Assessment of Environmental Sustainability Indicators through Problem-Based Learning

Evaluación de indicadores de sostenibilidad ambiental mediante el Aprendizaje Basado en Problemas

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Abstract

Bogotá exhibits alarming levels of air pollution, primarily caused by particulate matter (PM10 and PM2.5), especially in areas with high traffic congestion. This exceeds the limits established by the World Health Organization and reaches critical values in localities such as Kennedy. In response to this context, the study aimed to analyze the relationship between traffic and air quality at strategic points in the city, integrating an educational experience using the problem-based learning (PBL) methodology with Civil Engineering students. Real-time measurements were conducted using portable devices at three points in the Chapinero sector, selected based on traffic density levels, and complemented by manual traffic counts and analysis of climatic variables. The results showed that PM concentrations increase significantly under conditions of high congestion and solar radiation, with private vehicles being the most prevalent, followed by taxis and motorcycles. This experience provided scientific validation of the impact of traffic on poor air quality and demonstrated that PBL is an effective tool for fostering analytical and solution-oriented skills in engineering education, bridging theory, practice, and real urban contexts.

Keywords
air pollution, environmental sustainability, particulate matter, problem-based learning (PBL), vehicular congestion

Resumen

Bogotá presenta niveles alarmantes de contaminación atmosférica, causados principalmente por material particulado (PM10 y PM2,5), especialmente en zonas con alta congestión vehicular. Estos niveles superan los límites establecidos por la Organización Mundial de la Salud y alcanzan valores críticos en localidades como Kennedy. En este contexto, el estudio tuvo como objetivo analizar la relación entre el tráfico y la calidad del aire en puntos estratégicos de la ciudad, integrando una experiencia educativa mediante la metodología de Aprendizaje Basado en Problemas (ABP) con estudiantes de Ingeniería Civil. Se realizaron mediciones en tiempo real utilizando dispositivos portátiles en tres puntos del sector de Chapinero, seleccionados según los niveles de densidad vehicular, y se complementaron con aforos manuales de tráfico y análisis de variables climáticas. Los resultados mostraron que las concentraciones de material particulado aumentan significativamente en condiciones de alta congestión y radiación solar, siendo los vehículos privados los más prevalentes, seguidos de taxis y motocicletas. Esta experiencia aportó validación científica del impacto del tráfico sobre la mala calidad del aire y demostró que el ABP es una herramienta eficaz para fomentar habilidades analíticas y orientadas a la búsqueda de soluciones en la educación en ingeniería, articulando teoría, práctica y contextos urbanos reales.

Palabras clave:
contaminación atmosférica, sostenibilidad ambiental, material particulado, Aprendizaje Basado en Problemas (ABP), congestión vehicular.

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Pendiente

Introduction

Studies based on the guidelines of the World Health Organization (WHO) show that PM10 and PM2.5 concentrations in Colombia significantly exceed both national and international air quality standards [1]. A study conducted in the country reported that PM2.5 levels regularly exceed the national annual standard of 25 μg/m³ and the WHO guideline of 10 μg/m³, with satellite estimates in major cities indicating concentrations well above these limits [2]. In Bogotá, long-term monitoring recorded average PM2.5 levels of 20.05 μg/m³ (ranging from 1.5 to 416 μg/m³) and PM10 levels of 55.64 μg/m³ (ranging from 1.6 to 998 μg/m³) [1]. Additional studies highlight that air quality is especially critical in specific urban environments; for example, hourly PM2.5 averages reach 91.1 μg/m³ in the locality of Kennedy, and measurements near schools indicate that only 20 % of PM10 readings and less than 10 % of PM2.5 readings fall below the WHO limits [3], [4].

In cities such as Bogotá, Medellín, and Bucaramanga, spatial and monitoring analyses reveal that particulate matter (PM) levels are not only high but also highly variable [2]. Some studies describe a downward trend in PM10 levels in Bogotá and PM2.5 levels in both Bogotá and Medellín, with annual decreases ranging from 0.8 to 1.7 μg/m³. In contrast, Cali has reported an upward trend in PM2.5, with an annual increase of 0.8 μg/m³ [5]. Additionally, policy measures such as the 40 % traffic restriction during peak hours in Bogotá have been associated with a 14.8 % reduction in daily PM10 concentrations [6]. These findings underscore that PM concentrations in Colombia, particularly in Bogotá, exceed both national air quality standards and those set by the WHO, and vary significantly depending on location and weather conditions [1].

Several studies have documented the relationship between exposure to PM and increased mortality and morbidity in Colombia. [2] estimated that a significant portion of preventable deaths in the country is attributable to exposure to PM2.5 levels above national standards, with cardiopulmonary diseases being the leading causes of these fatalities. Similarly, [6] reported that in Bogotá, for every 10 % increase in the percentage of days exceeding the WHO standards for PM10, daily mortality rises by 0.313 %. In addition, they identified that areas with lower atmospheric instability and greater impervious surface coverage present higher mortality risks [7].

[3] found that elevated PM2.5 concentrations in Bogotá are associated with increased mortality risks, particularly with prolonged exposure. In the locality of Kennedy, which reports the highest PM2.5 levels, a 1.2 % increase in short-term cardiopulmonary mortality and a 9 % increase in long-term mortality were estimated due to these high concentrations. These findings are consistent with international research indicating that exposure to fine PM primarily affects individuals with heart or lung conditions, children, and the elderly, and may lead to various adverse outcomes such as premature death, heart attacks, aggravated asthma, and reduced lung function [4].

Regarding policy effectiveness, [1] observed that while PM10 concentrations in Bogotá have shown a downward trend, PM2.5 levels have remained stable despite an increase in mobile sources, suggesting that implemented policies have been more effective at reducing coarse PM than fine particles. Similarly, [6] highlighted that a 40 % traffic restriction during peak hours in Bogotá resulted in a 14.8 % reduction in daily PM10 concentrations and a 0.79 % decrease in daily mortality. Additionally, [8] documented significant reductions in both PM2.5 and PM10 during the COVID-19 lockdown, demonstrating the potential for air quality improvement through drastic reductions in human activities, particularly vehicular traffic [9].

Finally, [5] reported that while Bogotá and Medellín exhibit annual decreasing trends in PM2.5 concentrations due to effective policies, Cali shows an increasing trend, highlighting the need for differentiated, evidence-based strategies tailored to each city [10].

To address the environmental challenges associated with transportation in Bogotá, a formative experience was conducted within the Traffic Engineering course of the Civil Engineering program at the Universidad Católica de Colombia. This initiative aimed to integrate innovative pedagogical methods to strengthen students' professional competencies, employing problem-based learning (PBL) as a strategy to foster inquiry and critical thinking.

The activity was carried out in the Chapinero district, focusing on intersections with varying levels of vehicular traffic to examine their relationship with air pollution and modes of transportation. The primary objective was to highlight the importance of integrating theory and practice, promoting student engagement in projects related to civil engineering, the environment, and public health. Key locations were selected, including Carrera 7 with Calles 45 and 53, and Calle 47, located between Carrera 7 and Avenida Caracas. At these sites, students—previously trained—conducted 15 measurements of air quality and traffic flow at different times of the day. This experience enhanced their critical analysis skills regarding urban mobility, quality of life, and sustainability, reaffirming the value of hands-on work in their professional development [11], [12].

Materials and Methods

PBL is an educational methodology that integrates various disciplines and methods to strengthen autonomous and active student learning. This approach encourages self-management and the development of self-directed learning skills through a constructivist and adaptable dynamic. Within this model, students are challenged with meaningful problems that stimulate critical thinking, and mistakes are viewed as opportunities for improvement. Continuous, formative, and personalized assessment becomes essential to the process, as does self-assessment, which fosters ongoing reflection on one's own learning [13].

During the practical phase of the project, students from the Traffic Engineering course at the Universidad Católica de Colombia were tasked with analyzing air pollution in Bogotá caused by PM resulting from fossil fuel vehicle traffic. Teams of 4 to 5 students were trained to explore, from a theoretical and practical perspective, the relationship between traffic flow and pollution levels in the university area of Chapinero. The students consulted specialized bibliographic sources to understand the issue and propose potential urban solutions, integrating field data on air quality and traffic. The activity encouraged collaborative work, active participation, and leadership within the teams, which organized and shared their measurements and analyses with the rest of the class.

The students presented the results of their research, analyzing both the collected data and the environmental issues related to air pollution in Bogotá, particularly in connection with motor vehicle traffic. This activity fostered critical reflection on the current state of air quality in the city. For the analysis, the maximum permissible levels of atmospheric pollutants and their corresponding exposure times were taken as references, in accordance with the current Colombian regulations, specifically the resolution issued by the Ministry of Environment and Sustainable Development [14]. The established concentration limits for air pollutants and their associated exposure durations, as defined by the applicable regulations, are outlined below:

- PM10:
  - 50 μg/m^3 as an annual average
  - 100 μg/m^3 for a 24-hour period
- PM2.5:
  - 25 μg/m^3 as an annual average
  - 50 μg/m^3 for a 24-hour period

The PBL approach was validated through the selection of two road corridors in the Chapinero sector of Bogotá: one with high vehicular flow (Carrera 7 between Calles 45 and 53) and another with lower congestion (Calle 47 between Carrera 7 and Avenida Caracas). Monitoring was conducted on September 27 during peak hours (7:00 to 9:00 a.m.) using portable devices—BR-8A and PMS5003—to measure real-time concentrations of PM (PM2.5) across five routes. According to environmental monitoring scales, the study is classified as local, as it covers areas with relatively homogeneous land use within a range of 0.5 to 4 kilometers [15].

To accurately compare the pollutant concentrations obtained during field monitoring with the limits established in current regulations, it was necessary to adjust the data to reference conditions. Since the recorded average values reflect local pressure and temperature conditions, they were corrected to Bogotá's standard reference parameters: 298.15 K (25 °C) for temperature and 101.325 kPa (760 mmHg) for pressure. This adjustment enabled a valid comparison with the maximum permissible air quality levels set by legislation [16].

The conversion to reference conditions was calculated using Equation 1:

$$CCR = ((CL \times PL) / 760) \times (298\ K / (273 + TL)) \tag{1}$$

Where:

- CCR: Concentration of the pollutant under reference conditions in μg/m^3 (micrograms per cubic meter)
- CL: Concentration of the pollutant under local pressure and temperature conditions in μg/m^3
- PL: Local barometric pressure in mmHg (millimeters of mercury)
- TL: Average local ambient temperature in °C (degrees Celsius)

This formula allows field measurements to be adjusted to standard conditions (25 °C and 760 mmHg), ensuring comparability with regulatory air quality limit values.

To conduct the manual traffic count, a PBL-based method was employed. The process began with the delimitation of the study area, selecting key intersections in the Chapinero district: Carrera 7 with Calles 45 and 53, and Calle 47 with Carrera 13. At each point, elements such as traffic lights, light cycles, signage, pedestrian crossings, bike lanes, and sidewalks were analyzed. The objective of the observation was defined, specifying the transportation modes to be recorded: private vehicles, public transportation, freight vehicles, taxis, motorcycles, bicycles, and pedestrians. A data collection template was then designed to record the sample type, travel direction, and transportation modes. Student teams were assigned to specific traffic lights and tasked with monitoring specific types of mobility. Counts were conducted during peak congestion periods (e.g., between 7:00 and 8:00 a.m.) in 15-minute intervals. The collected data were consolidated and analyzed to estimate mobility flows and produce interpretations that could inform proposals for improvement [17].

Results and Analysis

During the field visits conducted across different segments and time slots, the following climatic observations and average PM concentrations (PM10 and PM2.5) were recorded using two measuring devices, the Household Air Quality Detector PMS5003 and the BR-8A Air Quality Tester PM2.5:

At 7:20 a.m., on a rainy day, along Carrera 7 from Calle 45 to Calle 53, average concentrations recorded were 62.2 μg/m^3 of PM10 and 59.6 μg/m^3 of PM2.5 using the PMS5003, and 58.2 μg/m^3 of PM10 and 55.3 μg/m^3 of PM2.5 using the BR-8A.

At 7:50 a.m. on a rainy day, along Carrera 7 from Calle 53 to Calle 45, average values were 44.9 μg/m^3 of PM10 and 42.1 μg/m^3 of PM2.5 using the PMS5003, and 40.1 μg/m^3 of PM10 and 38.8 μg/m^3 of PM2.5 using the BR-8A.

At 8:20 a.m. on a cloudy day, along Carrera 7 from Calle 45 to Calle 53, the PMS5003 recorded 74.6 μg/m^3 of PM10 and 66.9 μg/m^3 of PM2.5, while the BR-8A showed 85.5 μg/m^3 of PM10 and 81.7 μg/m^3 of PM2.5.

At 8:50 a.m. on a sunny day, along Carrera 7 from Calle 53 to Calle 45, averages were 84 μg/m^3 of PM10 and 89 μg/m^3 of PM2.5 using the PMS5003, and 75 μg/m^3 of PM10 and 76 μg/m^3 of PM2.5 using the BR-8A.

At 9:20 a.m. on a sunny day, along Calle 47 from Carrera 7 to Avenida Caracas, the PMS5003 recorded 48 μg/m^3 of PM10 and 41.7 μg/m^3 of PM2.5, while the BR-8A measured 43.3 μg/m^3 of PM10 and 36.3 μg/m^3 of PM2.5.

On the other hand, during monitoring rounds conducted at various sections and times, the following weather conditions and average PM concentrations (PM10 and PM2.5) were recorded using two measuring devices: the Household Air Quality Detector PMS5003 and the BR-8A Air Quality Tester PM2.5.

At 7:20 a.m. on a rainy day, along Carrera 7 from Calle 45 to Calle 53, average values were 66.8 μg/m³ for PM10 and 64.0 μg/m³ for PM2.5 using the PMS5003, and 62.5 μg/m³ for PM10 and 59.4 μg/m³ for PM2.5 using the BR-8A.

At 7:50 a.m., along Carrera 7 from Calle 53 to Calle 45, the average concentrations were 48.2 μg/m³ for PM10 and 45.2 μg/m³ for PM2.5 using the PMS5003, and 43.1 μg/m³ for PM10 and 41.7 μg/m³ for PM2.5 using the BR-8A.

At 8:20 a.m. on a cloudy day, along Carrera 7 from Calle 45 to Calle 53, the average concentrations were 80.1 μg/m³ for PM10 and 71.8 μg/m³ for PM2.5 using the PMS5003, and 91.8 μg/m³ for PM10 and 87.7 μg/m³ for PM2.5 using the BR-8A.

At 8:50 a.m. on a sunny day, along Carrera 7 from Calle 53 to Calle 45, the averages were 90.2 μg/m³ for PM10 and 95.6 μg/m³ for PM2.5 using the PMS5003, and 80.5 μg/m³ for PM10 and 81.6 μg/m³ for PM2.5 using the BR-8A.

At 9:20 a.m. on a sunny day, along Calle 47 from Carrera 7 to Avenida Caracas, average values were 51.5 μg/m³ for PM10 and 44.8 μg/m³ for PM2.5 using the PMS5003, and 46.5 μg/m³ for PM10 and 39.0 μg/m³ for PM2.5 using the BR-8A.

As evidenced by the average data collected in both a high-traffic corridor (Carrera 7) and a low-traffic area (Calle 47), the two air quality monitoring devices used for measuring PM yielded comparable results across sensors. Both instruments demonstrated consistent responsiveness to fluctuations in PM concentrations associated with the presence of vehicles. These findings confirm the reliability and relevance of both devices for in situ environmental monitoring of air pollution.

Based on the information previously described, traffic counts were carried out on the selected road segments as outlined in the methodology. For this activity, students recorded on the count sheets the number of units corresponding to each mode of transportation, categorized according to the different traffic movements or turning directions permitted by the traffic signals.

Additionally, data were recorded on the number of pedestrians crossing at designated crosswalks and the number of bicycles in circulation, both those traveling in the regular direction of vehicular flow and using the existing bike lanes (such as Calle 45 in the west–east direction), as well as those bicycles that crossed via pedestrian crosswalks. All of this was carried out in accordance with the methodology previously described.

In this regard, the traffic count conducted at the intersection of Carrera 7 and Calle 53 in Bogotá, Colombia, provides a detailed record of both vehicular and pedestrian flow in the area. The following is an interpretation of the data collected:

- Private Vehicles: These dominated traffic at the intersection, with a total of 2,577 units, indicating that the majority of vehicular flow consisted of private cars.
- Trucks/Heavy Load Vehicles: With 97 units recorded, they represented a small fraction of the traffic, suggesting a lower volume-related impact.
- Taxis: They accounted for a significant portion of traffic, with 1,168 units, underscoring the city's high reliance on this mode of transportation.

- SITP (Integrated Public Transport System): A total of 113 SITP buses were recorded, showing a moderate presence in the intersection's traffic.
- Mid-size Buses ("busetas"): These had a comparable presence, with 126 units, reflecting their ongoing use as a public transportation option.
- TransMilenio: With 188 units, this Bus Rapid Transit system accounted for a notable share of the traffic flow, underscoring its significant role in mass urban mobility.
- Motorcycles: Representing a considerable share with 420 units, they appeared as a popular choice for fast and efficient transportation.
- Service Vehicles (ambulances, police, fire brigade, etc.): These were the least frequent, with only 23 units, reflecting their specific and sporadic use.
- Bicycles (bike lane): A total of 231 bicycles utilized the dedicated bike lane, indicating a high level of adoption of sustainable transportation alternatives.
- Pedestrians (crosswalk): 1,644 pedestrians were counted using the crosswalk, underscoring the importance of pedestrian flow and the need for proper safety infrastructure.
- Bicycles (crosswalk): 70 bicycles were recorded crossing via the pedestrian crosswalk, suggesting that some cyclists prefer to use pedestrian infrastructure to navigate the intersection.

The traffic count conducted at the intersection of Carrera 7 and Calle 45 in Bogotá, Colombia, provides a detailed breakdown of vehicular and pedestrian flow in the area. The following is an interpretation of the recorded data:

- Private Vehicles: These dominated the traffic at the intersection, with a total of 2,188 units, indicating that private cars account for the majority of vehicular flow.
- Trucks/Heavy Load Vehicles: With 66 units recorded, these represented a small fraction of the traffic, suggesting limited volume impact.
- Taxis: They accounted for a significant portion of the traffic, with 626 units, reflecting the city's high dependence on this transportation mode.
- SITP: A total of 125 SITP buses were recorded, showing moderate participation in the intersection's traffic.
- Mid-size Buses: These had a moderate presence with 80 units, indicating their continued use as a public transportation option.
- TransMilenio: With 156 units, this mass transit system had notable representation, contributing significantly to the overall traffic flow.
- Motorcycles: With 760 units, they comprised a considerable share of the traffic, suggesting their popularity as a fast and efficient means of transportation.

- Service Vehicles: These specialized vehicles were the least frequent, with only 38 units, reflecting their specific and non-continuous usage.
- Bicycles (bike lane): A total of 157 bicycles were observed using the bike lane, indicating a healthy level of adoption of sustainable transportation.
- Pedestrians (crosswalk): A total of 545 pedestrians utilized the designated crosswalk, underscoring the importance of pedestrian movement in the area and the necessity for adequate safety infrastructure.
- Bicycles (crosswalk): 49 bicycles were recorded crossing at the pedestrian crosswalk, suggesting that some cyclists prefer to use pedestrian crossings to navigate the intersection.

Regarding the traffic count conducted on Calle 47—which, unlike Carrera 7 at both intersections, does not experience high traffic volumes—the recorded flow of vehicles, pedestrians, and bicycles was notably lower than in the other two monitored locations.

The traffic count at the intersection of Calle 47 and Carrera 13 in Bogotá, Colombia, provides a detailed breakdown of vehicular and pedestrian activity in the area. Below is the interpretation of the collected data:

- Private Vehicles: These dominate the intersection's traffic, with a total of 1,055 units, indicating that the majority of vehicular flow consists of personal automobiles.
- Trucks/Heavy Cargo Vehicles: With only 29 units, these represent a small fraction of the traffic, indicating a relatively low volume impact.
- Taxis: They account for a significant portion of traffic, with 562 units recorded, reflecting a high reliance on this mode of transportation in the city.
- SITP: A total of 61 SITP buses were recorded, showing moderate participation in the traffic flow at this intersection.
- Mid-size buses: They are moderately present, with 58 units, indicating their continued use as an alternative to public transportation.
- TransMilenio: No TransMilenio buses were recorded at this location.
- Motorcycles: They comprise a substantial portion of the traffic, with 173 units, indicating their popularity as a fast and efficient transportation option.
- Service Vehicles: These specialized vehicles were the least frequently observed, with only 12 units noted, consistent with their specific and occasional use.
- Bicycles (bike lane): A total of 144 bicycles were recorded using the designated bike lane, indicating a healthy level of adoption of sustainable transportation.
- Pedestrians (crosswalk at the traffic light): 1,003 pedestrians utilized the crosswalk, underscoring the significance of pedestrian traffic in the area and the necessity for adequate infrastructure to ensure safety.

- Bicycles (crossing via the crosswalk): 53 bicycles were recorded using the pedestrian crosswalk, suggesting that some cyclists prefer this route to navigate the intersection.

Discussion and Conclusions

The results obtained from the PBL experience align closely with the atmospheric pollution context described in the introduction and documented in the scientific literature. As highlighted in previous studies, concentrations of PM10 and PM2.5 in Bogotá and other cities consistently exceed both national standards and the WHO recommended limits, with average PM2.5 levels of 20.05 µg/m^3 and PM10 levels of 55.64 µg/m^3, including critical episodes such as those observed in Kennedy, where hourly PM2.5 averages reach 91.1 µg/m^3 [1], [3]. In practice, students measured PM10 concentrations ranging from 44.9 to 84.9 µg/m^3 and PM2.5 concentrations between 38.8 and 99 µg/m^3, demonstrating that several measurements surpassed national and international limits, particularly under conditions of high vehicular congestion and climatic variations.

During the monitoring, it was observed that in three out of five measurement rounds, PM2.5 levels exceeded the daily threshold of 50 µg/m^3, allowing students to understand the link between prolonged exposure to fine PM and respiratory health risks, as highlighted by the WHO. Although PM10 levels did not surpass the limit of 100 µg/m^3, the elevated PM2.5 values—close to those of PM10—underscore the hazardous air quality in areas such as the university zone of Chapinero, where a large portion of PM can penetrate the respiratory system, increasing the risk of diseases by reaching the alveoli and facilitating processes like cellular apoptosis.

Classroom discussions facilitated an analysis of how urban mobility—particularly the prevalence of private cars and the reliance on fossil fuels—exacerbates air pollution and its adverse effects on public health [18]. Students recognized that vehicular restrictions can reduce daily PM10 concentrations by up to 14.8 % [5], [6] and reflected on the critical importance of prioritizing sustainable mobility in urban planning [19], [20].

The implementation of PBL enabled students not only to validate scientific data but also to develop practical and reflective skills, enhancing their ability to critically analyze environmental issues and propose comprehensive solutions from the perspectives of civil engineering, health, and environmental science. This exercise demonstrated the value of integrating theory and practice to train professionals capable of addressing environmental challenges [21].

The experience conducted in the university zone, utilizing the PBL methodology, enabled the systematic documentation of Bogotá's atmospheric pollution challenges, validating previous scientific reports and fostering meaningful academic learning. The PM measurements revealed that PM10 and PM2.5 concentrations in the urban environment frequently exceed both national and international air quality standards, particularly during peak traffic hours. Recorded PM2.5 values often surpassed the daily threshold of 50 µg/m^3, reaching averages as high as 95.6 µg/m^3 under heavy traffic conditions. These findings confirm the severity of the problem and align closely with critical pollution episodes documented in vulnerable areas such as Kennedy, where hourly concentrations exceed 90 µg/m^3 [1], [3].

The integrated analysis of vehicular counts and air quality measurements revealed a direct correlation between the predominance of private automobiles, the substantial presence of both public and private transportation vehicles, and the deterioration of air quality. This evidence confirms that approximately 43 % of air pollution in Bogotá originates from mobile sources, particularly diesel-powered cars. Although sustainable modes such as cycling and walking were identified, their contribution is insufficient to offset the significant impact of motorized mobile sources on air quality. Nonetheless, the finding that management measures like vehicular restrictions can reduce daily PM10 concentrations by up to 14.8 % [5], [6] highlights the potential effectiveness of comprehensive sustainable mobility policies in mitigating atmospheric pollution.

From an educational perspective, the implementation of PBL proved to be a highly effective strategy for contextualizing and experiencing urban environmental challenges, transforming the classroom into a living laboratory that fostered the development of analytical, reflective, and solution-oriented competencies among civil engineering students. This experience successfully bridged theoretical knowledge with local realities, promoting a critical understanding of contemporary urban issues and highlighting the need for interdisciplinary solutions that effectively integrate engineering, public health, and environmental sustainability.

In summary, the study confirms that PM pollution in Bogotá remains a persistent challenge for public health and urban quality of life, necessitating comprehensive interventions in both mobility management and the training of professionals equipped to address these issues. The research highlights that the education of future engineers should integrate active and context-based methodologies that enhance their ability to analyze, intervene in, and transform the urban environment from a sustainable, multidisciplinary, and socially responsible perspective, preparing them to face 21st-century environmental challenges with innovative technical and pedagogical tools that promote participation.

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