Behavior of the Average Concentrations As Well As Their PM$_{10}$ and PM$_{2.5}$ Variability in the Metropolitan Area of Lima, Peru: Case Study February and July 2016

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Abstract—This research focused on analyzing the behavior of the hourly average concentrations of PM$_{10}$ and PM$_{2.5}$ in relation to vehicular traffic, as well as the effect of relative humidity on these concentrations. Measurements of hourly particulate matter concentrations were recorded by the National Meteorology and Hydrology Service of Peru (SENAMHI) at five surface air quality stations. The profiles of PM$_{10}$ concentrations are related to traffic behavior, showing high levels of concentrations at peak hours, while the PM$_{2.5}$ profiles are flatter and better related to traffic in February (summer). The decrease in relative humidity between 80 to 65% in the mornings has a greater effect on the increase in PM$_{10}$ and PM$_{2.5}$ concentrations in February than in July (winter), and the increase in relative humidity between 65 to 80% in the afternoon, it has a greater effect on the decrease in the concentration of PM$_{2.5}$ in February than in July. The air quality in the north (PPD and CRB stations) and east (SJL station) of the Metropolitan Area of Lima (MAL) are the most polluted. The factors that relate PM$_{10}$ concentrations with the Peruvian standard in February at these stations were 2.79, 1.78 and 1.26, and in July 2.74, 1.28 and 1.36 respectively. The highest and lowest variability of PM$_{10}$ and PM$_{2.5}$ in February and July occurred in the northern area (PPD and SMP stations).

Index Terms—Air quality, air pollution, particulate matter, PM$_{10}$, PM$_{2.5}$, Lima, Peru.

I. INTRODUCTION

Sixty-six percent of the cars nowadays in Peru, circulate in the Metropolitan Area of Lima and Callao, and some of the types of vehicles are automobiles, station wagons, pickups, rural cars, buses, removers, trailers, and semi-trailer. In 2016, 1,752, 919 vehicles were registered in Lima [1]. This number of vehicles are undoubtedly generate of air pollution. Clean air is vital for the quality of life of human beings. Particles with aerodynamic diameters smaller than 2.5 µm (PM$_{2.5}$) and smaller than 10 µm (PM$_{10}$) are dangerous for human health [2]-[6]. They can penetrate and lodge deep inside the lungs. The particles that cause damage to health most are those with less diameter (≤ PM$_{2.5}$). They can penetrate the lung barrier and enter the blood system [7]. There are serious risks to health from exposure to these air pollutants. The most common indicators of air quality are particulate matter (PM) [7], and gases SO$_2$ [8], NO$_2$ [9] and O$_3$ [7]. Public transportation generates pollutants that have harmful effects on health and the environment [10], [11] Natural photochemical reaction [12], volcanic eruptions [13] and forest fires [14], and anthropogenic (http://www.who.int/airpollution/ambient/pollutants/en/) sources are responsible for air pollution. According to the WHO in 2012, 7 million people died due to air pollution [15], [16]; (http://www.who.int/sustainable-development/cities/en/). Research reveals that there is a link between air pollution and cardiovascular disease [17] and cancer [18]; (http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/). The major components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water [7]. They consist of a complex mixture [19], [20] of solid and liquid particles of organic and inorganic substances suspended in the air [7], [21], besides vary in number, size, shape, surface area, chemical composition, solubility, and origin [21]. The pathogenicity of PM is determined by the above-mentioned factors and their ability to produce reactive oxygen [5]. Oxidative stress entails lipid peroxidation, depletions of antioxidants, and activation of pro-inflammatory signaling. The pro-inflammatory signaling sets off a cascade of events that may affect distant organs [22]; The physical-chemical processes that occur in the atmosphere have an effect on air quality. Meteorological conditions can prevent or favor the dispersion of pollutants in the atmosphere by diffusion, dilution and accumulation [23]-[25]. If they prevent it (e.g. low wind speed, orography, etc.), the immediate effect will be the increase in the concentration of pollutants that is not related to the increase in emissions [26]-[28]. More than 90% of people in the world live in polluted areas that do not comply with WHO...
recommendations [29]. WHO has recommended the concentration levels for particulate material with aerodynamic diameters of 2.5 and 10 µm, defined as PM$_{2.5}$ and PM$_{10}$ at (25 µg/m$^3$, 24-hour mean) and (50 µg/m$^3$, 24-hour mean) respectively [30], [31]. Inhalation of these particles can affect various organs of the human body (e.g., lung, heart etc.) increasing morbidity and mortality [5], [32], [33]. The upper respiratory tract is affected by PM$_{10}$ while lung alveoli is affected by fine (PM$_{2.5}$) particles (2.5 <PM≤10µm), fine particles (PM≤2.5µm), and ultrafine (PM$_{0.1}$) particles [22], [34]. Human health and the environment are severely affected in recent decades by air pollution [16]. Cities with more than 10 million people (e.g Lima city) are known as megacities [35], and as they are large cities they have air pollution problems due to toxic gases (e.g NOx, CO, CO$_2$, SO$_2$, SO$_3$, H$_2$S, VOCs etc.) and particulate material (PM) that people can inhale [36], [37], and that do not meet the guidelines of the World Health Organization (WHO) [38], [39]. The impacts of the environment on our health have different routes [40], and meteorological conditions affect aerosol and gas concentrations [41]-[43]. Cerebrovascular, respiratory and cardiovascular diseases generated by airborne PM, as well as their effects on morbidity and mortality are not yet well understood [44]-[47]. Diseases due to air pollution can be reviewed in [48]. Economic activities continuously lead to deterioration of air quality, which represents a health hazard [49]. The metallurgical industries generate a wide variety of hazardous wastes that contain dissolved toxic metals [50]. Heavy metals are a danger to humans and animals when inhaled, and they can act as catalysts in chemical reactions in the atmosphere forming secondary pollutants etc. [51]. The size distribution depends on aerodynamic diameter and is trimodal, including coarse particles [22], [34]. Human health and the environment are severely affected in recent decades by air pollution [16]. Cities with more than 10 million people (e.g Lima city) are known as megacities [35], and as they are large cities they have air pollution problems due to toxic gases (e.g NOx, CO, CO$_2$, SO$_2$, SO$_3$, H$_2$S, VOCs etc.) and particulate material (PM) that people can inhale [36], [37], and that do not meet the guidelines of the World Health Organization (WHO) [38], [39]. The impacts of the environment on our health have different routes [40], and meteorological conditions affect aerosol and gas concentrations [41]-[43]. Cerebrovascular, respiratory and cardiovascular diseases generated by airborne PM, as well as their effects on morbidity and mortality are not yet well understood [44]-[47]. Diseases due to air pollution can be reviewed in [48]. Economic activities continuously lead to deterioration of air quality, which represents a health hazard [49]. The metallurgical industries generate a wide variety of hazardous wastes that contain dissolved toxic metals [50]. Heavy metals are a danger to humans and animals when inhaled, and they can act as catalysts in chemical reactions in the atmosphere forming secondary pollutants etc. [51]. The size distribution depends on aerodynamic diameter and is trimodal, including coarse particles (2.5 <PM≤10µm), fine particles (PM≤2.5µm), and ultrafine particles (PM<0.1µm) [21], [52]-[54]. Each distribution has its own characteristics, including its origin and composition, which is explained in detail by [21], [55]. Air pollution is heterogeneous in Lima, due to different population densities and wind patterns. Besides the short-term exposure to ambient PM$_{2.5}$ is associated with increases in emergency room visits for respiratory diseases, stroke, and ischemic heart disease [36]. In the Metropolitan Area of Lima (MAL), the National Service of Meteorology and Hydrology (SENAMHI) reported high concentrations of PM$_{10}$ in the months of February and March (summer) and low concentrations in the months of July and August (winter) [57]. From 00:00 to 05.00 hours, the air quality stations recorded the highest concentrations of PM$_{10}$ whose values were: ATE (123.8 µg/m$^3$), VMT (162.2 µg/m$^3$), and STA (123.3 µg/m$^3$) stations compared to the SBJ (67.7 µg/m$^3$) and CDM (53 µg/m$^3$) stations, due to the influence of prevailing winds on the dispersion of pollutants in these areas. In morning hours, from 06:00 to 12:00, the maximum concentrations at these stations were 177.1 µg/m$^3$, 195.1 µg/m$^3$, 156.5 µg/m$^3$, 84.2 µg/m$^3$ and 75.7 µg/m$^3$, respectively [57]. When looking at the results of this report, we can say that there is poor air quality in the south (VMT Station), as well as in the east (ATE and STA Stations), areas with high vehicular traffic as well as having industries there [58]. The air quality at the CDM station and the SBJ station is as good as the air quality in residential areas. The main source of PM is associated with the growing size of the automotive fleet (1,195,353 in 2010 to 1,674,145 in 2015) [59] and the use of fossil fuels [60]. Some of the older public transportation vehicles have been removed from Lima’s roads, but 50% of Lima’s busses and minivans are over 18 years old [61]-[63]. The objective of this study was to analyze the behavior of the concentration profiles of the hourly average values of PM$_{10}$ and PM$_{2.5}$, as well as their variabilities in the MAL with the information measured by SENAMHI at five air quality stations during the months of February (summer) and July (winter). The variability indicates how far the concentrations are from the hourly average values and they serve to make important social decisions.

II. METHODOLOGY

A. Study Area

The study area corresponds to the MAL which is located at coordinates (Longitude: 77°1’41.66”W, Latitude: S12°2’35.45’S). SENAMHI provided the air quality data. Table I and Fig. 1 show the location and distribution of air quality stations respectively in the MAL. In Lima, climate is very peculiar: It is a subtropical desert climate, with a warm season from December to April, and a cool, humid, and cloudy season from June to October, with May and November as transition months. During summer, from December to April, sunshine is frequent, at least during the warmest hours of the day, while in the early hours of the day, fog may still form.

| TABLE I: LOCATION OF AIR QUALITY MONITORING STATIONS OF THE NATIONAL SERVICE OF METEOROLOGY AND HYDROLOGY OF PERU: SENAMHI-LIMA |
| Station / District in MAL | Central Area | Northern Area | Eastern Area |
|--------------------------|--------------|---------------|--------------|
| SBJ/San Borja            | 12° 6’ 31.06” S 77° 0’ 27.96” W | 11° 51’ 47.71” S 77° 0’ 26.88” W | 12° 1’ 8” S 76° 59’ 57.29” W |
| PPD/Puente Piedra        | 12° 0’ 32” S 77° 0’ 26.88” W | 11° 54’ 7.9” S 77° 0’ 21.1” W | 12° 0’ 32” S 77° 54’ 1” W |
| CRB/Carabayllo           | 12° 0’ 32” S 77° 54’ 1” W | 11° 54’ 7.9” S 77° 0’ 21.1” W | 12° 0’ 32” S 77° 54’ 1” W |
| SMP/San Martin de Porres | 12° 1’ 8” S 76° 59’ 57.29” W | 12° 0’ 32” S 77° 54’ 1” W | 12° 1’ 8” S 76° 59’ 57.29” W |

Fig 1. Geographical location of SENAMHI-Lima air quality stations.
B. Observed Data

The equipment used by the National Meteorology and Hydrology Service of Peru (SENAMHI) for PM$_{10}$ data collection was the TEOM 1405 monitor. This monitor uses a Tapered Element Oscillating Microbalance (TEOM) to continuously measure mass PM concentrations. The filter and the sampled air passing through filter are conditioned to a constant temperature (30°C or 50°C) to minimize interference of water condensation and temperature variations with mass measurement. The fundamental principle of measurement by the TEOM PM$_{10}$ can be reviewed in [64], [65]. However the principle Beta attenuation monitoring (BAM) of measurement for PM$_{2.5}$ concentration described by [66], [67]. Table II shows the percentages of data in each air quality station of PM$_{2.5}$ and PM$_{10}$ in the months of February and July.

| Station | SBJ | CRB | PPD | SMP | SJL |
|---------|-----|-----|-----|-----|-----|
| February 29 days | Data percentage (%): | | | | |
| PM$_{10}$ | 100 | 79 | 78 | 93 | 100 |
| PM$_{2.5}$ | 100 | 86 | 78 | 86 | 100 |
| July 31 days | Data percentage (%): | | | | |
| PM$_{10}$ | 76 | 83 | 98 | 100 | 82 |
| PM$_{2.5}$ | 82 | 84 | 98 | 100 | 100 |

III. RESULTS AND DISCUSSION

A. Descriptive Statistics of the Hourly Average Concentrations of PM$_{10}$ and PM$_{2.5}$: Minimum(Min), Average(Mean), and Maximum(Max).

Table III shows higher mean PM$_{10}$ values in summer than in winter at the SBJ, PPD and CRB stations in 1%, 22.53% and 4.82% respectively. In the SMP and SJL stations the highest values were in winter than in summer and 15.38% and 18.91% respectively. Similar and opposite behavior are reported in [2], [68]. Average PM$_{2.5}$ values were higher in all seasons in winter than in summer in 33.01%, 34.62%, 53.06%, 49.40% and 54.74% respectively. A similar result is shown in [69]. However other results show opposite results [70], [71]. Some climatological factors that help to explain these results are the absence of rain in Lima city and the decrease in wind speed in summer [57], [72]. Transportation and dispersion of air pollutants is affected by the land-atmosphere interactions, atmospheric transportation and mixing [73], [74].

Average maximum concentrations were recorded in summer in the central and northern areas, and in winter in the eastern area. The PM$_{10}$ and PM$_{2.5}$ concentrations in SBJ and SMP stations are very similar. The PM$_{10}$ and PM$_{2.5}$ standard deviations are higher in summer and winter respectively, indicating a greater dispersion of pollutants than PM$_{10}$ in summer and PM$_{2.5}$ in winter. PM$_{2.5}$ concentrations are higher in winter. They can be related to thermal inversion [75], [76] and domestic heating emissions [77]. The average values of PM$_{10}$ and PM$_{2.5}$ given by the Peruvian Air Quality Standard are 100 µg / m$^3$ and 50 µg / m$^3$, 24-hour average (DS No. 003-2017-MINAM). The values recommended by WHO are more demanding [31]. Many factors such as local and regional meteorology, wind speed and wind direction, control the reduction of the PM concentration [77], [78]. The PM$_{10}$ (mean) / PM$_{10}$ (Peruvian standard) ratio at in the PPD station in February and July are 1.25 and 1.02, respectively. Regarding [31] the values are 2.50 and 2.04 respectively. A value greater than the unit indicates that the standard value was exceeded and the air quality is not good, indicating possible risks to public health. The average PM$_{2.5}$/PM$_{10}$ ratios at the SBJ, PPD, CRB, SMP and SJL stations are lower in summer than in winter (0.30 ± 0.06 and 0.41 ± 0.09), (0.24 ± 0.05 and 0.39 ± 0.09), (0.25 ± 0.03 and 0.41 ± 0.09), (0.33 ± 0.05 and 0.42 ± 0.11) and (0.30 ± 0.04 and 0.39 ± 0.08) respectively. It is proportional to the average relative humidity [79]. Wet deposition has a stronger effect on coarse particles than on fine particles, so the PM$_{2.5}$/PM$_{10}$ should increase during wet periods with respect to dry periods. Similar results for Lima were found in the study conducted by [80]. The behavior of the height of the mixed layer in Lima in the months of January to April decreases (782 to 374 m), and from April to June it increases (374 to 995.8 m) (Sánchez-Coyollo & Ordóñez, 2016), which contributes to the increase and decrease of the concentration of the particulate material concentration. Other studies also show the same behavior [81]-[84]. The growth in particle size due to the increase in humidity reaches a point where dry deposition occurs, and the atmospheric concentration of PM$_{10}$ is reduced [85], [86].

| Station | Central Area (SBJ, station) | Northern Area (PPD, Station) | CRB, Station |
|---------|----------------------------|----------------------------|-------------|
| February (Summer) | PM$_{10}$ µg/m$^3$ | PM$_{2.5}$ µg/m$^3$ | February (Summer) |
| 31.94 | 48.78 | 63.78 | 10.08 | 8.73 | 14.54 | 20.05 | 3.13 |
| July (Winter) | 32.16 | 48.31 | 60.84 | 8.33 | 13.85 | 19.34 | 25.58 | 3.72 |
| February (Summer) | 69.43 | 125.14 | 175.54 | 32.30 | 20.75 | 28.39 | 38.07 | 5.06 |
| July (Winter) | 76.45 | 102.13 | 135.41 | 18.02 | 31.31 | 38.22 | 45.32 | 4.16 |
| February (Summer) | 46.52 | 84.02 | 116.86 | 19.35 | 14.07 | 20.60 | 28.83 | 4.36 |
| July (Winter) | 51.51 | 80.16 | 97.37 | 14.70 | 20.51 | 31.53 | 45.11 | 7.46 |
| February (Summer) | 22.42 | 39.40 | 48.69 | 8.66 | 8.33 | 12.53 | 17.71 | 2.37 |
| July (Winter) | | | | | | | | |

TABLE III: Minimum (Min), Average (Mean) and Maximum (Max) Values in the Study Areas: SDmean, Standard Deviation of the Mean Value.
### B. Behavior of Average Hourly Concentrations of PM\textsubscript{10} and PM\textsubscript{2.5} in February and July

Fig. 2 shows the behavior of the average hourly concentrations of PM\textsubscript{10} in February (summer) and July (winter) in the study areas. The concentrations in both months follow the behavior of vehicular traffic. They decrease from 00:00 to 05:00 hours due to the decrease in vehicular flow and increase from 05:00 to 09:00 hours in the morning due to the increase in vehicular flow. Other studies also show the same trends [70], [87], [88]. Peak concentrations are recorded between 6:00 and 10:00 hours in the morning and a second peak between 18:00 and 23:00 hours (PPD station was the exception in summer). Work conducted by [61] indicates similar ranges of hours. The SBJ, SMP and SJL stations registered PM\textsubscript{10} concentrations that did not exceed the Peruvian air quality standard. The PPD and CRB stations registered PM\textsubscript{10} concentrations higher than the Peruvian air quality standard. One of the causes is the problem of traffic congestion, in the mornings from 06:00 to 10:00 and after 17:00 to 10:00 at night. Poor air quality involves risks to human and animal health. Very valuable information can be reviewed in [52], [89]-[92]. The behavior of PM\textsubscript{10} concentrations are flatter in July than in February, the wet deposition has a greater effect on coarse particles than on fine particles. The same results were found in [81]-[84], [88]. The concentration and composition of aerosols can vary strongly at the same place. Hygroscopic aerosols can be affected by increasing or decreasing relative humidity shrink or grow respectively [93]. Average PM\textsubscript{10} concentrations at the SMP station are lowest in February and July. The PM\textsubscript{10} / PM\textsubscript{10}(SMP) ratio in February at the SBJ, SJL, CRB and PPD stations were 1.27 ± 0.18, 1.94 ± 0.35, 2.13 ± 0.25, 3.18 ± 0.30. In July, they were 1.06 ± 0.10, 1.96 ± 0.31, 1.76 ± 0.27 and 2.27 ± 0.40 respectively. In February and July, the PPD station is 3.18 and 2.27 times more polluted with PM\textsubscript{10} than the SMP station.

Fig. 3 shows the average hourly concentrations of PM\textsubscript{2.5} in the months of February and July. In February there is a trend related to traffic, while in July there are greater variations in the PM\textsubscript{2.5} concentrations. Lima is characterized by having calm weather from December to May (February: T = 19 to 29 °C, 0 day rain, 65 to 88 RH%, 12 km/h average wind speed), and the windiest weather from May to December (July: T = 14 to 19 °C, 0.3 mm average rainfall, 70 to 95 RH%, 15.2 km/h average wind speed). In winter, concentrations are higher than in summer. Other studies also show this trend [2]. In places where the summer season is rainy and the winter has much less rainfall, the effect may be the opposite [94].

#### Meteorological conditions can reduce PM\textsubscript{2.5} concentration by at least 16% [26], [95], [96]. In both months, concentrations did not exceed the Peruvian standard, which was modified in 2014. The Peruvian standard for PM\textsubscript{2.5} was changed from 25 to 50 µg/m\(^3\). This constitutes a serious error, because PM\textsubscript{2.5}, due to its size and higher concentration, was
allowed to be exposed and could be inhaled by humans whereby their health is affected. The value recommended by the World Health Organization is smaller, and serves to protect people’s health. The PM$_{2.5}$/PM$_{10}$ ratio in February at the SBJ, SJL, CRB and PPD stations were 1.16 ± 0.14, 1.80 ± 0.30, 1.65 ± 0.19, 2.31 ± 0.26. In July they were 1.05 ± 0.18, 1.86 ± 0.23, 1.79 ± 0.70 and 2.10 ± 0.26 respectively. In February and July the PPD station is 2.31 and 2.10 times more polluted with PM$_{2.5}$ than the SMP station. Fine particles have seasonal patterns and the tropospheric residence time is variable and is affected by climate. The most important role of meteorology is in the dispersion, transformation and removal of air pollutants from atmosphere [88]. The heating of the earth by the sun induces thermal turbulence during hot seasons. It determines change of air temperature with altitude [97] and increases the mixing height, contributing to the dispersion of pollutants [88]. The heating of air by the solar radiation minimizes atmospheric temperature nearer to the surface of the earth [88]. The air layer nearer to the surface of the earth becomes colder than the upper layers. It is also stable, thus, reducing the up-going air currents and leading to the increase of pollutant concentrations [88], [89].

C. Profiles of Mean PM$_{10}$ and PM$_{2.5}$ Concentrations with Respect to Relative Humidity in February and July

In Lima, summers are hot, muggy, arid, and cloudy, and winters are long, cool, dry, windy, and mostly clear. Figures 4 and 5 show the effect of RH% on the mean concentrations of PM$_{10}$ and PM$_{2.5}$ in February and July. In February the relative humidity decreases between 65% to 80% during the mornings between 7:00 and 10:00 a.m, and increases between 65% and 80% between 2:00 and 8:00 p.m. In July in the mornings between 8:00 a.m and 11:00 a.m, the relative humidity drops between 85% to 67%, and between 4:00 p.m and 10:00 p.m it increases between 67% to 85%. Under these conditions, the average concentrations of PM$_{10}$ and PM$_{2.5}$ can be analyzed jointly at all stations. Outside of these ranges, each station has a different behavior. In February when the relative humidity decreases, PM$_{10}$ concentrations increase, in the central area (SBJ station) by 32.88%, in the northern area (PPD, CRB and SMP stations) by 26.41%, 71.61% and 30.46%, respectively, and, in the eastern area (SJL station) at 64.63%. When the relative humidity increases, the concentrations vary by 23.00%, -13.55, -4.10%, -3.15% and 2.35% respectively. The behavior of PM$_{2.5}$ concentrations at these stations increases by 52.82%, 42.74%, 40.75%, 29.66% and 47.04% in the mornings. In the afternoons, they decrease by -15.07%, -8.42%, -28.01% -17.18% and -15.06%, respectively. In July when relative humidity decreases, PM$_{10}$ concentrations vary by -16.55%, 10.30%, 19.94%, -4.76% and 20.44%, and when the relative humidity increases the concentrations vary by 7.46%, 3.50%, 5.97%, -1.12% and 10.47%, respectively.

The concentrations of PM$_{2.5}$ with the decrease and increase of relative humidity vary in -40.07%, 1.31%, 24.61%, 2.26% and 4.83%, and in 1.59%, -2.13%, -32.24%, -3.00% and -0.65% respectively. Meteorological variability (RH%, wind speed and pressure) typically accounts for 20-50% of particulate material (PM) variability [26], [98]. The relative humidity has the ability to affect PM concentration [99]-[102]. A study conducted in Bogotá, Colombia showed a 30% reduction in PM$_{10}$ on rainy days and 21% in PM$_{2.5}$ [103]. High relative humidity values have a great effect on PM$_{10}$ concentration [104]. It also favors the formation of solutions and with it the development of chemical reactions at surface level. Abrupt changes in RH could influence the growth of PM$_{2.5}$ concentration [100]. The formation and accumulation processes of particulate material (PM$_{2.5}$) are closely related to meteorological conditions [105].
traffic.

Fig. 5. PM$_{2.5}$ concentrations and relative humidity (HR%) in February and July.

TABLE IV: Hourly Monthly Average Values of the Variabilities

|                | Mean   | Mean+SD  | Mean   | Mean+SD  |
|----------------|--------|----------|--------|----------|
|                | PM$_{10}$ µg/m$^3$ | PM$_{2.5}$ µg/m$^3$ |
| February       |        |          |        |          |
| Central area (SBJ) | 30.56±8.48 | 8.71±2.59 |
| Eastern Area (SJI) | 51.51±8.82 | 7.54±1.64 |
| July           |        |          |        |          |
| Central area (SBJ) | 28.38±6.67 | 8.81±1.62 |
| Eastern Area (SJI) | 66.68±19.33 | 13.75±2.79 |

The highest and lowest mean hourly mean values of PM$_{2.5}$ of Mean + SD in February and July were (27.31 and 12.99 µg / m$^3$, at 10:00 and 5:00 hours), (57.30 and 31.82 µg / m$^3$, at 10:00 and 5:00 hours), (38.98 and 20.51 µg / m$^3$, at 10:00 and 19:00 hours), (47.67 and 23.69 µg / m$^3$, at 10:00 and 18:00 hours), and (40.49 and 18.67 µg / m$^3$, at 0.00 and 15:00 hours) respectively, and (40.49 and 18.67 µg / m$^3$ at 0.00 and 15:00 hours), (63.51 and 40.47 µg / m$^3$ at 10:00 and 19:00 hours), (67.60 and 30.97 µg / m$^3$, at 10:00 and 19:00 hours), (40.75 and 17.12 µg / m$^3$, at 0.00 and 18:00 hours) and (62.05 and 37.37 µg / m$^3$, at 3:00 and 16:00 hours) respectively. In February at the PPD station the factor was 1.45, and, in July, at the PPD, CRB and SJI stations the factors were 1.27, 1.35 and 1.24, respectively. Factors greater than unity indicate deficiencies in air quality in both months.

IV. CONCLUSION

An anthropogenic source of emissions in urban areas is vehicular transport [106], [107], and PM is one of the most dangerous pollutants [106]. Older automobiles [97], [108] emit considerable pollutants [97].

The profiles of the average concentrations of PM$_{10}$ in February and July follow traffic behavior, while the profiles
of the concentration of PM$_{2.5}$ are rather flattened. Air quality in the study area is influenced by vehicular transportation, and the northern (PPD and CRB stations) and eastern (SIL station) areas are the most polluted by PM$_{10}$ and PM$_{2.5}$ concentration.

In February, the decrease in relative humidity in the morning has a strong effect on the increase in concentrations of PM$_{10}$ and PM$_{2.5}$ in the central, northern and eastern areas. When the relative humidity increases in the afternoon, PM$_{10}$ concentrations in the central and eastern areas increase and decrease in the northern area, and PM$_{2.5}$ concentrations decrease in the study areas.

In July, the decrease in relative humidity in the mornings generates a decrease in PM$_{10}$ concentrations in the central and northern areas (SMP station) and an increase in concentration in the northern area (PPD and CRB stations), and in the central area the PM$_{2.5}$ concentration decreases, and, in the northern and eastern areas it increases. When the relative humidity increases in the afternoon, PM$_{10}$ concentrations increase except in the northern area (SMP station), and PM$_{2.5}$ concentrations increase in the central area and decrease in the other areas.

The highest and lowest variability of the hourly average concentrations PM$_{10}$ and PM$_{2.5}$ occurred in the northern area (PPD and SMP stations) in the months of February and July.

**CONFLICT OF INTEREST**

The authors declare no conflicts of interest regarding the publication of this paper.

**AUTHOR CONTRIBUTIONS**

W.Reátegui, W.F.Zaldívar, and O.R.Sánchez wrote the article. W.Reátegui, S.Paesi, A.E.Garcí a and A.Moya, analyzed the particulate matter concentration data. W.Reátegui and O.R.Sánchez constructed the figures, tables and their description of them. All authors provided bibliographic references, final comments, and approved the final version of the article. We appreciate the collaboration of María E. King Santos, Ricardo A. Yuli Posadas and Manuel A. Leiva Guzman for their suggestions and final revision of the manuscript.

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