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An Analysis of Bird Strike Trends at Akanu Ibiam International Airport, Enugu State, 2012-2022

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ABSTRACT
Bird strikes at airports pose significant risks to aviation safety, potentially leading to accidents, damage to aircraft, and financial losses. This research focused on comprehensive analysis of bird strike trends at Akanu Ibiam International Airport, Enugu over the period 2012 to 2022. A mixed-methods approach was used to collection and analyses of the data. The results of the study showed that black kite emerges as the predominant bird species involved in bird strikes, accounting for 52% of incidents, followed by guinea fowl (22%), hawk (13%), gull (10%) and common kestrel (3%). Bird strikes exhibit temporal variations, with the highest occurrences in 2021) and the lowest in 2019. Weather conditions are the pivotal factors influencing the occurrence of bird strikes at Enugu with the clear skies (41%) as the highest and the raining condition as the lowest. (21%). Factors contributing to bird strikes extend beyond weather conditions and include the proximity of trees, refuse dumpsites, and farmlands near the airport perimeter. Current bird strike mitigation measures were found to be moderately effective, with 92% of respondents indicating their perceived effectiveness. Ultimately, this research underscores the proactive management of bird strikes as a paramount priority to ensure the safety of passengers, crew, and the aviation industry as a whole....
Keywords: Bird, Strike, Akanu Ibiam, International, Airport, Enugu.

INTRODUCTION:

Bird strike has become a major threat to air safety globally (Usuman et al, 2012; Ekici et al, 2023). Since 1912 when the first fatal collision between bird and aircraft was recorded, over 500 people around the world have died from plane crashes caused by bird strikes (Bird Strike Control Programme, 2009a). Over the years, collision between birds/wildlife and aircrafts has resulted in the death of hundreds of people and is responsible for annual losses worth about US $1.2 billion to the global aviation industry (Usuman et al, 2012). The most fatal air crash recorded and caused by birds occurred in Boston, USA in 1960 killing 62 people (Celebrate Boston.com, 2008). Enugu Airport, officially known as Akanu Ibiam International Airport Enugu (AIIAE), is a vital transportation hub located in Enugu State, Nigeria, facilitating both domestic and international travel. Nevertheless, similar to airports globally, Enugu Airport is also confronted with a significant challenge of bird strikes, where birds collide with aircraft during takeoff, landing, or mid-flight. Bird strikes present substantial hazards to aviation safety, causing damage to critical components such as aircraft engines, nose cones, and windshields and, in extreme cases, leading to accidents. Any attempt at reducing or preventing bird and other wildlife hazards at an airport requires a thorough training and experience, knowledge of the local and regional landscape, ecological conditions and avifauna (Soldatini et al. 2010; Dessalegn 2011). Again, preventing bird strike requires training and experience (Plate 1)(Sgt. Amber Monio, 2023)



Plate 1: An Incident of Bird Strike on an aircraft's Windshield(Sgt Amber Monio, 2023)

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Conducting a comprehensive study on bird strike trends at Enugu Airport is of paramount importance for some reasons. Bird strikes can result in human casualties and financial losses, affecting both the aviation industry and the wider economy. It has been estimated that Nigerian airline operators lose about N15 billion to bird strikes annually(This Day Online, 2010). Understanding the contributing factors to bird collisions is also crucial in developing effective strategies to minimize such incidents, thereby ensuring the safety of passengers, crew, and overall aircraft operations.

Enugu Airport is located in an environment that is highly prone to bird strike incidents. The airport's proximity to natural habitats, water bodies, and agricultural areas attracts various bird species, thus increasing the risk of conflicts between these avian populations and aircraft. This situation poses a significant threat to aircraft safety. By analyzing bird strike trends, it is possible to identify spots within the airport vicinity that have a high risk of such incidents. This valuable information can then be utilized to implement targeted mitigation measures.

The most famous case of a bird strike involved US Airways Flight 1549 in 2009 (popularly known as the "Miracle on the Hudson"). Several minutes before landing, the aircraft crashed into a flock of wild geese, which caused damage to its engines and forced the pilot to perform an emergency landing on the Hudson River. Thanks to the pilot's skills, all the passengers survived the crash. The economic impact of bird strikes at Enugu Airport is substantial. Costly repairs and replacements of damaged aircraft components add financial burdens to airlines. Flight delays and disruptions caused by bird strikes result in revenue losses and diminished customer satisfaction. Moreover, the negative perception of Enugu Airport's safety due to bird strike incidents can negatively affect tourism, thus impacting the local and regional economy Effective bird strike management strategies are economy imperative to safeguard aviation safety and ensure the economic vitality of Enugu State and its surrounding area. Bird strikes are a common phenomenon in the aviation industry and have become a major threat to air safety globally. It is simply a collision between an airborne animal (most likely a bird) and an aerial vehicle, usually an aircraft (MMS PLUS NG, 2021). Nigerian carriers are not left out of these circumstances as they continue to grapple with the challenges of bird strikes resulting in loss of aircraft engines, loss of revenue and operational equipment. Mr. Bola Ahmed, an official from the Nigeria Airspace Management Agency (NAMA) during the maiden edition of a symposium on Reduction on Wildlife Strike Hazard at Nigerian Airports in Lagos, said that 127 bird strike cases were recorded in 2019, 193 recorded in 2017, while 98 and 58 cases were recorded in 2016 and 2015 respectively(MMS PLUS NG , 2021). This shows increasing trends over time

These incidents demonstrate that bird strikes are a global concern and highlight the necessity for proactive measures to enhance aviation safety.. High incidence of bird/wildlife strikes in Nigeria has been attributed to the attraction of many species of wildlife to the airports due to the presence of thick bushes, waste dumps and farmlands around the airports (Leadership Online, 2011 and The Nation Online, 2011). It is against this background that this paper aimed to examine the bird/wildlife strike situation in Nigeria and the control measures adopted to reduce the risk/hazards in ensuring safer air transportation in the Country Furthermore, insights from previous studies and incidents related to bird strikes at Enugu Airport or similar locations can provide valuable knowledge. These studies shed light on the occurrence of bird strikes at Nigerian airports, including Enugu Airport. They highlight the prevalence of certain bird species and identify actual and potential factors contributing to bird collisions, such as inadequate waste management practices and proximity to natural habitats. Additionally, incidents involving bird strikes at Enugu Airport have been documented in aviation safety databases and incident reports. The Wildlife/Pest Hazard Control in under the Environment Department is the one in charge of this report at Enugu Airport. These records underscore the urgent need for comprehensive research to understand the specific dynamics of bird strike occurrences at the airport and develop targeted strategies to mitigate the associated risks. This study aimed to investigate bird strike trends at Enugu Airport from (2012-2022) and develop effective strategies to mitigate bird collisions. To achieve this aim, the following specific objectives were pursued to: identify the bird species involved in bird strikes at Enugu Airport; analyze temporal patterns of bird strikes at Enugu Airport (2012-2022); identify the factors responsible for the occurrence of bird strike at Enugu airport; assess the effectiveness of current bird strike mitigation measures at Enugu Airport.

LITERATURE REVIEW

Bird strikes in Nigeria and world-wide appear to be increasing over the last few years. Bird strikes are defined as a collision between a bird and an aircraft which is in flight or on a take off or landing roll(European Organization for the Safety of Air Navigation, 2019). A bird strike occurs when a bird collides with an aircraft or is ingested into an engine. While many bird strikes cause minor damage, some can result in engine failure, structural damage, flight delays, or emergency landings (FAA, 2025). International aviation organizations, such as the International Civil Aviation Organization (ICAO), recognize bird strikes as a continuing safety hazard that requires structured management rather than ad hoc control (ICAO, 2023). Globally, wildlife strikes (primarily birds) have caused over 643 fatalities and destroyed more than 360 aircraft from 1990 to 2024. In the United States, over 319,000 strikes were reported from 1990 to 2024, including 82 fatalities and 126 aircraft destroyed, with strikes rising 14% from 2023 to 2024 to reach 22,372 incidents (about 61 per day) (FAA, 2025). Over 90% occur below 500 feet

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above ground level during takeoff and landing phases. Aircraft collisions with birds and other wildlife cost the airline industry, and ultimately the flying public, approximately US $2 billion, annually (USA, 2009). The greatest loss of lives directly attributed to bird strike occurred on 4th October 1960 when a Lockheed L-188 Electra flew through a flock of starlings during take-off damaging all four engines. The aircraft crashed shortly after take-off into Boston Harbour USA, killing 62 out of 72 passengers. On the average, aircraft crashes every eighteen months as a result of a bird strike related incident in Manchester Airport (Thomas, 1990).Traditionally, bird strike prevention relied on human patrols, scare tactics, and visual monitoring. These methods are limited by weather, visibility, and human reaction time. Modern sensor detectors have therefore become essential tools for understanding when, where, and why bird strike risks increase. By collecting accurate data over time, these sensors allow airports to manage bird strike trends rather than simply reacting to individual events (Dolbeer et al., via FAA, 2025; Robin Radar Systems, 2025)

Barras et al. (2002) reviewed published studies to summarize findings on habitat management techniques that have shown potential for wildlife strike reduction. Habitat components that may attract wildlife to airports include food, cover, water, and loafing areas. Although maintaining tall herbaceous vegetation on airfields may reduce the attractiveness of loafing and feeding sites for some species of birds such as gulls, this strategy may also increase cover and food resources for other hazardous species. Thus, optimum vegetation height management strategies require further research and may be site-specific. According to Beason and Begier (2006), assessing wildlife hazards to aviation in the airport environment is typically initiated by conducting wildlife hazard assessment (WHA). Ecological relationships between wildlife populations and habitat are usually discerned through observations during the course of one annual cycle. He opined that proximate hazards on the airport are well defined during the WHA process, off-airport features also can attract wildlife. Wildlife species can transit airport property travelling to and from habitat attractants.

In Kenya, Nasirwa (2001) observed that approximately 21% of all Kenya's bird species are migratory. The migrants include 171 palaearctic, 55 Afro tropical and four Malagasy migrant species. Non-migrant species too are very mobile. The bulk of migratory birds visiting or passing through Kenya use the Rift Valley, coast, eastern bush lands, central and western grasslands as their flyway. About 46% of Kenya's migratory species are water birds. These migrate mainly along the Rift Valley and the coast. Over 70% of the water bird populations concentrate in the major Rift Valley lakes. These lakes are also on the flight path of most international airline routes to and from Nairobi. While en route, airplanes fly at higher altitudes than migrating birds.

In Nigeria, the airline operators are bleeding financially to fix damaged parts of aircraft due to bird strikes running into billions of dollars. In 2008, Arik Air, the largest domestic carrier, experienced over 34 incidents of bird strike attacks on its aircraft, costing the manager over N3.2 billion (US $20.67 million) to fix its aircraft struck by birds. Another operator Dana Air lost over N270 million (US $1.7 million) in 2010 due to the attack of birds on its aircraft. In fact, Harold Demuren, director general, Nigerian Civil Aviation Authority (NCAA), had in June 2010 lamented that bird strike incidents account for over 40% of all incidents that occur within the airports, adding that the Mallam Aminu Kano International Airport, Kano, is among the list of airports where aircraft engines and other parts had been badly damaged by such occurrence (Dumerun, 2010). Over 850 species of birds have been documented in the country which is associated to some particular environment (Shobakin, 2009). Adekola (2022) reported that at least 93 bird strike incidents occurred in our airports across the nation between January and June 2022, and out of this number, 54 of it happened in Lagos Airport alone, which represents about 70 per cent of the total occurrence. In 2019, Federal Government of Nigeria threatened to shut down Akanu Ibiam International Airport Enugu because of the proximity of the airport to a market which also houses an abbatior that exposes the airport regular bird strikes at the airport(Quadri 2019). Any attempt at reducing or preventing bird and other wildlife hazards at an airport requires a thorough knowledge of the local and regional landscape, ecological conditions and avifauna (Soldatini et al. 2010; (Dessalegn 2011). Based on this background, this study aimed to investigate bird strike trends at Enugu Airport from (2012-2022).

Conceptual Clarifications

1.0 Introduction

A bird strike occurs when a bird collides with an aircraft or is ingested into an engine. While many bird strikes cause minor damage, some can result in engine failure, structural damage, flight delays, or emergency landings (FAA, 2025). International aviation organizations, such as the International Civil Aviation Organization (ICAO), recognize bird strikes as a continuing safety hazard that requires structured management rather than ad hoc control (ICAO, 2023). Globally, wildlife strikes (primarily birds) have caused over 643 fatalities and destroyed more than 360 aircraft from 1990 to 2024. In the United States, over 319,000 strikes were reported from 1990 to 2024, including 82 fatalities and 126 aircraft destroyed, with strikes rising 14% from 2023 to 2024 to reach 22,372 incidents (about 61 per day) (FAA, 2025). Over 90% occur below 500 feet above ground level during takeoff and landing phases.

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2.0 Regulatory background and reporting systems

ICAO requires certified aerodromes to establish Wildlife Hazard Management Programmes (WHMPs). These programmes focus on continuous monitoring, risk assessment, mitigation, and evaluation. ICAO also operates the Bird Strike Information System (IBIS), which collects verified bird strike reports from member states and produces global trend analyses (ICAO, 2023).

At the national level, authorities such as the Federal Aviation Administration (FAA) in the United States, the European Union Aviation Safety Agency (EASA), and the Nigerian Civil Aviation Authority (NCAA) provide detailed guidance on wildlife hazard management. These documents explicitly encourage the use of technology, including radar and surveillance systems, to improve detection and reporting accuracy (FAA Advisory Circular 150/5220-25, 2010; EASA, 2021; NCAA, 2017, with 2023 updates).

3.0 Airport-based sensor detectors

3.1 Avian radar systems

Avian radar is currently the most advanced and widely accepted sensor technology for bird detection at airports. Unlike conventional air traffic radar, avian radar is designed to detect small biological targets such as birds and bird flocks at low altitudes. These systems continuously track bird movement around runways, approach paths, and departure corridors (FAA Advisory Circular 150/5220-25, 2010; DeTect, 2025). Avian radar allows airport operators to see bird activity invisible to the human eye, especially at night or in poor weather. The radar data can show flight direction, altitude, speed, and bird concentration. When bird activity exceeds predefined risk thresholds, alerts can be sent to wildlife control units and air traffic controllers.

Over time, avian radar data helps airports identify recurring hotspots, high-risk times of day, and seasonal migration patterns. This makes it possible to predict periods of increased bird strike risk and take preventive action, such as adjusting runway use or delaying departures. By 2025, systems like Robin Radar's MAX and DeTect's MERLIN are deployed at over 820 airports worldwide, with documented reductions in strikes (Robin Radar Systems, 2025; DeTect, 2025). A notable case is Aalborg Airport (Denmark), where avian radar implementation led to a **75%drop** in strikes by 2018, with continued benefits reported in recent integrations (Innovation News Network, 2022).

3.2 Visual camera systems and artificial intelligence

Electro-optical cameras are widely used at airports to monitor runway environments. Modern systems are often combined with artificial intelligence software that automatically detects and tracks birds. These systems provide clear visual confirmation of bird presence and are especially useful for identifying birds on the ground or near runway edges (EASA, 2021).

Visual systems support bird strike trend management by recording when and where birds repeatedly appear. They also help verify radar detections and provide evidence for safety audits and training. However, their effectiveness is reduced in fog, heavy rain, or darkness.

3.3 Thermal and infrared sensors

Thermal and infrared cameras detect heat signatures rather than visible light. This makes them particularly effective during night operations and low-visibility conditions. Birds standing on runways or grass areas can be detected even when they are not visible to pilots or ground staff (DeTect, 2025).

Thermal sensors are often used alongside visual cameras and radar to improve detection reliability. Their contribution to trend management lies in identifying nocturnal or early-morning bird activity that may otherwise go unrecorded.

3.4 Acoustic monitoring systems

Acoustic sensors use microphones to detect bird calls and environmental sounds. While they cannot prevent bird strikes directly, they help identify patterns of bird presence, such as breeding or roosting periods. This information supports long-term planning and habitat management (EASA, 2021).

Visual camera systems and artificial intelligence

4.0 Aircraft-based sensor technologies

4.1 Onboard radar systems

Standard aircraft weather radar is not designed specifically to detect birds. Although large flocks may sometimes appear on radar displays, this method is not reliable for routine bird avoidance. For this reason, bird strike prevention relies more heavily on airport-based detection systems rather than aircraft-mounted radar (FAA, 2025).

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4.2 Engine and vibration monitoring sensors

Modern aircraft engines are equipped with sensors that continuously monitor vibration, temperature, and rotational speed. When a bird is ingested into an engine, these sensors can detect abnormal changes. This allows flight crews and maintenance teams to identify possible bird strikes even when external damage is not visible (FAA, 2025). These sensors play an important role in trend management by improving the accuracy of bird strike reporting and enabling better analysis of strike severity and frequency.

4.3 Structural health monitoring

Structural Health Monitoring systems use embedded sensors to detect impacts and structural changes in aircraft components. Although still developing in commercial aviation, research shows that these systems can identify impact events such as bird strikes and help assess damage severity. This supports maintenance decisions and improves long-term safety data (emerging studies referenced in FAA wildlife reports, 2025).

4.4 Use of sensor data for bird strike trend management

The greatest benefit of sensor detectors comes from integrating their data into airport safety management systems. By combining radar, camera, thermal, and aircraft sensor data with weather information and flight records, airports can identify trends rather than isolated incidents (DeTect, 2025; Robin Radar Systems, 2025). Trend analysis allows airports to determine which runways are most affected, which species pose the greatest risk, and which times of year are most dangerous. It also enables evaluation of mitigation measures, helping airports decide whether control strategies are effective or need improvement.

5.0 Relevance to airports in developing regions

Studies conducted at airports in developing regions, including Nigeria, show that bird strike risks are strongly influenced by surrounding land use, waste disposal practices, and local bird species. Limited access to advanced detection systems often results in moderately effective bird control measures.

Recent Nigerian data highlights the urgency: Murtala Muhammed International Airport (MMIA), Lagos, recorded four bird strikes on Runway 18R in a single day in 2025—the highest daily rate nationally. Between 2021–2022, at least 127 incidents were reported nationwide, with Lagos as a hotspot. In early 2025, airlines like Air Peace grounded aircraft due to multiple strikes (NCAA reports via Leadership.ng, 2025; Premium Times, 2025).

A phased approach is recommended, starting with improved reporting and basic surveillance, followed by the gradual introduction of advanced sensors such as avian radar. This approach aligns with ICAO guidance and allows airports to build capacity sustainably (ICAO, 2023; NCAA, 2017/2023).

Conclusion

Modern sensor detectors have transformed bird strike management from a reactive process into a proactive and data-driven safety system. Airport-based sensors, particularly avian radar combined with visual and thermal monitoring, provide the most effective means of detecting and managing bird activity—with proven reductions (e.g., up to 75% in cases like Aalborg). Aircraft-based sensors support accurate reporting and post-strike assessment. When properly integrated into wildlife hazard management programmers, these technologies significantly reduce risk and improve understanding of bird strike trends, especially amid rising global incidents from 2020–2026.

STUDY AREA

Akanu Ibian International Airport(Enugu Airport), is located in Emene, a suburb of Enugu city, serving as a key gateway for southeastern Nigeria, located approximately 2km north of Enugu City in the southeastern part of Nigeria. As a crucial transportation hub for the region, Enugu Airport plays a significant role in facilitating domestic and international travel flight and cargo services(Vanguard, 2020). Situated at approximately 6.4744° N Latitude and 7.5619° E Longitude, (Fig. 1).

Enugu Airport rests at an elevation of around 366 meters (1,200 feet) above sea level. Its single asphalt runway stretches for approximately 3,600 metres (11,811 feet), accommodating various types of aircraft(Fig. 2). Enugu Airport facilitates connections to major Nigerian cities like Lagos, Abuja, and Port Harcourt, as well as international destinations, making it a key contributor to economic activities, tourism, and travel in southeastern Nigeria.

The area surrounding Enugu Airport exhibits diverse landscapes, including urban areas, agricultural land, forests, and water bodies. The airport's location in this region brings it close to natural habitats, such as wetlands, rivers, and areas abundant in vegetation. These environmental features can attract bird populations and potentially contribute to bird strike incidents.

Akanu Ibiam International Airport is surrounded by a thriving network of rapidly growing cities and towns. Notable among these are Nsukka, Awka, Abakaliki, Onitsha, Okigwe, Afikpo, Nnewi, and Owerri. Positioned at the heart of the region, the study area serves as a central hub, benefiting both residents and travellers from nearby regions.

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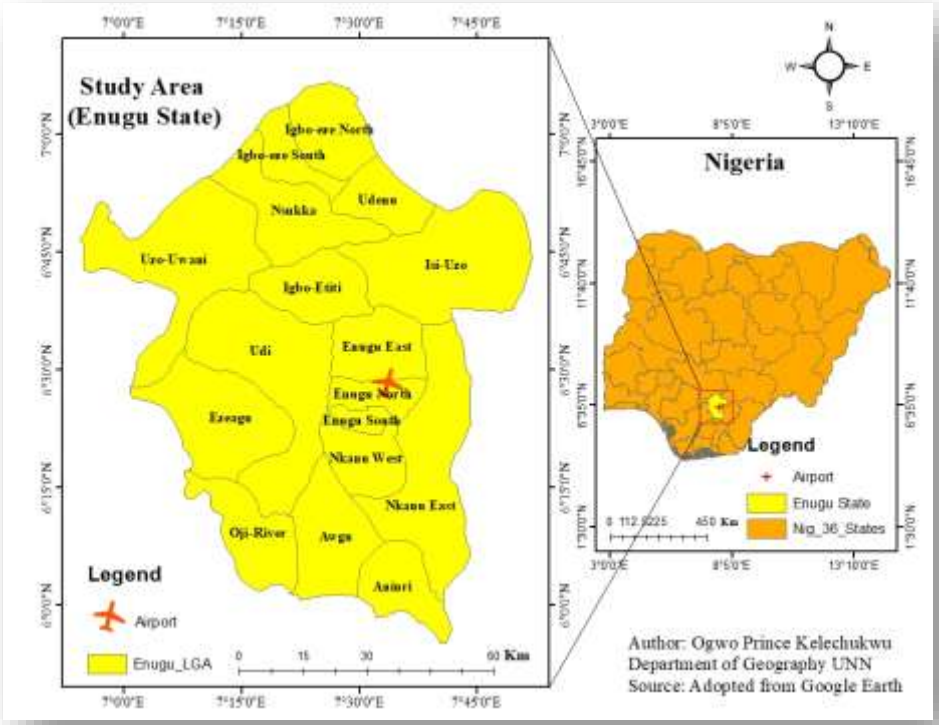


Fig 1: Nigeria showing Enugu state

Source: Adapted from Google maps (2023

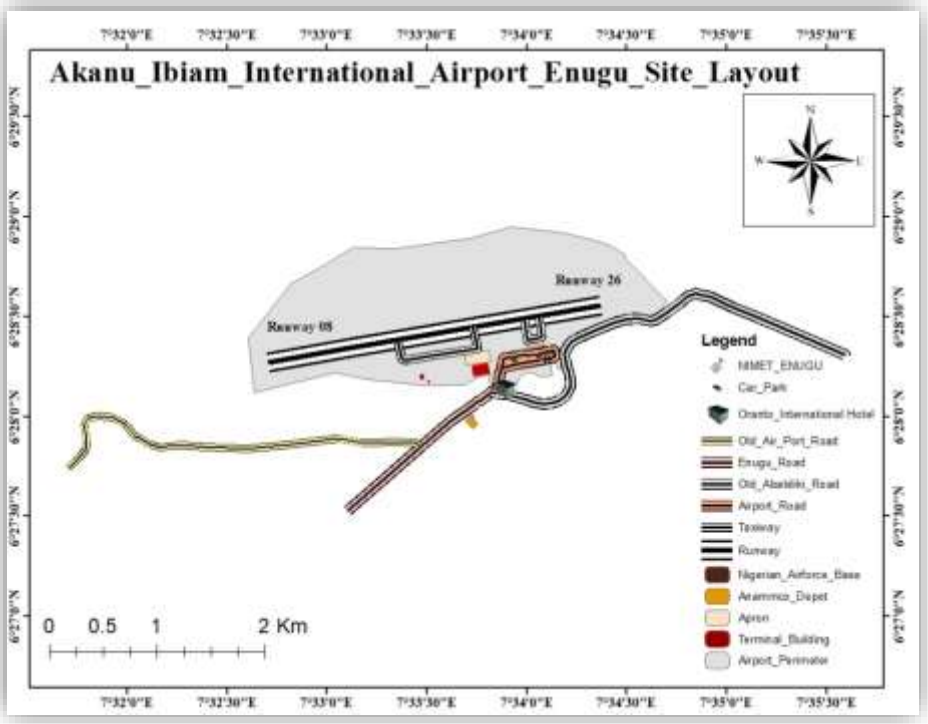


Fig 2: Map Sowing Enugu State and the study area: Akanu Ibiam International Airport

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Source : Adopted from Google Maps (2023)

METHODOLOGY

This study adopts a comprehensive approach, integrating both quantitative and qualitative methods, known as a mixed methods approach. The data collection comprises primary data collection, field observations, and secondary data collection To investigate birdstrike trends at Akanu Ibiam International Airport, Enugu (AIIAE), bird-strike incident data was obtained from the Airport Bird and Wildlife Hazard Control Department. Additionally, to provide context, field observations were conducted to gain crucial insights into bird behaviour and habitat characteristics. Field observations were conducted at the Airport to supplement the questionnaire data. Trained observers who have full experience in the field were deployed to record bird species present in the airport vicinity, their behaviors, and the potential hazards they pose to aircraft operations. The observations were carried out at various times of the day and during different seasons to capture a comprehensive picture of bird activities and their variations over time. These field observations provided valuable insights into the actual presence and behavior of bird species, complementing the self-reported data obtained through the questionnaires.

The secondary data collected involved historical birdstrike incident reports, spanning from 2012 to 2022, were meticulously sourced from the archived records maintained by AIIAE, which operates under the management and jurisdiction of the Federal Airports Authority of Nigeria (FAAN). These records contain comprehensive information about past birdstrike incidents, including the date, time, location, and bird species involved.

DATA ANALYSIS

The data analysis involved a dual approach employing both descriptive statistics and time-series analysis to comprehensively explore the temporal patterns and trends in birdstrike incidents at Enugu Airport from 2012 to 2022.Descriptive statistics, including frequency distributions, were utilized to summarize birdstrike incidents during various temporal periods such as months, seasons, and years. To delve deeper into the temporal dynamics, a time-series analysis was conducted. This involved plotting the birdstrike data over ten years and employing appropriate statistical models to discern significant trends, seasonal variations, and recurring patterns. Inferential statistical techniques, such as ANOVA, were employed to explore relationships between birdstrike incidents and various factors, including time of day, weather conditions, and specific bird species. These analyses identified significant associations between these factors and birdstrike occurrences, offering valuable insights into potential risk factors.

RESULTS AND DISCUSSIONS

Bird Species Involved in Bird Strikes at Enugu Airport (AIIAE)

The comprehensive analysis conducted to identify the bird species involved in bird strike incidents at Enugu Airport over the period from 2012 to 2022 has yielded significant insights into the composition of avian species contributing to these incidents. The data categorization reveals the following distribution of bird species responsible for bird strikes:

Black Kite (*Milvus migrans*) – 52%:

In Table 1 among the identified species, the Black Kite emerges as the most prevalent avian species involved in bird strike incidents, constituting a substantial 52% of all reported cases. (See Fig. 3). The black kite, a raptor known for its adaptable behavior and scavenging tendencies, appears to be drawn to the airport environment due to factors that warrant further investigation. The prevalence of this species underscores the necessity of targeted management strategies to mitigate its attraction to areas of high aviation activity. Also, the territorial behaviour of the black kite is a major reason for having the highest incidents of 52%. The Black kites always view an incoming aircraft as an opposition, which makes them adamant until they are struck by an aircraft. One of the intriguing aspects of the Black kite's diet is its feeding behavior concerning termites. Termites constitute a significant portion of the Black kite's diet, especially in certain regions and during specific times of the year. These birds are highly adaptive predators, often observed hovering and swooping over grassy areas to catch termites emerging from their nests.

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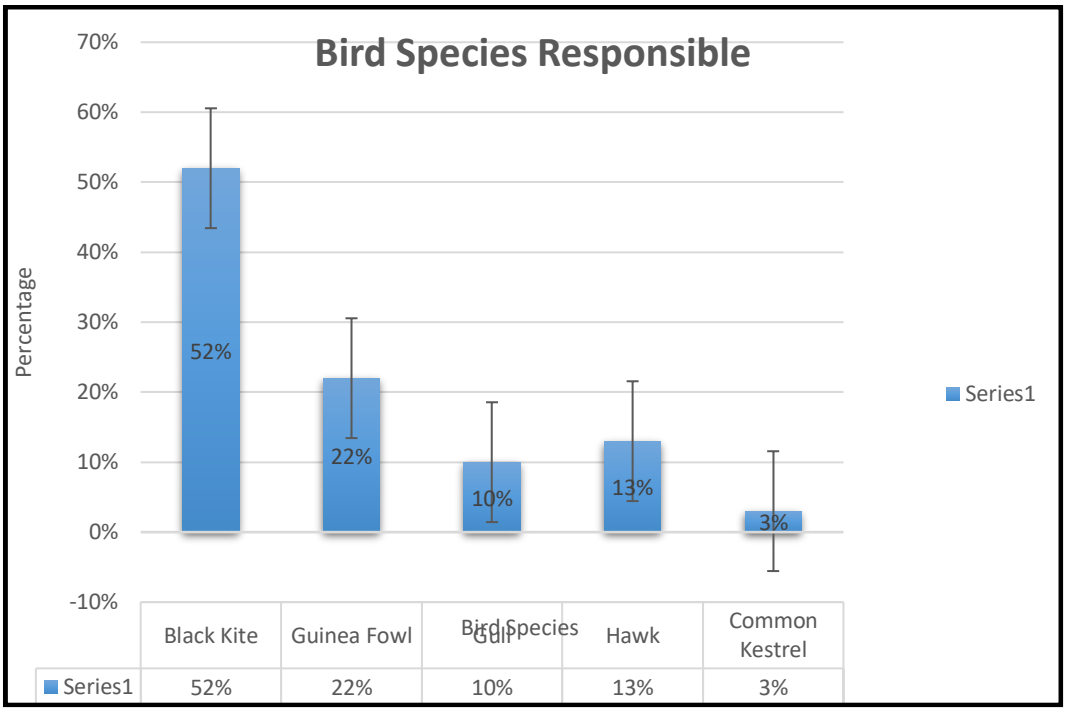


Fig 3: Bird Species Involved in Bird Strikes at Enugu Airport (AIIAE)

Guinea Fowl (*Numididae*)- **22%:**
In Table 4 and Fig 4, Guinea fowl occupies a prominent position with 22% representation among bird strike incidents, necessitating a nuanced comprehension of its behavioral proclivities and habitat affinities. Guinea fowl, characterized by its terrestrial feeding practices and communal behavior, tends to congregate in locales adjacent to grasslands and open expanses. This behavioral disposition renders guinea fowl particularly susceptible to heightened exposure to aircraft encounters. Their ground-feeding habits, which involve foraging for seeds, insects, and other small invertebrates, inherently necessitate movement across open areas, potentially intersecting with aircraft flight paths. The guinea fowl's habitat choices reveal insights into its sustained presence in proximity to the airport. Notably, guinea fowl displays an established residency in habitats characterized by grasslands and open areas. This habitat affinity aligns with the airport's surroundings, which often feature grassy patches and adjacent expanses. Unlike migratory species, guinea fowl's year-round residence in its chosen habitats underscores its propensity to remain in areas where habitat suitability and resource availability converge. Consequently, the presence of guinea fowl near the airport might be a result of habitat factors that promote both their sustenance and congregation. The guinea also moves in flocks and they fly at very low altitudes and short distances. Their flight is usually low to the ground and may involve short hops or gliding rather than extended soaring. Due to their relatively heavy bodies and limited flying capabilities, guinea fowl typically remain close to the ground when they do fly.

Gull(*Larinae*) **-10%:**
In Table 4 and Fig 3, the presence of gulls in 10% of bird strike incidents at Enugu Airport underscores the significance of examining their behavior and habitat tendencies to elucidate their coexistence with aviation activities.
Many gull species exhibit migratory patterns, traversing extensive distances. The presence of water bodies, such as ponds or lakes, near the airport can attract migrating gulls, thereby influencing their involvement in bird strike incidents. Gulls' penchant for aquatic habitats aligns with the availability of water features near the airport. The presence of these habitats contributes to gulls' propensity to co-occur with aviation operations.

Hawk(*Buteo*) **– 13%:**
In Fig 3, the analysis reveals that hawks, comprising around 13% of bird strike incidents, are also significant contributors to avian collisions with aircraft. Hawks are predatory birds with keen visual acuity, often occupying elevated perches that offer a vantage point for hunting. Their presence in the airport vicinity raises questions about the correlation between their hunting behaviors and flight patterns. A thorough investigation into the interactions between hawks and airport operations could illuminate strategies for reducing their presence in areas of high flight traffic. Hawks' predatory nature and aerial prowess render them susceptible to inadvertent intersection with

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aircraft. Their vigilance during hunting, coupled with their soaring capabilities, amplifies their presence near aviation facilities. Hawks' habitats typically encompass diverse landscapes, often including open areas suitable for hunting. The presence of these habitat features near the airport's vicinity can foster their sustained presence.

Common Kestrel(*Falco tinnunculus*) – 3%:

In Table 4 and Fig.3, the Common Kestrel, constituting approximately 3% of bird strike incidents, is an additional species with notable involvement in avian collisions with aircraft. Despite its smaller size relative to other species, the common kestrel's contribution underscores the significance of understanding factors that attract even smaller raptors to the airport area. Investigating the habitat preferences, foraging patterns, and nesting behaviors of the common kestrel could inform strategies aimed at minimizing its interactions with aviation infrastructure**.**

In conclusion, the findings of this study shed light on the diverse bird species contributing to bird strike incidents at Enugu Airport. The prevalence of each species underscores the necessity of understanding their behavioral propensities and habitat preferences to devise effective strategies for aviation safety and wildlife management.

The black kite, constituting 52% of bird strike incidents, draws attention due to its territorial behaviour and adaptability to various habitats. The intersection of its migratory routes with the airport vicinity necessitates a focused approach to mitigate risks, especially in light of its perception of aircraft as opposition. The coexistence of grass-covered runways and kite-foraging habitats warrants tailored strategies for cohabitation and safe aviation operations.

Gulls, representing 10% of incidents, exhibit opportunistic behavior and adaptability to water-associated habitats. Migratory tendencies further accentuate the need for proactive measures to address their presence around aviation facilities. The intersection of water bodies and airport surroundings necessitates wildlife management approaches that account for their potential interactions with aircraft.

Contributing 13% to incidents, hawks present heightened susceptibility due to their predatory characteristics and soaring abilities. Varied migratory behaviors and habitat choices underscore the need for comprehensive wildlife management strategies that encompass their presence, thus reducing the risks associated with their interaction with aviation operations.

The common kestrel, involved in 3% of incidents, showcases agile hunting behavior and migratory inclinations. Its presence near the airport is underlined by habitat affinities, necessitating an understanding of their interactions with aviation activities and tailored mitigation approaches.

In conclusion, an intricate understanding of the behavioral tendencies and habitat preferences of the bird species involved in bird strike incidents is paramount. By leveraging these insights, airports can develop robust and adaptive wildlife management plans that ensure harmonious coexistence between aviation operations and avian fauna, ultimately enhancing aviation safety

Temporal Patterns of Bird Strikes at Enugu Airport

The investigation into the temporal patterns of bird strike incidents at Enugu Airport from 2012 to 2022 has uncovered intricate trends that shed light on the dynamics of these incidents. During the initial years (2012-2015), bird strike incidents exhibited a remarkable consistency, with incident percentages fluctuating modestly between 8% and 11%, indicating a persistent baseline level of risk(Fig. 4). A noticeable transition in bird strike patterns occurred in the years 2016 and 2017, with declines attributed to interventions or alterations in airport operations. The year 2018 witnessed a sudden increase, illustrating the evolving relationship between avian populations and the changing landscape of aviation activities.

In the years 2019 and 2020, lower percentages of incidents were observed, possibly due to heightened mitigation efforts, changing weather patterns, or shifts in local bird populations. However, 2021 saw a resurgence, emphasizing the resilience of bird populations.

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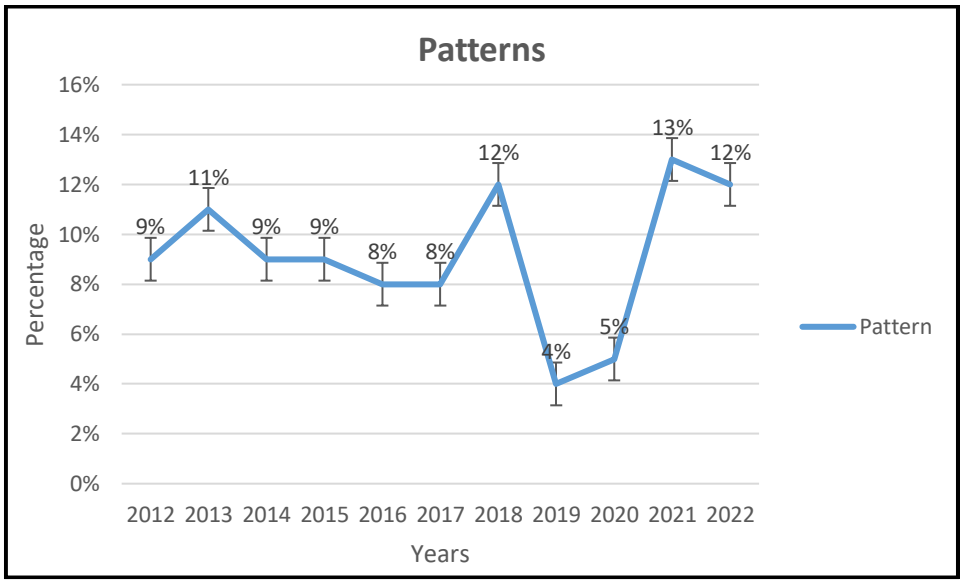


Fig 4: Temporal Patterns of birdstrikes at Enugu Airport

The final year of the study, 2022, recorded bird strike incidents at 12%, underscoring the enduring challenge of mitigating bird strikes in a dynamic environment. These insights guide the development of targeted strategies that address both immediate and long-term challenges, ensuring the safety and security of aviation operations.

Factors Responsible for The Occurrence of Bird Strikes

Table 3 shows weather conditions and percentages.

Weather Condition	Percentages (%)
Clear	41
Foggy	37
Raining	21
Total	100

One of the pivotal factors influencing the occurrence of bird strikes at Enugu Airport is weather conditions. The analysis, visually represented in a circle diagram, encapsulates the distribution of bird strike incidents concerning three primary weather conditions: Clear, Foggy, and Raining.

Clear weather conditions account for the highest proportion at 41%, signifying favorable visibility. Foggy conditions represent 37% of bird strike incidents, highlighting the critical role of reduced visibility in facilitating bird strikes. Raining conditions comprise 21% of the analyzed bird strike incidents, with rain potentially increasing bird activity near airport runways and impacting takeoff and landing procedures.

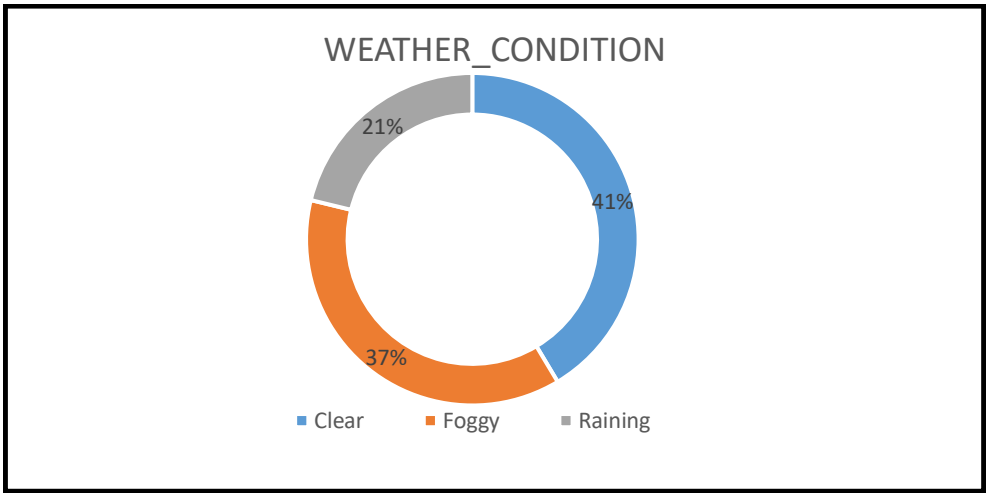


Fig 5: Factors (Weather conditions) Responsible for The Occurrence of Birdstrike at Enugu Airport

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In conclusion, the graphical representation of weather condition-related bird strike incidents provides a tangible visualization of the multifaceted interplay between avian activity and varying atmospheric conditions, illuminating the need for comprehensive strategies that account for weather-related risks.

The ANOVA analysis was conducted to assess the impact of weather conditions on bird strike incidents at Enugu Airport. The table 4 summarizes the ANOVA results. From In Table 4, the ANOVA results reveal a statistically significant effect of weather conditions on the number of bird strike incidents at Enugu Airport at the p-value associated with the "Between Groups" factor is 0.0033, which is below the commonly used significance level of 0.05. This indicates that weather conditions significantly influence the occurrence of bird strike incidents. Consequently, the null hypothesis is rejected, affirming that differences in weather conditions contribute to variations in bird strike incidents.The F-Statistic of 6.9695 exceeds the critical table value of

Table 4 ANOVA Summary

	D.F	**Sum of Squares**	**Mean Square**	**F-Stat**	**Critical table Value**	**P-Value**
Between Groups	2	21.8786	10.9393	6.9695	3.32	0.0033
Within Group	30	47.0885	1.5696			
Total	32	68.9671				

3.32, further corroborating the statistical significance of the results. The analysis underscores the importance of considering weather conditions as a factor in addressing bird strike incidents and implementing suitable mitigation strategies.

OTHER FACTORS CONTRIBUTING TO BIRDSTRIKE OCCURRENCE

Proximity and Diversity of Habitats: The immediate proximity of varied natural habitats, encompassing wetlands, grasslands, and aquatic ecosystems, directly influences bird activity around the airport. Such habitats provide vital sustenance and nesting sites for avian species, amplifying the attraction of birds towards the airport's vicinity and elevating the potential for hazardous interactions with aircraft.

Land Utilization Practices: The dynamics of land utilization in the airport's vicinity exert a pronounced impact on avian presence. Farmlands, characterized by potential food sources and open spaces, inadvertently become alluring foraging grounds. Similarly, urbanized zones may inadvertently offer roosting opportunities for birds, collectively contributing to their congregational presence near the operational areas of the airport, particularly the runway.

Waste Management Strategies: Scrutiny of waste management practices highlights the inadvertent role they play in birdstrike risk. Sites designated for refuse disposal, positioned in proximity to the airport, inadvertently entice scavenger species like gulls and crows. These areas act as significant feeding grounds, invariably resulting in heightened bird activity close to critical operational zones such as runways and taxiways.

Influence of Migration: The airport's strategic positioning along migratory routes assumes significance. During migration seasons, the airport may witness an influx of migratory bird species seeking reprieve during their long journeys. This congregation magnifies the risk of birdstrikes and requires a meticulous understanding of migration patterns to effectively mitigate hazards.

Airport Infrastructure: The physical elements of the airport's infrastructure hold an unforeseen sway over bird presence. Lighting systems, towering structures, and accessible waste containers can inadvertently attract avian attention. Lights can disorient nocturnal birds, structures can inadvertently serve as roosting sites, and accessible waste bins facilitate easy access to food sources.

Effectiveness of Current Bird Strike Mitigation Measures

Mitigation Measures.

The assessment of the prevailing bird strike mitigation measures at Enugu Airport, as reported by relevant stakeholders, reveals diverse perspectives regarding their effectiveness.

A minor proportion of respondents, constituting 1%, regarded the current measures as "very effective." The majority, comprising 92%, characterized the current measures as "moderately effective," indicating positive

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outcomes with room for optimization. A minority of 7% perceive the measures as "not effective," emphasizing areas requiring targeted improvements(See Table 4)

Table 4 shows the effectiveness of the mitigation measures

Effectiveness	Percentage (%)
Very Effective	1
Moderately effective	92
Not effectively	7

Source: Authors' fieldwork 2023

Moreover, an in-depth examination of the spatial distribution of bird strike incidents at Enugu Airport revealed critical insights into areas of heightened risk. This analysis pinpointed 'hotspots' within the airport's vicinity where bird strikes occurred more frequently. Identifying these hotspots is pivotal for the strategic placement of mitigation measures, such as bird deterrent systems and habitat management. Concentrating efforts in these high-risk zones can significantly reduce the probability of bird strikes, thereby enhancing safety. Additionally, the study explored the correlation between bird strike incidents and flight paths, helping aviation authorities optimize routes to minimize interactions with bird-prone areas.

CONCLUSION

In the pursuit of understanding birdstrike trends at Enugu Airport and devising effective mitigation strategies, this study has unveiled crucial insights that bear significance for both aviation safety and wildlife management. The comprehensive analysis conducted over the ten years, from 2012 to 2022, provides valuable findings and recommendations.

First and foremost, the identification of bird species contributing to bird strikes reveals the multifaceted composition of avian species involved in these incidents. The prevalence of species such as the black kite, guinea fowl, gull, hawk, and common kestrel underscores the need for a nuanced approach to mitigate the risks associated with their presence. Understanding their behavioural tendencies and habitat preferences is paramount in formulating targeted strategies for harmonious coexistence.

The temporal analysis of birdstrike incidents illuminates the nuanced nature of bird strike patterns, revealing phases of stability, transition, and resurgence. These temporal patterns underscore the necessity of a multifaceted approach to birdstrike mitigation, taking into account factors such as avian behaviors, habitat changes, and evolving aviation operations. Such insights guide the development of strategies that address both immediate and long-term challenges, ensuring the safety and security of aviation operations.

Furthermore, this study delves into the factors responsible for birdstrike occurrences, with weather conditions playing a pivotal role. The interplay between clear, foggy, and rainy conditions provides valuable insights into the complex dynamics that influence avian activity near the airport. These insights underscore the need for comprehensive strategies that account for weather-related risks and help in reducing potential avian collisions with aircraft.

Lastly, the evaluation of the effectiveness of current birdstrike mitigation measures at Enugu Airport reveals that while the prevailing measures are considered moderately effective by a majority of stakeholders, there is room for optimization. Holistic approaches encompassing habitat modification, perimeter management, runway, and taxiway vigilance, chemical treatments, and auditory deterrents are instrumental in reinforcing the comprehensive nature of the mitigation strategy. This demonstrates the unwavering dedication of Enugu Airport to enhancing aviation safety and preserving the ecological equilibrium.

In conclusion, the findings of this study provide a comprehensive understanding of birdstrike phenomena at Enugu Airport, from the species involved to the temporal patterns and the factors influencing these incidents. The insights derived from this research serve as a cornerstone for the development of effective strategies aimed at reducing bird strike occurrences. The collaborative efforts of aviation authorities, wildlife management experts, and environmental stakeholders are pivotal in ensuring the safe coexistence of aviation activities and avian fauna.

As the aviation industry evolves, the continuous research and adaptation of mitigation measures are essential to meet the ever-changing challenges. By leveraging these insights, Enugu Airport and similar aviation facilities can develop robust and adaptive wildlife management plans that ensure harmonious coexistence between aviation operations and avian fauna, ultimately enhancing aviation safety.

Recommendations

An avian radar system should be installed to alert control tower operators, allowing them to inform pilots of birds on the runway. Due to the high speeds and reduced noise of modern aircraft, it is essential to implement specialized bird deterrence systems at airports and on planes to prevent collisions. Integrating these protective measures helps mitigate the increased risk of bird strikes caused by quieter, faster flights. Again, to reduce bird

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foraging sites caused by increased farming, a buffer zone should be established at a reasonable distance between the airport and farmland."

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