January 23rd, 2001, a terrible plane crash was recorded in Maiduguri at about 2020 GMT as a result of reduction in visibility to about 150metersdue to thick harmattan dust haze. Investigations further shows that during flight phases, storms dust particles rubbing against the air crafts skin can increase the process of charging it, (Matsusaka, et al (2020) Again, a continuous occurrence makes the aircraft to reach an electrostatic equilibrium. This then can induce noise in radio communications of the aircraft, (Alozie et al, 2023). This electrostatic charging also represents potential hazard for ground personnel during refuelling or loading operations and this can equally a problem for onboard electronic devices that are not well protected from electromagnetic interference, (Lekas, 2019). Conversely too, Smialek (1991) and Brun et al (2012) the long term exposure to thick dust haze during flight can scrape aircraft surface including windscreens, landing light screens, and propeller and jet engine blades, as well as avionics. Erosion of external surfaces increase total drag and results in higher thrust settings and fuel consumption (leading to economic and environmental impacts) as well as reduced endurance and range of the aircraft. Surface damage of an engine can lead to gas flow deterioration and a gradual loss of the engine's performance and efficiency, (Hamed et al, 2006; Bojdo and Filippone 2019; Clarkson and Sapson 2017). In the works of Wood et al (2017) increased maintenance intervals and economic costs can result from aircraft flying through moderately dusty regions on a regular basis. He added that this has become a more prominent issue in recent years due to; the rise in air craft in dusty environments like Middle East; and the use of engines which are less tolerant to atmospheric aerosols because of increasing operating temperatures. Ryder et al (2024) show that this can aggravate when hold patterns coincide with the altitude of the local elevated dust plume but could be mitigated by night time takeoffs and landings.

Volcanic ash particles have been considered almost exclusively as a severe hazard because of melting in jet engines and depositing on the blades and inner parts. However, the continuous increase in turbine operating temperatures also raises the danger of dust melting (Wood et al. 2017) despite having up to a few hundred Kelvin higher melting points than volcanic ash. Furthermore, dust melting inside engines can lead to blockage of cooling holes (Cardwell et al. 2010).Therefore, dust exposure leads to a gradual reduction in engine efficiency and durability of certain components, mainly in the hot section of the engine.

The amount of melted dust deposit that builds up is a function of dust concentration, exposure time, engine thrust, and mineralogical composition (Clarkson and Simpson2017;Wood et al. 2017; Bojdo and Filippone 2019). Mineralogical composition of transported dust depends on the soil characteristics at dust sources (e.g., Nickovic et al. 2012; Gonçalves Ageitos et al. 2023). Mineralogical characteristics of transported thick dust haze are also important to predict because the combination of different molten minerals can exhibit different chemical properties and lead to thermal corrosion of engine components or electronic devices (Elms et al. 2021). Thus, due to the semi-arid and arid dusty soils in northern Nigeria this creates adverse effect on flight operations.

3.1.3 Impact during aircraft cruising at high flight levels: While volcanic ash is a severe risk at cruise levels (usually at an altitude between10and12km), the main threat from dust at these altitudes is associated with icing in and around convective weather systems. Thick dust haze particles can nucleate ice crystals in deep convective anvil cirrus. Over the last two decades, commercial airplanes have reported more than 150 cases of engine power losses and damage caused by cloud ice crystals (Haggertyet al. 2019). Furthermore, icing of instruments and sensors can result in false readings (e.g., barometric altimeters and airspeed and vertical speed indictors). Pitot tubes are particularly sensitive to icing which can cause obstruction and a bad airspeed indication, confuse pilots, and therefore degrade the flight safety.

Dust aerosols at a small concentrations in the upper troposphere can initiate efficient ice nucleation (Cziczo et al. 2013; Froyd et al. 2022). Aircraft on board weather radars often fail to observe ice crystals in anvils of convective clouds and so increase the risks due to icing (Haggerty, et al.2019).The role of dust in ice formation along the routes of two flights with catastrophic outcomes has been studied by Nickovic et al (2021).Official investigation reports identified icing along the routes crossing the periphery of the convective system as the cause of both accidents (BEA 2012; CEAIAC, 2016). Observations indicated the presence of high-altitude dust lifted from African sources by convection to the upper troposphere (Nickovic et al, 2012).

3.2.0 Impact of Dust Haze on Human Health over northern Nigeria

3.2.1 General Overview of Dust Haze on Human Health

According to Liu and Huza (1995) due to the small sizes of dust haze particulate matters, almost all dust haze particles, that is, airborne particles (PM) can enter the respiratory tracts. Larger particles are often deposited in the upper respiratory tract (nasopharyngeal region, tracheobronchial region), while smaller particles can enter deep lung tissue. Further studies reveal that the physical, biological, and chemical properties of these particles can cause disorders in the health of the body, and in addition to the respiratory tract, can damage other systems of the body, including the cerebral, cardiovascular, skin, blood, and immune systems, (Goudie, 2014). He further highlighted that contact to dust particles, which can remain in the air from hours to days, can result in other problems like conjunctivitis, meningitis, and yellow fever. In unusual cases, it can even lead to death. According to him frequent exposure to dust hazes can lead to increased adverse health effects in people of almost all age races and genders. Chen and Ng (2011) and Chen et al 2004) explained that people with a history of diabetes, hypertension, cerebrovascular, or pulmonary diseases are also at higher risk. Many epidemiological studies have determined the health effects of dust haze by comparing outcomes during dust hazes periods with- outcomes during non-dust haze periods and by assessing the relationship between dust haze or PM_{10} exposure and health outcomes. Many researchers have acknowledged the existence of a significant association between dust exposure and increased morbidity or mortality, but there is no consensus in this regard to date. Gianndaki et al stated that increased PM during dust storms caused a significant increase in mortality rate in Barcelona. Similarly, Chen et al. (2008), Kashima et al., (2012), and Delangizan and

Jafari (2013) also noted that increased PM_{10} levels during Asian dust hazes increased cardiovascular mortality.

Thalib and AL-Taiar (2012) and Trianti (2017) reported that Middle Eastern dust haze can affect inflammation and coagulation markers in young adults, and have adverse effects on pulmonary function, and increase the number of asthma patients. For humans, inhaling fine particles can generate and aggravate asthma, bronchitis, emphysema and silicosis. Finer dust haze also can deliver a range of pollutants, spores, bacteria, fungi and allergens. Other common problems include: eye infections, skin irritations and fever. In countries of the Sahel, dust haze loads arriving from the Sahara correlate strongly with meningitis outbreaks. Chronic exposure to fine dust contributes to premature death from respiratory and cardiovascular diseases, lung cancer and acute lower respiratory infections. According to Corfidi (2013), cited in Igbo- Uchi, (2020) poor visual air quality causes heightened levels of anxiety, tension and depression in humans, as well as interpersonal aggression and hostility. In other words, dust haze usually leads to multitudes of diseases.

Modarres (2008) in his study explains how dust hazes affect various aspects of human life. Aghababaeian et al (2012) explained that the current analysis indicated that the effects of dust storms on health can be divided into 2 general sections: short- and long-term effects. The researchers further explained that short-term effects have been defined here in as human health problems that occurred during or immediately after a dust haze storm, and long-term effects are defined as human health problems that occurred after a long exposure to several periods of thick dust storms. The short-term effects included all-cause mortality, emergency dispatch or air medical retrieval service, hospitalization or admission, healthcare visits, daily symptoms, decreased pulmonary function, and other problems, (Aghababaeian et al 2012).

According to Igbo –Uchi (2020) aerosol surface properties such as adhesion, sorption (i.e. adsorption and absorption), and condensation are involved in a large number of chemical reactions including surfaces for micro-organism transport and the spread of air borne diseases. It will therefore be interesting to know the influence of the Saharan dust on children and diseases like irritation in the throat, cold symptoms, catarrh and cerebrospinal meningitis (CSM), whose outbreak occurs in the harmattan period. This conclusion is in line with, Hayward and Oguntoyinbo (1987).The Saharan dust aerosol fills the surrounding air within which all atmospheric processes occur. The particles can directly affect the eye and skin, physically causing irritation to them. The Saharan dust also dehydrates the body causing injury to the parts sensitive to dryness such as the sides of the feet and lip sof the mouth. The major effect is on the respiratory system of man and animals since dust particles smaller than 2.5 μm diameter can penetrate through the non-ciliated airways and then induce specific effects on the lungs (Wilson and Spengler, 1996). Scientists will therefore be interested in the Saharan dust particle size distribution, particularly over northern Nigeria.

Similarly, the Saharan dust aerosol particles reaching northern Nigeria are mostly less than 20 μm in diameter. Tsor (2003) and Sunnu (1997) observed that 95 per cent of the number of particles of the Saharan dust is composed of particle numbers with sizes less than 10 μm in diameter and the number of particles in the range 0.5-1.0μm constitute 80percent of the sample size range of 0.5-25 μm while studies other places northern Nigeria found 98.7percent of the number of particles of the Saharan dust particle numbers to be composed of less than orequalto5μm diameter particles. Hence, the Saharan dust particle size range reaching northern Nigeria is very significant for breathing, which involves particles less than 2.5 μm diameter. Therefore, through respiration, harmattan aerosol particles can reach the lungs, with possible health consequences on the respiratory system of mammals. The inhalation of large quantities of dust can result in a variety of lung damage, the degree of damage depending on the composition of the dust. Although particle size is important, the shape e.g. asbestos, density and reactivity of the particles together determine how the particles are transported and react in the human respiratory tract. Target sites within the respiratory tract vary with aerodynamic size of particles as well as other factors. This can be seen by examining the variation of respiratory penetration and retention with particle size shown in the Table1.1 below (Wilson and Spengler, 1996). Most of the particles greater than 10μm in diameter and about6 0- 80 percent of particles between 5μm and10μm are trapped in the nasopharyngeal region of the respiratory system. Larger particles are subject to inertial and centrifugal deposition before reaching the deeper respiratory system.

Very small particles (<0.1 μm diameter) penetrate and deposit deeper in lungs by diffusion forces.

Here, the air movement is slow and distances between surfaces are short. The lungs are least efficient at retaining the particle sizes that accumulate in the atmosphere. These particles circumvent many of the respiratory system's defense mechanisms, such as cilia, and are capable of delivering relatively high concentrations of potentially harmful substances, often causing severe damage at the cellular level. Thus it is observed that the effect on health due to aerosol particles inhalation is associated with fine particles rather than coarse particles.

Table 1: Respiratory Penetration versus Particle Size. After Wilson and Spengler (1996)

Particlesize (µm)	Respiratory penetration
11 ≤	Particles do not penetrate
7-11	Particles penetrate nasal passage
4.7-7	Particles penetrate pharynx
3.3-4.7	Particles penetrate the trachea and Primary bronchi
2.1-3.3	Particles penetrate secondary Bronchi
1.1-2.1	Particles penetrate terminal bronchi
0.65-1.	1Particles penetrate bronchioli
0.43-0.65	Particles penetrate alveoli

The following are some mechanisms underlying association between atmospheric particulate dust pollution and mortality: increased airways permeability and airways inflammation leading to impaired gas exchange and hypoxia (or acute oxygen deficiency), increased susceptibility to infection from impaired host defences, increased lung permeability leading to pulmonary oedema, provocation of alveolar inflammation by ultra-fine (<0.02 µm) particles with release of mediators that exacerbate underlying lung disease and increase blood coagulability and specific toxicities, among others. Generally, ultra-fine particles cause greater inflammation than larger (coarse) particles of the same substance (Wilson and Spengler, 1996).Therefore, increased dust level in the tidal (respiratory/respirable) air can also put alot of stress on the respiratory system of mammals, resulting in chest and respiratory disease and sickness thus capable of increasing morbidity and mortality.

3.2.1 Impact of Dust Haze on Human Health and Mortality over northern Nigeria

Researches from almost all regions and most especially at the study area indicate that mortality due to dust storms by means of different health problems, such as increased total non- accidental deaths, cardiovascular deaths, mortality due to acute coronary syndrome and respiratory mortality are common among patients where the thick dust haze regions is quite eminent, (Crooks, et al 2016). Some studies reported, however, that the number of cases was not increased significantly for all causes, (Al-Taiar and Thalib 2014; Chawartz, 1999) respiratory (Chen, Ng 2011; Al-Taiar and Thalib 2014) cardiovascular mortality (Diaz, Tobias, Linares, 2012). As was cited by Aghababaeian (2012). reported that associations for respiratory mortality was -0.76 (-4.69.3.28) on thick dust days have a protective effect on non- accidental deaths, respiratory deaths and death in people older than 65 years of age.

3.2. 2 Hospitalization or admission due to Dust Haze Storm Phenomena

Studies have shown that almost all over the study area, there are cases of hospitalization or admission due to dust storms by means of different health problems or diseases. Jimme et al (2020) who conducted a research on the Human Perception on the effects of Dust Storm on the Health of Residents' of Damaturu Metroplis, Yobe (which is part of the study area of this work) asserted that the winds caused blowing sand and dust increases hospital admissions as well as increases in asthma and respiratory diseases. Thus, at the fringes of northern Nigeria due to the semi- arid and arid nature of the environment with limited vegetation, this scenario seems to be worse. Outdoor environmental dust has been linked to numerous health problems. Fine dust particles can carry a range of other harmful things including bacteria, virus, fungi, pollutants and allergies. Dust haze exposure may cause or worsen: irritation of the eyes, nose and throat, coughing and wheezing, low respiratory tract infections (viral bacterial and fungal including cococidiomyosis), obstructive airway diseases (asthma, bronochitis, COPD), lung fibrosis (sand and dust associated silicosis), interstitial lung diseases and cardiovascular diseases. The results indicated that in many studies, dust storms were associated with an increased risk of hospital admission due to cardiovascular, cerebrovascular, and respiratory diseases, among others.

3.2. 3 Other impacts

Some articles explored the relationship of dust storms with road traffic accidents, risk of suicide, placental abruption, and the health-related quality of life. Soy, Yaziel, and Kulduk et al (2016) found that sand- storms and number of vehicles were significantly responsible for road traffic accidents. They further reported that dust storms can have adverse effects on the quality of life of patients with asthma and allergies. Rutherford et al (1999) on their part too reported that, dust storms can decrease health-related quality of life in everyone exposed to them. It has been noted in several studies that exposure to dust storms was associated with even an increased risk of suicide.

4, Conclusion

Thick dust haze is among the natural environmental hazards that are most violent and unpredictable phenomena. Strong and gusty winds lift dust and sand particles into the atmosphere, unleashing a turbulent, suffocating cloud that can reduce visibility to almost zero level in a matter of second sand cause catastropheric effects on the entire environment, including the aviation industry and human health that result to property damages, incident sand fatalities. Thick dust haze therefore has a strong correlation between dust events, aviation industry and human health, ranging from flight delays, cancellations, diversions, airport congestions, as well as flight incidents and accidents. This in turn increased workload for airport and airline staff, an inconvenience for passengers, and a considerable economic loss for the aviation industry. More so, thick dust haze causes a substantial cost of maintenance due to deterioration in aircraft and engine performance and in-service life. For instance, Luthansa Technik (2022) estimated that the engine can deteriorate up to 3 times quicker in dusty arid regions. Driven by military and civil aviation as it is the fastest means of transportation for socio-economic and political gains, the understanding of dust haze impacts on aircraft systems and aviation operations has improved in recent years. However, while individual effects such as dust damage to turbine blade are already known from the maintenance expert’s point of view, they are not necessarily well quantified and cannot be prevented in an operational environment due to missing data and the missing information flow from data providers to aviation end users. In view of this, more information is a requirement also for more realistic and accurate cost benefit analysis.

Besides the increasing frequency and intensity of weather extremes and other climate hazards, (IPCC 2021) there are increasing risks of favourable conditions for more globally distributed, more frequent and more intensive thick dust haze and other dust-related events (blowing dust, long –range dust transport and deposition). Land use and cover change due to agriculture, retreat of glaciers, drying of lakes and rivers, among others, can expose land to wind erosion in areas which do not currently recognize thick dust haze hazards and their impacts. For this reason, development and implementation of knowledge of all hazards, including the ones related to air borne dust, is welcomed in all sectors, especially in aviation which targets proactive mitigation measures to prevent great losses in lives and money. More so, the aviation sector should be better recognized as a beneficiary of implementation of climate change and land degradation targets, defined by UNFCCC and UNCCD.

Conversely, although thick dust haze which affects a range of human health issues, including respiratory problems, cardiovascular complaints, meningococcal meningitis, conjunctivitis, skin irritation, and deaths and injuries associated with transport accidents in obscured visibility are enormous, inhabitants of such environments are taking the meteorological hazards with less caution. In view of this, there is strong need for public enlightenment and advocacy on the health and socio- economic implication of thick dust haze. Based on the insights gained from the research, residents should use a facial nose and mouth mask always. The eyes should be protected during a dust storm using spectacles to offer minimal protection from blowing microscopic particles and sand; protect themselves properly by avoiding exposure to thick dust haze and by staying indoors against flying objects moving around.

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