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

Warren Reátegui-Romero, Walter F. Zaldivar-Alvarez , Sergio Pacsi–Valdivia, Odón R. Sánchez-Ccoyllo, Alberto E. García-Rivero, and Aldo Moya–Alvarez

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, depletion 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

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Warren Reátegui-Romero and Walter F. Zaldivar-Alvarez are with the Faculty of Chemical Engineering and Textile (FIQT), National University of Engineering (UNI), Peru (e-mail: wreategui@uni.edu.pe, walterzaldivar@hotmail.com).

Sergio Pacsi-Valdivia is with the National Agrarian University La Molina (UNALM), Lima, Peru (e-mail: spv@lamolina.edu.pe).

Odón R. Sánchez-Ccoyllo is with the National Technological University of South Lima (UNTELS), Lima, Peru (e-mail: osanchez@untels.edu.pe).

Alberto E. García Rivero is with the School of Geography, Universidad Nacional Mayor de San Marcos, Perú (e-mail: albertoenrique.garcia@unmsm.edu.pe).

Aldo Moya–Alvarez is with the Geophysical Institute of Peru (IGP), Calle Badajoz 169 Urb. Mayorazgo, Peru (e-mail: amoya@igp.com.pe).

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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 ($PM_{2.5}$) 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_2S, 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 [56]. 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	Latitude	Longitude	Elevation (m)
	Central Area		
SBJ/San Borja	12 °6' 31.06" S	77 °0'27.96" W	136
	Northern Area		
PPD/Puente Piedra	11 °51' 47.71" S	77 °04'26.88" W	180
CRB/Carabayllo	11 °54'7.9" S	77 °2'1.1" W	190
SMP/San Martin de Porres	12 °0'32" S	77 °5'4.1" W	56
	Eastern Area		
SJL/San Juan de Lurigancho	12 °1' 8" S	76 °59'57.29" W	239

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 ℃ or 50 ℃) 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.

TABLE II: PERCENTAGE OF $PM_{2.5}$ AND PM_{10} DATA IN THE MONTHS OF FEBRUARY AND JULY AT EACH STATION IN 2016

Station	SBJ	CRB	PPD	SMP	SJL
February 29 days				Data porcentage (%):	
PM_{10}	100	79	78	93	100
$PM_{2.5}$	100	86	78	86	100
July 31 days				Data porcentage (%):	
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 $PM_{2.5}/PM_{10}$ ratio 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-Ccoyllo & 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].

TABLE III: MINIMUM (MIN), AVERAGE (MEAN) AND MAXIMUM (MAX) VALUES IN THE STUDY AREAS: SDMEAN, STANDARD DEVIATION OF THE MEAN VALUE

Min	Mean	Max	SDmean	Min	Mean	Max	SDmean
Central Area (SBJ, station)							
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
Northern Area							
(PPD, Station)							
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
CRB, Station)							
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
(SMP,Station)							
February(Summer)							
22.42	39.40	48.69	8.66	8.33	12.53	17.71	2.37
July(Winter)							

32.70	45.46	58.77	6.97	12.14	18.72	24.91	3.35
Northern Area							
Average: (PPD, CRB, SMP stations)							
February (Summer)							
43.55	76.46	95.61	17.12	14.02	19.57	25.94	3.40
July(Winter)							
54.49	74.66	90.74	11.27	22.9	29.23	35.57	3.05
Eastern (SJL, Station)							
February(Summer)							
56.71	73.40	96.21	10.45	16.65	22.03	33.82	4.37
Winter (July)							
71.77	87.28	103.01	9.53	26.73	34.09	40.65	4.88

B. *Behavior of Average Hourly Concentrations of PM_{10} and $PM_{2.5}$ in February and July*

Fig. 2 show the behavior of the average hourly concentrations of PM_{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_{10} concentrations that did not exceed the Peruvian air quality standard. The PPD and CRB stations registered PM_{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_{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_{10} concentrations at the SMP station are lowest in February and July. The PM_{10} / $PM_{10\,(SMP)}$ 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_{10} than the SMP station.

Fig. 3 shows the average hourly concentrations of $PM_{2.5}$ 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 $PM_{2.5}$ 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].

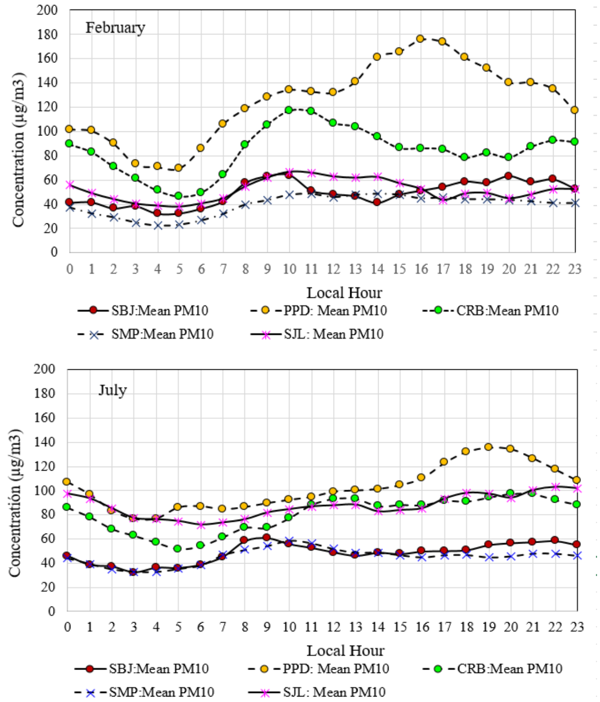


Fig. 2. Average hourly concentrations of PM_{10} at the SBJ, PPD, CRB, SMP and SJL air quality stations.

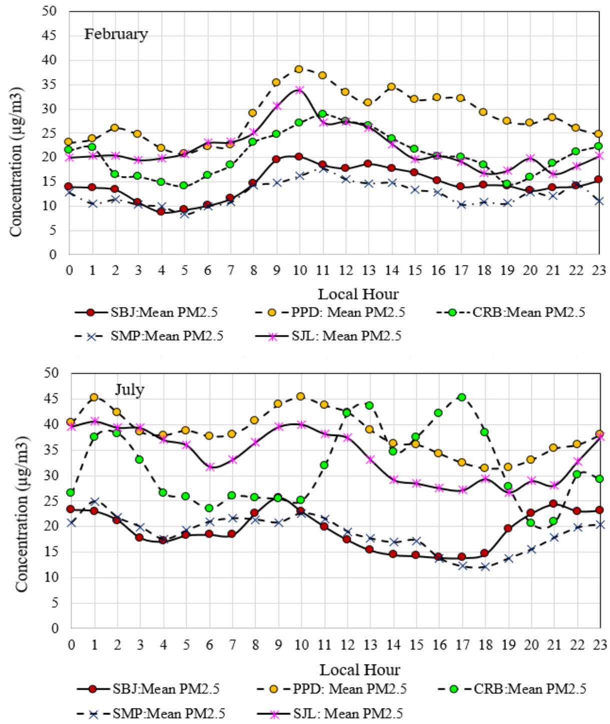


Fig. 3. Average hourly concentrations of $PM_{2.5}$ at the SBJ, PPD, CRB, SMP and SJL air quality stations.

Meteorological conditions can reduce $PM_{2.5}$ 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 $PM_{2.5}$ was changed from 25 to 50 μg/m^3. This constitutes a serious error, because $PM_{2.5}$, 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 $PM_{2.5}$ / $PM_{2.5\ (SMP)}$ 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].

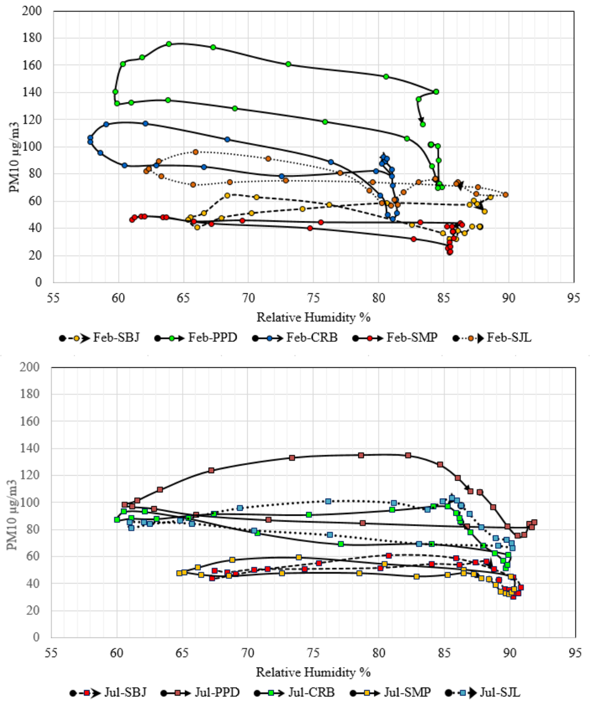
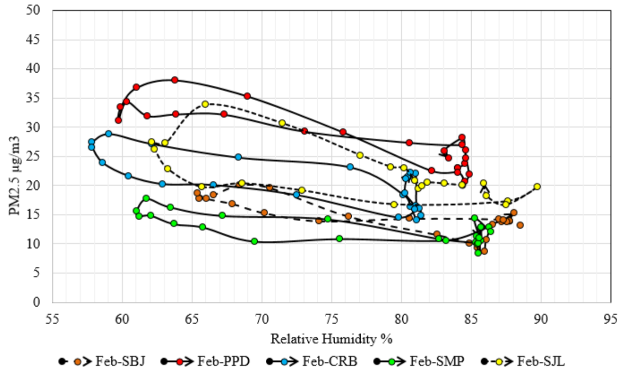


Fig. 4. PM_{10} concentrations and relative humidity (HR%) in February and July.

D. Descriptive Statistics of the Mean-SD and Mean + SD Variability of PM_{10} and $PM_{2.5}$ in February and July

Table IV shows the average hourly variability (Mean –SD) and (Mean + SD) of PM_{10} and $PM_{2.5}$ in February and July. At the PPD station, the highest SD value of PM_{10} in February indicates greater fluctuations of the hourly mean values of Mean + SD, and at the SMP station the lower value of SD indicates less fluctuations in the mean hourly values of Mean-SD . At both stations the same behavior occurs for $PM_{2.5}$. The highest and lowest hourly mean values of PM_{10} of Mean + SD in February at the SBJ, PPD, CRB, SMP and SJL stations were (86.13 and 46.63 µg / m^3, at 20:00 and 4:00 hours), (279.86 and 102.60 µg / m^3 , at 16:00 and 5:00 hours), (178.24 and 73.50 µg / m^3 , at 10:00 and 5:00 hours), (67.81 and 28.38 µg / m^3 , at 14:00 and 4:00 hours), (125.76 and 75.51 µg / m^3, at 10:00 and 5:00 hours) respectively. At the PPD, CRB and SJL stations, these hourly average values exceed the Peruvian norm by a factor of 2.79, 1.78 and 1.26 respectively. In July the values were (86.59 and 46.33 µg / m^3 , at 8:00 and 3:00 hours), (273.66 and 107.50 µg / m^3, at 18:00 and 3:00 hours), (128.35 and 75.93 µg / m^3 , at 12:00 and 5:00 hours), (84.93 and 48.41 µg / m^3, at 10:00 and 4:00 hours), (135.52 and 106.91 µg / m^3 , at 1:00 and 14:00 hours), and the factors were 2.74, 1.28 and 1.36 respectively. The highest concentrations correspond to hours of high vehicular traffic.



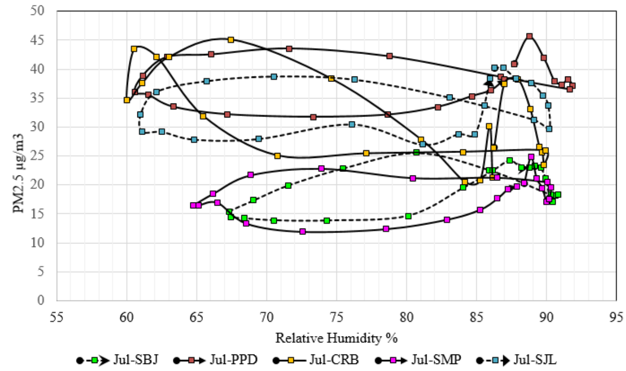


Fig. 5. $PM_{2.5}$ concentrations and relative humidity (HR%) in February and July.

TABLE IV: HOURLY MONTHLY AVERAGE VALUES OF THE VARIABILITIES

Mean-SD	Mean	Mean+SD	Mean-SD	Mean	Mean+SD
	PM_{10} µg/m^3			$PM_{2.5}$ µg/m^3	
		February			
		Central area (SBJ)			
30.56±8.48	48.78±10.08	66.99±12.28	8.71±2.59	14.54±3.12	20.38±4.06
		Northern Area			
		PPD			
60.85±14.21	125.14±32.30	189.43±51.57	13.74±2.98	28.39±5.06	43.05±7.43
		CRB			
41.30±11.94	84.02±19.35	126.74±27.57	11.04±3.70	20.60±4.36	30.15±6.17
		SMP			
26.47±5.45	39.40±8.66	52.33±12.82	7.54±1.64	12.53±2.37	17.51±3.70
		Eastern Area (SJL)			
51.51±8.82	73.40±10.45	95.28±13.29	13.40±3.95	22.03±4.37	30.67±5.43
		July			
		Central area (SBJ)			
28.38±6.67	48.13±8.32	68.25±10.90	8.81±1.62	19.34±3.72	29.87±7.34
		Northern Area			
		PPD			
66.68±19.33	102.13±18.02	137.58±17.82	25.16±2.79	38.22±4.16	51.28±6.36
		CRB			
54.00±15.51	80.16±14.70	106.32±15.02	15.10±4.67	31.53±7.46	47.97±11.69
		SMP			
26.96±5.57	45.46±6.97	63.97±9.27	8.69±1.51	18.72±3.35	28.75±5.98
		Eastern Area (SJL)			
52.95±14.70	87.28±9.53	121.62±8.45	18.57±3.52	34.09±4.88	49.61±8.34

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 1:00 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 SJL 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 (SJL 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.Zaldivar, and O.R.Sánchez wrote the article. W.Reátegui, S.Pacsi, A.E.García 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.

References

[1] C. Posada, “Aumento continuo del parque automotor, un problema que urge solucionar,” *Comercio Exterior Magazine*, pp. 1-3, 2018.

[2] A. Kamruzzaman, A. Nayeem, N. Ahmmed, and W. Carter, “Temporal variation of ambient particulate matter in Chattogram city, Bangladesh,” *Journal of Air Pollution and Health*, vol. 5, pp. 33-42, 2020.

[3] F. Rahimi, “Study of the effect of fuel consumption and geographic conditions on Tehran’s air pollution,” *Journal of Air Pollution and Health*, vol. 5, pp. 71-88, 2020.

[4] T. Ngoc, D. Park, Y. Lee, and L. Young, “Particulate matter (PM10 and PM2.5) in subway systems: Health-based economic assessment,” *Sustainability*, vol. 9, pp. 1-17, 2017.

[5] X. Yu, X. Yue, S. Min, and L. Yi, “The impact of PM2.5 on the human respiratory system,” *Journal of Thoracic Desease*, vol. 8, pp. E69–E74, 2016.

[6] TheWorldBankGroup, “Project guidelines: Pollutants,” *Pollution Prevention and Abatement Handbook*, pp. 179–440, 1998.

[7] WHO, “Ambient (outdoor) air pollution,” WHO, Geneva, 2018.

[8] EPA, “Review of the primary national ambient air quality standards for sulfur oxides,” EPA, Washington, DC, 2019.

[9] EPA, “Review of the primary national ambient air quality standards for oxides of nitrogen,” EPA, Washington, DC., 2018.

[10] N. Rivers, S. Saberian, and B. Schaufele, “Public transit and air pollution,” *Social Science Research Network (SSRN) Electronic Journal*, vol. 9, pp. 1-41, 2017.

[11] C. Dora and M. Phillip, “Transport, environmentand health-WHO regional publications, European series, No. 89,” World Health Organization (WHO), Austria, 2000.

[12] I. Hossan, V. Vamsi, H. Du, R. Rao, and Z. Huque, “Air quality impact of biomass co-firing with coal at a power plant in the greater houston area,” *Open Journal of Air Pollution*, vol. 7, pp. 263-285, 2018.

[13] B. Sharma, *Environmental Chemistry*, Delhi: Krishna Prakashan Media, 2007.

[14] B. Gurjar, L. Molina, and C. Ojha, *Air Pollution: Health and Environmental Impacts*, Boca Raton: CRC Press, 2010.

[15] WHO, “Health and sustainable development: Air pollution,” 2014.

[16] A. Ghorani, B. Riahi, and M. Balali, “Effects of air pollution on human health and practical measures for prevention in Iran,” *Journal of Research In Medical Science*, vol. 21, pp. 1-36, 2016.

[17] R. Saunders and D. Waught, “Variability and potential sources of summer PM2.5 in the Northeastern United States,” *Atmodpheric Environment*, vol. 117, pp. 259-270, 2015.

[18] A. Nascimento, M. SantosI, J. Mill, J. Bottoni, N. Costa, and V. Anselmo, “Association between the concentration of fine particles in the atmosphere and acute respiratory diseases in children,” *Revista de Saúde Pública*, vol. 51, pp. 1-10, 2017.

[19] ASSA, BAS, GNASL, USNAM, and USNAS, “Air pollution and health — A science-policy initiative,” *Annals of Global Health*, vol. 85, pp. 1-9, 2019.

[20] X. Xu, J. Zhang, X. Yang, Y. Zhang, and Z. Chen, “The role and potential pathogenic mechanism of particulate matter in childhood asthma: A review and perspective,” *Journal of Immunology Research*, vol. 2020, pp. 1-8, 2020.

[21] C. Pope III and D. Dockery, “Health effects of fine particulate air pollution: Lines that connect,” *Journal of the Air & Waste Management Association*, vol. 56, p. 709–742, 2006.

[22] D. Schraufnage, J. Balmes, C. Cowl, S. Matteis, H. Soon, K. Mortimer, R. Perez, M. Rice, H. Riojas, A. Sood, G. Thurston, T. To, A. Vanker, and D. Wuebbles, “Air pollution and noncommunicable diseases a review by the forum of international respiratory societies’ environmental committee, Part 1: The damaging effects of air pollution,” *CHEST*, vol. 155, pp. 409-416, 2019.

[23] J. Wang and S. Ogawa, “Effects of meteorological conditions on PM2.5 concentrations in Nagasaki, Japan,” *International Journal of Environmental Research and Public Health*, vol. 12, pp. 9089-9101, 2015.

[24] M. Pohjola, A. Kousa, J. Kukkonen, J. Härkönen, A. Karppinen, P. Aarnio, and T. Koskentalo, “The spatial and temporal variation of measured urban PM10 and PM2.5 in the helsinki metropolitan,” *Water, Air and Soil Pollution*, vol. 2, pp. 189–201, 2002.

[25] A. Tai, J. Loretta, and J. Daniel, “Correlations between fine particulate matter (PM2.5) and meteorological variables in the United States: Implications for the sensitivity of PM2.5 to climate change,” *Atmospheric Environment*, vol. 44, pp. 3976–3984, 2010.

[26] J. Radaideh, “Effect of meteorological variables on air pollutants variation in arid climates,” *Journal of Environmental & Analytical Toxicology*, vol. 7, pp. 1-12, 2017.

[27] A. Gorai, F. Tuluri, P. Tchounwou, and S. Ambinakudige, “Influence of local meteorology and NO2 conditions on ground-level ozone concentrations in the eastern part of Texas, USA,” *Air Quality, Atmosphere and Health*, vol. 8, pp. 81-96, 2015.

[28] C. Shouquan, M. Campbell, Q. Li, G. Li, H. Auld, N. Day, D. Pengelly, S. Gingrich, and D. Yap, “A synoptic climatological approach to assess climatic impact on air quality in South-Central Canada. Part II: Future estimates,” *Water, Air, and Soil Pollution*, vol. 182, pp. 117-130, 2007.

[29] HEI, “State of global air 2019 — A special report on global exposure to air pollution and its disease burden,” *Health Effects Institute (HEI)*, Boston, MA., 2019.

[30] WHO, “WHO air quality guideline values-particulate matter (PM),” 2005.

[31] WHO, “Air quality guidelines global update 2005: Particulate matter, ozone, nitrogen dioxide and sulfur dioxide. Copenhagen: WHO Regional Office for Europe,” Copenhagen, 2006.

[32] M. Franklin, P. Koutrakis, and P. Schwartz, “The role of particle composition on the association between PM2.5 and mortality,” *Epidemiology*, vol. 19, pp. 680-689, 2008.

[33] J. Schwartz, "Harvesting and long term exposure effects in the relation between air pollution and mortality," *American Journal of Epidemiology*, vol. 151, pp. 440-8, 2000.

[34] R. E. Morabet, "Effects of outdoor air pollution on human health," *Encyclopedia of Environmental Health (Second Edition)*, Michigan, United States., Elsevier, 2019, pp. 278-286.

[35] UN, "The world's cities in 2018," United Nations (UN), 2018.

[36] D. Morata, M. Polvé, A. Valdés, M. Belmar, M. Dinator, M. Silva, M. Leiva, T. Aigouy, and J. Morales, "Characterisation of aerosol from Santiago, Chile: An integrated PIXE–SEM–EDX study," *Environmental Geology International Journal of Geosciences*, vol. 56, pp. 81–95, 2008.

[37] C. Chan and Y. Liu, "Air pollution in mega cities en China," *Atmospheric Environmental*, vol. 42, pp. 1-42, 2008.

[38] WHO, "Health, environment, and sustainable development — Health as the pulse of the New Urban Agenda-United Nations conference on housing and sustainable urban development. Quito-Ecuador. Urban Development: Quito-Ecuador.," 2016.

[39] WHO, "Air pollution levels rising in many of the world's poorest cities: Geneva," 2016.

[40] K. Remoundou and P. Koundouri, "Environmental effects on public health: An economic perspective," *International Journal of Environmental Research and Public Health*, vol. 6, pp. 2160-2178, 2009.

[41] A. Singh, W. Bloss, and F. Pope, "60 years of UK visibility measurements: Impact of meteorology and atmospheric pollutants on visibility," *Atmospheric Chemistry and Physics*, vol. 17, pp. 2085–2101, 2017.

[42] W. Wang, "Progress in the impact of polluted meteorological conditions on the incidence of asthma," *Journal of Thoracic Disease*, vol. 8, pp. E57-E61, 2016.

[43] I. Barmpadimos, J. Keller, D. Oderbolz, C. Hueglin, and A. Prévot, "One decade of parallel fine (PM2.5) and coarse (PM10–PM2.5) particulate matter measurements in Europe: Trends and variability," *Atmospheric Chemistry and Physics*, vol. 12, pp. 3189–3203, 2012.

[44] M. Leiva, D. Santibañez, S. Ibarra, and P. S. R. Matus, "A five-year study of particulate matter (PM2.5) and cerebrovascular deseases," *Environmental Pollution*, vol. 181, pp. 1-6, 2013.

[45] M. Zeller, M. R. C. Giroud, I. Benatru, J. Besancenot, L. Rochette, and Y. Cottin, "Air pollution and cardiovascular and cerebrovascular disease — Epidemiologic data," *Presse Med.*, vol. 35, pp. 1517-1522., 2006.

[46] C. Chan, K. Chuang, L. Chien, W. Chen, and W. Chang, "Urban air pollution and emergency admissions for cerebrovascular diseases in Taipei, Taiwan.," *European Heart Journal*, vol. 27, pp. 1238-1244, 2006.

[47] W. Chit, R. Atkinson, H. Anderson, A. Hedley, S. Ma, P. Yuen, and T. Lam, "A tale of two cities: Effects of air pollution on hospital admissions in Hong Kong and London compared," *Environmental Health Perspectives*, vol. 110, pp. 67-77, 2002.

[48] J. Byeong, B. Kim, and K. Lee, "Air pollution exposure and cardiovascular disease," *Toxicologycal Research*, vol. 30, pp. 71-75, 2014.

[49] B. Chen and H. Kan, "Air pollution and population health: a global challenge," *Environmental Health and Preventive Medicine*, vol. 13, pp. 94–101, 2008.

[50] S. Ramachandra, "Resource recovery and recycling from metallurgical wastes," First ed., Ontario, Elsevier, 2006, p. 557.

[51] R. Lee and D. J. Lehmden, "Trace metal pollution in the environment," *Journal of the Air Pollution Control Association*, vol. 23, pp. 853-857, 1973.

[52] P. Kumar, I. Rivas, A. Pratap, V. Ganesh, M. Ananya, and H. Frey, "Dynamics of coarse and fine particle exposure in transport microenvironments," *Climate and Atmospheric Science*, vol. 1, pp. 1-12, 2018.

[53] A. Taiwo, D. Beddows, Z. Shi, and R. Harrison, "Mass and number size distributions of particulate matter components: Comparison of an industrial site and an urban background site," *Science of the Total Environment*, vol. 475, pp. 29-38, 2014.

[54] J. Seinfeld and S. Pandis, *Atmospheric Chemistry and Physics from Air Pollution to Climate Change*, Hoboken, New Jersey: Jhon Wiley & Sons, INC., 2006.

[55] M. Jacobson, *Atmospheric Pollution, History Science and Regulation*, New York: Cambridge University Press, 2002.

[56] V. Tapia, K. Steenland, S. Sarnat, B. Vu, Y. Liu, O. Sánchez, V. Vasquez, and G. Gonzales, "Time-series analysis of ambient PM2.5 and cardiorespiratory emergency room visits in Lima, Peru during 2010–2016," *Journal of Exposure Science & Environmental Epidemiology*, vol. 30, pp. 680–688, 2019.

[57] O. Sanchéz-Ccoyllo, C. Ordóñez, J. Ibarra, and R. Aliaga, "Evaluación de la calidad del aire en lima metropolitanA, 2013. Lima:SENAMHI," Dirección de Proyectos de Desarrollo y Medio Ambiente de la Dirección General de Investigación y Asuntos Ambientales del Servicio Nacional de Meteorología e Hidrología del Perú (Senamhi), Lima, 2015.

[58] O. Sánchez-Ccoyllo, C. Ordoñez, A. Muñoz, A. Llacza, M. L. Y. Andrade, W. Reátegui, and G. Brasseur, "Modeling study of the particulate matter in Lima with the WRF-Chem model: Case study of April 2016," *International Journal of Applied Engineering Research*, vol. 13, pp. 10129-10141, 2018.

[59] MTC, "Estimated National Vehicle Park, according to Department: 2007–2016. Lima Peru," 2016.

[60] L. Dawidowski, O. Sánchez-Ccoyllo, and N. Alarcón, "Estimation of vehicular emissions in Metropolitan Lima. Final report (in Spanish). Lima, Peru: Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI). Report within the framework of the project South American Emissions, Megacities and Climate," 2014.

[61] J. Silva, J. Rojas, M. Norabuena, C. Molina, and R. Toro, "Particulate matter levels in a South American megacity:the metropolitan area of Lima-Callao, Peru," *Environmental Monitoring and Assessment*, vol. 189, pp. 1-18, 2017.

[62] L. Carbajal, A. Barraza, R. Durand, H. Moreno, R. Espinoza, P. Chiarella, and I. Romieu, "Impact of traffic flow on the asthma prevalence among school children in Lima, Peru," *The Journal of Asthma*, vol. 44, pp. 197–202, 2007.

[63] L. Underhill, S. Bose, D. Williams, K. Romero, G. Malpartida, P. Breysse, E. Klasen, J. Combe, W. Checkley, and N. Hansel, "Association of roadway proximity with indoor air pollution in a peri-urban community in Lima, Peru," *International Journal of Environmental Research and Public Health*, vol. 12, p. 13466–13481, 2015.

[64] L. Qian, L. Wang, Z. Liu, and A. Heber, "Field evaluation of particulate matter measurements using tapered element oscillanting microbalance in a layer house," *Journal of the Air & Waste Management Association*, vol. 62, pp. 322-335, 2012.

[65] M. Viana and C. Hueglin, "Description of automated technologies for air pollutants and air quality metrics," *Air Pollution Monitoring Technologies for Urban Areas*, 2012.

[66] L. Chun, A. Awasthi, H. Yi, B. Gugamsetty, T. Chuen, W. Yueh, and C. Chung, "Differences in 24- h average PM2.5 concentrations between the beta attenuattion monitor (BAM) and the dichotomous sampler (Dichot)," *Atmospheric Environment*, vol. 75, pp. 341-347, 2013.

[67] P. Salomon and C. Sioutas, "Continuous and semicontinuous monitoring techniques for particulate matter mass and chemical components: A synthesis of findings from EPA´s particulate matter supersites program and related studies," *Journal of the Air & Waste Management Association*, vol. 58, pp. 164-195, 2008.

[68] S. Hamed, M. Birjandi, M. Reza, and A. Fatehizadeh, "Analysis of Particulate matter (PM10 and PM2.5) concentration in Khorramabad city," *International Journal of Environmental Health Engineering*, vol. 1, pp. 1-4, 2012.

[69] X. Qiu, L. Duan, J. Gao, S. Wang, F. Chai, J. Hu, J. Zhang, and Y. Yun, "Chemical composition and source apportionment of PM10 and PM2.5 in different functional areas of Lanzhou ,China," *Journal of Environmental Sciences*, vol. 40, pp. 75-83, 2016.

[70] M. Werner, M. Kryza, H. Ojrzyńska, C. W. K. Skjøth, and A. Dore, "Application of WRF-Chem to forecasting PM10 concentration over Poland," *International Journal of Environment and Pollution*, vol. 58, pp. 280-292, 2015.

[71] M. Hafizur, V. Sharma, S. Kundu, and A. Datta, "Seasonal variation of potential source locations of atmospheric particulates over the Indo-Gangetic plain of India," *Open Journal of Air Pollution*, vol. 9, pp. 1-10, 2020.

[72] O. Sanchéz-Ccoyllo and C. Ordóñez, "Evaluación de la Calidad del Aire en Lima Metropolitana, 2015," SENAMHI (Dirección de Meteorología y Evaluación Ambiental Atmosférica), Lima, Perú, 2016.

[73] S. Wekker, M. Kossmann, J. Knievel, L. Giovannini, E. Gutmann, and D. Zardi, "Meteorological applications benefiting from an improved understanding of atmospheric exchange processes over mountains," *Atmosphere*, vol. 9, pp. 1-23, 2018.

[74] S. Zeng and Y. Zhang, "The effect of meteorological elements on continuing heavy air pollution: A case study in the Chengdu area during the 2014 spring festival," *Atmosphere*, vol. 8, pp. 1-17, 2017.

[75] O. Sánchez-Ccoyllo and C. Ordóñez, "Evaluación de la calidad del aire en Lima Metropolitana 2015. Lima: SENAMHI," Dirección General de

Investigación y Asuntos Ambientales del Servicio Nacional de Meteorología e Hidrología del Perú (SENAMHI), LIMA, 2016.
[76] T. Olszowski, "Influence of individual household heating on PM2.5 concentration in a rural settlement," *Atmosphere*, vol. 10, pp. 1-14, 2019.
[77] L. Hakan, P. Suren, O. Alagha, F. Karaca, and G. Tuncel, "Effect of meteorological parameters on fine and coarse particulate matter mass concentration in a coal-mining area in Zonguldak, Turkey," *Journal of the Air & Waste Management Association*, vol. 58, pp. 543–552, 2008.
[78] N. Galindo, M. Varea, J. Gil, E. Yubero, and J. Nicolás, "The influence of meteorology on particulate matter concentrations at an urban mediterranean location," *Water Air Soil Pollution*, vol. 215, pp. 365–372, 2011.
[79] Q. Yin, J. Wang, M. Hu, and H. Wong, "Estimation of daily PM2.5 concentration and its relationship with meteorological conditions in Beijing," *Journal of Environmental Sciences*, vol. 48, pp. 161–168, 2016.
[80] S. Pacsi, "Spatial and temporal analysis of the air quality determined by particulate matter PM_{10} and $PM_{2.5}$ in metropolitan Lima," *Anales Científicos*, vol. 77, pp. 273-283, 2016.
[81] D. Li, J. Liu, J. Zhang, H. Gui, P. Du, T. Yu, J. Wang, Y. Lu, and Y. Cheng, "Identification of long-range transport pathways and potential sources of $PM_{2.5}$ and PM_{10} in Beijing from 2014 to 2015," *Journal of Environmental Sciences*, vol. 56, pp. 1-16, 2016.
[82] M. Koçak, C. Theodosi, P. Zarmpas, U. Im, A. Bougiatioti, O. Yenigun, and N. Mihalopoulos, "Particulate matter (PM_{10}) in Istanbul: Origin, source areas and potential impact on surrounding regions," *Atmospheric Environment*, vol. 45, pp. 6891- 6900, 2011.
[83] A. Balzarini, G. Pirovano, L. Honzak, R. Zabkar, G. Curci, R. Forkel, M. Hirtl, R. S. José, P. Tuccella, and G. Grell, "WRF-Chem model sensitivity to chemical mechanisms choice in reconstructing aerosol optical properties," *Atmospheric Environment*, vol. 115, pp. 604-619, 2015.
[84] J. Gu, Z. Bai, A. Liu, Y. Xie, W. li, H. Dong, and X. Zhang, "Characterization of atmospheric organic carbon and element carbon of $PM_{2.5}$ and PM_{10} at Tianjin, China," *Aerosol and Air Quality Research*, vol. 10, pp. 167–176, 2010.
[85] G. Hernandez, B. Terri, S. Wallis, and D. Poyner, "Temperature and humidity effects on particulate matter concentrations in a sub-tropical climate during winter," *International Proceedings of Chemical, Biological and Environmental Engineering*, vol. 102, pp. 41-49, 2017.
[86] C. González, J. Cortés, and B. Aristizábal, "Influence of meteorology and source variation on airborne PM Andean city," *Revista Facultad de Ingeniería Universidad de Antioquia*, no. 74, pp. 200-212, 2015.
[87] C. Hogrefe, G. Pouliot, D. Wong, A. Torian, S. Roselle, J. Pleim, and R. Mathur, "Annual application and evaluation of the online coupled WRF-CMAQ system over North American under AQMEII phase 2," *Atmospheric Environment*, vol. 115, pp. 683-694, 2015.
[88] S. Oji and H. Adamu, "Correlation between air pollutants concentration and meteorological factors on seasonal air quality variation," *Journal of Air Pollution and Health*, vol. 5, pp. 11-32, 2020.
[89] L. Chestnut, J. Schwartz, D. Savitz, and C. Burchfiel, "Pulmonary function and ambient particulate matter: Epidemiological evidence from NHANES I," *Archives of Environmental Health: An International Journal*, vol. 46, pp. 135-144, 1991.
[90] M. Bobak and D. Leon, "Air pollution and infant mortality in the Czech Republic, 1986-88," *Tha Lancet Epidemiology*, vol. 340, pp. 1010-1014, 1992.
[91] I. Bos, L. Jacobs *et al.*, "No exercise-induced increase in serum BDNF after cycling near a major traffic road," *Neuroscience Letters*, vol. 500, pp. 129-132, 2011.
[92] A. Sharma, K. Ki, A. Ji, S. Zang, S. Jong, L. Jin, M. Chang, and R. Brown, "Ambient particulate matter (PM_{10}) concentrations in major urban areas of Korea during 1996–2010," *Atmospheric Pollution Research*, vol. 5, pp. 161-169, 2014.
[93] N. Mölders and G. Kramm, *Springer Atmospheric Sciences: Lectures in Meteorology*, Springer International Publishing Switzerland, 2014.
[94] P. Houngbégnon, G. Ayivi-Vinz, H. Lawin, K. Houessionon, F. Tanimomon, M. Kêdoté, M. Fayomi, S. Dossou-gbété, and A. Agueh, "Exposure to $PM_{2.5}$ related to road traffic: comparison between crossroads and outside of crossroads at Cotonou, Benin," *Open Journal of Air Pollution*, vol. 4, pp. 108-117, 2019.
[95] L. Yang, W. Ye, M. Jerry, and J. Hao, "Estimating the effects of meteorology on PM2.5 reduction during the 2008 summer Olympic games in Beijing, China," *Frontiers of Environmental Science & Engineering*, vol. 5, pp. 331–341, 2011.
[96] S. Ocak and F. Turalioglu, "Effect of meteorology on the atmospheric concentrations of traffic-related pollutants in Erzurum, Turkey," *Journal of International Environmental Application & Science*, vol. 3, pp. 325-335, 2008.
[97] J. Wallace and P. Hobbs, *International Geophysics Series: Atmospheric Science An Introductory Survey Second Edition*, Canada: Academic Press, 2006.
[98] E. Wise and A. Comrie, "Meteorologically adjusted urban air quality trends in the Southwestern United States," *Atmospheric Environment*, vol. 39, pp. 2969-2980, 2005.
[99] R. Goverdhan, T. Sankarappa, J. Ashwajeet, and R. Ramanna, "Effect of temperature, humidity and other physical pollution in and around Belagavi, Karnataka, India," *International Research Journal of Environment Scie*, vol. 4, pp. 55-62, 2015.
[100] L. Zhang, Y. Cheng, Y. Zhang, Y. He, Z. Gu, and C. Yu, "Impact of air humidity fluctuation on the rise of PM mass concentration based on the high-resolution monitoring data," *Aerosol and Air Quality Research*, vol. 17, pp. 543–552, 2016a.
[101] L. Zhang, Z. Gu, Y. C. Y. Zhang, and Y. and Cheng, "Surface charges on aerosol particles–Accelerating particle growth rate and atmospheric pollution," *Indoor and Built Environment*, no. 25, pp. 437–440, 2016.
[102] S. Tian, Y. Pan, Z. Liu, T. Wen, and Y. Wang, "Size-resolved aerosol chemical analysis of extreme haze pollution events during early 2013 in urban Beijing, China," *Journal of Hazardous Materials*, vol. 279, pp. 452–460, 2014.
[103] B. Blanco, R. Gáfaro, and R. Rojas, "Influence of precipitation scavenging on the $PM_{2.5}/PM_{10}$ ratio at the Kennedy locality of Bogotá Colombia," *Revista Facultad de Ingeniería, Universidad de Antioquia*, vol. 76, pp. 58-65, 2015.
[104] D. Giri, V. Krishna, and P. Adhikary, "The influence of meteorological conditions on PM10 concentrations in Kathmandu Valley," *International Journal of Environmental Research*, vol. 2, pp. 49-60, 2008.
[105] C. Lou, H. Liu, Y. Li, Y. Peng, J. Wang, and L. Dai, "Relationships of relative humidity with $PM_{2.5}$ and PM_{10} in the Yangtze River delta, China.," *Environmental Monitoring and Assessment*, vol. 189, pp. 1-16, 2017.
[106] K. Slezakova, D. Castro, D. Delerue, M. Alvim, S. Morais, "Impact of vehicular traffic emissions on particulate-bound PAHs: Levels and associated health risks," *Atmospheric Research*, vol. 127, pp. 1-7, 2012.
[107] F. Cassee, H. Marie, M. Gerlofs, and F. Kelly, "Particulate matter beyond mass: Recent health evidence on the role of fractions, chemical constituents and sources of emission," *Inhalation Toxicology*, vol. 25, no. 14, pp. 802–812, 2013.
[108] S. Avdakovic, M. Muftic, N. Dautbasic, and J. Dizdarevic, "The influence of wind speed, humidity, temperature and air pressure on pollutants concentrations of PM10 – Sarajevo case study using wavelet coherence approach," presented at XI International Symposium on Telecommunications (BIHTEL), Sarajevo, Bosnia and Herzegovina, 2016.

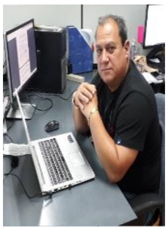
Warren Reátegui- Romero received the bachelor degree in chemical engineering and a master's degree both from National University of Engineering (UNI) in 1989 and 2011 respectively, and a Ph.D in engineering and environmental science from the National Agrarian University La Molina (UNALM), Peru in 2018. He is a principal professor in the Faculty of Chemical Engineering and Textile (FIQT-UNI, Peru). He has approximately 20 publications in Spanish and English, related to air quality and effluent treatment. W. Reátegui's primary scientific interests are questions related to urban and industrial air pollution and atmospheric chemistry. He also works as a consultant in atmospheric pollution and industrial effluent treatment.

Walter F. Zaldivar-Alvarez is a principal professor in the Faculty of Chemical Engineering and Textile (FIQT) at the National University of Engineering (UNI). He received the BS in chemical engineering from National University of Engineering (UNI) of Lima Peru, and a master's degree in science with mention in chemical engineering from Université Laval – Canada. He is a candidate for a doctor of environment and development. He was the dean of the Faculty of Chemical and Textile Engineering (FIQT-UNI) twice, and Vice-rector of the National University of Engineering (UNI).

Sergio Pacsi-Valdivia is a meteorologist engineer by the La Molina National Agrarian University (UNALM) of Lima-Peru and received a Ph.D. degree in geography at the Russian State Hydrometeorological Institute. Currently is a principal professor in the Science Faculty, Environmental Engineering Department of the UNALM. He is specialist and consultant in atmospheric pollution, global atmospheric processes and environmental management systems. He is the author and co-author of 15 scientific publications in peer-reviewed journals.

Odón R. Sánchez-Ccoyllo is principal professor in the School of Environmental Engineering at the National Technological University of South Lima (Universidad Nacional Tecnológica de Lima Sur- UNTELS). He received the BS in meteorology and engineering in Meteorology from National Agrarian University La Molina. a master's degree in meteorology from the University of São Paulo (1998) and a PhD in meteorology from the University of São Paulo (2002). Sánchez-Ccoyllo's primary scientific interests are questions related to climate change, receptor modeling, urban air pollution and numerical model of air quality. He has authored or co-authored approximately 24 publications in the peer-reviewed literature.

Alberto E. García-Rivero, is a Principal Professor in the School of Geography at San Marcos National University (Universidad Nacional Mayor de San Marcos, Lima, Perú) and invited Professor of other Latin-American universities. He received his degree in Geography from Havana University, Cuba. A Master's degree in Education from the EUCIM Busines of Madrid, Spain and a Ph.D. in Geophysics from the Cuban Academy of Sciences (1995). Garcia-Rivero primary scientific interests are questions related to integrated management of water resources, disaster risk management, geoecology, tourism and air quality. He has authored or co-authored approximately 20 publications in the peer-reviewed literature.



Aldo Moya-Alvarez is graduated from the Odessa Hydrometeorological Institute as meteorological engineer. He has 23 years of experience in the branch of meteorology dedicated to the prediction of weather and meteorological phenomena that cause disasters, such as heavy rains and strong winds. Doctorate in Meteorological Sciences, I have developed multiple works of investigation, most of them with applied character, cocretely of numerical modeling of forecasts of atmospheric variables and climate, as well as of air quality. The results of these investigations have been published in journals indexed in different databases and on the website: www.cmp.vcl.cu. Among the results of the investigations is a book, dedicated to the psychrometric tables used in the network of stations of the meteorological service of Cuba to measure the characteristics of the humidity of the air. He is currently a researcher at the Geophysical Institute of Peru in atmospheric modeling.