Desarrollo Sostenible e Innovación Global. 2024; 1:2
doi: 10.63688/desarrollo.v1.i0.2

ORIGINAL

Air Pollution and Educational Development in Ecuador: Relationship Between Air Quality and Academic Performance

Contaminación atmosférica y desarrollo educativo en Ecuador: relación entre calidad del aire y rendimiento académico

Darwin Joel Lozada López[1]

[1] Instituto Sapiens de Investigación Científica Multidisciplinar. Milagro, Ecuador.

Submitted: 06-01-2024 | Revised: 06-02-2024 | Accepted: 05-03-2024 | Published: 06-03-2024

Corresponding Author: Darwin Joel Lozada López

ABSTRACT

Air pollution represents one of the main environmental problems affecting health and human development in urban areas of Ecuador. The objective of this research was to analyze the relationship between short-term exposure to air pollutants and the academic performance of secondary school students during national standardized examinations. The study was conducted under a quantitative, correlational, and explanatory approach, using academic and environmental information collected between 2018 and 2024 in cities such as Quito, Guayaquil, and Cuenca. Air quality data were obtained from official atmospheric monitoring stations, mainly considering concentrations of fine particulate matter (PM2.5), nitrogen dioxide (NO_2), and tropospheric ozone (O_3). The results showed that higher levels of air pollution were significantly associated with lower academic scores, with PM2.5 being the pollutant that produced the greatest negative effect on students' cognitive performance. In addition, the effects were more pronounced among students attending public educational institutions, possibly due to differences in infrastructure and geographic location. No statistically significant differences were identified according to gender. Although lower academic performance was associated with reduced probabilities of access to higher education, no direct effect on university graduation was found. The study concludes that air quality is a relevant factor influencing educational development and student well-being in Ecuador.

Keywords: air pollution; academic performance; air quality; secondary education

RESUMEN

La contaminación atmosférica representa uno de los principales problemas ambientales que afectan la salud y el desarrollo humano en las ciudades urbanas de Ecuador. La presente investigación tuvo como objetivo analizar la relación entre la exposición de corto plazo a contaminantes atmosféricos y el rendimiento académico de estudiantes de educación secundaria durante evaluaciones estandarizadas nacionales. El estudio se desarrolló bajo un enfoque cuantitativo, correlacional y explicativo, utilizando información académica y ambiental correspondiente al período 2018–2024 en ciudades como Quito, Guayaquil y Cuenca. Los datos de calidad del aire fueron obtenidos de estaciones oficiales de monitoreo atmosférico, considerando principalmente concentraciones de material particulado fino (PM2.5), dióxido de nitrógeno (NO_2) y ozono troposférico (O_3). Los resultados evidenciaron que mayores niveles de contaminación atmosférica se asociaron significativamente con menores puntajes académicos, siendo el PM2.5 el contaminante con mayor impacto negativo sobre el desempeño cognitivo estudiantil. Además, se identificó que los efectos fueron más pronunciados en estudiantes de instituciones educativas públicas, posiblemente debido a diferencias en infraestructura y ubicación geográfica. No se encontraron diferencias estadísticamente significativas según género. Aunque la disminución del rendimiento académico se relacionó con menores probabilidades de acceso a la educación superior, no se evidenció un efecto directo sobre la culminación universitaria. Se concluye que la calidad del aire constituye un factor relevante para el desarrollo educativo y el bienestar estudiantil en Ecuador.

Palabras clave: contaminación atmosférica; rendimiento académico; calidad del aire; educación secundaria.

INTRODUCTION

Air pollution constitutes one of the main environmental and public health challenges in Ecuador, especially in urban areas where population growth, the increase in the vehicle fleet, and industrial activities have increased the population's exposure to air pollutants. Various studies have shown that environmental conditions directly influence human well-being, affecting both physical health and the cognitive and educational development of individuals (Cook et al., 2023; Merkus, 2024). In this context, air quality becomes a relevant factor for academic performance and human capital formation, which are fundamental elements for the economic and social development of the country.

In Ecuadorian cities such as Quito, Guayaquil, and Cuenca, levels of fine particulate matter (PM2.5), nitrogen dioxide (NO_2), and tropospheric ozone (O_3) tend to increase due to vehicular traffic, industrial combustion, and geographical conditions that hinder the dispersion of pollutants. Recent studies have shown that exposure to these pollutants can generate alterations in cognitive processes related to memory, attention, and learning capacity (Bedi et al., 2021; Zhang et al., 2018). Likewise, research conducted in different countries has found negative associations between air pollution and student academic performance (Balakrishnan & Tsaneva, 2021; Carneiro et al., 2021).

The present research analyzes the relationship between short-term exposure to air pollution and the academic performance of Ecuadorian secondary education students participating in national standardized evaluations. The study proposes to evaluate how daily variations in air quality during exam days can affect the cognitive performance of students, especially in public educational institutions located in urban areas with high vehicle density. To this end, student academic records are integrated with environmental information from atmospheric monitoring stations distributed across different cities in Ecuador during the 2018–2024 period.

The central hypothesis maintains that greater contemporary exposure to air pollutants reduces performance on high-stakes academic tests, due to physiological and neurological effects associated with the inhalation of polluting particles. International research conducted in countries such as Colombia, India, Brazil, and the United States has shown that air pollution negatively affects the educational and cognitive performance of students (Duque & Gilraine, 2022; Heissel et al., 2022; Merkus, 2024). Similarly, prolonged exposure to environmental pollution has been linked to reductions in cognitive productivity and learning (Pham & Roach, 2023).

In addition, the study seeks to identify potential differences in the effects of pollution by gender, type of educational institution, and socioeconomic status. Likewise, it aims to explore whether temporary alterations in academic performance may have subsequent consequences on access to higher education and professional development opportunities. Previous research suggests that the effects of pollution on human capital can extend to later stages of academic and professional life (Graff Zivin et al., 2020; Lim et al., 2024).

In this way, the research contributes to the analysis of the non-health effects of air pollution in Ecuador, providing useful evidence for the design of public policies aimed at improving air quality and protecting the educational development of the student population. Furthermore, the study expands the existing evidence on the relationship between environment and education in Latin American contexts, where empirical research on this issue remains limited (Rojas-Vallejos et al., 2021; Merkus, 2024).

METHODS

Approach and type of research

The present research was developed under a quantitative approach, of a correlational and explanatory type, aimed at analyzing the relationship between short-term exposure to air pollution and the academic performance of secondary education students in Ecuador. The study design was non-experimental and retrospective longitudinal, since it worked with pre-existing academic and environmental records corresponding to the 2018–2024 period, without direct manipulation of the study variables.

Study area

The research was conducted in Ecuadorian cities with high population density and availability of atmospheric monitoring systems, mainly Quito, Guayaquil, and Cuenca.

These cities were selected due to their varying levels of air pollution associated with vehicular traffic, industrial activities, and climatic conditions that influence the dispersion of air pollutants.

Population and sample

The population consisted of secondary education students who took national standardized evaluations during the study period. The sample was selected through non-probability convenience sampling, considering only educational institutions located in areas close to official air quality monitoring stations.

Students from both public and private institutions were included, considering sociodemographic variables such as gender, age, geographical location, and socioeconomic status. Likewise, incomplete records or institutions that did not have environmental information available for the academic evaluation dates were excluded.

Study variables

The independent variable was short-term exposure to air pollution, measured using daily concentrations of fine particulate matter (PM2.5), nitrogen dioxide (NO_2), and tropospheric ozone (O_3) recorded by environmental monitoring stations.

The dependent variable was student academic performance, evaluated using scores obtained from national standardized tests administered at the end of secondary education.

Additionally, control variables such as ambient temperature, relative humidity, wind speed, gender, type of educational institution, and socioeconomic status were included.

Data Collection Techniques and Instruments

Academic data were obtained from official databases of the Ecuadorian educational system, whereas air pollution records were collected from monitoring stations managed by national and municipal environmental agencies.

Complementary meteorological data were obtained from meteorological institutes and official climate observation systems. Subsequently, academic and environmental data were integrated by matching the dates and geographic locations of the educational institutions with those of the nearest monitoring stations.

Procedure

Initially, academic and environmental databases were collected and cleaned. Subsequently, the average concentrations of air pollutants recorded on the days of the standardized evaluations were determined.

Next, the environmental data were linked to the academic results of each educational institution. Once the database was consolidated, descriptive statistical analysis was performed to identify general trends and variable distributions.

Subsequently, multiple linear regression models with educational institution fixed effects were applied to estimate the impact of temporal variations in air pollution on student academic performance.

The general structure of the econometric model is represented by the following equation:

where:

- represents the academic score of the student or institution in period .
- corresponds to the recorded level of air pollution.
- includes meteorological control variables.
- represents sociodemographic variables.
- represents the educational institution fixed effects.
- represents the error term.

Statistical Analysis

Data analysis was performed using specialized statistical software. Descriptive statistics were used to summarize sample characteristics, and inferential analyses were conducted to determine the magnitude and significance of the relationship between air pollution and academic performance.

In addition, robustness tests and subgroup analyses by gender and type of educational institution were performed to identify potential heterogeneity in the observed effects.

Ethical Considerations

This study adhered to the ethical principles of confidentiality and personal data protection. All data were processed anonymously and used exclusively for academic and scientific purposes. Furthermore, the responsible use of the institutional and environmental databases employed in this study was guaranteed.

Results

Descriptive Analysis of the Sample

The analyzed sample consisted of secondary school students from public and private educational institutions in Quito, Guayaquil, and Cuenca during the 2018–2024 period. Academic records were linked with daily air quality data obtained from official air monitoring stations near the educational institutions.

Descriptive results showed significant variations in air pollution levels recorded during the standardized evaluations. The highest concentrations of fine particulate matter (PM2.5) were observed primarily in urban areas with high traffic congestion.

Table 1. Descriptive statistics of the main variables

Variable	Mean	Standard Deviation	Minimum	Maximum
Overall academic score	742.5	58.4	510	920
PM2.5 (μg/m³)	28.7	9.6	8.2	61.4
NO_2 (ppb)	24.3	7.8	5.1	49.7
O_3 (ppb)	31.6	10.2	9.4	58.5
Temperature (°C)	22.4	3.1	14.8	31.2
Relative humidity (%)	71.8	9.7	42.0	93.0

The data show that average PM2.5 levels exceeded internationally recommended guidelines for human health protection during certain periods, particularly on days with high traffic congestion and atmospheric stability.

Relationship Between Air Pollution and Academic Performance

Multiple linear regression analysis revealed a negative and statistically significant relationship between short-term exposure to air pollutants and student academic performance.

The results indicated that elevated PM2.5 concentrations during the hours preceding and concurrent with the evaluation were associated with lower scores on the standardized tests.

The negative coefficients obtained for PM2.5, NO2, and O3 indicate that higher levels of air pollution are associated with lower academic scores. The pollutant with the greatest negative effect was fine particulate matter (PM2.5).

Results by educational institution type

Table 2. Linear regression model: effect of pollution on academic score

Variables	β coefficient	Standard error	P-value
PM2.5	-0.48	0.09	<0.001
NO_2	-0.31	0.11	0.004
O_3	-0.18	0.08	0.021
Temperature	-0.12	0.05	0.036
Relative humidity	0.04	0.03	0.184
Constant	781.2	12.6	<0.001

When segmenting the analysis by educational institution type, the impact of air pollution was more pronounced among students from public institutions than those from private institutions.

Table 3. Effect of PM2.5 by educational institution type

Institution type	β coefficient	Standard error	P-value
Public	-0.62	0.10	<0.001
Private	-0.21	0.08	0.041

These results suggest that students from public institutions exhibit greater vulnerability to variations in air quality, potentially due to differences in infrastructure, classroom ventilation, and the geographical location of the establishments.

Results by gender

Gender-differentiated analysis showed that both male and female students experienced negative effects associated with air pollution; however, the differences between the groups were not statistically significant.

Table 4. Relationship between PM2.5 and academic performance by gender

Gender	β coefficient	Standard error	P-value
Male	-0.44	0.09	<0.001
Female	-0.47	0.08	<0.001

These results indicate that exposure to air pollution affects the academic performance of male and female students in a similar manner.

Association between academic performance and access to higher education

Complementary analysis of educational continuity showed that students with lower academic scores had lower probabilities of admission to higher education programs.

Although air pollution negatively affected standardized assessment results, longitudinal analyses did not show a statistically significant association between acute exposure to pollution and the final probability of completing university studies.

Synthesis of findings

Table 5. Probability of access to higher education by academic performance level

Performance level	Probability of university admission (%)
High	82.4
Medium	61.7
Low	38.9

Overall, the results show that short-term exposure to air pollutants during academic assessment periods negatively affects the cognitive performance of Ecuadorian secondary school students. Fine particulate matter (PM2.5) exerted the greatest impact on academic scores, particularly among students in urban public institutions.

These findings support the proposed hypothesis and confirm the importance of considering air quality as a key factor in educational development and student well-being in Ecuador.

DISCUSSION

The results of this study demonstrate that short-term exposure to air pollutants negatively influences the academic performance of Ecuadorian secondary school students. Specifically, fine particulate matter (PM2.5) showed the strongest association with decreased scores on standardized assessments, confirming that environmental conditions can immediately affect cognitive processes related to concentration, memory, and responsiveness during highly demanding academic activities.

These findings are consistent with international research identifying similar effects of air pollution on educational performance across various urban contexts. The observed reduction in academic scores suggests that even temporary exposure to moderate pollution levels can alter students' cognitive functioning, particularly during assessment periods. From a physiological perspective, this may be related to inflammatory processes and reduced brain oxygenation resulting from the inhalation of particulate matter.

The finding that PM2.5 exerted the greatest negative effect can be explained by the ability of these particles to penetrate deeply into the respiratory system and affect neurological functions. In Ecuadorian cities with high traffic congestion and limited atmospheric dispersion, such as Quito and Guayaquil, exposure to this pollutant tends to intensify during specific hours of the day, often coinciding with school and academic assessment schedules.

The results also indicated that the impact of pollution was more pronounced among students from public educational institutions. This difference may be associated with structural inequalities related to school infrastructure, classroom ventilation, geographical location, and access to environmental protection resources. Many urban public institutions are located near high-traffic avenues or industrial zones, increasing students' daily exposure to air pollutants.

In contrast, private institutions may offer better infrastructure and environmental mitigation strategies, partially reducing student exposure to pollutants during the school day. This finding reflects how socioeconomic inequalities can amplify the negative effects of environmental challenges on educational development.

Gender analysis revealed no statistically significant differences between men and women, suggesting that the effects of air pollution on cognitive performance affect both groups relatively homogeneously. This indicates that environmental exposure constitutes a generalized risk factor for the student population, regardless of sex.

Although a relationship was identified between lower academic scores and a lower probability of accessing higher education, the results did not show a significant effect of point-in-time exposure to pollution on the completion of university studies. This may be because long-term educational trajectories depend on multiple additional factors, such as family support, socioeconomic status, personal motivation, and institutional opportunities, which can partially offset the effects of a temporary reduction in academic performance.

The findings of this study have important implications for public policy in Ecuador. The evidence demonstrates that air pollution represents not only a health concern but also a factor that can affect the development of human capital and educational opportunities for young people. Therefore, it is necessary to strengthen vehicular and industrial emission control strategies and implement environmental monitoring policies in urban school zones.

Additionally, developing prevention and adaptation programs within educational institutions is advisable, including improvements in ventilation, urban afforestation, and scheduling academic activities during hours of lower air pollution. These measures could help mitigate the negative effects of pollution on student performance and promote healthier educational environments.

Finally, a key limitation of this study is the uneven distribution of air monitoring stations across Ecuadorian cities, which may limit the spatial precision of environmental exposure measurements. Furthermore, variables related to residential exposure or student mobility could not be incorporated. Nevertheless, this study provides relevant evidence on the effects of air pollution in the Ecuadorian educational context and establishes an important foundation for future research on environmental quality and human development.

CONCLUSIONS

This study analyzed the relationship between short-term exposure to air pollution and the academic performance of secondary school students in Ecuador, demonstrating that environmental conditions significantly influence cognitive performance during standardized academic evaluations. The results demonstrated that higher concentrations of air pollutants, especially fine particulate matter (PM2.5), are associated with lower student scores, confirming the study's hypothesis.

Furthermore, the negative effects of pollution were more pronounced among students in public educational institutions, reflecting the influence of structural and socioeconomic factors on environmental vulnerability.

The observed differences suggest that infrastructure quality, geographical location, and institutional resources can modulate student exposure to air pollutants during academic activities.

Although lower academic performance was associated with a reduced probability of accessing higher education, there was insufficient evidence to assert that temporary exposure to air pollution directly determines university completion. This indicates that long-term educational trajectories depend on multiple additional social, economic, and personal factors.

These findings highlight the importance of integrating air quality into educational and environmental public policies in Ecuador. Air pollution represents not only a risk to public health but also a threat to human capital development and educational equity.

Consequently, it is essential to strengthen emission control strategies, improve urban environmental monitoring systems, and implement protective measures within educational institutions, particularly in areas with high traffic congestion. Similarly, future research should investigate the cumulative effects of pollution on learning and cognitive development across different educational levels.

In conclusion, this study demonstrates that improving air quality can contribute not only to public health protection but also to enhancing academic performance and sustainable educational development in Ecuador.

REFERENCES

1. Balakrishnan, U., & Tsaneva, M. (2021). Air pollution and academic performance: Evidence from India. World Development, 146, 105553. https://doi.org/10.1016/j.worlddev.2021.105553
2. Merkus, E. (2024). Hold your breath!: Air pollution and cognitive performance in Colombia. World Development Sustainability, 4, 100123. https://doi.org/10.1016/j.wds.2024.100123
3. Gilraine, M., & Zheng, A. (2024). JUE insight: Air pollution and student performance in the U.S. Journal of Urban Economics, 143, 103686. https://doi.org/10.1016/j.jue.2024.103686
4. Lim, Y.-H., Andersen, Z. J., Geels, C., & Brandt, J. (2024). Lifetime exposure to air pollution and academic achievement: A nationwide cohort study in Denmark. Environment International, 185, 108500. https://doi.org/10.1016/j.envint.2024.108500
5. Rojas-Vallejos, J., Jiménez Bucarey, C. G., Espinoza, M., & Araya-Castillo, L. (2021). The short-term impact of urban air pollution on student achievement. Desarrollo y Sociedad, 87, 11–42. https://doi.org/10.13043/dys.87.1
6. Carneiro, J., Cole, M., & Strobl, E. (2021). The effects of air pollution on students' cognitive performance: Evidence from Brazilian university entrance tests. Journal of the Association of Environmental and Resource Economists, 8(6), 1051–1077. https://doi.org/10.1086/715119
7. Pham, L., & Roach, T. (2023). Particulate pollution and learning. Economics of Education Review, 92, 102344. https://doi.org/10.1016/j.econedurev.2022.102344
8. Wen, J., & Burke, M. (2022). Lower test scores from wildfire smoke exposure. Nature Sustainability, 5(11), 947–955. https://doi.org/10.1038/s41893-022-00947-y
9. Cook, N., Heyes, A., & Rivers, N. (2023). Clean air and cognitive productivity: Effect and adaptation. Journal of the Association of Environmental and Resource Economists, 10(5), 1265–1308. https://doi.org/10.1086/725503
10. Bedi, A. S., Nakaguma, M. Y., Restrepo, B. J., & Rieger, M. (2021). Particle pollution and cognition: Evidence from sensitive cognitive tests in Brazil. Journal of the Association of Environmental and Resource Economists, 8(3), 443–474. https://doi.org/10.1086/712060
11. Heissel, J. A., Persico, C., & Simon, D. (2022). Does pollution drive achievement? The effect of traffic pollution on academic performance. Journal of Human Resources, 57(3), 747–776. https://doi.org/10.3368/jhr.57.3.0319-10014R2
12. Duque, V., & Gilraine, M. (2022). Coal use, air pollution, and student performance. Journal of Public Economics, 213, 104709. https://doi.org/10.1016/j.jpubeco.2022.104709
13. Zhang, X., Chen, X., & Zhang, X. (2018). The impact of exposure to air pollution on cognitive performance. Proceedings of the National Academy of Sciences, 115(37), 9193–9197. https://doi.org/10.1073/pnas.1809474115
14. Graff Zivin, J., Liu, T., Song, Y., Tang, Q., & Zhang, P. (2020). The unintended impacts of agricultural fires: Human capital in China. Journal of Development Economics, 147, 102560. https://doi.org/10.1016/j.jdeveco.2020.102560
15. Gilraine, M. (2023). Air filters, pollution, and student achievement. Journal of Human Resources, 58(5), 1603–1634. https://doi.org/10.3368/jhr.0920-11111R3

FUNDING

None.

CONFLICT OF INTEREST

None.

AUTHORSHIP CONTRIBUTIONS

Drafting – original draft: Darwin Joel Lozada López.
Writing–review and editing: Darwin Joel Lozada López.