

School Children's exposure to PM_{2,5} in a high pollution area of Bogotá, Colombia

Exposición de niños en edad escolar a PM_{2,5} en una zona de alta contaminación de Bogotá, Colombia

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ABSTRACT

Approximately 93% of the world's children under 15 are exposed to ambient PM_{2,5} levels exceeding the World Health Organization's guidelines. PM_{2,5} and other air pollutants affect children's mental and motor development, as well as their lung function, even at low concentrations. In low- and middle-income countries, the effects are potentially stronger because of the weaker land-use policies in place, which increases households' proximity to industrial sources. Such is the case of areas with mixed land use in western Bogotá, Colombia. In this work, the exposure of children to PM_{2,5} at a school in the Puente Aranda district was estimated. PM_{2,5} concentrations were measured using low-volume area samplers during school hours in February 2020. Information on the children's daily activity was recorded in order to estimate the physical effort applied during their normal school activities, and the minors' respiratory symptomatology was consulted with their parents. The inhaled dose was estimated using inhalation rates. The results showed that children aged three to five inhale the highest doses and report higher rates of respiratory symptoms. Indoor PM_{2,5} concentrations were consistently higher, agreeing with previous reports, probably because of dust resuspension and poor classroom ventilation. Air pollution mitigation measures must be put into effect in order to protect this highly vulnerable population. These measures will also positively affect the safe return of students to school activities after the pandemic lockdown.

Keywords: air pollution, children's exposure, fine particulate matter, inhalation of pollutants

RESUMEN

Aproximadamente el 93 % de los niños menores de 15 años del mundo están expuestos a niveles ambientales de PM_{2,5} que superan las directrices de la Organización Mundial de la Salud. El PM_{2,5} y otros contaminantes del aire afectan el desarrollo mental y motor de los niños, así como su función pulmonar, incluso en concentraciones bajas. En los países de ingresos bajos y medios, los efectos son potencialmente más fuertes debido a la existencia de políticas de uso de la tierra más débiles, lo cual aumenta la proximidad de los hogares a las fuentes industriales. Tal es el caso de las áreas con uso mixto de suelo en el occidente de Bogotá, Colombia. En este trabajo se estimó la exposición de niños a PM_{2,5} en una escuela del distrito de Puente Aranda. Las concentraciones de PM_{2,5} se midieron utilizando muestreadores de área de bajo volumen durante el horario escolar en febrero de 2020. Se registró información sobre la actividad diaria de los niños para estimar su tasa metabólica en base al esfuerzo físico aplicado a cada actividad escolar. Además, la dosis inhalada se estimó utilizando las tasas de inhalación, y se consultaron sintomatologías respiratorias de los menores con sus padres. Los resultados mostraron que los niños de 3 a 5 años inhalan las dosis más altas y reportan las tasas más altas de síntomas respiratorios. Las concentraciones de PM_{2,5} en interiores fueron consistentemente más altas, probablemente debido a la resuspensión del polvo y la mala ventilación del aula. Se deben implementar medidas de mitigación de la contaminación del aire para proteger a esta población altamente vulnerable. Estas medidas también afectarán positivamente el retorno seguro de los estudiantes a las actividades escolares después del confinamiento de la pandemia.

Palabras clave: contaminación atmosférica, exposición infantil, material particulado fino, inhalación de contaminantes

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Introduction

Air pollution is the world's most considerable environmental risk to human health, according to the World Health Organization (WHO, 2019). It has become a global problem of great importance, which is associated with environmental deterioration and morbidity from respiratory diseases in specific populations such as children, pregnant women, and elderly adults (UNICEF, 2016). In the case of children, vulnerability is due to their higher breathing rate, lower body mass, and developing immune system (American Academy of Paediatrics, 2004). Fine particles can penetrate deep into the airways and even reach the bloodstream, causing a variety of harmful effects (Oyarzún, 2010). Increases in PM_{2,5} concentrations are associated with increases in daily and long-term mortality and morbidity (WHO, 2018), and they can entail school absenteeism for children under

the age of five in areas of high air pollution. On the other hand, and considering the current situation with

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regard to COVID-19, scientific studies have shown that air pollution increases the risk of medical complications. In countries such as Italy, France, Germany, and Spain, it is inferred that high concentrations of pollutants in the air could be the most critical aggravating factor of the mortality caused by the virus (Ogen, 2020). Multiple scientific studies worldwide have analyzed schoolchildren's exposure to PM_{2,5} in order to assess impacts. In China, Chen *et al.* (2019) determined the exposure of minors to PM_{2,5} concentrations by gravimetric analysis using a battery-powered mini-sampler, taking samples for 24 hours for two years and evidencing long-term problems in the neuronal, respiratory, and cardiac systems. Likewise, in a study carried out in New Zealand, Bennett *et al.* (2019) performed measurements of PM_{2,5} indoors in order to analyze the concentrations and sources of air pollution in a primary school for children between the ages of five and 11 over a period of three weeks, indicating that the main driver of PM_{2,5} indoors was the infiltration of pollutants, whose main contributor were the by-products of emissions from motor vehicles. On the other hand, in the national context, Franco *et al.* (2009) characterized the concentration levels of PM₁₀, for district schools located in high traffic corridors of the city of Bogotá, obtaining high concentrations of the pollutant inside the institutions, which exceeded the values considered harmful for sensitive populations according to the WHO.

This study aimed to evaluate particulate matter concentrations to which schoolchildren are exposed, as well as the potential inhaled doses that they may receive during their schooling time in an industrial sector of Bogotá.

Materials and methods

Sampling site selection

The interest of this study was to evaluate the air quality of a school located within industrial area of the city, in order to assess the levels of PM that students are exposed to. The district of Puente Aranda was designated as an industrial zone since 1974 and became a pole of industrial development in the capital, with an extensive production of plastic, chemicals, textiles, metalworking, beverages, and food, with a large number of industries in the sector. However, its use has been changing, and it has lately become a more commercial and residential area. A number of industrial plants have left the area for other municipalities, especially Mosquera, Funza, Madrid, and Fusagasugá in the outskirts of the city (Bogotá City Hall, 2012).

For this study, the sampling sites were located in Gimnasio San Valery, which offers grades from preschool to fifth grade and a total of 103 students with an age range between four and ten. The school is located in a single, three-level building with immediate access to a public park for recreational and sport activities. This school maintains the typical structure of many small private institutions, nowadays common in the city, with a single building containing all academic spaces and using the public parks nearby for sport and leisure activities.

The Puente Aranda and Carvajal-Sevillana stations of the air quality monitoring network (RMCAB) are located 1,9 km north and 3,6 km southwest of the school (Figure 1), respectively. This study used PM_{2,5} concentrations

and wind direction reports from these stations for reference. Data are accessible in the network's website <http://rmcab.ambientebogota.gov.co/>.

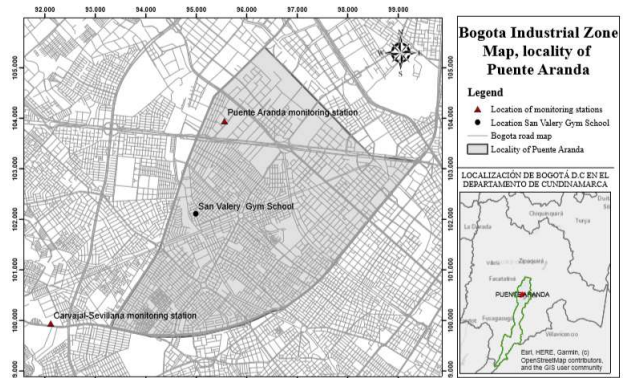


Figure 1. Location of the sampling site and the Puente Aranda and Carvajal-Sevillana air quality monitoring stations

Source: Authors

Data obtained from the RMCAB allowed for a comparison of concentration behaviors with the *in situ* samplings carried out during this research, in ranges of 48 hours corresponding to the same sampling times.

In the surroundings of the sampling site (Gimnasio San Valery School, Figure 2), there is a road axis with circulation of collective public transport, as well as abundant adjacent industries outside a radius of 1 km. In the district, the landscape is predominantly industrial, with warehouses, factories, and large houses established for commerce and services.



Figure 2. Images of Gimnasio San Valery and its surroundings

Source: Authors

A green zone in the area corresponds to the Camelia neighbourhood park, located in front of the school, an area used daily as a rest area, as well as for recreation and school activities, as seen in Figure 2.

Estimation of potential doses inhaled and inhalation rates

To calculate the potential dose inhaled by age range and gender, the following relationship was used:

$$\text{Potential dose} = PM_{2,5} \cdot \text{ventilation rate} \cdot t \quad (1)$$

where the potential dose is in μg , $PM_{2,5}$ denotes the particulate matter concentration ($\mu\text{g}/\text{m}^3$), the ventilation

rate is in m^3/min , and t is the exposure time by exertion level (min).

As a method to calculate the inhalation rate and obtain statistical data regarding human exposure to environmental agents, the *EPA Exposure Factors Handbook* was used as a reference document (EPA, 2011), which provides inhalation rates with descriptive statistics for the average ventilation rate (m^3/min), based on variables of gender and age range for activities of diverse exertion levels.

Sedentary and passive activities are defined as sitting and standing; light intensity activities as walking at a speed between 0,7 and 1,3 m/s ; moderate intensity activities as fast walking (between 1,4 and 1,8 m/s) and slow running (between 1,6 and 1,8 m/s); and high intensity activities are defined as fast running (between 2,0 and 2,7 m/s).

Through a rubric, the activities performed by the students and their times were collected, in order to establish a relationship with the inhalation rates and the duration of such events. The activities considered in this study were class time, recess time in common areas (indoors), and outdoor sports activities.

PM_{2,5} mass concentrations

Particulate matter concentrations were determined during school days for sampling periods of 48 hours over a two-week sampling campaign. Indoor and outdoor $PM_{2,5}$ sampling was performed using two low-volume area samplers (Chemcomb 3500) (Figure 3) and 37 mm, 2 microns pore Teflon filters (Whatman, GE Healthcare). The filters were weighed before and after sampling using a Sartorius analytical balance (M5P-000V001), after conditioning in a desiccator at 23 °C and 45% relative humidity for 24 hours.

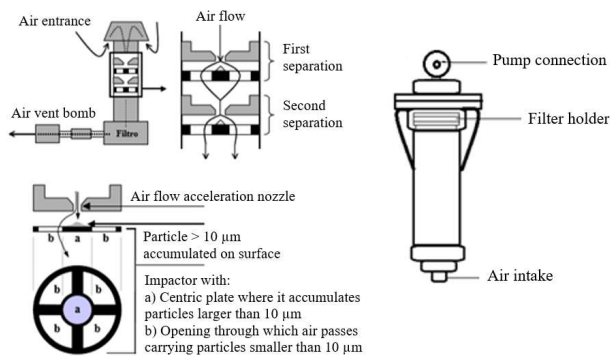


Figure 3. Schematic diagram of the area samplers
Source: Oliva et al. (2001)

Respiratory symptoms in children

A survey was conducted to characterize children's respiratory symptoms, which was based on the ISAAC questionnaire (International Study on Asthma and Allergies in Childhood) and its adaptation in Colombia, i.e., *Validation of the Spanish version of the ISAAC phase III questionnaire on asthma* (Mata-Fernández et al., 2005), which collected information on intramural and extramural factors, referring to the existing conditions both in Gimnasio San Valery and at the students' homes.

Results and discussion

PM_{2,5} concentrations in the study area

Figure 4 shows the $PM_{2,5}$ concentrations obtained *in situ* during the monitoring campaign. Similarly, Figure 5a shows the concentrations at the Puente Aranda and Carvajal-Sevillana stations, reported by RMCAB in the same time frame, vs. the *in situ* concentrations. During the sampling period, a high air pollution alert was declared in the city, whose duration can be observed in the Figure (shadow colors).



Figure 4. Concentrations of extramural vs. intramural $PM_{2,5}$ from the sampling site
Source: Authors

Within the school, indoor concentrations were off up to $19,3 \pm 0,6 \mu g/m^3$, always higher than those outdoors, where concentrations reached $15,6 \pm 0,2 \mu g/m^3$. This difference is considered to be possible due to the resuspension of dust and the low air exchange capacity, which causes the particles to accumulate inside. These findings are in apparent agreement with Bennett et al. (2019), Carrion et al. (2019), Hernández et al. (2013), and Franco et al. (2009), where indoors concentrations were reported over the outdoor levels.

An inversion of indoors and outdoors concentrations occurred from 02/19/2020 onwards (Figure 5a). Outdoor concentrations followed a similar trend to that of Puente Aranda station, evidencing a more significant influence of industrial emissions from the air currents of this specific area, which was caused by the local winds.

The concentrations determined *in situ* were found to be lower than those reported by the monitoring stations, albeit with similar trends. During 12/02/2020, a $PM_{2,5}$ concentration peak was observed (the maximum for the period analyzed). This behavior may be associated with the low wind speeds that occurred on that date, reducing the dispersion capacity of the atmosphere and causing higher concentrations of $PM_{2,5}$. Under those meteorological conditions, which were occurring for some days at the time, the environmental authority of the city (SDA) responded to the contingency by declaring a yellow alert for some districts, including the one studied herein (i.e., Puente Aranda). This is represented in Figure 5a with a yellow shadow for the duration of the yellow alert, with green showing the sampling concentrations after the yellow alert was lifted. The Puente Aranda monitoring station recorded concentrations of up to $32,42 \mu g/m^3$, and Carvajal-Sevillana significantly showed higher concentrations, i.e., up to $43,73 \mu g/m^3$, possibly evidencing regional transport (Carrion et al., 2019). For the sake of comparison regarding the pollution levels in this industrial area, it is possible to visualize the difference

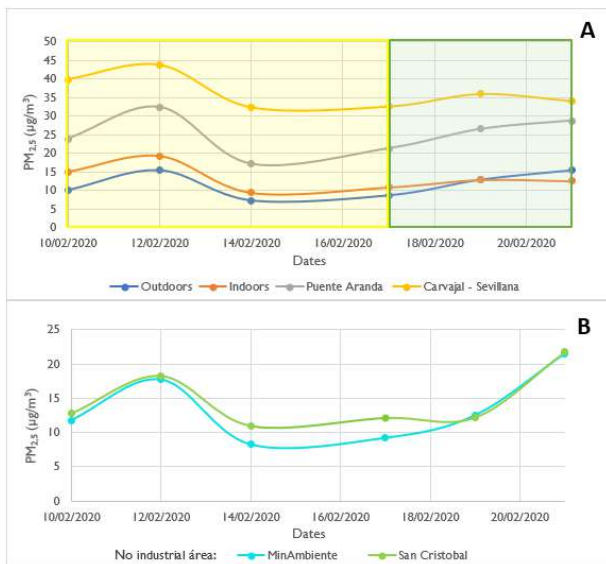


Figure 5. a) PM_{2,5} concentrations from the sampling site and the air quality monitoring stations (Puente Aranda and Carvajal-Sevillana), b) monitoring stations in non-industrial areas of the city for the same period

Source: Authors

in concentration with non-industrial areas of the city for the same sampling period, as shown in Figure 5b. The selected non-industrial areas are located in the district of Santa Fe, in the Northeast (NE) of Bogotá, as reported by the MinAmbiente air quality monitoring station; and in the district of San Cristóbal, in the Southeast (SE) of the city, via the San Cristóbal station. In Figure 5b, it can be seen that the concentrations in this industrial zone can double the exposure concentrations of the other two non-industrial stations. Note that the MinAmbiente monitoring station reaches concentration peaks of up to 21,49 µg/m³, followed by San Cristóbal with concentrations of up to 21,76 µg/m³, unlike the industrial zone corresponding to the Carvajal-Sevillana monitoring station, with significantly higher PM_{2,5} concentrations (up to 43,73 µg/m³) and the Puente Aranda station, with concentration peaks of up to 32,42 µg/m³.

Estimated inhalation rates

The inhalation rates of children shown in Tables 1 and 2, which are presented by gender, age-range, and type of activity as indicated in the EPA Exposure Factors Handbook, along with the daily activity times, allowed assessing the air volumes that each evaluated group might be inhaling during

Table 1. Descriptive statistics for average ventilation rate, unadjusted for body weight, while performing activities within the specified category (males by age category)

Age	Activity level	Inhalation rate (m ³ /min)
3 to <6	Sedentary	0,00458
	Light	0,0114
	Moderate	0,0210
	Heavy	0,0390
6 a <11	Sedentary	0,00487
	Light	0,0116
	Moderate	0,0223
	Heavy	0,0436

Source: EPA (2011)

Table 2. Descriptive statistics for average ventilation rate, unadjusted for body weight, while performing activities within the specified category (females by age category)

Age	Activity level	Inhalation rate (m ³ /min)
3 to <6	Sedentary	0,0044
	Light	0,0109
	Moderate	0,0200
	Heavy	0,0345
6 a <11	Sedentary	0,00464
	Light	0,0111
	Moderate	0,0210
	Heavy	0,0394

Source: EPA (2011)

their school time. The volume of inhaled air was determined by multiplying the activity time by the inhalation rate according to the level of activity or physical effort of each time slot, by course and by gender.

The children activities considered herein are categorized as sedentary activity (sitting and standing), light activity (walking), moderate activity (fast walking and slow running), and heavy activity (fast running during sports classes). All these activities were recorded by gender and age range (three to five and six to ten years old) (Tables 3 and 4):

Table 3. Daily activity times for preschool and first grade (three to five years of age)

	Duration (min)	Description of activities	Activity density
Time in class-rooms	355	The school day begins at 6:30 a.m. and continues until 9:30 a.m. It is resumed at 10:15 a.m. and goes until 1:00 p.m. Students generally remain in the classroom during each class, sitting at their desks or sometimes doing short play activities in the classroom.	Sedentary
Recreation time, common areas within the institution	20	At this time, the students eat their snacks on the first floor in a small patio and then go out to the park. In this space, they remain mostly seated, except when they go to throw the garbage in the trash can.	Light
Exposure time outside	25	The students are accompanied by their course director to move around the park as they wish while sharing with their classmates. Some children sit and others participate in play and recreation activities, being active and dynamic, such as running or moving to the small playground.	Moderate
Sports class	45	Sports classes last 45 minutes and are given once a week, where the students, accompanied by the teacher, in charge go out and perform an exercise routine, such as running, fast walking, and active games. This, in order to develop coordination and object manipulation skills.	Heavy

Source: Authors

Table 4. Daily activity times for second to fifth grades (six to ten years of age)

	Duration (min)	Description of activities	Activity density
Time in class-rooms	355	Classes start at 6:30 a.m. and continue until 9:30 a.m.. They are resumed at 10:15 a.m. and go until 1:00 p.m. Students generally remain in the classroom during each class hour, sitting at their desks. Here, they sometimes carry out short play activities.	Sedentary
Recreation time, common areas within the institution	20	Students in second and third grade share in the first-floor hallway, whereas the fourth and fifth grades are usually in the classrooms. Fifth graders are also selected to help maintain order in the classrooms. Once the snack time is over, the children leave for the park.	Light
Exposure time outside	25	Students in second and third grade move around the park as they please, walking or sitting beside their peers. Fourth and fifth graders mostly play soccer or run around the park. They are active and dynamic.	Moderate
Sports class	90	Physical education classes for grades 2-5 last 90 minutes and are given once a week, where the students, accompanied by the teacher in charge, go out and perform an exercise routine based on speed, coordination, and motor skills development.	Heavy

Source: Authors

Estimated potential doses

The $PM_{2.5}$ dose was determined via Equation 1, with the inhalation volumes and the concentrations determined *in situ*. The following Figures display the daily doses by age and gender evaluated.

Figure 6 presents the behavior of the potential doses received in each analyzed group during the sampling period. The greatest dose values correspond to boys, in comparison with girls' doses during different activities, which is due to their slightly larger inhaled volumes. The trend observed in the Figures is similar to that of Figure 5a, implying that the $PM_{2.5}$ concentrations in the children's environment are directly proportional to the potential dose that can be received, particularly during sports class day. Hence, heavy activity is the most significant parameter, even with less exposure time, due to the greater exertion required during the activity.

Preschool grade children reported high dose peaks on 12/02/2020 and 19/02/2020 for activities of heavy intensity, where the daily doses reached maximum levels (Figure 6a). On those dates, these children were exposed to an outdoors average hourly concentration of $14,3 \pm 0,2 \mu g/m^3$ during their sports class, ordinarily lasting 45 minutes. During this time, the inhalation rate increased significantly, so the children received a higher potential dose. For the whole

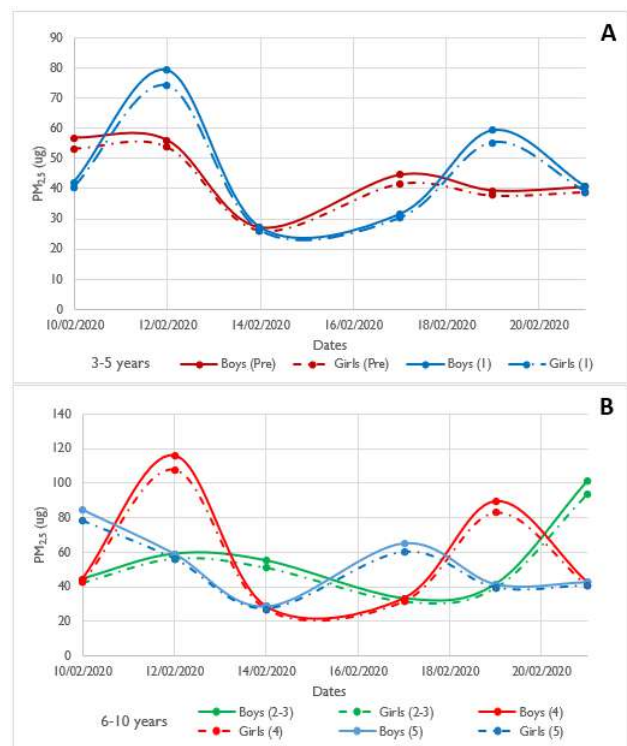


Figure 6. Potential dose by gender and grade: a) three to five years old (preschool, first year), b) six to ten years old (second, third, fourth, and fifth years). Dashed lines for girls, continuous lines for boys.

Source: Authors

sampling period, the potential inhaled doses of $PM_{2.5}$ ranged from a maximum of $70,1 \mu g$ to a minimum of $21,6 \mu g$.

A similar case occurred with older children (Figure 6b) on 12/02/2020 and 21/02/2020. They reported the highest peaks within an exposure time of 90 minutes, facing average hourly concentrations of up to $15 \mu g/m^3$ during sports class, reaching higher doses than first-year children (up to $102 \mu g$), only because of higher environmental concentrations.

Figure 7 shows that boys and girls in the fourth grade received the highest calculated total dose for the entire sampling period (355 and $332,5 \mu g$, respectively). This is followed by the second and third grades (both with equal doses, i.e., $334,9$ and $314,4 \mu g$, given that both sport classes take place on the same weekday).

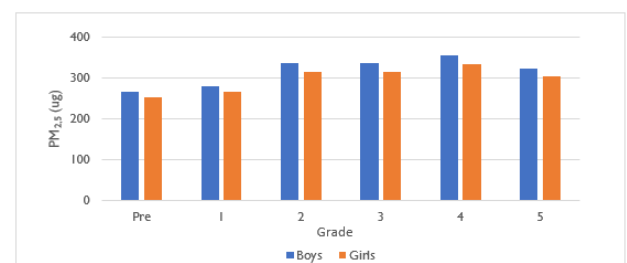


Figure 7. Total potential inhaled dose by grades for boys (blue) and girls (orange)

Source: Authors

Findings of respiratory symptoms in children

The survey was applied to 62 students (parental authorization was provided for their participation) in order

to find out about any respiratory symptoms associated with PM_{2,5} pollution exposure. When implementing the ISAAC questionnaire, the following results were obtained for the symptomatology variables: cough, expectoration or phlegm, nasal congestion, nasal discharge, wheezing, dyspnea, and school absenteeism due to some respiratory disease (Figures 8 and 9).

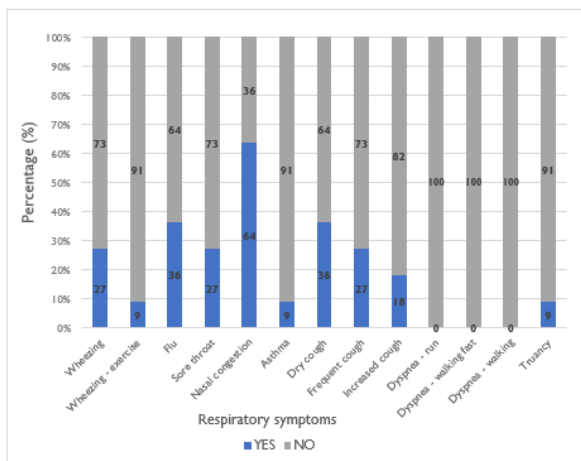


Figure 8. Respiratory symptoms for children three to five years of age
Source: Authors

The group with the highest incidence of respiratory symptoms corresponds to children three to five years of age (transition and first grade). This might be due to their higher respiration rate, lower body mass, and the incomplete development of their respiratory system, as their calculated doses were shown to be lower. Those with wheezing in the chest correspond to 27%, but few reported this symptom during or after physical activity. As for wheezing with flu symptoms (36%), children are more prone to contracting this type of symptoms due to their weak immune systems. Some minors (27%) reported a sore throat when swallowing. The most common symptomatology (64%) is nasal congestion and discharge, which could be associated with exposure to PM_{2,5}. Minors who have a dry cough at night which cannot be linked to a cold or chest infection amount to 36%, out of which 27% cough frequently, and that cough occurs when getting up or when they first go out to the street. Likewise, 18% of the minors reported an increase in coughing. According to the survey, no children reported dyspnea when performing physical activity, but a case of asthma (four years old) reported absenteeism in the group.

On the other hand, children between six and ten years of age (grades 2 to 5) reported dyspnea when performing physical activities such as running (10%), fast walking (6%), and walking (2%), which was directly proportional to the level of physical exertion. For this age range, a case of asthma (six years old) was found, with frequent school absenteeism. In light of these findings, within education institutions in this industrial area, but also in others with similar conditions, administrators and educators must perform a daily review of the air quality before allowing outdoor sports activities. Although this study found differences between the PM_{2,5} concentrations reported by the RMCAB and the *in situ* measurements, there is a similar trend between them than can be informative of the local situation. Sports activities should only be carried out

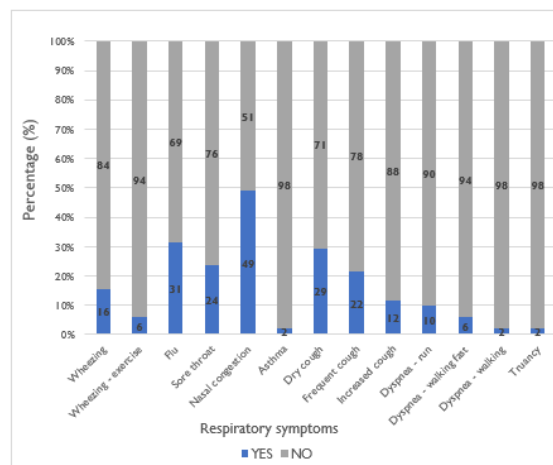


Figure 9. Respiratory symptoms of children six to ten years of age
Source: Authors

during the appropriate days and times, so the students are not forced to receive exaggerated doses of pollutants. Institutions should also consider implementing local air quality monitors both indoors and outdoors in order to obtain more accurate information. Low-cost monitors are gaining momentum around the world, providing good high spatial and temporal resolutions regarding air pollution (Bulot *et al.*, 2019; Wallace *et al.*, 2021), and there are already applications in school environments (de Souza *et al.*, 2017; Kazemi, 2018; Rogulski, 2018).

Finally, the ventilation of the premises must be ensured at all times. This is particularly relevant nowadays, when these institutions are resuming in-person activities after the national lockdown caused by COVID-19. A final recommendation would be the continuous cleaning of surfaces and floors in order to minimize dust accumulation and resuspension, and as well as to prevent fomite contagion.

Conclusions

This study dealt with the collection of PM_{2,5} samples in 48-hour periods for 15 days using Harvard impactors in Gimnasio San Valery (located in Puente Aranda), finding indoor concentrations ranging between 9,45±0,1 and 19,32±0,6 µg/m³. Outdoors concentrations varied, with minimum and maximum values of 7,28±0,1 and 15,60±0,3 µg/m³, respectively. Indoor concentrations were consistently higher than those outdoors. However, although the sources were not evaluated in this study, it is concluded that the intramural values are due to the resuspension of particles, the penetration of emissions from motor vehicles, insufficient ventilation in the area, and transport from local sources.

By using rubrics, it was possible to analyze children's daily activities according to gender and age range during the established school day. Theoretical inhalation rates were established from the *EPA Exposure Factors Manual* for sedentary, light, moderate, and heavy activities depending on physical effort.

Maximum and minimum potential doses were calculated for the evaluated period, finding a maximum dose of 102 µg for boys and 94,1 µg for girls. It is important to underline

the need for limiting the air quality conditions under which sports activities must be performed. Institutions must complete daily validations of pollutant concentrations from the RMCAB to ensure that children are not exposed to elevated values.

Symptomatology variables such as cough, expectoration or phlegm, nasal and nasal discharge, wheezing, dyspnea, and school absenteeism due to respiratory diseases were consulted using a validated survey. The results suggested a larger prevalence of symptoms in students three to five years of age. However, dyspnea under different physical exertion levels is only reported for the higher grades.

Finally, the education sector must ensure appropriate ventilation and surface cleaning to guarantee air exchange rates that allow minimizing pollutant concentrations indoors. The implementation of new low-cost technologies may help to locally monitor air quality and ventilation conditions. This is of particular importance nowadays, when in-person activities have been fully resumed after the COVID-19 pandemic. This simple measure would reduce transmission rates, but also fine particle matter exposure from concentrations building up indoors.

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Author contributions

YAV-L and OAF-M conceived the idea. YAV-L did the background research and developed the project proposal. YAV-L and AKT collected the data and developed the workflow. YAV-L and OAF-M performed the data analysis. NYR-R and OAF-M supervised the research and provided critical feedback. NYR-R provided resources through the air quality research group of Universidad Nacional de Colombia as part of the development of the methodology. YAV-L reviewed and edited final manuscript. All authors approved the final manuscript for publication.

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