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AIRPORT NOISE IMPACT ASSESSMENT USING NOISE MAPS AND PITTSBURGH SLEEP QUALITY INDEX: A CASE STUDY IN BOGOTÁ, COLOMBIA*

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Abstract

A study was carried out in the Fontibón District in order to assess the impact of the El Dorado Airport on the environmental noise component in this community. The environmental noise levels were characterized at 32 points within the town using the methodology indicated in Resolution 627 of 2006 from the Ministry of Environment and Sustainable Develop with a type II sound level meter, observing the environmental noise distribution with noise maps designed with Arc-GIS 10.5 and the Pittsburgh Sleep Quality Index, Colombia version. In order to quantify the impact of the environmental noise from the activities of the El Dorado Airport, the methodology proposed by Conesa-Fernández was applied, which was adapted to the characteristics of the project to define and weigh the evaluation criteria and determine the importance of the effects. The results from the monitoring points were compared with required values, showing 16% noncompliance for the daytime hours and 66% noncompliance for the night-time hours. The Pittsburg Sleep Quality Index showed that more than 90% of the surveyed residents present a disturbance in sleep quality.

Keywords: environmental impact, noise, noise map, Pittsburgh quality index, sleep quality

1. Introduction

Pollution from environmental noise generated by air traffic is one of the main limitations of development of an airport (Ganic et al., 2015), because the acoustic energy impacts a large area, which is characterized as an environmental risk because of the change

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in the sound pressure level, affecting the physical and mental health of the population through modifications in the sleep quality (Gutierrez and Guzman, 2016).

El Dorado International Airport operations in the city of Bogotá (El Dorado) are not exempt from this problem, mainly affecting residents of the Fontibón District, which borders El Dorado as the result of the disproportionate population growth that is characteristic of developing countries, as seen for the last three decades in Bogotá, which has led to uncontrolled and unplanned development in the areas near the airport complex, which is currently being totally absorbed by the city (Diaz Olariaga O., 2018), That is to say, as urban growth increases around El Dorado, the number of people living in the impacted area increases.

In accordance with Colombian environmental regulations, in April of 2014, the Aeronáutica Civil de Colombia (Aerocivil) monitored residential areas to identify compliance with the maximum permissible standard noise emission levels, which exceeded 65 dB (daytime) and 50dB (night-time) (Casallas and Porras, 2017).

This type of monitoring captures a cartographic representation of sound levels (noise map), which was used as a tool to evaluate the behavior of current environmental noise with an environmental engineering approach.

The main objective of this study was to evaluate the environmental impact of the noise component generated by activities at El Dorado on the Fontibón District using noise maps and the Pittsburgh Sleep Quality Index.

To assess sleep quality in the population, the Pittsburgh Sleep Quality Index (Buysse et al., 1989) was implemented, which has validated Spanish versions (Escobar Córdoba and Eslava Schmalbach, 2005), (Luna-Solis et al., 2015), in order to determine if the index exceeded a score of 4 in the sampled populations, indicating that medical treatment is required.

Finally, the degree of importance of the identified environmental impacts (modification in sound pressure and sleep quality) was evaluated with the methodology for environmental impact assessments created by Conesa-Fernández, 2010. The results described the current situation in the Fontibón District, which is subjected to the environmental noise (noise levels) generated by activities at El Dorado.

2. Material and methods

2.1. Study area

This study took place in the Fontibón District, which is located in the northwest of Bogotá DC, at 4° 40' 43" N, 74° 08' 28" W, with an elevation of 2,548 meters above sea level, an average temperature of 13°C and a population of 413,743 inhabitants. Fig. 1 shows the location of the study area with the respective sampling points.

2.2. Characterization of environmental noise

To measure the environmental noise, a Type II sound level meter (dB (A)) was used, installed at a height of 4 meters above the ground and at a distance of 4 meters from the facades, barriers or walls on the sides of the point. During the monitoring, the microphone was protected with a wind screen; in addition, it was ensured that, for each measurement, the wind speed was less than 3m/s. Measurements were taken at each sampling point for fifteen (15) minutes, distributed in 5 partial measurements lasting three (3) minutes for each monitored direction: North, South, East, West and Vertical upwards, carried out during the daytime (7:01 a.m. to 9:00 p.m.) and at night-time (9:01 p.m. to 7:00 a.m.). To calculate the equivalent level of the measurements (LAeq), the following equation was used in accordance with Colombian environmenta regulations:

$$L_{Aeq} = 10 * \log\left(\left(\frac{1}{5}\right) * \left(10^{\frac{LN}{10}} + 10^{\frac{LO}{10}} + 10^{\frac{LS}{10}} + 10^{\frac{LE}{10}} + 10^{\frac{LV}{10}}\right)\right) \quad (1)$$

L_{Aeq}: Equivalent level of the measurement
LN: Equivalent level measured at the microphone position facing North
LO: Equivalent level measured at the microphone position facing West
LS: Equivalent level measured at the microphone position facing South
LE: Equivalent level measured at the microphone position facing East
LV: Equivalent level measured at the microphone position oriented vertically

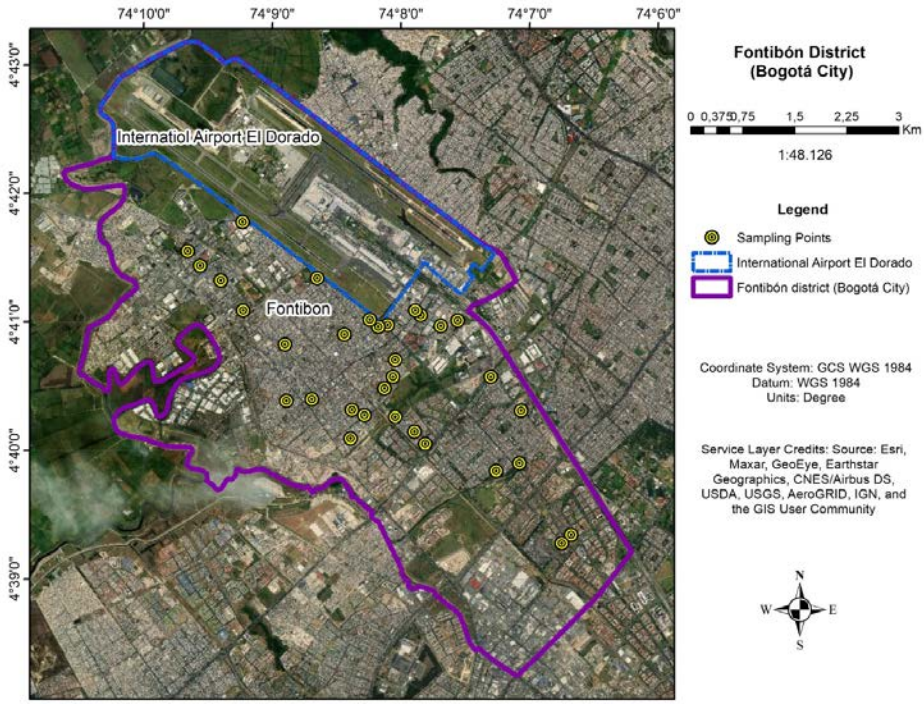


Fig. 1. Environmental noise sampling points in the Fontibón District (Bogotá D.C)

The environmental noise was monitored at 32 points in the Fontibón District, which were georeferenced and identified in sectors and subsectors in order to establish the maximum levels of environmental noise. Noise maps were generated with ArcGis 10.5 for the daytime and night-time, where each monitoring point had the sound pressure levels and their respective coordinates. This information was used for the Inverse Distance Weighting (IDW) interpolation method to find the sound pressure level of the unmeasured areas. The output was classified in accordance with Colombian environmental regulation (complies or does not comply).

2.3. Pittsburgh Sleep Quality Index

The sleep quality of the population was evaluated with simple random sampling using the Pittsburgh Sleep Quality Index (PSQI), adapted for Colombia, which has been validated in various countries and translated into many languages. The questionnaire had 19 self-assessment questions and 5 questions directed towards roommates or bed partners (Luna-

Solis et al., 2015). This tool was applied to 354 people, taking into account the number of inhabitants of the Fontibón District.

2.4. Noise Impact Assessment

The evaluation of the impacts generated by El Dorado Airport activities was carried out using the Conesa Methodological Guide for Environmental Impact Assessment, taking into account the characteristics of the project and the evaluation criteria, thus determining the importance of the effects (Conesa-Fernandez, 2010). This guide was adapted to the characteristics of the project in order to define and weigh the evaluation criteria and determine the importance of the effects. Table. 1 describes the criteria. The impacts evaluated for the noise component included modification of sound pressure levels and modification of sleep quality.

The significance of an impact was determined by combining the rating criteria described in Table. 1. The importance was defined as the result of the sum of all criteria evaluated for each impact, except magnitude, which was multiplied by three (3), and coverage, which was multiplied by two (2) (Table. 2), because these two criteria, according to experience, help determine the value of an impact. Importance prioritizes impacts and, thus, determines the required environmental management actions (Conesa-Fernandez, 2010).

Table 1. Criteria for determining environmental impact values

Criteria	***Classification***	***Value***
Character (CR)	**Positive** if generates favorable changes in the affected environmental element	(+)
	Negative if the change is detrimental.	(-)
Magnitude (MG)	Magnitude low	1
	Magnitude medium	4
	Magnitude high	8
Coverage (CO)	Point: effects generated in the area evaluated by the project.	1
	Local: effects that transcend the areas evaluated by the project.	4
	Regional when the social, physical or biotic effect covers the study area in its entirety and/or may transcend the borders.	8
Duration (DR)	Fleeting: if the effect persists for less than one (1) year	1
	Temporary: if the effect persists for 1 to 10 years.	4
	Persistent: if the effect persists from 11 to 15 years.	8
	Permanent: if the effect persists for an indefinite time or longer than 15 years.	12
Reversibility (RS)	Short Term: natural recovery can occur in less than two (2) years.	1
	Medium Term: natural recovery can occur between two (2) years and six (6) years.	4
	Long Term: natural recovery can occur between six (6) years and fifteen (15) years.	8
	Irreversible: natural recovery without management measures is not possible.	12
Recoverability (RE)	Short Term: the effect can be eliminated in less than one (1) year.	1
	Medium Term: the effect can be eliminated between one (1) year and three (3) years.	4

	Long Term: the effect can be eliminated between four (4) years and ten (10) years.	8
	Unrecoverable: the effect cannot be eliminated or mitigated with socio-environmental management measures.	12
Period (PE)	Irregular: the effect manifests sporadically and unpredictably throughout the duration of the project.	1
	Periodic: the effect manifests itself regularly but intermittently throughout the duration of the project.	4
	Discontinuous: the effect manifests itself unevenly throughout the duration of the project.	8
	Continuous: the effect manifests itself constantly or permanently throughout the duration of the project.	12
Tendency (TD)	Simple: When an action is manifested on a single environmental component.	1
	Cumulative: When an action is prolonged over time, it progressively increases the magnitude of the effect.	4
Type (Ti)	Direct: occurs when the effect that is being evaluated is a consequence of the activity or action that is being developed.	4
	Indirect: occurs when the effect on a socio-environmental variable is a consequence of the interaction with another variable.	1
Synergy (SI)	No synergy**:** When the multiplying potential of the effects is low	1
	Synergy: When the multiplying potential of the effects is high	4

Table 2. Environmental impact negative importance

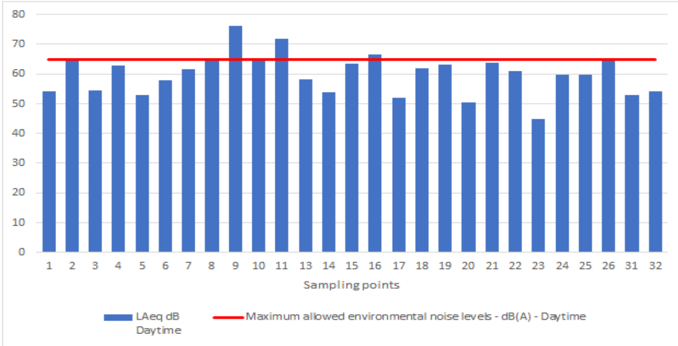
IMPORTANCE (I)= - (3MG+2CO+DR+RS+RE+PE+TD+TI+SI)	Irrelevant	<-25
	Moderate	-25 A <-50
	Severe	-51 A -75
	Critical	>-75

3. Results and discussion

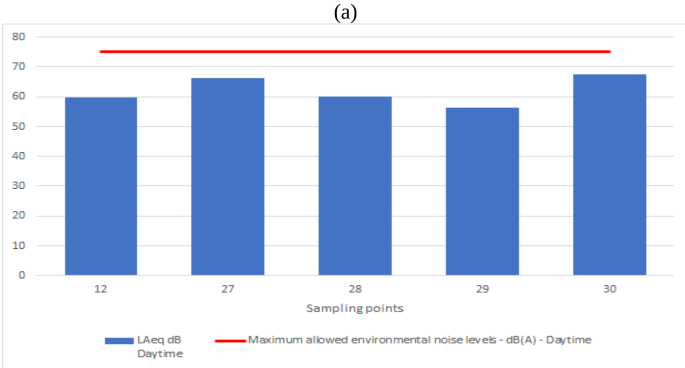
The results from the monitored points were compared with current Colombian standards, Resolution 627 of 2006. During the daytime, 84% of the sampling points for the environmental noise levels were below the maximum allowed. Whereas, 16% of the sampling points did not comply (Fig. 2). On the other hand, for the night-time environmental noise levels, 66% of the sampling points were above the maximum allowed; only 34% of the points complied (Fig. 2). Regulations are more restrictive for night-time levels because this time should be quieter as rest is needed.

Figs. 3 and 4 show the noise maps for the Fontibón District for the daytime and night-time. It can be observed that most of the area has sound pressure levels above the maximum standards allowed for night-time hours.

It was possible to evaluate and contrast between different variables, the perception that the local population has about environmental noise and sleep quality. In general, the inhabitants agreed that the noise produced by the El Dorado Airport is equally noisy and moderately audible inside their homes both during the day and night; likewise, 93% of the population believes that environmental noise is a major quality of life issue.



(a)



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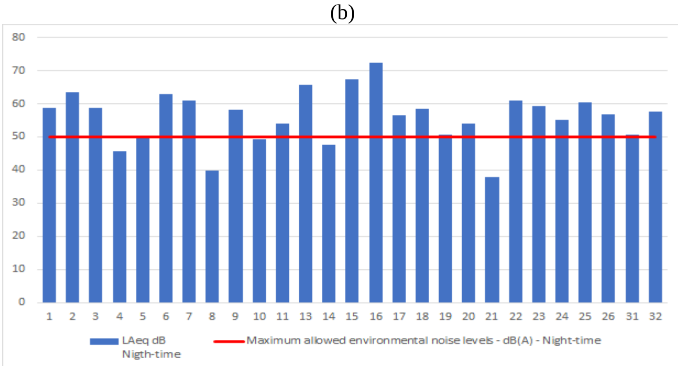

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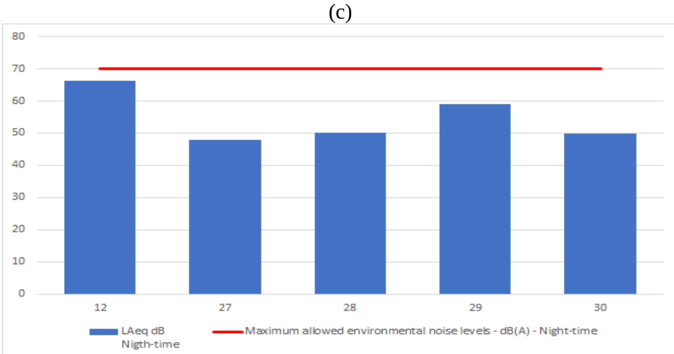

(d)

Fig. 2. Environmental levels compliance (a) Zone B. Quietness and moderate noise daytime; (b) Zone C. Intermediate restricted noise daytime (c) Zone B. Quietness and moderate noise nigh-time (d) Zone C. Intermediate restricted noise night-time

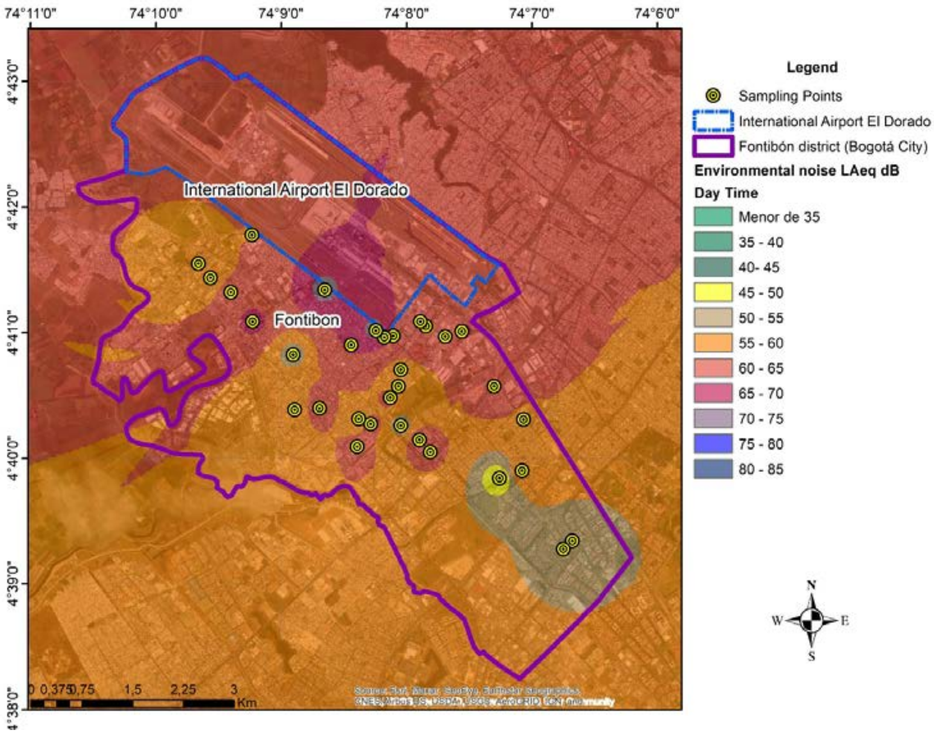

Fig 3. Daytime environmental noise map

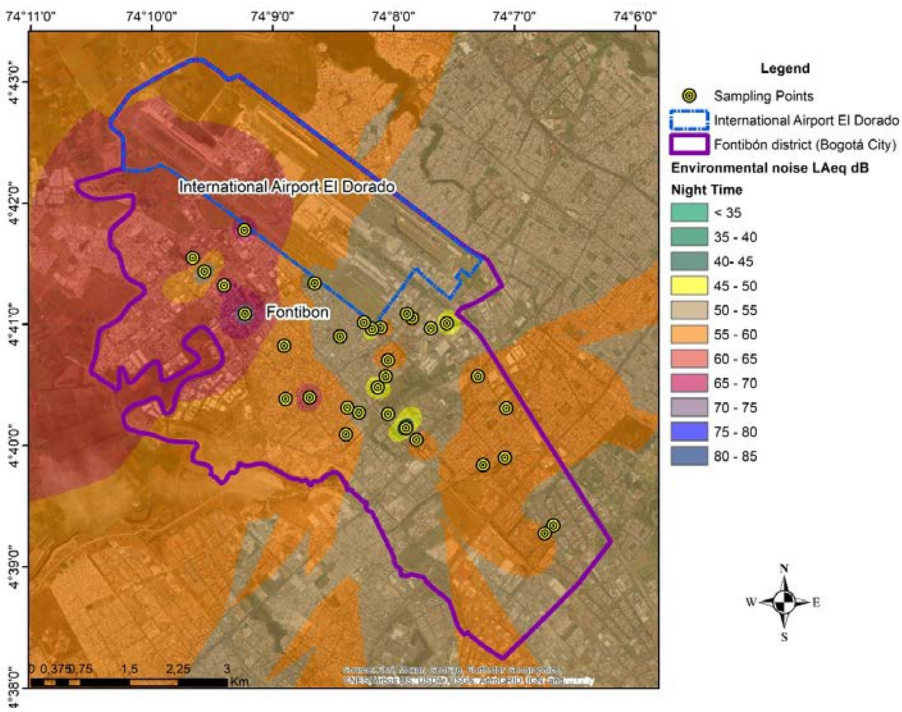

Fig. 4. Night-time environmental noise map

During the application of the survey, it was evidenced that a low percentage of the population has filed complaints for noise with the relevant authorities, such as: Aeronáutica Civil, Junta de acción comunal and the mayor's office, which were established more than 10 years ago when they were needed for the El Dorado Airport to take environmental management measures for noise, such as changes in the glass used for windows and doors and acoustic insulation on the roofs of homes, although most indicate that these measures have moderately mitigated noise.

Fig. 5. presents the results of the categorization of the survey applied to determine the Pittsburg Index in the Fontibón District. Since 92.08% of those surveyed presented high Pittsburgh index values and an overall PSQI-VC score of 8.62 (See Table 3), it is likely that sleep disorders are linked to the impact of the environmental component (noise levels) of the El Dorado International Airport because the resident population of the Fontibón District is located in the area of influence (Callejas et al., 2015). Thus, sleep disturbances may be due to excess environmental noise, one of the more common reasons for noise complaints, causing mental and physical problems, potentially serious disorders and reactions in the human body to continuous noise pollution over time (Fyhri and Aasvang, 2010).

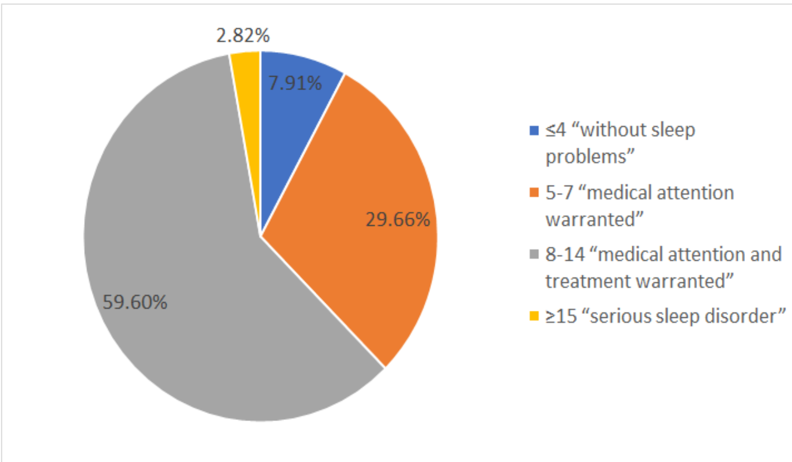

Fig 5. Consequences of the PSQI for Fontibón

Table 3. PSQI results for Fontibón per component

Component	***Percentage***
1. Subjective sleep quality	1.41
2. Sleep Latency	1.19
3. Sleep Duration	1.37
4. Sleep Efficiency	1.37
5. Sleep Disturbance	1.44
6. Use of sleep aids	0.31
7. Daytime Dysfunction	1.5
TOTAL, PSQI FONTIBÓN	8.62

Based on the results from the noise maps and PSQI, the environmental impacts, modification in sound pressure levels and modification in sleep quality were evaluated. Table 4 presents the results of the evaluation, where the importance of the environmental impacts was severe in both cases.

Table 4. Calculation of the importance for the impacts identified for the El Dorado Airport

Environmental Impact	***Aircraft landing and take-off activity at El Dorado airport***										
	CR	***MG***	***CO***	***DR***	***RS***	***RE***	***PE***	***TD***	***Ti***	***SI***	***I***
Modification of the sound pressure levels	-1	8	8	1	1	1	12	1	4	1	-61
Modification of the sleep quality	-1	8	8	4	4	4	12	1	4	1	-70

Airports have several concentrated, negative effects, such as generating noise, which modifies the sound pressure levels of surrounding areas. However, although environmental management measures are used, it is difficult to mitigate impacts, as seen by the Autoridad Nacional de Licencias Ambientales, ANLA, in an environmental evaluation of the El Dorado International Airport project, which stated that the mitigation mechanisms of the airport operation were not effective enough to guarantee the well-being and quality of life of the population residing in the surrounding area.

4. Conclusions

This paper verified the environmental impact of airport activities at the El Dorado Airport on the Fontibón District of Bogotá using noise maps and the Pittsburgh quality index. This study confirmed that the strategies that are currently being implemented by the El Dorado International Airport are not correcting or mitigating the environmental impact that airport activities are causing on the levels of environmental noise and sleep quality in nearby towns. It is necessary for the government, communities and El Dorado International Airport to propose new strategies to mitigate the environmental impact resulting from airport activities.

Currently, stage II of the El Dorado Airport is being planned, which consists of expanding airport operations to another area; however, those in charge should also attempt to relocate the totality of airport operations.

Now is the time to propose a site where the environmental impact will be much lower. Likewise, the areas near the new airport should not be used as residential areas.

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