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Association between Ambient Air Pollution by Particulate Matter ($PM_{2.5}$) and Vehicular Traffic in Downtown Port City of Tampico, Mexico †

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Abstract: The objective of this study was to statistically analyze the concentration of pollution in the air by $PM_{2.5}$ particulate matter and vehicular traffic using a methodology based on quadrants, considering the periods of "working" and "holiday" activities in the downtown area from the port city of Tampico, Mexico. The vehicular traffic count was carried out in three hourly ranges per day for a week in each period. Moreover, an analysis of the correlation coefficient based on the Spearman method was carried out, both in the working and vacation periods, between the variables of $PM_{2.5}$ concentration and total vehicular traffic by the hourly range and by day in each quadrant. A strong to very strong correlation ($0.828 \geq r \leq 0.960$) was identified between pollutant concentration and vehicular traffic on several days and quadrants in the work period. On the other hand, in the holiday period, a weak to moderate correlation was observed on most of the days considered in this study.

Keywords: $PM_{2.5}$; vehicular traffic; air pollution; correlation

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1. Introduction

The presence of harmful substances or matter in the atmosphere in concentrations that cause damage to the population and ecosystems is identified as air pollution [1]. Various factors that contribute to the increase in air pollution concentration levels have been identified, including meteorological conditions, sociodemographic characteristics, and various activities carried out by humans, among which motorized vehicles stand out [2]. Vehicular traffic has been identified as one of the main sources of air pollution [3]. In this sense, fine particulate matter is identified among criterion-type air pollutants, with diameters of 1.0 to 2.5 µm (µm), known as $PM_{2.5}$ [4]. This pollutant is estimated to come from 20% of fixed sources, while the remaining 80% is contributed by mobile sources [5]. In previous studies, vehicle exhaust represents an important anthropogenic source of fine airborne particles in urban areas [6]. Furthermore, the friction of automobile tire generates with the pavement during the braking process or with successive rapid braking events contributes 34% to the total emission of particles in the air [7,8].

The importance of studying pollution by particulate matter is that it produces adverse health effects, such as premature death, ischemic heart disease, stroke, lung cancer, chronic obstructive pulmonary disease, and respiratory infections [1]. The authors in [9] report that an increase of 2 $\mu g/m^3$ in the concentration of $PM_{2.5}$ and its exposure over a long period is related to a reduction in seven months of life. Furthermore, with the increase in the contaminant's concentration, mortality risk increases by 3.7% [9]. Therefore, particulate matter pollution impacts air quality, human health, and meteorological conditions [10]. In Mexico, the Ministry of Health issued a maximum permissible annual exposure limit of 12 $\mu g/m^3$ and 45 $\mu g/m^3$ in 24 h for $PM_{2.5}$ to protect the health of the population [11].

Therefore, in this study, the relationship between vehicular traffic and $PM_{2.5}$ concentration levels recorded in the central area of the City of Tampico, Tamaulipas, in the northeastern region of Mexico, was evaluated. This study considers the vehicular flow of three quadrants surrounding the location of the air quality monitoring station, considering two periods of work and vacation activities. On the one hand, we analyze the relationship between variables considered in this study, using Spearman's correlation coefficient to measure the effect of vehicular traffic on the concentration of pollutants in the port area.

2. Materials and Methods

2.1. Area of Study

The present study was carried out in the city of Tampico, Tamaulipas, in the north-east of Mexico, which is characterized by a predominantly tropical, subhumid, and warm climate, with an average annual temperature of 25 °C, with a maximum temperature of 34 °C daily average in the months of July and August 2022. The Pánuco and Tamesí rivers stand out in their hydrography, which flow into the Gulf of Mexico. In addition, it is the principal commercial maritime port on the east coast of Mexico, with an extension of 44 km [12]. Furthermore, the city of Tampico is part of a metropolitan area comprising the cities of Altamira, Madero, and Tampico, located in Tamaulipas state, Mexico [13]. According to official public data, the city has a registered vehicle fleet of 121,077 units in circulation [14].

2.2. Data Collection and Analysis

The data on pollution concentration were obtained through an air quality monitoring system installed on the roof of a building with an approximate height of 15 m. The incidence of vehicle flow was obtained by counting all types of combustion cars circulating in three quadrants. The first quadrant is made up of the four avenues surrounding the monitoring station building with an approximate distance of 100 m. The second and third quadrants comprise the following avenues with an approximate distance of 200 and 300 m. Vehicle count was carried out using a manual counting methodology established by the Ministry of Communications and Transportation in Mexico [15], which consists of carrying out a visual count with the help of a manual counter every 15 min with a duration of 5 min. The sampling was performed between 09:00 and 11:00 (morning), 12:00 and 14:00 (noon), 15:00 and 17:00 (afternoon). In a preliminary study using the Google Maps tool, these three-time ranges with the most significant presence of vehicular traffic (peak hours) were identified. Vehicle counting was carried out for seven days (Monday to Sunday) in the month of January 2022 (identified as a work period) and in the second week of April 2022, identified as a vacation period (holiday Easter week). Concentration levels of pollutants in the air and meteorological factors were statistically analyzed using the Kolmogorov–Smirnov Lilliefors test to determine the normality of the data. Moreover, a descriptive analysis was performed by calculating the median, interquartile range (IQR), and minimum and maximum values for the continuous variables of concentrations of air pollutants. The datasets were identified as non-parametric distribution, for which it was determined to apply a Spearman correlation analysis.

3. Results and Discussion

3.1. Descriptive Analysis

A non-parametric distribution was observed to evaluate the normality of the data of the average concentration of $PM_{2.5}$ for each period (Kolmogorov–Smirnov Lilliefors test, p-value < 0.05). Figure 1 shows that the highest average concentration of $PM_{2.5}$ was recorded on a Tuesday, with a median (interquartile range) of 38.4 (38.9) $\mu g/m^3$, and on Wednesday, an average concentration of 29.6 was recorded, with an IQR value of 45.8$\mu g/m^{3.}$. These values were recorded during a workweek. On Wednesday, the concentration levels of $PM_{2.5}$ were very variable compared to the rest of the week, as seen in the box plot in Figure 1. Furthermore, it was identified that the average concentration of

$PM_{2.5}$ decreases on the days of the weekend during the work period. On the other hand, during the holiday period, an increase in $PM_{2.5}$ concentration levels was observed during the weekend, with medians of 35.3 (36.4), 33.5 (34.1), and 27.7 (30.3) µg/m^3 on Thursday, Friday, and Saturday, respectively. This increase is possibly because these days coincided with the Catholic holiday of Holy Week. In this sense, Ref. [16] report the influence of human activities on air quality on short time scales caused by changes in usual activities due to the lifestyle and culture of the region.

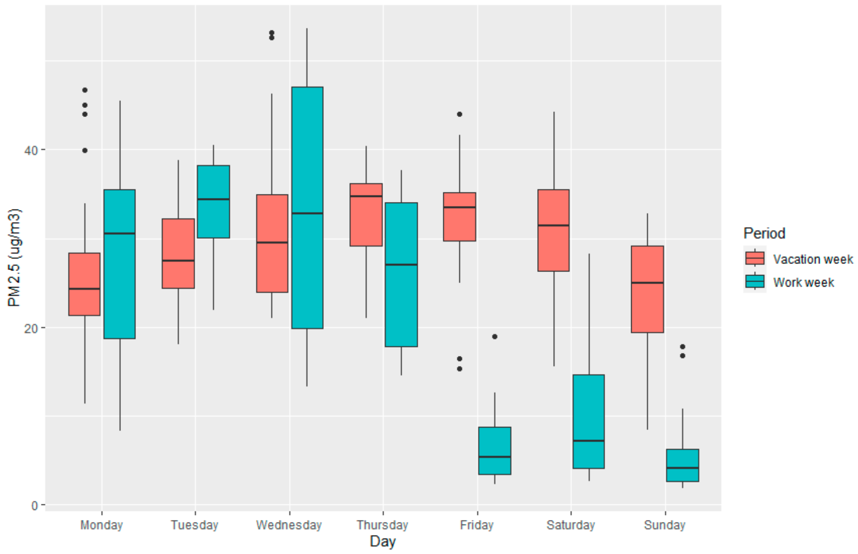

Figure 1. $PM_{2.5}$ concentration level during work period versus holiday period.

Figure 2 shows the $PM_{2.5}$ concentration levels, classifying the recorded values in the morning, noon, and afternoon range for the work week. This period was defined according to the time ranges in which the vehicular traffic count was carried out in each quadrant. Based on the median concentrations of $PM_{2.5}$, it is shown that in the work week, the highest pollution level occurred on Wednesday morning, with a value of 52.4 (53.0) µg/m^3. On Thursday morning and noon in the holiday period (vacation week), values of 36.2 (36.4) and 36.3 (37.6) µg/m^3 were observed, respectively (see Figure 3). The above agrees with the results obtained by [17], which mention that $PM_{2.5}$ pollution levels are high on workdays. However, they are even higher during the holiday period, as shown by our research results (see Figure 3).

3.2. Correlation Analysis

The results of the correlation analysis between the number of vehicles per quadrant and the $PM_{2.5}$ concentration levels, calculated using the Spearman correlation coefficient (see Table 1), show a strong negative association between quadrant 1 (Q1) and the concentration of the pollutant recorded on Wednesday and Friday (working period) of −0.943 (p-value < 0.01) and −0.895 (p-value < 0.01), respectively. It is important to consider that the degree of correlation can be influenced by the wind speed (gusts) that occurred on the mentioned days, as [18] reported, where wind currents drag or disperse the pollutant to other areas. Similarly, a moderate to strong positive relationship is identified between the $PM_{2.5}$ concentration recorded on Sunday and the vehicular flow of C1 of 0.771 (p-value > 0.05). In quadrant 2 (Q3), a moderate to strong positive correlation coefficient of 0.543 and 0.648 was identified for Monday and Tuesday, respectively. Wednesday shows a strong relationship with a correlation coefficient of 0.829 (p-value < 0.05), unlike Friday and Saturday, where a strong negative relationship of −0.828 and −0.943 is observed, with p-value < 0.05 and p-value < 0.01, that is, the greater the number of vehicles, the concentration levels of $PM_{2.5}$ increase. In quadrant (Q3), Friday shows a very strong (almost perfect) positive correlation coefficient of 0.960 (p-value < 0.01); this means that there is a strong relationship between vehicular traffic and the emission/generation of $PM_{2.5}$ in this quadrant. In the correlation analysis on Saturday, quadrant 3 shows a negative relationship of −0.838 with a significance level of less than 0.05 (see Table 1).

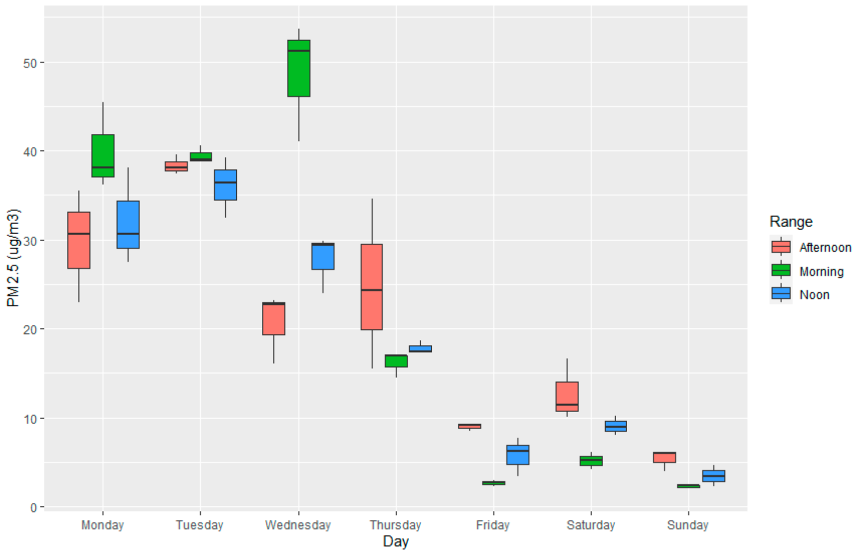

Figure 2. Analysis of the concentration of $PM_{2.5}$ in ranges per day during a week of work activities.

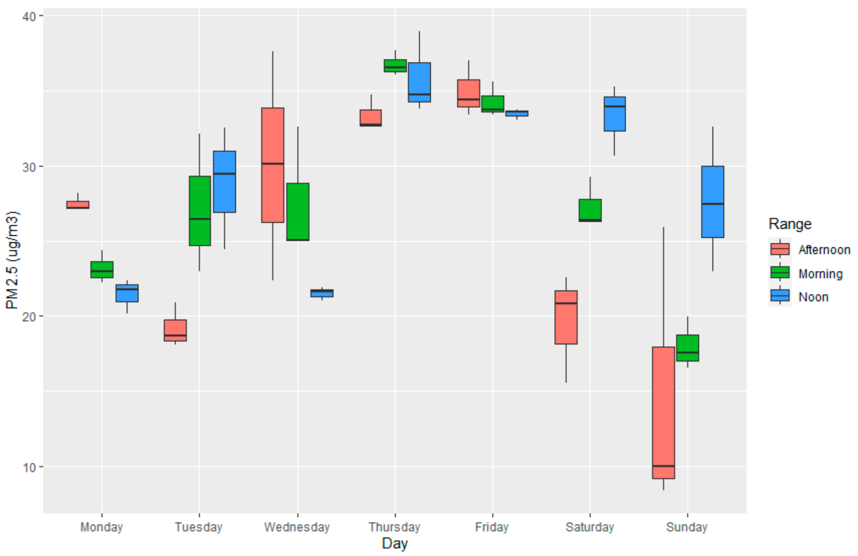

Figure 3. $PM_{2.5}$ level recorded in ranges per day during a holiday week.

Table 1. Analysis of the Spearman correlation coefficient considering all variables in a workweek.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Q1	0.486	−0.437	−0.943 **	−0.257	−0.895 **	0.290	0.771
Q2	0.543	0.648	0.829 *	−0.371	−0.828 *	−0.914 *	−0.371
Q3	−0.543	−0.561	0.029	0.371	0.960 **	0.838 *	0.371

** *p*-value < 0.01, * *p*-value < 0.05.

The analysis of the Spearman correlation coefficient of the data collected on the days of a week of the vacation season is shown in Table 2. Important changes are identified between the coefficients of the work period versus the vacation period, with relationships being mainly weak to moderate in this last period. A moderate to strong negative correlation of −0.796 is perceived between the $PM_{2.5}$ concentration recorded on Tuesday and the number of vehicles counted in C1. Furthermore, it is observed that a weak association remains between $PM_{2.5}$ and Q2, as well as $PM_{2.5}$ and Q3 on Sunday. Furthermore, a moderate correlation was identified in Q2 with $PM_{2.5}$ concentrations on Monday, Wednesday, and Friday. On Friday, the highest correlation coefficient (0.857, p-value < 0.05) was registered in Q2 and $PM_{2.5}$. This positive correlation between vehicular traffic and air pollution by $PM_{2.5}$ during the holiday period is understood by the activities carried out in this area due to the Good Friday festivities, as mentioned by [19], that with greater vehicular traffic, a high concentration of $PM_{2.5}$ occurs.

Table 2. Analysis of the Spearman correlation coefficient during the vacation period.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Q1	0.331	−0.796 *	−0.657	−0.504	−0.551	0.261	−0.257
Q2	−0.591	−0.107	0.600	0.631	0.857 *	0.486	0.314
Q3	0.444	−0.097	−0.257	0.454	−0.442	−0.486	0.257

* p-value < 0.05.

Finally, the correlation analysis considers the variables of the periods of the day (morning, noon, and afternoon) both on a workweek and on vacation. Moderate correlation coefficients of 0.580 and 0.534 between Q1 and midday and afternoon are identified in the work period, respectively. These correlation results are like those reported by [3], where they showed a moderate correlation, with a correlation coefficient of 0.496 in the work period. On the other hand, in the vacation period, a moderate positive correlation was identified between Q3 and the "morning" period, with a value of 0.571 and a p-value less than 0.05.

4. Conclusions

According to the data analyzed in this study, it is concluded that, during the work period, the highest $PM_{2.5}$ concentration levels occurred on Tuesdays and Wednesdays. On the other hand, during the holiday period, the highest concentration levels of the pollutant were recorded on Thursdays and Fridays, possibly caused by the religious festivities celebrated in most locations in the country on the days. On the other hand, in the correlation analysis between vehicular traffic and $PM_{2.5}$ pollution levels, there is a very strong correlation in Q3 on Friday during the work season. Furthermore, the negative correlation coefficients may be influenced by wind currents that carry the pollutant and may also be due to the type of traffic in Q1 during the work season. Finally, when analyzing the correlations between the variables considering the parts of the day during the holiday season, there is a permanent moderate relationship between vehicular traffic and the concentration of $PM_{2.5}$ in Q1. The above is because, on vacation, people use their vehicles at any time of the day and week, not only to travel to their work activities as they usually do during the work period.

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