

The focus on noise metrics in the sustainable planning of airport environments: An Argentinian case study

El enfoque en las métricas de ruido en la planificación sostenible del entorno aeroportuario: un caso de estudio argentino

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ABSTRACT

Successful airport noise management is based on the effective description and communication of aircraft noise exposure, which can be expressed through a number of noise metrics. The choice of metric is significant, given that noise maps are likely to be used by decision-makers as the main input for land-use planning of areas surrounding airports, and can also be used by the general public as a source of information of interest. The noise contours of Córdoba International Airport, in Argentina, were developed for a future operational scenario in accordance with two noise metrics: Day-Night Average Sound Level (DNL or L_{DN}) and A-weighted Equivalent Continuous Sound Level (LA_{eq}). Exposure to aircraft noise in residential areas and educational establishments around the airport was analyzed through GIS. Results indicated that the population numbers exposed to DNL airport noise of 65 dBA in 2028 will be six times greater than the amount constituted by LA_{eq} Day-Afternoon and Night metrics combined. At the same time, the number of educational establishments likely to be affected by DNL aircraft noise (55 dBA) in 2028 will be six times greater than LA_{eq} Day-Evening and Night combined. This demonstrates that the selection of noise metrics has important implications for noise exposure analysis and communication, which in turn could potentially impact airport noise management decisions, noise communication, and even land-use policies in areas surrounding airports.

Keywords: airport noise, noise mapping, noise descriptors, noise exposure, acoustic contours

RESUMEN

La gestión exitosa del ruido aeroportuario está basada en la descripción y comunicación efectiva de la exposición al ruido de las aeronaves, la cual puede expresarse a través de varias métricas de ruido. La selección de una métrica es de interés considerando que los mapas de ruido pueden ser usados por los tomadores de decisiones como el principal insumo para la planificación de los usos del suelo alrededor de un aeropuerto, y por el público general como una fuente de información de interés. Se desarrollaron los contornos de ruido del Aeropuerto Internacional Córdoba, Argentina, para un escenario operacional futuro usando dos métricas de ruido: el Nivel Sonoro Promedio Día-Noche (DNL o L_{DN}) y el Nivel Sonoro Continuo Equivalente Ponderado A (LA_{eq}). Se analizó la exposición a ruido aeroportuario de áreas residenciales y establecimientos educativos mediante SIG. Los resultados indicaron que la cantidad de población que estaría expuesta al ruido Aeroportuario de DNL 65 dBA en 2028 será seis veces mayor respecto a la cantidad bajo las métricas LA_{eq} Día-Tarde y Noche combinadas. A su vez, la cantidad de establecimientos educativos que podrían estar expuestos en 2028 a ruido aeroportuario de DNL 55 dBA es más de seis veces mayor respecto al número bajo las métricas LA_{eq} Día-Tarde y Noche combinadas. Esto evidencia que la selección de la métrica de ruido tiene implicaciones importantes para el análisis y comunicación de la exposición al ruido, lo cual en consecuencia podría impactar las decisiones vinculadas a la gestión del ruido aeroportuario, su comunicación e incluso el ordenamiento territorial del entorno aeroportuario.

Palabras clave: ruido aeroportuario, mapeo de ruido, descriptores de ruido, exposición acústica, contornos acústicos



Introduction

In the context of exponential global growth in air traffic, it is essential that the issue of aircraft noise be addressed, as it constitutes an inherent and unavoidable impact of aeronautical activity. Aircraft noise is the main issue affecting the development, operations and capacity of airports across the globe (Upham *et al.*, 2003) and it is the main cause of adverse reactions from communities living in areas surrounding airports (Payán Sánchez *et al.*, 2018). Exposure to aircraft noise has been associated with physical and mental health issues—including sleep disturbance, cardiovascular disease and hearing impairment—and with an overall reduction in quality of life (Dobruszkes and Efthymiou, 2020).

The management of airport noise is a key tool for making airport operations compatible with their surroundings, particularly when an airport seeks to expand its operational capacity. Successful airport noise management is based on the effective description and communication of acoustic exposure, as well as on an understanding of the impacts on people’s quality of life. To this end, it is necessary to implement appropriate analytical tools for describing noise and its impacts, so that decision-makers—environmental managers, land-use planners, airport authorities—have an adequate set of results with which to work (Licitra *et al.*, 2014).

Noise maps are widely used for airport noise management because they are useful for assessing sound exposure in a specific area, before action plans to manage noise are implemented (Kiani Sadr *et al.*, 2014; Gasco *et al.*, 2017). They also constitute an effective communication channel to the general public regarding airport noise levels—one that does not necessarily utilize technical language. Consequently, how these maps are presented is important, not only in terms of graphic presentation—noise contours or their variants—but also in terms of the noise descriptor or metric employed (Gasco *et al.*, 2017).

A noise metric is a unit that quantitatively measures the effect of noise on communities and the environment (Orikpete *et al.*, 2020). Noise metrics aim to capture the different aspects of noise over time, as well as the subjective experience of noise annoyance (Independent Commission on Civil Aviation Noise, 2020). Selection of the noise metric for acoustic maps varies among regions and countries, in accordance with local regulations. In Europe, noise maps of the continent’s main airports must use Day-Evening-Night Sound Level (L_{den}) and Night Sound Level (L_{night}) metrics, as established by the European Parliament’s Directive 2002/49/EC on Environmental Noise Evaluation and Management (Gasco *et al.*, 2017). In contrast, in the United States the Federal Aviation Administration (FAA) has adopted Day-Night Average Sound Level (DNL or L_{DN}) as the standard metric used to determine the cumulative exposure of individuals to airport noise (FAA, 1984). In Australia, the noise contours

defined by the Australian Noise Exposure Forecast (ANEF) are used to coordinate land use in the vicinity of airports. In Brazil, aeronautical legislation establishes the use of DNL to define zoning in areas surrounding airports, while at the same time the Brazilian Association of Technical Standards (ABNT) authorizes use of the A-weighted Equivalent Continuous Sound Level¹ (LA_{eq}) metric for zoning and noise monitoring (Revoredo and Slama, 2008). As for Argentine airports, the 2019 Manual for Integrated Airport Environmental Management, published by the National Civil Aviation Administration of Argentina (ANAC) recognizes the suitability of multiple metrics for describing noise exposure and recommends the use of DNL in the development of noise contours and LA_{eq24} (average LA_{eq} over a 24-hour period) for *in situ* noise measurements (ANAC, 2019).

This study focuses on the use of DNL and LA_{eq} (Day-Evening and Night) in the development of noise contours for Córdoba International Airport, in Argentina. DNL has been widely recommended for the assessment of community noise exposure, as it adds an extra 10 dB adjustment to sound levels between 10 pm and 7 am, in order to account for expected increased sensitivity to noise intrusion during the nighttime hours (Bennett and Pearsons, 1981; Bentes, Heleno and Slama, 2013). DNL is defined as follows:

$$L_{DN} = 10 \log_{10} \left[\frac{1}{86400} \left(\int_{0000}^{0700} 10^{[L_A(t)+10]/10} dt + \int_{0700}^{2200} 10^{[L_A(t)]/10} dt + \int_{2200}^{2400} 10^{[L_A(t)+10]/10} dt \right) \right] \quad (1)$$

Where

t = time in seconds

86400 = number of seconds in 24 hours

$L_A(t)$ = time-varying value of A-weighted sound level

0000/2400, 0700, 2200 = midnight, 7 am and 10 pm respectively. The range of the integrals is defined by the time interval during which LA is sampled (United States Federal Government, 2011).

LA_{eq} indicates the average sound level resulting from integration over a period of time, as defined by the logarithmic sum of all sound levels (Heleno *et al.*, 2014). It describes the cumulative effect of multiple acoustic events over a given time interval (T); for example, the effect of several aircraft flying over schools during school hours for a given number of days. It is defined by the following equation:

$$L_{Aeq} = 10 \log \left\{ \frac{1}{T} \int_{t_1}^{t_2} (P_{A(t)}/P_0)^2 dt \right\} \quad (2)$$

¹ A-weighted sound level is sound pressure level modified to approximate the sensitivity of the human ear to various sounds. It aids in the assessment of the perceived loudness and more accurately matches the human response to noise, compared to other weightings (FAA, 2018; Metropolitan Washington Airports Authority, 2005).

Where

$P_{A(t)}$ = instantaneous A-weighted sound pressure level

P_0 = reference sound pressure level

T = time interval, defined by t_1 and t_2

To obtain LA_{eq} for a whole day or particular time period such as day, evening or night, the terms t_1 and t_2 take the following values:

- For LA_{eq24} : $t_1 = 00$ and $t_2 = 24$
- For LA_{eq} Day: $t_1 = 07$ and $t_2 = 19$
- For LA_{eq} Evening: $t_1 = 19$ and $t_2 = 22$
- For LA_{eq} Night: $t_1 = 22$ and $t_2 = 07$

When mapping airport noise, in addition to the defining of the metric, it is also important to include the different land uses in areas surrounding the airport, as these may be incompatible with the airport's operations. Different land uses can develop around an airport, attracted by the economic activity fostered by its existence, including industrial, commercial, recreational and residential uses. Certain land uses are considered 'noise-sensitive', because they host critical receivers, for example schools, hospitals, nursing homes and places of worship (FAA, 2022; Kiani Sadr *et al.*, 2014). In the case of residential areas, exposure to aircraft noise has been widely associated with effects on human health, both psychological and physiological, such as auditory impairment, interference in communication, sleep disorder and cardiovascular and psychological effects (Taufner *et al.*, 2020). Under FAA regulations, for instance, residential land use is incompatible with noise levels above DNL 65 dBA (FAA, 2022). As for educational areas, low performance in reading and math, as well as issues associated with short-term memory, have been linked to chronic exposure to aircraft noise. Some studies have used L_{eq} to assess noise exposure, as it enables a focus on a specific time interval of interest, such as the hours of the day when children are in school (Buchari and Matondang, 2017; Novanta *et al.*, 2020). For its part, the FAA recommends the use of *School Hour* L_{eq} or $L_{eq(8)}$, a metric specifically designed to determine total noise level during an 8-hour school day (FAA, 2007). This demonstrates that selection of noise metric is also conditioned by the type of land use being analyzed as part of a given noise exposure assessment, as well as the activities that take place in the context of land use.

The aim of this article was to study the use of DNL and LA_{eq} (Day-Evening and Night) metrics in noise maps of Córdoba International Airport, and the implications for analysis of noise exposure for different land uses in the areas surrounding the airport. We hypothesized that use of one descriptor or the other was significant, because the magnitude of noise exposure varies significantly according to each metric. At the same time, the choice of metric is significant because noise maps are likely to be used by decision-makers as the main input for land-use planning

of areas surrounding airports, and by the general public as a source of information of interest.

Materials and methods

Study area

Córdoba's «Ingeniero Ambrosio Taravella» International Airport is one of the four Argentinian airports classified as being of maximum complexity—together with Aeroparque, Ezeiza and San Fernando—by the ANAC. In 2016, it broke the 2 million passenger barrier, and in 2018 came third in the TOP20 ranking of Argentinian airports in terms of frequencies and passengers (ANAC, 2018). The airport is located north of the center of the city of Córdoba, on a 982-hectare site within the city's urban limits. It is an OACI 4E category airport, operated by the Argentinian company Aeropuertos Argentina 2000 S.A. It has two operational runways: 18-36, 3200 m long and 45 m wide, with a north-south orientation; and 05-23, 2200 m long and 45 m wide, oriented from northeast to southwest. The runways' orientation reflects the prevailing wind direction.

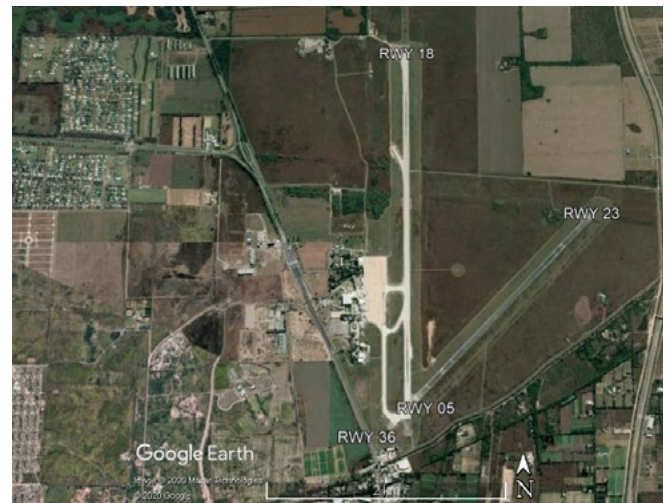


Figure 1. Physical layout of Córdoba International Airport.

The airport's Master Plan (ORSNA, 2015) contemplates additional infrastructure work designed to expand operational capacity. At maximum capacity, the airport is expected to receive around 9.8 million passengers.

Córdoba's urban area is also experiencing ongoing expansion, as a continuation of the city's original municipal urban layout. The Córdoba Metropolitan Institute of Planning (the municipal authority responsible for land use policymaking), considers the land adjacent to the airport a «priority development area», in accordance with provincial laws N° 9.841 and N° 10.004, meaning that urban growth around the airport is stimulated by the local land use policy. There exists the potential for the triggering of social conflict associated with the airport's noise emissions, making necessary an analysis of the population's exposure to airport noise.

Noise modeling and mapping

Córdoba International Airport’s noise contours were developed using the FAA’s AEDT 2d (FAA, 2017), in accordance with the methodology proposed by Vanoli et al. (2018). AEDT 2d is an acoustic impact prediction software that enables dynamic modeling of the noise levels, emissions and fuel consumption generated by aeronautical activity, either at the scale of a single flight, or at a regional, national or global level. Its predictive or prospective function stems from its ability to model future noise levels, projecting an increase in the number of operations, in addition to the possibility of modeling both historical and current acoustic scenarios. AEDT is an evolved version of the FAA’s Integrated Noise Model (INM), used by the civil aviation community worldwide to assess the impact of aircraft noise in the vicinity of airports (Arafa, Osman and Abdel-Latif, 2007), and employed by Vanoli et al. (2018) in the case of Córdoba International Airport. AEDT’s main output are noise contours, which are the main input for sound cartography or noise maps.

According to Córdoba International Airport’s Master Plan (ORSNA, 2015), the expansion of its operational capacity through infrastructure work will enable an increase in passenger traffic, reaching a maximum of 9,875,000 passengers. We assumed that such an increase in passenger traffic will be accompanied by an increase in the number of flights and, therefore, in noise levels. On this basis, we developed noise contours for a future acoustic and operational scenario representing the situation by the time the airport reaches its maximum operational capacity. We estimated the year when the airport will reach its maximum operational capacity and the number of flights that will operate on a peak day during that year. We also estimated the population growth in the areas surrounding the airport, in order to account for future noise exposure.

2017 acoustic scenario

The base year for projections was 2017, since it was the last year in terms of complete data availability at the time the research was conducted. November 21st was identified as the day in 2017 with the most flights, and it was therefore used as the baseline for projections. The data regarding the flights that operated on that day was obtained from open source databases managed by the airport authorities. An analysis of the fleet mix (aircraft model, engine and weight) and flight time distribution for November 21st showed a concentration of flights during daytime hours (for details, see Supplementary Material - Tables S1a and S1b).

Acoustic scenario by 2028

Based on data published in EANA’s 2008 and 2016 annual reports (EANA, 2008; 2016), we estimated an 11% annual growth rate in the number of passengers for Córdoba International Airport. Over 11 years, an annual

11% increase represents growth in passenger numbers from 2,901.691—the number of passengers in 2017—to its maximum operational capacity of 9,875,000 passengers by the year 2028. Based on the number of passengers and frequencies for the 2017 scenario, it was possible to estimate the number of movements for a peak day in 2028 (Table 1).

Table 1. Number of passengers, departures and arrivals for each acoustic scenario under consideration.

2017 scenario		2028 scenario	
Number of passengers	Number of movements (departures + arrivals)	Number of passengers	Number of movements (departures + arrivals)
2,901,691	106	9,875,000	363

As previously mentioned, it is important to consider urban growth in the areas surrounding the airport occurring simultaneously with airport expansion. To estimate population exposure to airport noise in 2028, a growth rate for Córdoba’s population was also calculated, based on data from the 2001 and 2010 population censuses (INDEC, 2001; 2010), as follows:

$$Fp = Ip \times (1 + i)^n \tag{3}$$

Where

- Fp* = future population
- Ip* = initial population
- i* = growth rate. For the 2001-2010 period, *i* = 0.00833998.
- n* = number of years considered

This rate was applied to population data from each census tract in order to estimate the number of noise receivers by 2028. As for the distribution of population growth, we assumed that the city of Córdoba will grow through a process of uniform densification of each census tract, meaning that census tracts which are densely populated today will be more populated by 2028, with this being the case for the areas surrounding the airport.

Figure 2 summarizes the process of modeling the 2028 scenario for Córdoba International Airport, with sound cartography as the main output.

Results

In order to conduct a territorial analysis of noise exposure, noise contours generated in AEDT 2d were exported in shape file format for analysis using the geographic information system (GIS) software QGIS, version 3.16 Hannover (QGIS Development Team, 2009). The contours were overlaid with vectors containing information about the main land uses in the vicinity of Córdoba International Airport: residential and educational. The population density layer is the result of

the projection explained in Section 2.2.2. The educational institutions layer is an open source product developed by IDECOR (2018).

Future exposure to aircraft noise in residential areas around Córdoba International Airport

The airport’s 65 dBA DNL, LA_{eq} Day-Evening and LA_{eq} Night projected noise contours, overlaid with the city of Córdoba’s population density per census tract by 2028, are shown in Figure 3. The figure of 65 dBA was used as a threshold in accordance with FAA guidelines. The acoustic influence area according to DNL is significantly broader than the area covered by the LA_{eq} contours, which translates into more people being exposed to aircraft noise. More than 13,800 people are projected to be exposed to aircraft noise around Córdoba International Airport by 2028, according to the DNL contours. This figure falls to almost 2000 according to the LA_{eq} Day-Evening metric, and to 140 according to LA_{eq} Night. Our results indicate that the number of people exposed to aircraft noise by 2028 under the DNL metric will experience a six-fold increase compared to the number according to the LA_{eq} Day-Evening and Night metrics combined (for more details, see Supplementary Material – Tables S2 and S3).

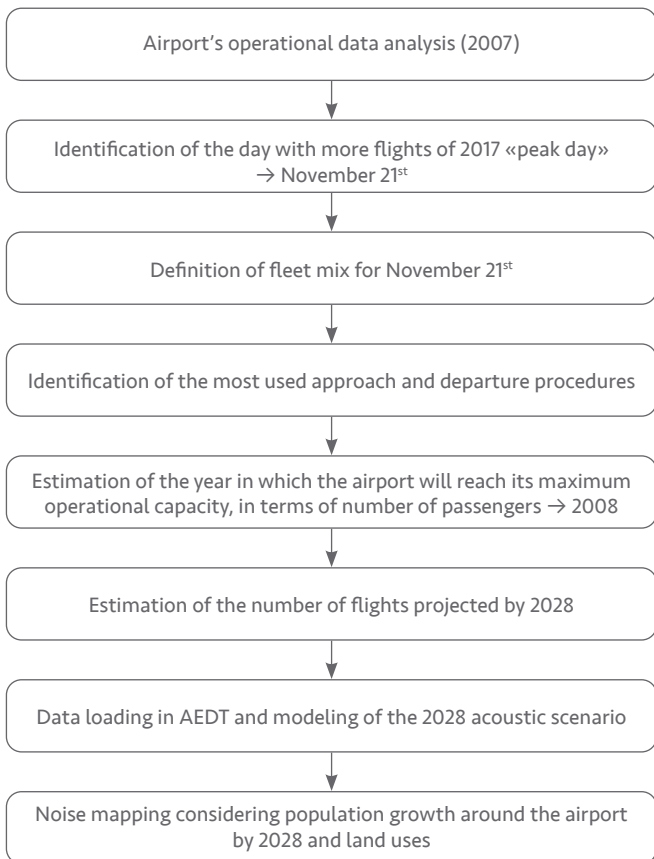


Figure 2. Flow chart of the construction of a future acoustic and operational scenario for Córdoba International Airport and the generation of noise maps.

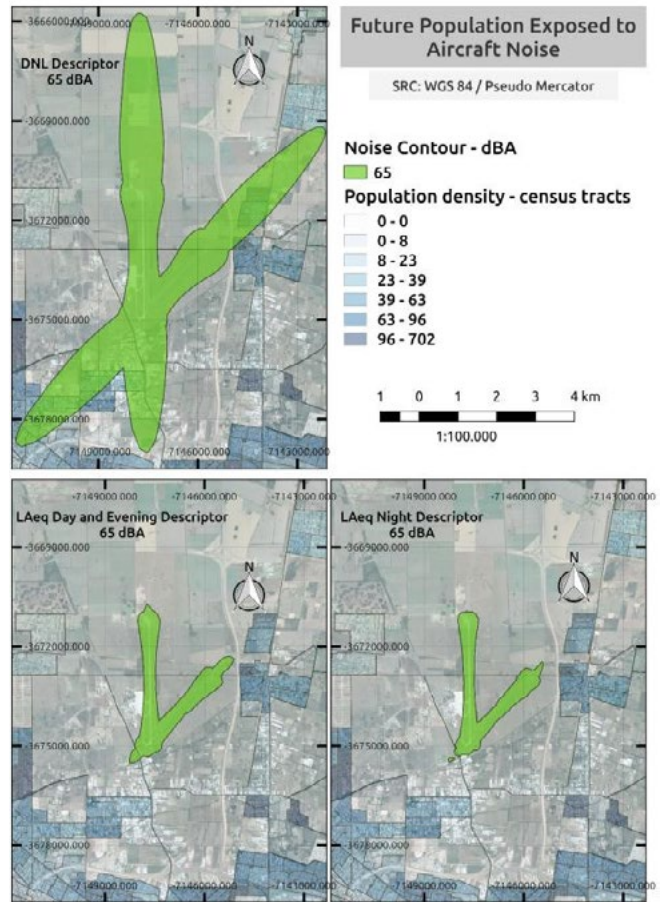


Figure 3. Future population exposed to aircraft noise around Córdoba International Airport in 2028, according to the DNL (top left panel), LA_{eq} Day-Evening (bottom left panel), and LA_{eq} Night (bottom right panel) metrics.

Future exposure to aircraft noise of educational institutions around Córdoba International Airport

Figure 4 shows Córdoba’s current educational institutions —kindergartens, elementary and secondary schools, daytime and nighttime schools, adult schools, both private and public— and the airport’s 55 dBA projected noise contours by 2028. The World Health Organization (WHO) sets 55 dBA LA_{eq} as the noise level from external sources that causes annoyance in schools during outdoor recreation (Berglund, Lindvall and Schwela, 1999)². Again, the acoustic influence area according to DNL is broader than that according to LA_{eq} Day-Evening and Night, and therefore the number of educational institutions exposed to noise varies considerably. According to DNL contours, nearly 1800 schools will likely be exposed to aircraft noise; under LA_{eq} Day-Evening, 148; and under LA_{eq} Night, 123. To summarize, the number of educational establishments that are likely to be affected by aircraft noise in 2028 according to DNL is more than six times the number according to LA_{eq} Day-Evening and Night combined (for

² In its 2018 Environmental Noise Guidelines, the WHO recommends 45 dB DNL, and 40 dB L_{Night}. This standard was not considered in this study, because it was developed for Europe (World Health Organization, 2018).



more details, see Supplementary Material – Table S4). Given the low proportion of nighttime schools around the airport, the use of DNL for its night-hour penalty would not be justified and could lead to biased results.

Discussion

The results of this study demonstrate that the use of the DNL metric for noise exposure analysis around Córdoba International airport results in a broader noise footprint and, consequently, a higher number of potentially exposed citizens and educational establishments, when compared to results according to the LA_{eq} metric.

These findings are comparable to those described by Rychtarikova *et al.* (2015, cited in Dobruszkes and Efthymiou, 2020) who compared the spatial extent of noise contours for Brussels airport according to L_{den} and Freq60 day metrics. The L_{den} contours were smaller than the Freq60day contours, and therefore the number of residents exposed to aircraft noise also varied according to the metrics employed.

Clearly, the choice of noise metric has important implications for noise exposure analysis and communication, which in turn could potentially impact

noise management decisions, noise communication and even land-use policies. As stated by the Independent Commission on Civil Aviation Noise (2020, p.12), «choosing the best metric is crucial for effective engagement between all parties who need to understand aviation noise». If, for example, the Córdoba International Airport authorities were to use DNL contours to assess the noise exposure of homes and educational institutions, it would likely result in more restrictive measures to mitigate its impacts—a larger area would be «protected» from noise—through acoustic zoning and the implementation of soundproofing technology at both residential and school levels.

As Orikpete *et al.* (2020) have pointed out, the metric chosen for the assessment of aircraft noise must be easily understandable for non-experts and also reflect the impact of noise on people, which makes its selection a complex task. We would also add that selection should be guided by the nature of the activities engaged in as part of the land uses being analyzed—including those which are engaged in during daytime and nighttime hours. For example, if authorities were to assess the impact of noise on daytime schools, neither the DNL 10 dB penalty nor its 24-hour period would be applicable. Thus, the use of alternative metrics seems more appropriate. For instance, LA_{eq} can be broken down into LA_{eqD} and LA_{eqN}, thereby accounting for the differential impact caused by aircraft noise in the daytime and at night. Other factors which should be taken into account are the purpose of the noise exposure analysis, the target audience for whom the sound cartography is intended, and criteria related to the metric itself, such as its transparency, practical applicability, and consistency.

Despite the fact that some metrics fit certain purposes better than others, for Porter *et al.* (2014) the effective management of aviation noise should rely on a set of metrics, rather than on a single metric, as a strategy to enrich the territorial analysis of noise exposure and provide a more complete and transparent picture of the acoustic scenario. Furthermore, Porter *et al.* (2014) recommend the complementing of ‘traditional’ or standard metrics based on long term averages with ‘supplementary’ metrics which have been refined to better reflect community experience with noise. For the case of Córdoba International Airport, combining different metrics that suit each aspect of land use in the areas surrounding the airport would facilitate a more tailored approach to noise exposure analysis. Rather than aiming to produce a single map describing overall exposure, several maps for each land use—like those included in this article— or type of critical receiver, using clear and appropriate metrics, would describe community experience more accurately and enable better noise management decision-making.

Concluding remarks

This study compared the cartographic products of the analysis of future aircraft noise exposure around Córdoba

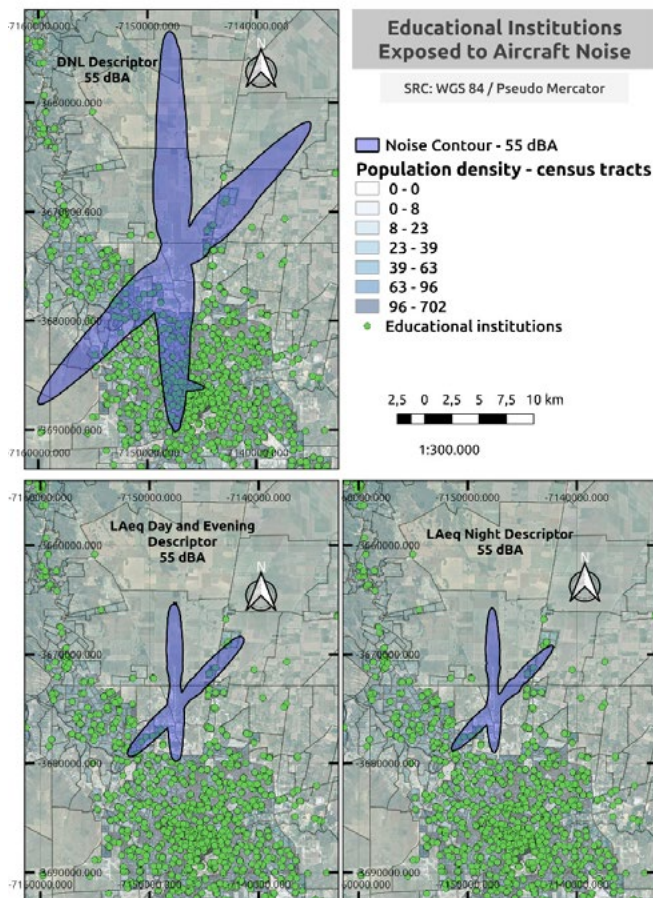


Figure 4. Educational institutions that are likely to be exposed to aircraft noise in 2028 according to DNL (top left panel), LA_{eq} Day-Evening (bottom left panel), and LA_{eq} Night (bottom right panel) metrics.

International Airport using two metrics, DNL and LA_{eq} , for a projected operation scenario situated in 2028 and for two types of land use, namely residential and educational. The results show that the population inhabiting the vicinity of the airport that will likely be exposed to noise (65 dBA) by 2028, according to the DNL metric, is over six times the figure produced using the LA_{eq} Day-Evening and Night metrics combined. Similarly, the number of educational establishments that are likely to be affected by aircraft noise (55 dBA) by 2028, according to DNL, is more than six times larger than according to the LA_{eq} Day-Evening and Night metrics combined. These differences are reflected in the variations in the size and shape of noise contours. In addition, while the DNL metric is appropriate for describing the experience of communities inhabiting residential areas, because it accounts for and penalizes nighttime disturbances, it does not appear suitable for assessing the noise exposure of educational institutions, given that they operate during the day (with the exception of night schools).

The choice of noise metric when conducting noise exposure analysis and generating noise maps is, therefore, of major importance, given the implications such a choice can have for noise management, noise communication, and even for land use regulation in the areas surrounding airports.

These findings add to the existing body of literature on the importance of thoughtfully selecting a suitable set of metrics in order to effectively assess, communicate and manage aircraft noise. Such selection should be based on a broad range of factors, such as the land uses exposed to noise and the nature of the activities being engaged in within each of them (for instance, whether they take place during the day or at night), the level of knowledge of the users of the sound cartography produced, the purpose of the analysis, and the intrinsic nature of the noise metrics.

This study offers an innovative approach to noise exposure analysis based on a future acoustic and operational scenario. We consider that predictive modeling is crucial for effective noise management, given that anticipating noise impacts can contribute to reducing the risk of social conflict resulting from the convergence of airport expansion and demographic growth.

Finally, it is important to highlight the need to refine the results of this study. For instance, the evolution of the aircraft fleet, in terms of the next generation of aircraft that will be in use by 2028, should be considered as part of noise analysis, as well as the percentage of use for each runway (we assumed 100% for both runways). Alternative scenarios should also be considered, particularly in order to account for the impact of the COVID-19 pandemic on the growth of Córdoba International Airport. The implementation of a network of sound level meters for *in situ* measurements would not only constitute an alternative approach to noise analysis, but would also serve in the calibration of models such as AEDT. Furthermore, the development of a public platform for the filing of complaints regarding aircraft noise annoyance would broaden the sources of the data employed in decision-making.

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Authorial contributions

The authors contributed equally to the paper.

Potential conflicts of interest

The authors declare no conflicts of interest.

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