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Effects of the vehicle fleet on air quality in an urban university environment of Ecuador

Efeitos da frota de veículos na qualidade do ar em abiente universitário urbano do Equador

Efectos del parque automovilístico en la calidad del aire en un entorno universitario urbano de Ecuador

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This study stresses the urgent need for university authorities to act on improving air quality by reducing vehicle emissions and enhancing campus environments.
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This research highlights pollutant levels in university parking lots, aiding the understanding of air quality impacts on academic environments and informing future environmental policies for developing nations.

ABSTRACT

Introduction: Air quality in university environments is critical for the health and well-being of students and staff. This study aims to identify the permissible pollutants emitted in the parking lots of the State Technical University of Quevedo (UTEQ) in the canton of Quevedo, province of Los Ríos, Ecuador. **Methods:** An abductive (inductive-deductive) approach was employed, utilizing statistical methods to analyze primary emission data. In-situ measurements of pollutants, specifically carbon monoxide (CO) and particulate matter (PM2.5 and PM10), were conducted monthly across three parking lots at the university. Each parking lot contained three strategically established monitoring points, where measurements were taken during peak entry and exit hours and on days of highest traffic, using the Temtop M2000C-2º sensor. **Results:** The findings revealed significant statistical differences in pollutant concentrations among the parking lots. CO levels were notably higher in the main parking lot during midday, while PM2.5 and PM10 exhibited greater dispersion in the rear parking lot. The maximum measured values were 456.71 ppm (CO) in the main parking lot, 22.29 μg/m³ (PM2.5) in the Produteq lot, and 32.54 μg/m³ (PM10) in the rear parking lot, all of which remain within the permissible limits established by Ecuadorian legislation. **Conclusion:** Although air pollution levels at UTEQ are classified as moderate, the results underscore the necessity for implementing short-term mitigation measures to enhance air quality. It is recommended that university authorities develop projects and actions aimed at reducing vehicular emissions and improving overall environmental conditions on campus.
Keywords: air quality, university environment, carbon monoxide, particulate matter, air pollution, environmental monitoring, vehicular emissions.

RESUMO

Antecedentes: A qualidade do ar em ambientes universitários é crítica para a saúde e o bem-estar de estudantes e funcionários. Este estudo tem como objetivo identificar os poluentes permissíveis emitidos nos estacionamentos da Universidade Técnica Estadual de Quevedo (UTEQ) no cantão de Quevedo, província de Los Ríos, Equador. Métodos: Foi empregado um enfoque abdutivo (indutivo-dedutivo), utilizando métodos estatísticos para analisar os dados de emissão primária. Medições in situ de poluentes, especificamente monóxido de carbono (CO) e material particulado (PM2.5 e PM10), foram realizadas mensalmente em três estacionamentos da universidade. Cada estacionamento continha três pontos de monitoramento estrategicamente estabelecidos, onde as medições foram realizadas durante os horários de pico de entrada e saída e em dias de maior tráfego, utilizando o sensor Temtop M2000C-2º. Resultados: Os achados revelaram diferenças estatísticas significativas nas concentrações de poluentes entre os estacionamentos. Os níveis de CO foram notavelmente mais altos no estacionamento principal durante o meio-dia, enquanto o PM2.5 e PM10 apresentaram maior dispersão no estacionamento traseiro. Os valores máximos medidos foram 456.71 ppm (CO) no estacionamento principal, 22.29 μg/m³ (PM2.5) no lote da Produteq, e 32.54 μg/m³ (PM10) no estacionamento traseiro, todos permanecendo dentro dos limites permissíveis estabelecidos pela legislação equatoriana. Conclusão: Embora os níveis de poluição do ar na UTEQ sejam classificados como moderados, os resultados enfatizam a necessidade de implementar medidas de mitigação a curto prazo para melhorar a qualidade do ar. Recomenda-se que as autoridades universitárias desenvolvam projetos e ações destinadas a reduzir as emissões veiculares e melhorar as condições ambientais no campus.

Palavras-chave: qualidade do ar, ambiente universitário, monóxido de carbono, material particulado, poluição do ar, monitoramento ambiental, emissões veiculares.

RESUMEN

Antecedentes: La calidad del aire en entornos universitarios es crítica para la salud y el bienestar de estudiantes y personal. Este estudio tiene como objetivo identificar los contaminantes permisibles emitidos en los estacionamientos de la Universidad Técnica Estatal de Quevedo (UTEQ) en el cantón de Quevedo, provincia de Los Ríos, Ecuador. **Métodos:** Se empleó un enfoque abductivo (inductivo-deductivo), utilizando métodos estadísticos para analizar los datos de emisión primaria. Se realizaron mediciones in situ de los contaminantes, específicamente monóxido de carbono (CO) y material particulado (PM2.5 y PM10), de manera mensual en tres estacionamientos de la universidad. Cada estacionamiento contenía tres puntos de monitoreo estratégicamente establecidos, donde se tomaron medidas durante las horas pico de entrada y salida y en los días de mayor afluencia, utilizando el sensor Temtop M2000C-2º. **Resultados:** Los hallazgos revelaron diferencias estadísticas significativas en las concentraciones de contaminantes entre los estacionamientos. Los niveles de CO fueron notablemente más altos en el estacionamiento principal durante el mediodía, mientras que el PM2.5 y el PM10 mostraron una mayor dispersión en el estacionamiento trasero. Los valores máximos medidos fueron 456.71 ppm (CO) en el estacionamiento principal, 22.29 μg/m³ (PM2.5) en el lote de Produteq, y 32.54 μg/m³ (PM10) en el estacionamiento trasero, todos los cuales permanecen dentro de los límites permisibles establecidos por la legislación ecuatoriana. **Conclusión:** Aunque los niveles de contaminación del aire en la UTEQ se clasifican como moderados, los resultados subrayan la necesidad de implementar medidas de mitigación a corto plazo para mejorar la calidad del aire. Se recomienda que las autoridades universitarias desarrollen proyectos y acciones destinadas a reducir las emisiones vehiculares y mejorar las condiciones ambientales en el campus.

Palabras clave: calidad del aire, entorno universitario, monóxido de carbono, material particulado, contaminación del aire, monitoreo ambiental, emisiones vehiculares.

INTRODUCTION

The vehicle fleet is recognized as one of the primary contributors to air pollution, posing significant risks to both human health and the environment, making it a global concern. Effective fleet management and modernization are therefore essential to mitigating air quality degradation and reducing its adverse effects (Brook et al., 2010; Holnicki, Nahorski, & Kałuszko, 2021). Road traffic remains a dominant source of various pollutants, particularly nitrogen oxides (NOx) and carbon monoxide (CO), with fleet modernization efforts showing promising reductions in NOx and CO emissions in urban areas (Holnicki et al., 2021).

In cities such as Warsaw, studies have demonstrated that upgrading vehicles to Euro 6 standards can significantly decrease air pollution-related health impacts, including a 47% reduction in deaths attributable to NOx pollution (Holnicki et al., 2021). Emissions of particulate matter (PM2.5 and PM10) and CO are among the most harmful pollutants, arising from both anthropogenic and natural activities, with mobile sources playing a critical role due to the rapid growth of the automotive fleet (Choi & Chong, 2022; Ke et al., 2017).

Research from diverse regions, including China and Tehran, underscores the profound impact of vehicle fleet electrification and emission reduction strategies on improving air quality. For instance, in the Yangtze River Delta (YRD), electrification of light-duty and commercial passenger vehicles is projected to reduce PM2.5 concentrations by 0.4 to 1.1 $\mu g/m^3$ by 2030, contributing to notable improvements in urban air quality (Ke et al., 2017). Similarly, in Tehran, eliminating emissions from passenger cars and motorcycles could lead to a substantial reduction in PM2.5 and NO2 concentrations during pollution episodes, demonstrating the critical role of targeted traffic policies (Shahbazi et al., 2019).

The study of air pollution within university settings is critical due to the significant volume of vehicular traffic concentrated in these areas, particularly around parking lots where emissions are more concentrated. Parking garages, especially those underground, have been identified as hotspots for air pollution, with emissions from vehicles, contributing heavily to air quality degradation. Research by Gonzalez et al. (2022) at the University of Minnesota highlights how pollutants such as CO, NO, NO_2, and $PM_{2.5}$ can reach levels in underground parking garages that are significantly higher than ambient air concentrations, sometimes by more than an order of magnitude.

These pollutants are not only harmful to the environment but also pose health risks to the campus community, including students, faculty, and staff. High concentrations of pollutants like $PM_{2.5}$ and CO can exacerbate respiratory conditions and contribute to long-term health risks, while the localized nature of these emissions provides an opportunity for targeted mitigation strategies.

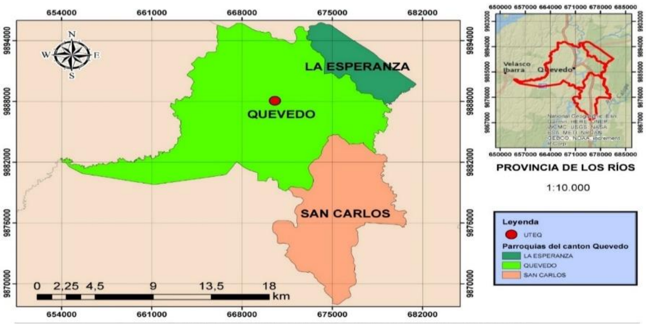
Moreover, since universities often serve as models for sustainability and environmental stewardship, addressing air quality issues aligns with broader institutional goals of promoting green and healthy campuses. In university environments, vehicle emissions also contribute significantly to CO2 levels. A case study in a university of Madrid by Sobrino and Arce (2021) found that, although public transport accounts for over 75% of trips, private vehicle users still generate more than 55% of the total CO2 emissions from commuting. This prove the need for policies promoting shared mobility and public transport systems as key measures to reduce urban emissions.

In the context of Ecuador, the automotive sector has experienced significant growth, contributing to the national economy through manufacturing and taxation (Ministry of Environment of Ecuador [MAE], 2015; Ministry of Industries and Productivity [MIPRO], 2017). However, this growth comes with increased emissions of PM2.5, PM10, and CO, which have been linked to serious health issues, including hypertension, stress, and cancer (Brauer et al., 2019; Pope et al., 2006). Studies from other countries suggest that integrating renewable energy sources with electric vehicle adoption could offer a pathway to reducing emissions without compromising energy demands (Longo, Yaïci, & Zaninelli, 2015). This approach could be particularly relevant for Ecuador as it seeks to balance economic growth with environmental sustainability.

This research was conducted in the canton of Quevedo, province of Los Ríos, Ecuador with the objective of identifying the most prominent air pollutants emitted in the parking lots of the State Technical University of Quevedo (UTEQ) during the second semester of 2023. The UTEQ, Central Campus "*Manuel Haz Alvarez*" is located within the territorial jurisdiction of the canton of Quevedo which is located to the north of the cantons Buena Fe and Valencia; to the south of the cantons Ventanas and Mocache; to the east with the canton Quinsaloma and to the west with the canton El Empalme of the province of Guayas (Figure 1).

Specifically, the study aims to investigate how pollution levels in university parking areas affect campus air quality and to provide data-driven recommendations for policies to reduce pollutant exposure.

Figure 1. Location map of the UTEQ's Central Campus



Source: Author's development

METHODOLOGY

The nature of the methodological approach employed in the present research are of type: diagnostic and exploratory, and the research methods used in the research are abductive (hybrid strategy between inductive and deductive) (Bell et al., 2022). With the purpose of identifying the areas of greatest influx of vehicular congestion, responsible for air pollution emitted by the vehicle fleet of the Central Campus "Manuel Haz Álvarez" of the UTEQ, an exhaustive investigation was carried out involving both primary and secondary sources (Nagendra et al., 2019), the construction of a detailed map was undertaken, which points out the points in which the possible pollutants have been identified (Montalvo et al., 2022). To carry out this task, the geomatics software "ArcGIS" was leveraged, whose capabilities proved fundamental (Weissert et al., 2019). In this process, the sources of information encompassed both the data obtained from the UTEQ itself, as well as those coordinates collected through the UTM Geo Map tool. These combined sources provided a complete and accurate picture of the distribution of contaminants in the study region. To measure the concentration levels of pollutants (CO, PM2.5 and PM10) of the vehicle fleet of the Central Campus "Manuel Haz Álvarez" of the UTEQ, a matrix was used to collect the data obtained with an air quality monitor, it is worth mentioning that it was considered to perform it during the month of June 2023, in three days (morning, noon and afternoon) because they are peak hours. The monitoring method considered for the determination of air pollution levels of the vehicle fleets had a period of 15 minutes for each of the points, all as established by 40 CFR Part 50, Appendix J or Appendix M (EPA). The equipment used was a Temtop M2000C-2º air quality monitor (Álvarez-Narvaez et al., 2016).

To formulate proposals to improve air quality and decrease its pollutants , a matrix of proposals was considered to develop a manual of recommendations, which will serve as a basis for taking actions based on the results obtained and compliance that the evaluated sites have according to current regulations (Liu & Ciro, 2018). To carry out the research, various research instruments were used, adapted to the different information gathering needs regarding air quality in the parking lots of the Central Campus "Manuel Haz Álvarez" of the UTEQ. First, detailed tours of the campus were conducted to identify and map the areas of greatest vehicular influx, recording coordinates and taking images to document areas of interest (Zhang & Cao, 2015). Then, an air quality monitor was employed to provide accurate, real-time measurements of specific parameters (Table 1): carbon monoxide (CO), fine particulate matter (PM2.5), and coarse particulate matter (PM10), allowing the concentration of pollutants in the environment to be assessed (Duyzer et al., 2015). In addition, specially designed surveys were administered to obtain the community's perception of the effects of air pollution, focusing on pollutants emitted by the vehicle fleet (Datta et al., 2020). These surveys were instrumental in gathering relevant opinions and knowledge in this context.

Table 1. Air Quality Monitor Specifications

Temtop M2000C-2º.	**Monitor Features**	
	**Brand**	Temtop
	Style	M2000C-2ND
	Power supply	Battery operated
	Color	M2000C-2ND
	Item dimensions LxWxH	2.89 x 1.48 x 8.8 in.
	Item weight	1.04 pounds
	Alarm	Audible
	Operating humidity	90 %
	Lower temperature classification	32 degrees Fahrenheit
	Higher temperature classification	50 degrees Celsius

Source: Model manufacturer

The data collected in the four weeks of monitoring carried out at the sampling points in the parking lots inside the UTEQ, Central Campus taken with the Temtop M2000C-2º monitor were recorded in a field sheet generated in Microsoft Excel. In order to show statistical differences between the parameters monitored at the different sampling points, the Kruskal Wallis non-parametric variance test and IBM SPSS Statistics software (Li et al, 2019) were used.

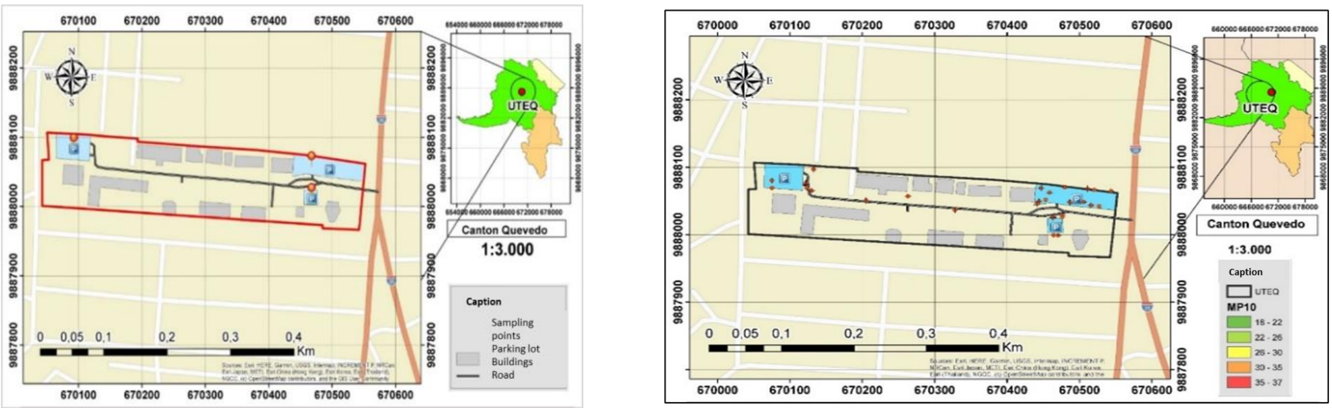
The processing of data analysis in relation to air quality affected by the impact of the vehicle fleet included the preparation of zoning maps. This technique consisted of dividing the study area into different zones, identifying and delimiting areas of greater vehicular traffic. This process was based on data collected during air quality monitoring at the "Manuel Haz Álvarez" Central Campus of the UTEQ. These maps provided a visual and geospatial representation of the distribution of air pollution generated by the vehicle fleet, which will allow a clearer and more detailed understanding of pollutant concentration patterns in the environment (Chowdhury et al., 2019).

RESULTS AND DISCUSSION

Zones of vehicular affluence in the Central Campus of UTEQ

For the determination and identification of the areas of greatest inflows, an approximate of 3 to 15 sampling points were estimated (Figure 2), this depended on the size and shape of the study area; to then be processed in Kriging (Vu et al., 2019); which is a method of spatial inference, which allows to evaluate the values of a variable in unsampled areas by handling the information provided by the sample taken.

Figure 1 *General Sampling Points*



Source: Authors' development with the research data

For the classification of the UTEQ motor pools: a compilation of coordinates was performed using the UTM Geo Map tool; this classification helped to determine which of the three motor pools has the greatest problem in terms of air pollution and which would be its most relevant pollutants (Marć et al, 2015).

Citizen perception : In order to have knowledge about the citizen perspective within the facilities of the UTEQ, Central Campus "Manuel Haz Álvarez", we proceeded to conduct a survey; which were conducted to teachers and administrative staff of the institution mentioned above, the survey was structured with closed questions of a number of 10 questions, which are of an environmental type; since it seeks to know the opinion of the university community regarding the levels of pollution emitted by vehicles (Lopez-Arboleda et al., 2021). In order to determine the size of the sample, the number of teachers and administrative personnel of the UTEQ was investigated, totaling 309 people at the Central Campus "Manuel Haz Álvarez", and then the corresponding equation was implemented to calculate the size of the sample, which yielded a value of 171 people.

Reliability Analysis - Cronbach's Alpha : At this point, the reliability of the survey was evaluated using Cronbach's Alpha. This tool allows determining the degree of reliability of the data collected by analyzing the correlation between the responses of the questionnaire, considering each individual response of the respondents (171 in total). The reliability levels were represented as Excellent (1.00-0.90), Very Good (0.90-0.70), Good (0.70-0.50), Fair (0.50-0.30) and Poor (0.30-0.00); by calculating the α coefficient using the formula the final result is 0.622 for the 171 items. Cronbach's Alpha values above 0.9 suggest that the instrument is highly reliable, while those below 0.3 indicate that the instrument may generate erroneous conclusions. In this study, the Cronbach's Alpha value for the entire questionnaire was 0.722 (72.2%), suggesting that the instrument is considerably reliable. This figure denotes stability and consistency in the measurements, leading to the conclusion that it has been able to accurately capture the respondents' perception of the methodology for service projects.

Survey: The survey was conducted through virtual forms such as the one generated by Google Forms; it was also elaborated with bibliographic bases such as "*Integration of a bikeway in the internal mobility of the technical university of Manabi*". Within the framework of the survey on air quality in the UTEQ, Central Campus "Manuel Haz Álvarez", the use of IBM SPSS will make possible the evaluation of the association between different groups of respondents (students, teachers and administrative staff) and how they perceive the air quality in the Institution. This technique provided significant statistical data that allows a deeper understanding of the survey results, which are detailed below.

Table 2. Results of citizen perception

Gender of respondent	**M**	**55.0%**
	F	45.0%
Degree of pollution produced by automobiles	Yes	77.2%
	No	22.8%
Emission of large quantities of polluting gases	Yes	79.5%
	No	20.5%
Knowledge of pollution produced by motor vehicle fleets	Yes	63.7%
	No	36.3%
Degree to which air pollution affects the environment	Nothing	3.5%
	Little	39.2%
	Much	57.3%
Discomforts presented: eye irritation, throat irritation, dry nostrils, unusual fatigue and headache.	Yes	81.3%
	No	18.7%
Relationship of discomforts to air pollution	Yes	84.0%
	No	16.0%
Severity of respiratory diseases and possible cause of premature deaths.	Yes	80.1%
	No	19.9%
Existing legal regulations to control pollution emitted by automobiles	Yes	47.4%
	No	52.6%
Implementation of training on strategies to prevent air pollution	Yes	64.9%
	No	2.3%
	Perhaps	32.7%
Willingness to give up or reduce the use of their vehicle on certain days in favor of an environmental improvement	Yes	41.2%
	No	10.6%
	Perhaps	48.2%

Source: Authors' development with the research data

Table 2 demonstrates that 55% of those surveyed at the UTEQ, Central Campus are women. Moreover, 77.19% are aware of automotive pollution and 80% believe that the university's vehicle fleet emits a lot of polluting gases. In addition, 84.29% have experienced discomfort related to this pollution, and 83.04% attribute these symptoms to air quality. Finally, 64.91% agree with implementing training to avoid pollution and 48.24% consider reducing the use of vehicles to improve the environment.

Concentration levels of CO, PM (2.5) and PM (10) in the Central Campus vehicle fleet.

The techniques and methods to be applied for the sampling and analysis of air quality pollutant gases are based on "reference methods" or "equivalent" in accordance with Title 40, Part 53 of the *EPA* Code of Federal Regulations (40 CFR Part 53). Research variables are anything that is measured, information collected, or data collected to answer the research questions stated in the objectives. Their choice is crucial to the research protocol (See Table 3).

Table 3 *Measurement variables*

Variables	Measuring range
PM 2.5 and PM10	0 μg/m^3 - 500 μg/m^3
CO	0 ppm - 1000 ppm
Temperature	0ºC - 50ºC
Relative humidity	0% - 100%

Source: Authors' development with the research data

Air Quality Index (AQI): The AQI (see Table 4) is a dimensionless value associated with a code that reports the state of air quality in relation to some general effects that should be considered to reduce the exposure of the population to high concentrations. The index is also used in air quality projections (Naranjo Reyes, 2021).

Table 4 Allowable Limits for ICA Criteria Contaminants

ICA	Color	Ranking	CO (ppm)	PM 2.5 (µg/m)^3	PM 10 (µg/m)^3
0-50	Green	Good	0-4.4	0-12	0-54
51-100	Yellow	Moderate	4.5-9.4	12.1-35.4	55-154
101-150	Orange	Sensitive groups	9.5-12.4	35.5-55-4	155-245
151-200	Red	Harmful to health	12.5-15.4	55.4-150.4	255-354
201-300	Purple	Very harmful to health	15.5-30.4	150.4-250.4	355-424
301-500	Brown	Dangerous	30.5-40.4	250.4-350.4	425-504

Source: EPA (2015).

By taking data through an air quality monitor in the area of the university parking lots for 12 days, it was possible to obtain an average value of the 3 pollutants that were set as a target (CO, PM 2.5 and PM 10). All data were processed in the ArcMap program to define the area of dispersion of CO, PM (2.5) and PM (10) pollutants. Sampling points were established in the university parking lots, being the main one with 12 sampling points, PRODUTEQ with 5 points, the rear parking lot with 7 points and finally 4 points were taken in the path between the parking lots.

CO, PM (2.5) and PM (10) concentration distribution : All data were taken during the 12 days at 7:30 am, 12:30 pm and 4:30 pm. Then, an average of the values in each sampling point was taken and the interpolation tool (IDW) was used to determine the concentration zones of CO, PM (2.5) and PM (10), a limit area was established to determine the area and dispersion separating them into 5 ranges. This resulted in 3 diffusion maps (CO, PM 2.5 and PM 10). The CO values range from 403 to 568 ppm, having a higher concentration in the main parking lot of the university, another near the business school and a small area in the parking lot, all with values of 480-568. For PM 2.5 concentrations, values ranging from 13 to 29 ppm were obtained. As in the previous case, the highest concentration values are found in the main parking lot and at the rear of the university (high 25-29 and medium 23-25 ppm). In the PM 10 distribution area, values ranging from 18 to 37 ppm were obtained. It can be seen that there is a higher concentration in the rear parking lot of the university and another in the main parking lot with values from 30 to 37 of PM 10. The statistical analysis is shown below:

CO parameter : The Tukey Method indicates that, during the four weeks of monitoring, the highest concentration of Carbon Monoxide (CO) was recorded in the main parking lot, with a mean of 456.71 In terms of the impact on air quality caused by vehicles, a standard error of approximately 2.96 was also found, which indicates the expected variability in the measurements or estimates related to this phenomenon (see Table 5). This underscores the urgency of implementing immediate strategies to improve air quality at the UTEQ, Central Campus "Manuel Haz Álvarez".

Table 5. *Comparison of means (Tukey) of CO monitoring for 4 weeks (*Alpha=0.05)

Sites	Stockings	n	Standard Error	Significance
P. Rear	431.69	84	3.88	A
P. Main	456.71	144	2.96	B
P. Produteq	421.50	60	4.59	A
P. Route	454.56	56	5.13	B

Source: Authors' development with the research data

When performing the non-parametric Kruskal Wallis analysis on the groups obtained from the grouping of concentration data according to the monitoring points, we obtained as a result that the CO parameter during the 4 weeks is the most prevalent, since it obtained a p=0.0001 with respect to the established acceptable probability comparison of p= 0.05 (Table 6).

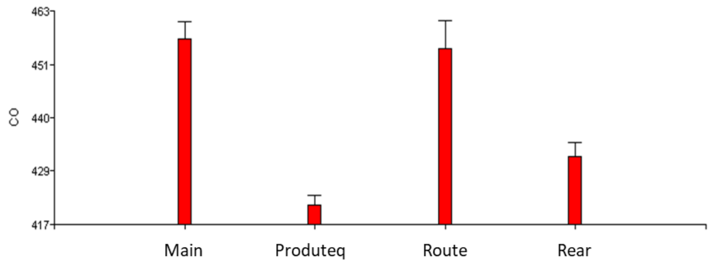
Table 6. *Kruskal Wallis test for the parameter CO*

Variable	Site	N	Stockings	D.E.	Medium	H	p
CO	P. Rear	84	431.69	27.01	429.00	54.59	<0.0001
CO	P. Main	144	456.71	43.00	450.00		
CO	P. Produteq	60	421.50	16.67	424.00		
CO	P. Route	48	454.56	41.12	449.00		

Source: Authors' development with the research data

The Kruskall Wallis test showed that there are statistically significant differences (<0.0001) in carbon monoxide concentrations in the three monitoring zones: main parking lot, produteq and rear parking lot; in which the main parking lot is the most relevant receptor of the CO pollutant, surpassing (Figure 3).

Figure 3. Average concentrations of Carbon Monoxide at UTEQ, central campus



Source: Authors' development with the research data

Parameter PM (2.5): For this parameter the Tukey method (Alpha=0.05) indicates that, during the four weeks of monitoring, the highest concentration of Particulate Matter (PM 2.5) was recorded in the rear parking lot this due to the proximity that this parking lot was with a construction site where an excessive amount was deployed, with a mean of 22.49. In terms of the impact on air quality caused by vehicles, we also found a standard error of approximately 0.53 points to the variability related to this phenomenon monitored at the UTEQ, Central Campus (see Table 7).

Table 7. *Comparison of means (Tukey) of PM (2.5) monitoring for 4 weeks*

Sites	Stockings	n	Standard Errors	Significance
P. Rear	22.49	84	0.53	A
P. Main	21.48	144	0.40	A
P. Produteq	21.35	60	0.63	A
P. Route	21.39	84	0.53	A

Source: Authors' development with the research data

When applying the non-parametric Kruskal-Wallis analysis to the groups derived from the classification of concentration data according to the monitoring points for the PM2.5 parameter, it was observed that the highest value was 84 during the four weeks of this process. The value obtained for p was 0.1037, which exceeds the established acceptable probability of p=0.05 (See Table 8).

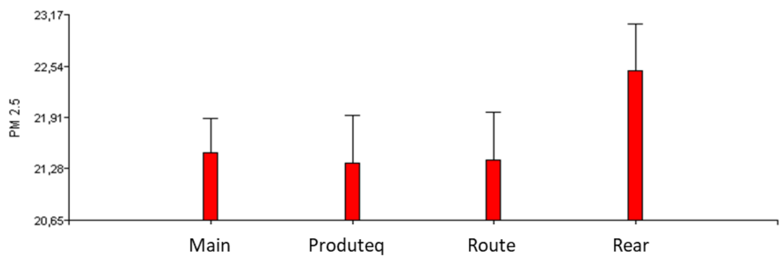
Table 8. Kruskal Wallis test for the PM parameter (2.5)

Variable	Site	N	Stockings	D.E.	Medium	H	p
PM 2.5	P. Rear	84	22.49	5.21	23.75	6.17	<0.1037
PM 2.5	P. Main	144	21.48	5.02	21.75		
PM 2.5	P. Produteq	60	21.35	4.54	21.15		
PM 2.5	P. Route	48	21.39	4.04	21.40		

Source: Authors' development with the research data

The Kruskal-Wallis test revealed that there are statistically significant differences (<0.1037) in the concentrations of Particulate Matter (PM 2.5) between the three monitoring zones: main parking lot, produteq and rear parking lot. It is important to note that the rear parking area is the one with the highest concentration of this pollutant (Figure 4).

Figure 4. Average concentrations of Particulate Matter (2.5) at UTEQ, Central campus



Source: Authors' development with the research data

Parameter PM (10): For this parameter, the Tukey Method (Alpha=0.05) reveals that, during the four weeks of monitoring, the highest concentration of Particulate Matter (PM10) was recorded at the Produteq parking lot, with a mean of 32.54, one of the highest amounts among the monitoring points In terms of the impact on air quality due to the influence of vehicles, a standard error of approximately 1.79 was identified, indicating the variability associated with this phenomenon observed at the UTEQ, Central Campus. (see Table 9).

Table 9. Comparison of means (Tukey) of PM (10) monitoring for 4 weeks

Sites	Stockings	n	Standard Error	Significance
P. Rear	30.16	84	1.52	A
P. Main	29.41	144	1.16	A
P. Produteq	32.54	60	1.79	A
P. Route	29.16	48	2.01	A

Source: Authors' development with the research data

Using the Kruskal-Wallis non-parametric analysis on the groups formed from the classification of concentration data according to the monitoring points for the PM10 parameter, it was observed that the highest mean concentration was 32.54, with a predominant sample number of 60. The p value obtained was 0.1735, which exceeds the acceptable significance threshold of p=0.05 (Table 10).

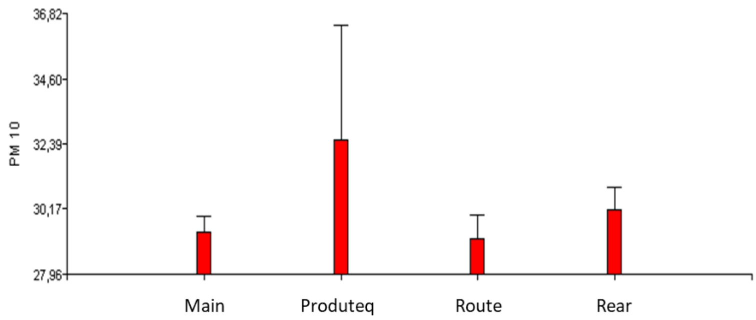
Table 10. *Kruskal Wallis test for parameter PM (10)*

Variable	Site	N	Stockings	D.E.	Medium	H	p
PM 10	P. Rear	84	30.16	6.76	32.45	4.98	<0.1735
PM 10	P. Main	144	29.41	6.33	30.75		
PM 10	P. Produteq	60	32.54	30.03	29.55		
PM 10	P. Route	48	29.16	5.52	30.30		

Source: Authors' development with the research data

The Kruskal-Wallis test revealed that there are statistically significant differences (<0.1735) in the concentrations of Particulate Matter (PM10) between the three monitoring zones: main parking lot, Produteq and rear parking lot. It is important to note that the Produteq parking area has the highest concentration of this pollutant (Figure 5).

Figure 5. Average concentrations of Particulate Matter (10) at UTEQ, Central campus



Source: Authors' development with the research data

The results align with existing literature on vehicle fleet modernization and its impact on air quality, particularly in university environments. For example, Sobrino and Arce (2021) analyzed commuting patterns at the Technical University of Madrid, highlighting the role of public transportation in reducing CO2 emissions, which resonates with our findings on the importance of fleet upgrades to reduce pollutants. Similarly, Holnicki et al. (2021) demonstrated how modernization significantly reduces NOx emissions, a trend also observed in our data.

However, both this study and the work of Holnicki et al. and Gonzalez et al. (2022) reveal limited reductions in particulate matter (PM) despite modernization efforts, suggesting the need for targeted interventions in high-traffic areas like university parking lots. Moreover, Ke et al. (2017) and Shahbazi et al. (2019) emphasize the potential of electric vehicles (EVs) in urban settings, which could further enhance the impact of modernization strategies at universities by integrating renewable energy sources, as proposed by Longo et al. (2015). These insights support the notion that universities, as microcosms of urban environments, are relevant replicable context to implementing and studying sustainable mobility solutions that significantly improve air quality.

Proposal to improve air quality and decrease its pollutants.

The development of this proposal was supported by an complete literature review (Weissert et al., 2019), where significant research such as Gu et al., (2019), as well as the contribution of Gulia et al., (2020) and the research of Kumar et al., (2019) stand out. These studies provided a solid basis for the formulation of proposals aimed at improving air quality and mitigating air pollution, crucial aspects in the environmental agenda (Rebs et al., 2019; Ren et al., 2015). Following this elaboration process promotes a comprehensive and effective approach that benefits both the health of the university community and the preservation of the environment (Morawska et al., 2018; Tan et al., 2018).

Table 11. *Proposal to improve air quality and reduce air pollutants*

NO.	ACTIVITY	RESPONSIBLE	INDICATOR
1	Environmental awareness campaign	Communications and environmental outreach team, students and teachers	25% increase in the participation of the university community in environmental awareness activities during the first week of the campaign.
2	Improved public transportation on campus	University authorities, student council, and public or private transportation companies	20% increase in the use of public transportation at the Central Campus during the first 3 months after the implementation of public transportation improvements.
3	Promotion of bicycle use	University authorities, sustainability and infrastructure maintenance committee	30% increase in bicycle use on campus during the first 2 months after the implementation of the bicycle infrastructure
4	Car-free day	Student sustainability committee	80% of the university community participated in the "Car Free Day".
5	Sharing trips through an application	Information Technology Department. FCI (System Engineering Career)	Registration of at least 500 users in the ridesharing application
6	Preferential parking lots for shared vehicles	Department of Campus Security	25% increase in carpooling occupancy in preferential spaces

Source: Authors' development through specialized literature review

FINAL REMARKS

The mapping of UTEQ's central campus clearly identified the areas of greatest vehicular congestion, especially in the main, produteq and rear parking lots. These critical points are responsible for the emission of air pollutants by the vehicle fleet. In addition, through the use of surveys and the IBM SPSS program, it was possible to validate the relevance of these areas in the context of vehicular congestion, highlighting the need to implement traffic management strategies and promote sustainable transportation alternatives to mitigate the environmental impact and improve the quality of life on the university campus.

Using the Temtop M2000C-2º air quality monitor, it has been identified that, among the three parking lots of the UTEQ Central Campus, the main parking lot exhibits the highest levels of CO contamination, with values ranging between 403 and 568 ppm. This situation is attributed to its extension and its location near a main avenue with high vehicular traffic. In addition, significant levels of particulate matter were observed, especially PM2.5, again predominating in the main parking lot, with values between 13 and 29 μg/m3. On the other hand, with regard to PM10, the main source of contamination was found in the rear parking lot, with levels between 18 and 37 μg/m3. Although not all parking lots present an excessive pollution index, these results underscore the need for managers to take immediate action to reduce the impact on the health of sensitive individuals by implementing appropriate mitigation actions.

The proposal presented is based on concrete and feasible solutions that promise a positive impact on both air quality and the health of the university community. The implementation of the suggestions detailed in this proposal has the potential to generate significant reductions in the emissions of pollutants detected in the parking lots of the UTEQ, Central Campus "Manuel Haz Álvarez". This implies an important step towards the creation of a healthier and more sustainable environment in the institution

The main limitations of this study include the inclusion of a single university environment, which may limit the generalizability of the findings to other institutions with different commuting behaviors or geographic contexts. Future research could expand by including multiple universities across different regions and integrating real-time monitoring of pollutants. Moreover, longitudinal studies could assess the long-term impact of fleet modernization and electric vehicle adoption on air quality within university campuses. Studies focusing on the behavioral aspects of students and staff, such as attitudes towards sustainable mobility, could also offer valuable insights for policy development.

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Task	**A1**	**A2**	**A3**	**A4**	**A5**
A. theoretical and conceptual foundations and problematization:	20%	20%	20%	20%	20%
B. data research and statistical analysis:	20%	20%	20%	20%	20%
C. elaboration of figures and tables:	20%	20%	20%	20%	20%
D. drafting, reviewing and writing of the text:	20%	20%	20%	20%	20%
E. selection of bibliographical references	20%	20%	20%	20%	20%
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