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STUDY OF CARBON MONOXIDE LEVELS IN THE MOST TRAVELED STREETS OF METROPOLITAN LIMA

Tesis para optar el Título Profesional de Ingeniero Industrial

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Study of carbon monoxide levels in the most traveled streets of Metropolitan Lima

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Abstract— This article seeks to determine the levels of carbon monoxide (CO) in the air in the busiest streets of modern Lima to which pedestrians are exposed. To measure the concentration of CO, measurements were taken five days a week at three different times of the day, considering the hours with the highest traffic congestion. Also, several factors were considered, such as traffic level, time of day, day of the week, and type of transport. The measurements were taken with a Cheffort portable CO detector, and the results were recorded continuously and in real time to identify if there is a correlation between the factors and the level of this pollutant. As a result, it was determined that there is a direct and statistically significant relationship between the level of traffic and the level of carbon monoxide. In addition, the days with the highest concentration are Fridays with an average of 38,259 ug/m^3 and the area with the highest CO levels is Javier Prado Avenue with an average of 38,514 ug/m^3, being this avenue, a main artery compared to Benavides Avenue. Finally, it is concluded that the levels of carbon monoxide emissions in the streets of Metropolitan Lima are around 29,789 ug/m3, which is very close to the Maximum Permissible Limits (MPL), high levels can affect the health of passersby, so it is important to take into account the factors that increase the levels of this pollutant in order to seek optimal solutions and avoid the continuous increase of carbon monoxide in the air.

Index Terms— Carbon monoxide, environmental pollution, environment, transportation, South America.

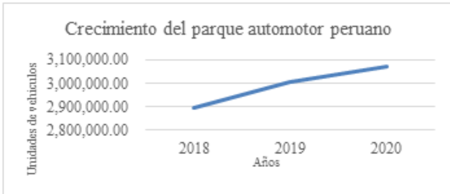
I. INTRODUCTION

"Nine out of ten people breathe polluted air" (WHO, 2018), this is due to the constant exposure to greenhouse gases (GHG) in the atmosphere, which represents a great threat to health. The World Health Organization (WHO, 2016) states that, 1 in 9 people die due to this cause and in Latin America; particularly in Peru, according to WHO "58 out of every 100 000 deaths are caused by air pollution" (as cited in "True or false? | Del Solar: Air pollution causes 7 million deaths per year", 2019).

Currently, the main culprits of polluting gas emissions are 6% from industrial processes, 27% from agriculture, 7% from waste and 60% from energy (Ministry of Environment [MINAM], 2016). Within the latter is the transportation sector, which maintains a fundamental role in the increase of atmospheric pollution. According to the Ministry of Transport and Communications (MTC, 2020), the purchase of circulating vehicles has increased by an average of 100 thousand vehicles per year during the last few years in Peru (Fig. 1). In Lima, for every thousand inhabitants, there are 73 registered vehicles, with a total of approximately 730,000 cars. As a result, the level of traffic has increased, placing Lima at number fifteen worldwide of the cities with the highest traffic congestion (TomTom, 2020) and number two in South America, maintaining an average of 42% traffic congestion (Statista, 2021).

As there is a direct relationship between the level of pollutants in the air and vehicular traffic (Segura-Contreras & Franco, 2015) the consequence of the facts mentioned before is that Lima is currently ranked number eight in the ranking of Latin American cities with the worst air quality (Statista, 2021).

Fig. 1
Growth of the Peruvian vehicle fleet in units



Note. Adapted from Boletín estadístico 2020-II. Ministry of Transport and Communications. By the Ministry of Transportation and Communications (2020). Peru. Retrieved from: https://cdn.www.gob.pe/uploads/document/file/1839085/Bolet%C3%ADn%20Estad%C3%ADstico%202020%20-%20II%20Semestre.pdf

In Lima, according to the management committee of the Clean Air initiative "70% of air pollution comes from the vehicle fleet" (as cited in "ONG Aire Limpio: Parque automotor origina el 70% de la contaminación del aire en Lima", 2017), this is because the age of Peruvian vehicles is on average 13.6 years (Asociación Automotriz del Perú [AAP], 2019), when it is recommended to be no older than 5 years. An old vehicle fleet is related to cars having obsolete engines that consume fuel faster (AAP, 2019), performing an "incomplete combustion, which results in high emissions of carbon monoxide and unburned hydrocarbons" (Pinedo-Jáuregui, 2020). According to Alegre, public transportation in Peru makes up a large part of this problem, because most of these vehicles are old and poorly maintained; therefore, in addition to generating vehicular congestion, they emit polluting gases contributing to the degradation of air quality. (As cited in "urban transportation is the second problem that most affects limeños", 2018).

On the other hand, the reality of a neighboring country, such as Mexico, is not the same. This country has a modern public transport system, in which emissions caused by private transport are the most significant. This is evidenced in a study conducted in the Metropolitan Zone of the Valley of Mexico in 2018, where it was determined that households with a higher socioeconomic level are the ones that pollute the most since they have the possibilities of acquiring a greater number of motor vehicles, which causes negative effects on the health of individuals who travel by public transport (Cirera, 2018).

Among the polluting gases expelled by vehicles are "sulfur dioxide (SO2), carbon dioxide (CO2), carbon monoxide (CO) and nitrogen oxide (NO2)," (Perez, 2017). With automobiles being responsible for 83.9% of the carbon monoxide found in the environment, of which 48.94% corresponds to "cabs" (MINAM, 2013).

According to a study conducted by the National Meteorology and Hydrology Service of Peru (SENAMHI, 2016) CO levels recorded in metropolitan Lima did not exceed the Maximum Permissible Limit established by the ECA, with the highest being 2,466.8 µg/m^3 measured at the Ate station and the lowest 466.8 µg/m^3 recorded at the San Borja station. However, measurements were increasing month by month with the highest increase being 440.9% at the Campo de Marte station (SENAMHI, 2016).

Taking as a reference the remarkable growth of pollution that was evidenced in a short term, this study aims to determine the level of carbon monoxide emissions at present due to the fact that CO is a gas, highly harmful to health. Causing diseases such as pulmonary deficiencies, bronchitis, hypoxia and can cause acute respiratory infections (Pérez-Cierra, et al., 2018). In addition, it has the facility to adhere to hemoglobin in the blood causing cardiovascular problems. Related to this, research was carried out in Huancayo, Peru in 2019, which evidenced elevated levels of carboxyhemoglobin in the blood of traffic policemen, due to constant exposure to atmospheric pollutants (Mallqui, 2019).

The concentration of Carbon Monoxide in areas of high vehicular traffic in Metropolitan Lima is not a topic currently much addressed by researchers, despite the fact that this has repercussions on the health of people such as policemen, as mentioned above. One of the most recent studies was in 2016, preceded by a graduate thesis conducted in 1969. For this reason, this article seeks to show and report on CO emitted by transport vehicles, with an emphasis on periods of high traffic in the busiest streets of Metropolitan Lima, such as Javier Prado Avenue and Benavides Avenue. In addition, the aim is to establish whether the type of transport, measurement schedules, day of the week and area influence the level of carbon monoxide in the air. The levels found will be contrasted with those reported by MINAM in 2016 to see if they exceed the estimates.

This research can lead to the proposal of preventive or corrective measures for environmental improvement, mitigating repercussions on the health of citizens and contributing to the reduction of air pollutants.

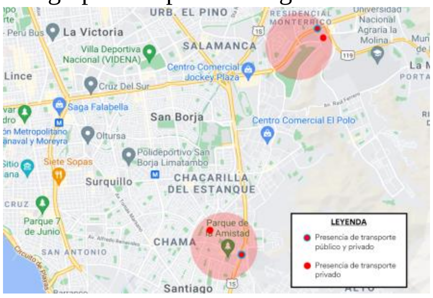
II. METHODOLOGY

This article corresponds to non-experimental research, with a quantitative approach maintaining an exploratory-descriptive scope, to report the concentration of carbon monoxide in µg/m^{3}in some of the busiest streets of modern Lima.

According to “Transitemos Foundation”, "38% of Lima's population travels by public transportation, losing a large part of the day in traffic” (As cited in “Un limeño pierde en promedio 20 días al año atrapado en el tráfico", 2018). For this reason, it was necessary to take measurements on roads where public transport is present, and on adjacent streets where only private cars travel. Two study areas were chosen both located in the district of “Surco” and in” La Molina” (Table 1). All of them belong to a sector with housing and a high level of vehicular traffic. Fig. 2 shows a geographical map showing the two study areas and the measurement points.

Fig. 2

Geographic map indicating measurement points



According to Aldo Bravo, expert in Traffic Engineering at UPC, "a driver loses on average up to 4 hours a day in Lima traffic" (as cited in: Users lose up to 12 years of their lives due to vehicular congestion in Lima, 2018), being Benavides Avenue one of the roads with the highest traffic, in which "traffic jams and disorder at the intersection with the Panamericana sur" (AMÉRICA TV 2019) is frequently reported by the media. Therefore, regarding the district of Surco, this street was considered as a measuring point where public transportation is present. In addition, according to the traffic police Velasco Astete Avenue with primavera is one of the "45 critical points where traffic becomes chaotic" (as cited in: "Tráfico en Lima: Conozca los 45 puntos críticos que aquejan a la ciudadanía", 2018), that is why this adjacent road was selected to take CO samples, which has only private transport presence.

As for the district of La Molina, the selected street with presence of public transport is Av. Javier Prado Este, because "according to Iván Strebel, CEO of the App "Voz Veloz "this is considered one of the roads with the highest overload of cars generating delays of up to 45 minutes" (as cited in "What points in Lima present greater vehicular congestion?", 2018). On the other hand, the second point of measurement within this area, through which only private cars transit is La Fontana Avenue.

Table 1

Characterization of the selected routes

Zone	District	Road Corridor (Avenue)	Measurement point	Type of Transport		Number of Samples
				Private	Public	
1	Surco	Benavides	Crossing with Panamericana Sur	X	X	15
		Velasco Astete	Block Nro. 20	X		15
2	La Molina	Javier Prado Este	Crossing with Los Frutales Avenue	X	X	15
		La Fontana	Block Nro. 01	X		15

In order to take the measurements, schedules were established according to "peak hours"; that is, the time interval in which there is a greater concentration of traffic. According to Strebel, "the hours of greatest vehicular traffic comprise between 7:00 and 8:30 am and in the afternoons between 6:30 to 8:00 pm" (as cited in "What points in Lima present greater vehicular congestion?", 2018). Therefore, 15 air CO concentration samples were taken with periodicity of 1 minute/sample, during the ranges of 7:30-8:30 am, 13:00-14:00 pm and 18:00-19:00 pm, in each of the previously mentioned areas to know the variation of monoxide according to the time of the day. These measurements were taken five days a week on Monday, Wednesday, Friday, Saturday and Sunday; during six (6) weeks. Four in August and two in September 2021.

During data collection, the presence of public transportation (yes, no) and the level of traffic (high, moderate, low) were recorded through video recordings. The recordings were taken three times a week at the three established times.

The main instrument used was a portable carbon monoxide meter, which has an electrochemical CO sensor that measures the concentration of this gas in ppm. Each CO sample was entered in a record card to eliminate zero and negative values, with a total of more than 5,000 samples. As for temperature, one sample was taken per point and time, with a total of 360 data for this variable. For the correct analysis of the data, the Spearman coefficient was used, which allows "to describe quantitatively the strength and direction of the relationship between two quantitative variables and helps to determine the tendency of two variables to go together" (Roi, 2019) and the analysis of variance for qualitative variables.

III. RESULTS

The direct relationship between CO levels in the air and the level of traffic was statistically evidenced. For this purpose, the Spearman coefficient was used, as can be seen in Figure 3.3, a correlation coefficient of 0.515 was obtained with a confidence level of 95%, according to Spearman, if this value is "greater than 0.5 and less than 0.8, there is a moderate correlation" (Roi, 2019). Therefore, it can be stated that the greater the vehicular congestion, the higher the CO levels in the air.

Fig. 3

Spearman coefficient analysis between traffic level and average measurements

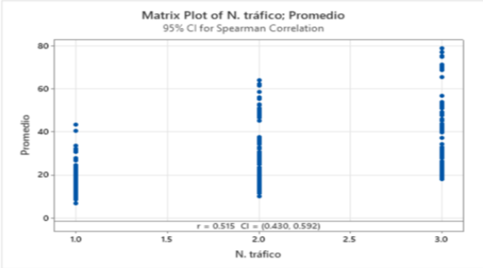
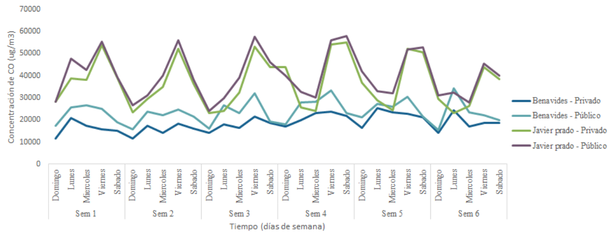


Fig. 4 shows the average carbon monoxide (CO) levels in µg/m^3 according to the zones, presence of public transportation and days of the week. It is evident that the presence of public transportation in both areas increases monoxide levels by 15%, with the highest peaks being 45,104 µg/m^3 in Benavides and 89,676 µg/m^3 in Javier Prado. In both cases, these maximum values are double the average concentration for the area, averaging 21,063 µg/m^{3}and 38,514 µg/m^3 respectively. In addition, Javier Prado has higher levels of CO in the air compared to Benavides with an increase of 17,451 µg/m^3; a possible explanation for this behavior is that Javier Prado has a greater flow of circulating vehicles, since, as previously demonstrated with the Spearman coefficient, the greater the vehicular congestion, the higher the level of monoxide in the air.

Likewise, it was found that the day with the highest amount of CO is Friday, with an average between both zones of 38,259 µg/m^3, which, when compared to the average of the other days of the week, is 38% higher.

Fig. 4

Series of average CO concentrations in µg/m^3 by day of the week



With respect to the time variable, the highest concentrations of CO in the air were found between 18-19pm in both the Benavides and Javier Prado sectors. An increase of 27% was observed in the first sector and 44% in the second compared to the average of the other hours of measurement (8am-9am and 1pm-14pm).

Likewise, these observations are statistically corroborated using the analysis of variance. The purpose of this analysis is to determine whether the null hypothesis is accepted or rejected. The null hypothesis (Ho) proposed is: Carbon monoxide levels in the air are the same at any time of the day and the alternative hypothesis (Ho) is: Carbon monoxide levels in the air are the same at any time of the day: Carbon monoxide levels in the air vary according to the time of day.

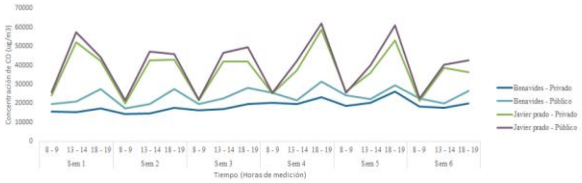
The f-value shown in Fig. 5 is greater than 1, indicating that the null hypothesis is rejected; therefore, it can be statistically affirmed that CO levels in the air vary according to the time of day.

Fig. 5
Analysis of Variance between CO level in the air and measurement times

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Horario	2	10856	5427.9	31.20	0.000
Error	357	62112	174.0		
Total	359	72968			

Fig. 6
Series of average CO concentrations in µg/m^3 by time of day and week



It was decided to project CO emissions for the month of July in order to estimate annual emissions for the current year (2021) and compare them with those reported by MINAM in 2016, for this, with the data obtained the average CO in µg/ m^3 for the month of July was calculated (29,878 µg/). By changing the monthly frequency to an annual one, the result was that emissions would be around 1,553,693 µg/. This projection was made based on 1,416,200 units circulating per month, 76% of them private cars and 24% public vehicles.

Fig. 8
Emissions estimated by MINAM in 2016.

Años	CO	HC	NOx	PM_{10}
2000	535 620	104 220	89 880	14 550
2001	562 930	108 360	94 460	15 290
2002	593 870	112 960	99 660	16 130
2003	629 480	118 180	105 640	17 090
2004	668 480	123 860	112 200	18 140
Proyecciones al...				
2005	668 510	127 000	115 560	18 720
2010	845 560	150 130	141 970	22 980
2015	1 053 550	180 080	176 940	28 660
2020	1 344 370	221 270	225 860	36 600
2025	1 715 580	273 230	288 280	46 730

Note: MINAM. (2016). Environmental performance study. MINAM https://www.minam.gob.pe/esda/wp-content/uploads/2016/09/estudio_de-desempeno_ambiental_esda_2016.pdf

IV. Discussion

Carbon monoxide emissions were quantified at four measurement points located in some of the busiest streets of modern Lima in order to identify the exposure of pedestrians to this pollutant. The level of CO concentration is affected by several factors, including the presence of public transport on the roads, which increases the levels of monoxide in the air. On the other hand, the time of day and traffic levels are related to each other since there is a higher concentration of traffic during "rush hour".

Javier Prado Avenue, being an arterial road that connects 4 districts, as well as being considered one of the main routes to go from the industrial zone to the dormitory zone, presented a greater vehicular flow between private and public vehicles in 35% compared to Benavides. Therefore, it is evident that Javier Prado has a higher level of CO, and pedestrians are advised to take nearby roads to reduce exposure to the pollutant.

According to a study conducted by the Ministry of the Environment (MINAM) in 2016, CO emissions from the vehicle fleet were projected for 2020 and 2025, which would be 1,344,370 and 1,715,580 µg/m^3 respectively (Figure 4.8), taking 870 033 cars as a base. However, according to the data collected this year, the emissions for 2021 are 1,553,693 µg/m^3, based on 1,416,200 units circulating per month, with 1,076,312 units of private transportation and 339,888 units of public transportation, which were recorded through recordings.

When comparing actual emissions in 2021 with MINAM's estimates, it can be mentioned that these are 10% higher than estimated. This could be explained by an underestimation of the number of cars and therefore of CO.

In other Latin American countries such as Argentina, CO levels "do not exceed the limits established by the Argentine law (LP) nor those of the World Health Organization (WHO)" (González, 2016) being the LP of 57,250 µg/m^3 and the WHO standards of 30,000 µg/m^3 for one hour. In the present article, although the measurements were not continuous, it is important to highlight that the average total concentrations (29,789 ug/m^3) are very close to the Maximum Permissible Limits (MPL) imposed in Supreme Decree N°074-2001-PCM; which determined that the MPL for carbon monoxide exposure is 30,000 µg/m^3 for 1 hour. However, it should be noted that there is evidence of daily peaks that exceed this value.

The above results demonstrate the criticality of the current pollution in the streets of modern Lima, the risks faced by passersby, and the importance of constantly monitoring air quality in order to improve current conditions. It is considered of utmost importance that corrective measures be taken to mitigate the environmental impact of CO emissions in order to reduce the health effect on passersby and traffic police who are constantly exposed, putting their health at risk on a daily basis. This could bring consequences such as high carboxyhemoglobin effects, as evidenced in the study of Huancayo, Peru in 2019 (Mallqui, 2019), causing respiratory difficulties, convulsions, coma and even death.

Conclusion

The CO measurements were higher than the projections made by MINAM in 2016, which shows a trend of constant growth in the concentration of this pollutant over the years. This is due to several factors which were statistically evaluated using analysis of variance and the Spearman coefficient to determine their direct relationship with CO concentration. Factors such as the level of traffic, the time of day and type of transport, influence the increase or decrease of CO in the air. On the other hand, it is known that at present the age of the vehicle fleet in Lima is greater than recommended, which added to the high vehicle concentrations at peak hours produces an increase in the levels of monoxide.

With respect to the measurement zones, the one with the highest CO concentrations was Javier Prado Avenue with a difference of 17,451 µg/m^3 compared to Benavides Avenue. This was related to the number of vehicles on this road, which was 35% higher than in Benavides. However, both areas had elevated CO levels, being higher than 10,000 µg/m^3

The levels of monoxide collected in this study represent a health risk for passersby and traffic police officers, who are constantly exposed to high levels of CO, which can cause illnesses such as pulmonary and cardiovascular deficiencies, bronchitis, hypoxia, among others. Therefore, Lima's air quality is considered an important environmental issue, which can be improved if the health and environmental authorities take preventive measures considering the factors mentioned above.

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