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Simulation of Noise Pollution Using the Integrated Noise Model (INM) in Airport Surroundings

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Abstract

Aircraft noise pollution is a significant concern for urban areas near large airports. This research focuses on the New Delhi Indira Gandhi International Airport (IGI) and attempts to model the noise impact of the aircraft and the noise-mitigating measures of the operational strategies. For the generation of Day–Night Average Sound Level (DNL) and Weighted Equivalent Continuous Perceived Noise Level (WECPNL) contours, a computational framework based on MATLAB and incorporating the Integrated Noise Model (INM) was created. Secondary sources were relied upon to provide input data, such as the Airports Authority of India (AAI) and the Directorate General of Civil Aviation (DGCA, 2022) for operational data, the International Civil Aviation Organization (ICAO) and Federal Aviation Administration (FAA, 2019) for acoustic parameters, the India Meteorological Department (IMD, 2021) for meteorological data, and the WorldPop and the Indian Census for demographic data. Outputs of the model were checked using

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measurements from the Central Pollution Control Board (CPCB). The findings indicate that noise impact is not uniform, as it is concentrated along extended contours oriented with runway 11/29, associated with the direction of aircraft arrivals and departures. Extending as far as 12 kilometres from the airport, the 55 dB(A) contour impacted about 164,000 residents. At the same time, WECPNL contours had an even larger coverage due to nighttime sensitivity. Validation showed a close match with the CPCB data, deviating by no more than 2 dB. Scenario testing showed a near 23-per-cent reduction in exposure above 65 dB(A) due to the NADP1 procedures; however, traffic redistribution showed no overall improvement. The exposure increase in the 20 per cent traffic growth scenario was close to 40 per cent, extending the population count to over 220,000. Taken together, this analysis underscores the importance of noise-sensitive planning, including tighter restrictions on nighttime operations, adoption of standard abatement procedures, and incorporating noise contours into urban land-use planning to prevent chronic health and social impacts in the future.

Keywords:

Airport, community exposure, integrated noise model, noise pollution, urban land-use planning.

Article history:

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Introduction

Aircraft noise pollution is fast becoming one of the primary environmental issues of global aviation because of its rapid growth (ICAO, 2018; Zhou et al., 2018). Although airports provide the means for economic growth and international relations, their operations lead to community noise around the areas where people live. Noise, apart from being a pollutant, unlike others, is a pollutant that adversely affects human well-being and health in a way that is perceivable instantly, through sleep disruption, annoyance, and cardiovascular and social disorders (Europe, W. H. O, 2018; Basner et al., 2014; Basner et al., 2017). Therefore, noise from aircraft has become a matter of concern within the context of aviation sustainability and urban environmental management (Purohit, 2023). The International Civil Aviation Organisation (ICAO, 2018) and the World Health Organisation (WHO) have set global standards that need to be met. WHO marks continuous exposure to 55 dB(A) as a long-term threat, whereas ICAO calls for the evaluation of the number of persons exposed to noise and noise levels (Europe, W. H. O. 2018; ICAO, 2018; EASA, 2016). Integration of intake levels and noise modelling has been a nod to these cross-border standards. Aircraft noise and its consequences on the general population are best assessed in the particular case of Indira Gandhi International (IGI) Airport located in New Delhi, India (Miedema & Oudshoorn, 2001; Van Kempen et al., 2018; Europe, W. H. O. 2018). This is the country's flagship airport serving over 72 million passengers annually (Airports Authority of India [AAI], 2023), alongside dual narrow- and wide-body aircraft operating on three runways. A significant portion of the operations are long-haul international flights that operate deep into the night, thereby causing the greatest disturbance to the nearby communities (DGCA, 2022; Sebastian et al., 2025). Rapidly expanding urban centres such as Dwarka, Vasant Kunj, Palam, and Mahipalpur are located in close proximity to the airport, and their increased populations generate more residents exposed to aircraft noise (Census of India, 2011; Lloyd et al., 2018; Babisch, 2014). IGI is therefore a perfect example of how an airport with heavy traffic and located near a highly populated area can be evaluated for the airport noise pollution it generates, its magnitude, and how it is distributed. Point-based monitoring undertaken by environmental authorities significantly limits the assessment of noise levels in the context of India. Even though such measurements are helpful in ensuring compliance with regulations, they are incapable of providing data on the spatial extent of noise exposure, for instance, the impact of changes in traffic or flight operational procedures on noise levels for communities adjacent to airports (CPCB, 2021). There is an ever-increasing urban sprawl around airport boundaries, subjecting more people to elevated noise exposure levels in the absence of detailed analytical frameworks to direct noise-lowering measures, zoning laws, or policies in the future. Unlike India, the ICAO-recommended practices and the WHO health-based guidelines integrate modelled noise contours with population data to enable proper zoning and mitigation measures, demonstrating the deviations from global best practices (ICAO, 2018; Europe, W. H. O. 2018; Van Kempen & Babisch, 2012). The hypothesis in this study assumes that a computational framework integrating aircraft operations data, acoustic reference data, and weather data could be used to create valid aircraft noise footprint simulations around IGI Airport. Models such as these are more useful than isolated field measurements as they provide spatially continuous estimates of noise exposure and allow alternative operational scenarios to be tested (Shaikh et al., 2025). As a next step in the analysis, combining noise contours and demographic information allows for estimating the scale of population exposure, establishing a link between technical modelling outputs and public health and policy concerns. The intent is to focus on the testing of the Integrated Noise Model (INM) within the MATLAB environment to analyse the noise pollution found in IGI Airport. In particular, the study intends to create corresponding noise contours for the normal operation of the airport, validate the model results through the monitoring data at hand, estimate the population exposed to different zones of noise, and assess the improvement through possible mitigations, such as the redistribution of aircraft movements and noise-abatement departure procedures (Mukhopadhyay et al., 2025). This study integrates the acoustic and population-based aspects of exposure reflected in the guidelines of ICAO and WHO, thus creating outputs that are internationally comparable as well as valuable for public policy (ICAO, 2018; Europe, W. H. O. 2018). In this regard, the study endeavours to illustrate the benefits of simulation-based tools not only for measuring and illustrating aircraft noise but also for crafting and backing strategies for noise control and sustainable urban planning within the framework of swiftly growing metropolitan areas (Abdullah, 2024).

Literature Review

In many ways, the noise from aircraft affects the people living near the airports. There is an impact on health, community, and urban growth in airport-proximate regions. The earliest of the epidemiological studies put a spotlight on the link between transportation noise in general and its impact on annoyance, sleep issues, and heart problems (Miedema & Oudshoorn, 2001; Van Kempen & Babisch, 2012; Babisch, 2014; Das & Kapoor, 2024). The latest meta-analyses and systematic reviews highlight the link between long-term exposure to aircraft noise and metabolic issues, hypertension, diabetes, and heart disease (Eze et al., 2017; Sebastian et al., 2025; Van Kempen et al., 2018; Nithyalakshmi et al., 2021; Nakamura & O'Donnell, 2025; Hartigan, 2023). The WHO Environmental Noise Guidelines have stipulated that continuous exposure over 55 dB(A) is a threat to public health (Kumar et al., 2025); Adeshina et al., 2025; Europe, W. H. O. 2018). This means policies must incorporate the offered methods to measure exposure. As far as policy goes, the ICAO, 2018) and the European Aviation Safety Agency (EASA, 2016) balance operational data with exposure assessments in their noise modelling frameworks, which many international studies have supported. The way an airport functions, including noise abatement procedures, clearly influences noise outcomes. This has been empirically verified by operational strategies, as (Clemente et al., 2005) proved in their noise study, which considerably strengthens the case for scenario-based modelling. Similarly, (Andreana et al., 2024) Flexible methods to airport noise assessment and mitigation have been proposed that address both technical and social factors (Damjanović et al., 2022).

Nowadays, researchers, governments and city planners are more attracted to applications related to noise mapping. As updated in 2019 and noted earlier by Zaporozhets in 2016, the FAA's Integrated Noise Model (INM) and its successors have continued to be the most effective tools for modelling

(Zhandildinova et al., 2022). The use of the Integrated Noise Model along with the Geographic Information System has proven that noise footprints extend beyond the airports as well as the urban residential areas (Andarani et al., 2016; Bentes et al., 2012; Tlałka & Rzucidło, 2023). Furthermore, (Xie et al., 2023) have shown that changes in fleet structures, growth estimation, and even different fleet operation strategies can be tested efficiently through simulation-based methodologies.

The Indian perspective is particularly important because of the increased air traffic and the expansion of cities near key airports such as IGI in Delhi. While the Central Pollution Control Board's CPMB, 2021) has monitoring data and has traditional methods of tracking surpassing limits, they are point-based and insufficient for scaled mapping of exposure. Noise contours in conjunction with the (Census of India, 2011; (WorldPop, 2020) permit population exposure analyses that are more revealing of the exposed population. Population-based exposure analyses are a combination of noise contours and the Census of India and WorldPop data, which offer better insights into the number of people exposed and the exposure levels than traditional methods. Such methods have been recommended for implementation in the European and North American regions as part of the best practices for bridging engineering evaluation and public health impact assessments (Eitelman et al., 2003).

In general, the literature highlights three key issues: (i) the public health weight of persistent aircraft noise is large and complex, (ii) INM and similar modelling frameworks are indispensable for measuring exposure as well as for testing operational or technological innovations, and (iii) integrating population data with acoustic contours connects aeronautical policy to public health and environmental sciences. This work validates the use of INM-based modelling for IGI Airport, thus allowing us to approach its noise management from both a policy and a technical standpoint.

Materials and Methods

Study Area

Our research was conducted within the premises of Indira Gandhi International Airport (IGI), New Delhi, India (28.556° N, 77.100° E). Indira Gandhi Airport is the busiest in our nation and serves as an international as well as a domestic airport, with the passenger count crossing over 72 million (AAI, 2022). The airport also has three runways (11/29, 10/28, and 09/27), each differing in length from 2813 to 4430 meters, which are used for both narrow-body and wide-body aircraft (DGCA, 2022). IGI is the proper focus for research due to its elevated traffic, especially the long-haul night flights. As such, IGI also enables the evaluation of the aircraft noise model in urban areas (Andarani et al., 2016). The research, in line with WHO and ICAO, goes beyond defining noise contours and includes assessing the population exposed to ensure the study captures the human aspect of aircraft noise (ICAO, 2018; Europe, W. H. O. 2018).

Data Sources

The entire set of operational information was gathered from open source datamines. Data on the number of flights, aircraft and flight schedule details were obtained from the Airports Authority of India (AAI) as well as the Directorate General of Civil Aviation (DGCA) (AAI, 2022; DGCA, 2022). The Aeronautical Information Publication (AIP) India publication provided runway details such as orientation, elevation, and dimensions, while published aerodrome charts were the source of standard operating flight paths. Weighting reference parameters, such as Sound Exposure Level (SEL) values and Noise–Power–Distance (NPD) curves, were obtained from ICAO Aircraft Noise Performance (ANP) and Federal Aviation Administration (FAA, 2019) Integrated Noise Model databases (FAA, 2020; ICAO, 2020). The average temperature, wind speed, humidity, and atmospheric pressure, in addition to meteorological data, were obtained from the India Meteorological Department (IMD, 2021) and applied in correcting the changes of the atmosphere on the propagation of noise. Population exposure was estimated by overlaying the generated noise contours with demographic data from the (Census of India 2011; the WorldPop gridded population dataset (2020). The work reviewed aligns with WHO/ICAO recommendations that focus on integrating demography with acoustic modelling in order to quantify the exposure of communities to aircraft noise (ICAO, 2018; Europe, W. H. O. 2018).

Model Development

In the latest iteration of MATLAB (MathWorks, 2025), I have been able to write a new algorithm that deals with the simulation and analysis of aircraft noise exposure. With this, I was able to generate noise contours and set them on top of population distribution and land-use data, so the algorithm could automatically detect and flag the residential areas that are affected by aircraft noise to the degree of international noise exposure mapping regulation. For each aircraft operation, the model computed sound levels based on SEL values modified for geometric spreading, atmospheric absorption, and ground reflection. Each operation was also associated with its specific NPD curve to model aircraft-specific noise behaviour (FAA, 2020; ICAO, 2020; Zaporozhets, 2016). Two standardised metrics were used to model the noise perception at different times of the day: Day–Day-Night Average Sound Level (DNL) with a 10 dB night penalty and Weighted Equivalent Continuous Perceived Noise Level (WECPNL), which models differentiated human response to daytime, evening, and nighttime noise.

Noise Contour Generation

The outputs of the MATLAB framework were used to generate noise contours around IGI Airport. Contours were produced at standard intervals of 5 dB for DNL and 5 units for WECPNL. The geographic coordinates of the runways and flight tracks are used to create a spatial grid that aids interpolation of noise levels for the contour maps, offering a spatial insight into the noise exposure from the aircraft (FAA, 2020; ICAO, 2020; Bentes et al., 2012).

Validation and Sensitivity Analysis

For the purposes of evaluating how reliable the model is, the results of the simulation were compared to publicly issued monitoring data, such as that of the Central Pollution Control Board (CPCB), for selected sites around the airport, such as Dwarka and Vasant Vihar. For the sensitivity analysis, key parameters such as volume of traffic, share of night operations, and growth in flight activity were varied systematically. These analyses helped understand how the operational patterns affect the changes in magnitude and distribution of the noise contours. The study evaluates not only the changes in the noise and its acoustic implications for the population, which is essential for bridging the gap between technical modelling and public health criteria, by using sensitivity analysis along with estimates of population exposure (Tlałka & Rzucidło, 2023).

Scenario Testing

The model was further used to examine alternative operational methods constructed to lessen the noise impact. Methods examined included the usage of Noise Abatement Departure Procedures (NADP1 and NADP2), changes in climbing profiles, and the redistribution of aircraft operations on different runways (ICAO, 2018; Andreana et al., 2024). Each method was examined properly and benchmarked against the natural baseline so as to determine the effectiveness in decreasing the noise contour sizes and, most importantly, the decrease in the number of residents exposed to noise using the WHO/ICAO exposure evaluation methods.

Tools and Software

All calculations, spatial analyses, and visualisations were done using MATLAB (MathWorks, 2025). Developing a flexible and lightweight modelling framework was made easier with this software because of the integration of matrix operations, application of acoustic formulas, spatial interpolation, and other spatial analyses. The framework did not rely on proprietary airport data systems, which made it easier to manage and update changes to parameters and to operational scenarios.

Results

Baseline Noise Exposure

The INM-based MATLAB framework was leveraged to replicate the simulation of aircraft noise exposure in the areas surrounding Indira Gandhi International Airport. Taking into consideration an average busy operational day with around 1,350 aircraft movements, noise contours were generated for the Day–Night Average Sound Level (DNL) and the Weighted Equivalent Continuous Perceived Noise Level (WECPNL) (ICAO, 2018; FAA, 2019). The simulations showed that the 55 dB(A) DNL contour reached almost 12 kilometres beyond the airport, impacting large residential areas of Dwarka and Mahipalpur. The 65 dB(A) contour stretched to 7 kilometres along the main takeoff path of Runway 11/29, while the 75 dB(A) contour was limited to 2 to 3 kilometres near the runway thresholds. In relation to WECPNL, the 75-unit contour was 8 kilometres along the takeoff paths, and this distance along the takeoff paths marks the increased impact of night-time activities and the stricter demand of this metric.

Spatial Distribution of Noise

The noise from aeroplanes is closely tied to the runway's direction, with a clear spatial pattern. Aeroplanes departing from Runway 29 mixed with the air traffic of southwest Delhi, where Dwarka and Palam Colony are located. Interestingly, air traffic from Runway 11 to land extended aeroplane noise to East Vasant Kunj and Mahipalpur. Adding to the noise concern, wide-body aeroplanes such as the Boeing 777 and Airbus A330 scheduled for late-night long-haul flights posed greater noise exposure, especially within the 65–70 dB range (Basner et al., 2014; Europe, W. H. O. 2018).

Population Exposure

The AI Simulated contour plot overlaid with the Indian (Census, 2011; WorldPop, 2020) datasets enabled us to approximate human exposure. Following a similar approach, the World Health Organisation (WHO) and the International Civil Aviation Organisation (ICAO, 2018) emphasise the importance of noise exposure mapping of populations in order to evaluate the health and social impacts of aircraft noise (Europe, W. H. O. 2018; ICAO, 2018; Basner et al., 2014). The analysis shows that about 118,000 people were exposed to noise between 55 and 60 dB(A), approximately 46,000 people experienced noise between 60 and 65 dB(A), and nearly 18,500 people were exposed to noise above 65 dB(A). Combining all the numbers, the report indicates that close to 164,000 inhabitants were exposed to noise above 55 dB(A), which is above the recommended limits by the World Health Organisation for chronic exposure. This data is aggregated in Table 1, which summarises the population exposed at various noise level ranges. As explained in Chart 1, the 55–60 dB(A) range captures a majority of the exposed population, while around 18,500 people are exposed to noise above 65 dB(A). This visualisation provides a clear picture of how exposure is distributed across different noise categories. According to ICAO guidance, reporting exposure in standardised noise bands (e.g., >55 dB(A), >65 dB(A)) is a key step in aligning local assessments with international best practices (Figure 1).

Table 1. Baseline population exposure by aircraft noise levels (≥55 dB(A)) around indira gandhi international airport

Noise Level Band (dB(A))	Estimated Exposed Population
55 – 60	118,000
60 – 65	46,000
> 65	18,500
Total ≥ 55 dB(A)	**164,000**

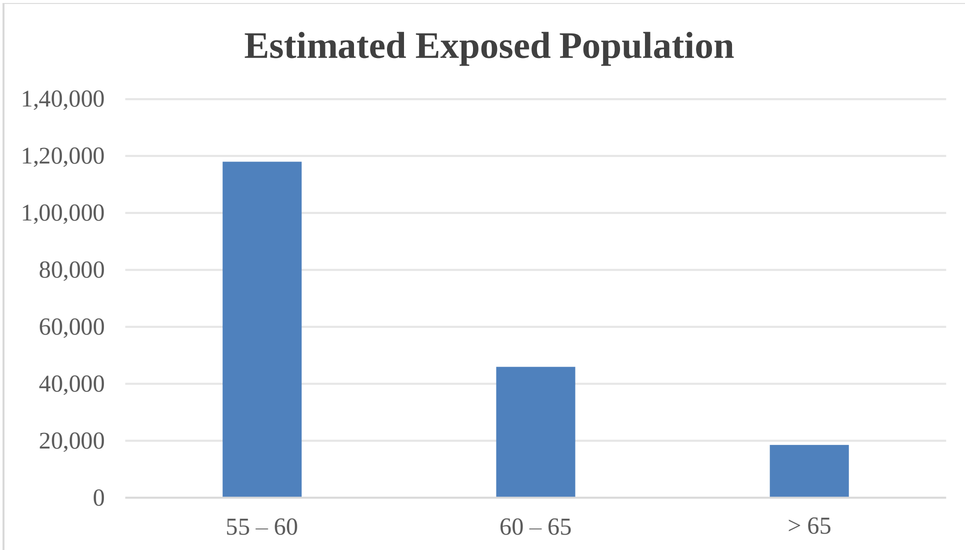

Figure 1. Baseline population exposure to aircraft noise levels around IGI airport (≥55 dB(A))

Model Validation

The noise data produced by the model was compared for its precision against the noise evaluation and monitoring data provided by the Central Pollution Control Board (CPCB, 2021). The CPCB data for Dwarka Sector 21 indicated an average noise level (LAeq) during the night of 64 dB(A), whereas the model predicted 62 dB(A). The 2 dB discrepancy is minimal and validates the simulation framework's ability to produce results consistent with actual observations; hence, the framework can be trusted for modelling aircraft noise within the IGI region.

Scenario Testing

To evaluate potential strategies, three alternative scenarios were simulated. The first scenario, which implemented the NADP1 noise abatement departure procedure, reduced the 65 dB contour length along Runway 29 by more than one kilometre. This adjustment lowered the number of residents exposed to noise levels above 65 dB(A) from 18,500 to approximately 14,200, representing a 23 per cent reduction. Such a result is consistent with WHO and ICAO priorities that encourage operational measures like NADP1 to minimise residential exposure to high noise levels (ICAO, 2018; Europe, W. H. O. 2018). The second scenario, which redistributed traffic across multiple runways, lessened exposure in Dwarka but simultaneously shifted the noise burden to East Delhi, producing no net improvement in total population exposure. The third scenario, representing a 20 per cent increase in traffic volume consistent with projected airport growth, expanded the 55 dB contour outward by 2.3 kilometres and increased the number of residents exposed above 55 dB(A) to nearly 226,000, marking a 40 per cent rise compared with the baseline case (Figure 2 and Table 2).

Table 2. Comparative outcomes of population exposure under baseline conditions, noise abatement departure procedure (NADP1), traffic redistribution, and projected 20% traffic growth scenarios

Scenario	Contour Change	Population Exposed	Δ% vs. Baseline
Baseline	—	18,500 (>65 dB)	—
NADP1	–1.0 km (65 dB)	14,200 (>65 dB)	–23%
Redistribution	↔ (shifted areas)	~18,500 (>65 dB)	≈0%
+20% Growth	+2.3 km (55 dB)	226,000 (>55 dB)	+40%

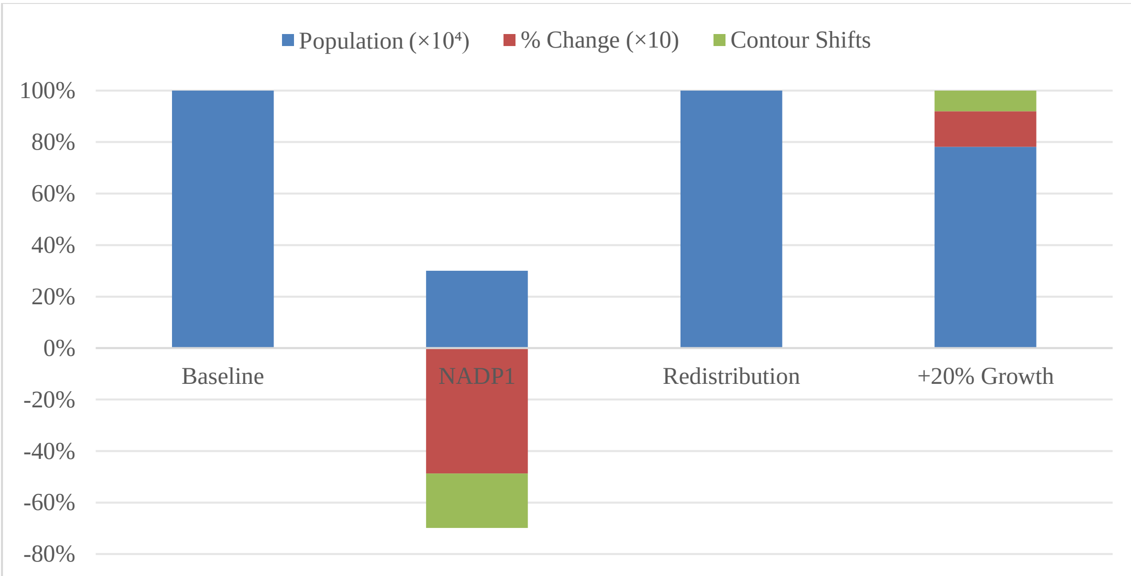

Figure 2. Scenario-wise comparison of population exposure, percentage change, and contour shifts

Sensitivity Analysis

The noise outcomes sensitivity analysis demonstrated the impact of operational and environmental factors. Across the study region, a 10 per cent increase in nighttime operations resulted in an increase of three to four units in WECPNL values (ICAO, 2018). An increase of 5°C in average temperature, as a form of meteorological variation, slightly reduced contour lengths due to increased sound attenuation. The replacement of 20 per cent of Boeing 777 departures with the quieter Airbus A320neo significantly decreased the number of residents exposed to noise levels above 65 dB(A) by about 30 per cent, which is in stark contrast to the other effects (Zhou et al., 2018; ICAO, 2018).

Discussion

The modelling results leave no doubt that there is a clear spatial and temporal variability in the noise environment around IGI Airport. The stretched-out shape near Runway 11/29 shows that noise isn't spread out evenly, but instead is focused in certain narrow areas. This one-way pattern of noise has a lot to do with why areas like Dwarka, Palam Colony, Vasant Kunj, and Mahipalpur get too much noise. The long-haul, wide-body aircraft during the nighttime stands out as the single most impactful finding. These operations are a major contributor to the 65-70 dB(A) noise level range, and they strengthen the global view that nighttime noise is the most challenging from the perspective of community health and acceptability. The greater expansion of WECPNL contours in comparison to DNL further corroborates the intense impact of nighttime operations. The population analysis highlights the importance of the issue with regard to public health. An estimated 164,000 people were subjected to noise above 55 dB(A), violating the WHO guideline limit for chronic noise exposure. The Lund study indicates that the number of people affected by environmental noise increases as the magnitude goes down. For two-thirds of the population affected by 55-60 dB(a), it is the smallest concern because there is a baseline to the effect. The approximately 18,500 people affected by 65 dB(a) or more are a critical group for the risk of annoyance and sleep disturbance. Testing the scenarios factored in mitigating the impact. The NADP1 departure procedure reduced the contour and the number of highly exposed residents in line with ICAO's balanced approach. Unlike the runways, their redistribution had no net reduction in exposure, as the benefits in Dwarka were cancelled by increased impacts in East Delhi. The 20% traffic increase projection demonstrated the magnitude of the impact in the future, with the exposed population expected to grow by 40% with the basic growth assumption. The significance of sensitivity analysis in operational and technological factors is demonstrated in the last point. Changes in the fleet composition, meteorological conditions, and nighttime traffic share altered the noise exposure results. When Airbus A320neo aircraft operating in place of Boeing 777 aircraft are quieter, the exposure reduction is significant, further supporting the fact that fleet modernisation works in synergy with procedural changes. Together with the results, it brings to attention the fact that while the operational changes such as NADP1 are helpful in relieving the noise burden in the immediate future, long-term efforts will be much more focused on noise mitigation strategies, including upgrades of the fleet, management of flights during nighttime, and land-use planning in the vicinity of IGI Airport.

Conclusion

In this study, we focus on the timeline impact of noise pollution around Indira Gandhi International Airport. The core factors of impact include noise timetables, the flight paths, and the runway directions. One of the key, verified findings includes long-haul night-time flights of wide-body aircraft as a major contributor to community exposure. The MATLAB-based INM framework, validated by CPCB data, allowed for accurate noise modelling with deviations under 2 dB. This, along with the WHO guidelines, further confirms the disproportional harm to public health as a result of runway night operations. The testing of scenarios indicated that operational strategies such as the NADP1 departure procedure are beneficial in reducing contour extent as well as the number of impacted residents, while runway redistribution simply relocates the issue. Traffic increase forecasts predicted a rapid rise in noise-affected communities, thereby heightening concerns. Quantifying these affected communities is crucial, since WHO and ICAO explicitly recommend population-based exposure assessment as the benchmark for evaluating noise mitigation options. The conclusion pointed out that a procedural fleet upgrade in combination with land-use planning and measures is effective in community mitigation. Implementing policies that address noise contour mapping and enforce stricter control over night operations are essential in ensuring airport development does not negatively impact the residents' quality of life. By enshrining these measures within a WHO/ICAO-based policy, the dual public health and aviation developmental concerns will be addressed.

Author Contributions

All Authors contributed equally.

Conflict of Interest

The authors declared that no conflict of interest.

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