Analysis Of The Particulate Matter Concentrations PM2.5 And The Weather Variables Of Precipitation And Temperature In The Dry Period (2018) And Rainy Period (2019) In The Universidad Libre- Bogotá Campus

Análisis de las concentraciones de particulas PM2.5 y las variables climáticas de precipitación y temperatura en el período seco (2018) y período de lluvias (2019) en el campus Universidad Libre- Bogotá

Análise da concentração de partículas PM 2.5 e das variáveis climáticas de precipitação e temperatura no período seco (2018) e período de chuvas (2019) no campus Universidad Libre - Bogotá

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Received: December 05th, 2020
Accepted: February 25th, 2021
Available: May 05th, 2021

How to cite this article:
F. Acosta Nieto, A. S. Altamar Consuegra, J. A. Aragón Moreno, “Analysis of The Particulate Matter Concentrations PM2.5 And The Weather Variables Of Precipitation and Temperature in The Dry Period (2018) and Rainy Period (2019) In The Universidad Libre- Bogotá Campus,” *Revista Ingeniería Solidaria*, vol. 17, no. 2, 2021.
doi: https://doi.org/10.16925/2357-6014.2021.02.10

Research article. https://doi.org/10.16925/2357-6014.2021.02.10

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Abstract

Introduction: This paper is the outcome of the research on the determination of the concentration of particulate matter $PM_{2.5}$, estimating the influence of temperature and precipitation, developed at the Universidad Libre, at the Bogotá campus during the years 2018-2019.

Problem: [$PM_{2,5}$] concentration near the University, Bosque Popular campus has increased in recent years, influenced by mobile sources, in spite of the green zones.

Objective: To determine the relationship of the particulate matter with the Precipitation and Temperature as meteorological variables, and the influence of the contributing sources of $PM_{2.5}$ in the studied area.

Methodology: For the determination of [$PM_{2.5}$] a WilBur model low volume sampler was used. The meteorological data were obtained from the Bogotá Air Quality Monitoring Network of the Secretariat of the Environment. Software such as ArcGis, WRPLOT and MiniTab were used for the graphical representation of the results.

Results: The average [$PM_{2.5}$] for the dry and wet season were 9.03 and 19.22 μm/m^3. For the meteorological variables, a precipitation of 40.4 and 373.6mm, and temperature of 14.3 and 15.32°C, respectively, were obtained.

Conclusion: There is a low relationship between meteorological variables and [$PM_{2.5}$] in both monitoring seasons, however, the concentration performance is similar to that found in the references.

Originality: $PM_{2.5}$ sampling in both seasons within the Universidad Libre, cataloged as a background area.

Limitations: The monitoring time was during the months of July and August for the year 2018 and March to May in the year 2019.

Keywords: Air pollution, particulate matter, precipitation, temperature, mobile sources and stationary sources.

Resumen

Introducción: El artículo es producto de la investigación de la determinación de la concentración de material particulado $PM_{2.5}$, estimando la influencia de la temperatura y precipitación, desarrollada en la Universidad Libre, Sede Bogotá entre los años 2018-2019.

Problema: Las [$PM_{2,5}$] en cercanías a la Universidad Libre sede Bosque Popular han incrementado en los últimos años debido a la influencia de fuentes móviles, a pesar de haber presencia de arborización.

Objetivo: Determinar la relación del Material particulado con las variables meteorológicas Precipitación y Temperatura, y la influencia de las fuentes aportantes de $PM_{2.5}$ en la zona estudiada.

Metodología: Para la determinación de [$PM_{2.5}$] se utilizó un muestreador de bajo volumen modelo WilBur, los datos meteorológicos se obtuvieron de la Red de monitoreo de Calidad del Aire de Bogotá de la Secretaria de Ambiente. Se utilizó Softwares como ArcGis, WRPLOT y MiniTab para la representación gráfica de los resultados.

Resultados: El promedio de [$PM_{2,5}$] para temporada seca y húmeda fue de 9,03 y 19,22μg/m^3. Para las variables meteorológicas se obtuvo una precipitación de 40,4 y 373,6 mm, temperatura de 14,3 y 15,32°C, respectivamente.

Conclusión: Existe una relación baja entre variables meteorológicas y [$PM_{2.5}$] en ambas temporadas de monitoreo, sin embargo, se presenta un comportamiento de concentraciones similar a lo encontrado en bibliografía.

Originalidad: Muestreo de $PM_{2,5}$ en ambas temporadas dentro de la Universidad Libre, catalogada como zona de fondo.

Limitaciones: El tiempo de monitoreo en el año 2018 fue en los meses de julio y agosto y el año 2019 de marzo a mayo.

Palabras clave: Contaminación atmosférica, material particulado, precipitación, temperatura, fuentes móviles y fuentes fijas.

Resumo

Introdução: Este artigo é o resultado da pesquisa sobre a determinação da concentração do material particulado PM2.5, estimando a influência da temperatura e da precipitação, desenvolvida na Universidad Libre, no campus de Bogotá, durante os anos 2018-2019.

Problema: a concentração de [PM2,5] próximo à Universidade, campus do Bosque Popular aumentou nos últimos anos, influenciada por fontes móveis, apesar das zonas verdes.

Objetivo: Determinar a relação do material particulado com a Precipitação e Temperatura como variáveis meteorológicas, e a influência das fontes contribuintes de PM2,5 na área estudada.

Metodologia: Para a determinação de [PM2.5] um amostrador de baixo volume modelo WilBur foi usado. Os dados meteorológicos foram obtidos da Rede de Monitoramento da Qualidade do Ar de Bogotá da Secretaria do Meio Ambiente. Softwares como ArcGis, WRPLOT e MiniTab foram usados para a representação gráfica dos resultados.

Resultados: A média [PM2,5] para a estação seca e chuvosa foi de 9,03 e 19,22 μm / m3. Para as variáveis meteorológicas, obteve-se precipitação de 40,4 e 373,6 mm e temperatura de 14,3 e 15,32 ° C, respectivamente.

Conclusão: Há uma baixa relação entre as variáveis meteorológicas e o [PM2,5] nas duas estações de monitoramento, porém o desempenho da concentração é semelhante ao encontrado nas referências.

Originalidade: amostragem de PM2.5 em ambas as temporadas dentro da Universidad Libre, catalogada como área de fundo.

Limitações: O tempo de monitoramento foi durante os meses de julho e agosto do ano de 2018 e de março a maio do ano de 2019.

Palavras-chave: Poluição do ar, material particulado, precipitação, temperatura, fontes móveis e fontes estacionárias.

1. INTRODUCTION

Air pollution is one of the most worrying environmental problems around the world, as in most countries its energy source is based on oil derivatives used as fuel by the vehicle fleet. Industry in general, energy use in homes, forest fires and natural sources also contribute to air pollution [1], [2].

One of the main components of atmospheric pollution is known as particulate matter (PM), defined as a set of solid and liquid particles suspended in the atmosphere [3]. Its composition is very variable since it adds to the natural atmospheric composition (since the atmosphere is made out of gases, particles, and clouds), finding different substances, such as sulfates, nitrates, ammonia, carbon, sodium chloride and of course water, depending on the source of emission, affecting peoples' health differently [4].

The particulate matter can be divided into two groups according to the particle diameter; the coarse fraction, which refers to PM10, between a diameter range greater than 2.5 micrometers (μm) and less than 10 μm, and the fine fraction more often known as $PM_{2.5}$, with a particle diameter of less than 2.5 μm [5].

Most of the particulate matter comes from fixed and mobile sources, where the fixed ones refer to industry and the mobile ones consider all forms of urban transport. Figure 1 shows the local contribution, at local level, of mobile and stationary sources to pollution by particulate matter referenced in the National Council for Economic and Social Policy (CONPES 2018) in which 78% of the pollutants are the result of mobile sources; it is specified that diesel engine heavy-vehicles are the largest source of particulate matter, with these being responsible for 80% of particulate matter emissions. On the other hand, there is a contribution of particulate matter from fixed sources of 22%, divided into the main sectors for the city of Bogotá between brick kilns and boilers [6].

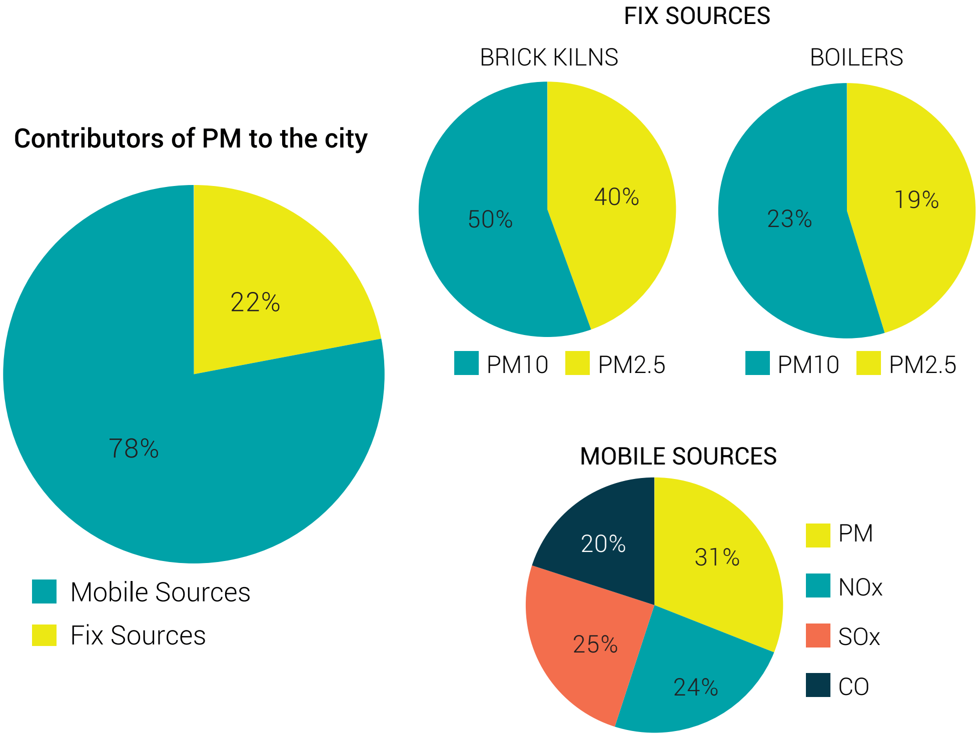

Figure 1. PM Percentage (%) locally contributed by mobile and fixed sources

Source : own work

Air quality of the City of Bogotá is in a state of constant deterioration, due to its fast economic growth, an increase in heavy-load vehicles and public transport, and in general manufacturing industries that use non-renewable energies on a daily basis, forced to burn fuel for their engines operation. For this reason, the concentrations of $PM_{2.5}$ increase as time goes by [7]; this increase in particulate matter undoubtedly generates an impact on people's health. Since this matter is very fine, it can easily enter the respiratory tract, generating cardiovascular and respiratory disorders and diseases such as cancer [8]. These effects have a significant impact on the population's life and on the country's economy, as ratified by the Ministry of Environment and Sustainable Development in 2019, referring to air pollution in Colombia as the third factor generating social costs after water contamination and natural disasters. These costs have been estimated as 1.5 trillion pesos annually and are related to effects on public health, mortality and morbidity [9].

The city of Bogotá has an Air Quality Monitoring Network (RMCAB for its acronym in Spanish), which is made up of 13 fixed monitoring stations and a mobile station, which are equipped with high-tech instruments that allow for constant monitoring of concentrations of particulate material (PM10, PM2.5, PST), of polluting gases (NO2, CO, 03, SO2) and data collection of temperatures, rainfall, wind speed and direction, relative humidity, among others [10], thus helping with the daily diagnose of air quality in Bogotá. It should be taken into account that by the end of the year 2020 [11], the Secretary of the Environment of Bogotá made valuable updates within the Air Quality Monitoring Network, implementing 7 new air quality stations operating at the end of January 2021 [12].

In this sense, between 2011 and 2015, the Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM) established in its report on the air quality status in Colombia that Bogotá monitoring stations (Kennedy and Carvajal neighborhoods), recorded the highest levels of average annual concentration of particulate matter (2.5 and 10 PM) in the entire country, during the 5 years monitored, exceeding concentrations of 100 μg / m^3, exceeding 32.32% of days with this type of excess [13]. According to the IDEAM report for the year 2019, air quality stations have increased considerably in the country in order to better diagnose the concentration of pollutants, asserting that since the 2011 report and the 2017 reports, Bogotá air quality stations (Kennedy Carvajal and Tunjuelito) have considerably improved their PM_{10} concentrations [14], [47]. This has been thanks to the governors and environmental authorities control over the car manufacturers in the capital and to the implementation of plans and programs to prevent, control and reduce athmospheric polution, along with the execution of cleaner production projects and the ending or suspension of emmiting sources by environmental authorities [6].

It is important to emphasize the relevance of meteorological variables in air quality, since in a study carried out in several Chinese cities, it is shown how $PM_{2.5}$ concentrations vary according to the season of the year [15], as well as the data taken within the campus of the Universidad Nacional Agraria La Molina, in Lima, Peru, where $PM_{2.5}$ concentrations are greater in winter compared to spring [16]. According to the above, the purpose of this research is to determine the relationship of the Particulate material ($PM_{2.5}$) with the meteorological variables (precipitation and temperature), taking into account that the main monitoring point is located in a background area within the facilities of Universidad Libre, Bosque Popular campus.

This particulate matter sampling was carried out during both the dry season and the rainy season. The dry season corresponds to the months of July and August of the year 2018 and the rainy season, during the months of March to May of the year 2019. The data of $PM_{2.5}$ concentrations from the RMCAB of the "Centro de Alto Rendimiento" station (CDAR) was used, as this station is closer to the main monitoring point (2.4 km).

1.1 Review of literature or research background

259 samples were taken in different Chinese cities between the years 2000 and 2011, showing mean values of $PM_{2.5}$ concentrations of 40.31 μg/m^3 for 2000, increasing this value by 54.57 μg/m^3 for 2011, which alarmingly exceeds the $PM_{2.5}$ annual standard given by the WHO, which shows the significance that China faces in the air quality issue [17].

The vehicle fleet is one of the main contributors to the air pollution, as with the case of Ho Chi Minh city, in Vietnam, where five monitoring points were installed, two of them on the roadside near the National University of Vietnam campus, another on the highly congested two-way street, while the remaining points were located in residential areas and background areas. These monitoring stations presented $PM_{2.5}$ concentrations exceeding both the air quality standards for Vietnam and the WHO standard, with concentrations of 39.1 μg/m^3 and 33.7 μg/m^3 for vehicular areas and 31.4 μg/m3, 41.1 μg/m^3 for the residential area and 35.4 μg/m^3 for background area [18].

In Dhaka, Bangladesh, which accounts for 10% of the nation's population due to the massive migration of people to improve their economic livelihood, a study was carried out in 12 points of the city, which considered the transport means on different categories of road located in Dhaka; these were as follows: mixed, non-motorized, and predominantly motorized with compressed natural gas vehicles. Maximum concentrations values were obtained at the different monitoring points, with close to 172.2 μg/m^3 in one of the largest intersections of four roads, and minimum values in Dash Street with 40 μg/m^3, a pedestrian street with no vehicles running; however, all the monitoring points exceeded the levels allowed by the WHO. It should be noted that some monitoring points located on roads exclusively for pedestrians were found within the Bangladesh Standard (65 µg/m^3) [19].

In Port Harcourt in Nigeria, where the commercial and economic activities grew over time, the increase in vehicles in the city, powered by fossil fuels, resulted in air quality degradation; so much so that in its four monitoring points, the $PM_{2.5}$ concentration levels exceeded the National Ambient Air Quality Standards (NAAQS) in an alarming and risky level for health, since the NAAQS is 35 µg/m^3, and its 4 monitoring stations recorded concentrations of 101.3 µg/m^3, 62.1 µg/m^3, 161.5 µg/m^3 and 117.8 µg/m^3 [20].

However, in Madrid, Spain, a study of atmospheric pollutants was carried out, among them $PM_{2.5}$, to evaluate how their concentration in the atmosphere was related to the daily mortality cases by respiratory disorders, reaching the conclusion that during the study monitoring time, the permissible WHO limit was exceeded in 23.9% of the days monitored, with concentrations between 5 µg/m^3 and 71 µg/m^3, with an average of 19.2 µg/m^3 , values for which mortality increased considerably [21].

In a study carried out in Los Angeles, California, U.S.A, in the Sepulveda vehicular tunnel, it was determined how the fuel type of the vehicles running through this tunnel had an impact on the pollutant type released into the atmosphere. That is the case of diesel-powered buses and trucks without particulate-traps, accounting for 52% of $PM_{2.5}$ emissions [22]. Similarly, a study carried out in Quito, Ecuador, showed that using the characteristics of local fuel and their respective partial mixtures of biofuel (B5, B10, B30) decreased particulate matter [23].

According to the World Health Organization (WHO) Guide, setting up the limit value for the mean PM_{10} concentration of 24 hours is 50 µg/ ^{3} [24], but in several countries such as Peru and Bolivia, this limit is exceeded. In particular in the Central Valley of Cochabamba, Bolivia, during the study performed in the winter season, the particulate matter levels increased so much that they clearly exceeded the WHO limit, indicating that these concentrations had a co-relation with the altitude of the monitoring point, which indicated that the higher temperature at the monitoring point (due to its low altitude), the better air quality was observed, compared to a higher altitude monitoring station [25]. Also, in Lima, Peru, where air was monitored in the winter season, during the months of July to November 2016, its concentrations exceeded the limit established by the WHO on all monitoring days, and in more than 41% of the daily concentrations obtained, the permissible limit value was doubled. This was the result of nearby emission sources, including the vehicle fleet and in general the meteorological conditions of the area [16].

Unlike the studies found in Bolivia and Peru, in the Colombian city of Bucaramanga, it was found that the relationship between temperature and particulate matter is directly proportional, that is, while higher temperatures prevailed, concentrations of particulate matter increased significantly, and inversely proportional for the variables of relative humidity, wind speed and solar radiation [26].

Meanwhile, in Riohacha the capital of La Guajira, Colombia, a desert area at sea level, a study revealed a different particulate matter because of its proximity to the sea made this pollutant to be made of calcium, magnesium, and sulfate, substances that come from natural sources such as marine aerosol, and of course other compounds related to vehicle traffic; Likewise, as in previous studies, it was determined that the concentrations exceed the national standard, Resolution 2254 of 2017, in the dry season and decrease in the rainy season [27].

2. MATERIALS AND METHODS

The project was executed in two main phases: 1) Measurement of particulate matter lower than 2.5 microns and 2) Comparison of particulate matter concentrations with the meteorological variables and their contributing sources.

2.1. Instruments and materials

For the accurate determination of particulate matter within the facilities of the Universidad Libre, a Wilbur model low volume environmental sampler was used for low flow PM $_{2.5}$ particulate matter with 16.7 L/min with US EPA approval [28], and being correctly calibrated. Additionally, micro quartz fiber filters were used to retain the particulate matter and filter holders containing quartz filter were used during their transportation to the laboratory. Desiccators were an instrumental part of the process, as they contained Silica Gel, a material whose purpose is to retain moisture and thus maintain the filters with the correct weight of material retained and a precise 5-digit scale.

2.2. Particulate Material Sampling [$PM_{2.5}$]

The Wilbur equipment was installed following the protocol of the Surveillance and Air Quality Manual [29] within the facilities of the Universidad Libre. It was then calibrated to have an adequate air flow, an ambient temperature, and a correct pressure. The protocols for sampling and determination of $PM_{2.5}$ were given in accordance with the provisions of the EPA Protocol CFR-50 Appendix L [30].

Before starting with the stipulated monitoring, the quartz filters must undergo a pre-treatment to totally eliminate the humidity retained caused by the environment. They were placed inside the desiccator for 24 hours, after which the filters should be weighed in a balance, to have the initial filter mass.

Once the filter is ready inside the laboratory, it will be taken to the field where the monitoring will begin. For this, the Wilbur equipment was programmed so that it will start its sampling at 00:00 and turn off at 00:00 the following day, totaling 24 hours of monitoring. Its purpose was to retain the $PM_{2.5}$ sample for a whole day. The particulate material sampling was carried out on an intermediate day basis (not counting weekends or holidays). After a while, the filter is weighed on the balance to carry out the gravimetric analysis of the filter.

From the weights before and after monitoring of the quartz filter, the net weight of the particulate material, less than 2.5 microns, is obtained. To obtain the concentration, the standard volume of air that the equipment filtered during the monitoring time, relative to the net weight of $PM_{2.5}$, must be taken into account as shown in the following equation:

$$[PM_{2,5}] = \frac{(W_f - W_i)10^6}{V_{std}} \tag{1}$$

Where:

$[PM_{2.5}]$: Concentration of particulate matter lower than 2.5 microns in (µg/m^3)

Wf: Final weight of the sample in g.

Wi: Initial weight of the sample in g

V_{std}: Volume of air sampled under standard conditions in m^3

It should be noted that the values of the weights are multiplied by 10^6 to obtain the weight in micrograms (µg).

2.3. Comparison of $PM_{2.5}$ concentrations with meteorological variables and fixed and mobile sources near the monitoring area.

To obtain the meteorological variables performance during the aforementioned sampling season, the Air quality Monitoring Network of Bogotá (RMCAB) installed by

Bogotá Secretariat of the Environment is taken into account as follows: The Centro de Alto Rendimiento station (CDAR), is closer to the monitoring point of the Universidad Libre; therefore, it has a greater representativeness of the area. From there the meteorological variables are extracted from the Bogotá Secretariat of the Environment [31] database, where data on precipitation (mm), temperature (°C), relative humidity (%) and wind speed (m/s) were downloaded for the months between July and August of the year 2018 and from March to May of the year 2019, taken every other day during the week, for a total of 40 data analyzed. To obtain data provided by fixed and mobile sources, databases of the National Planning Department (DPN) and the Ministry of Transportation were taken into account. Based on the previous data, using the ArcGis tool and the kriging interpolation method, a map was drawn to display the information graphically.

From the wind directions and speeds, data obtained from the CDAR station, wind roses were made for the two monitoring seasons, with the Free Software WRPLOT, so as to analyze the drag-wind direction of particulate matter in the area. Likewise, the descriptive statistics of the data obtained in both seasons with the MiniTab and Excel software was obtained, taking into account the student's t-test, which has a 5% significance level and thus establishes the relationship between average concentrations of particulate matter for the two seasons. In addition to this, dispersion graphs were drawn with the Minitab Software, considering precipitation variables and temperatures compared to the concentrations of particulate matter. Among the scatter plots, the Pearson coefficient (r), which measures the degree of linear affinity between two variables, was also analyzed. This value (r) can be located between the ranges -1 and +1, where $r = 0$ is a null hypothesis [32].

3. RESULTS

In the measurements carried out inside Universidad Libre campus, for the dry season in the months of July and August 2018, about 10 samples were taken, each with a monitoring time of 24 continuous hours, considering that the monitored days were interspersed without counting weekends or holidays, as well as for the rainy season between the months of March to May 2019, accounting for a total of 30 samples.

The two monitoring points are background stations, according to the air quality report of the Secretariat of the Environment [33]; stations located within an area far from vehicular traffic. In general, both locations are surrounded by large, wooded areas (as shown in Figure 2) where the Botanical Garden of Bogotá, the Institute of Recreation and Sports, among other areas favors air quality to the population.

Figure 2. Location of the 2 Monitoring points.
Source: Google Earth Pro [34].

The monthly average values of $PM_{2.5}$ were calculated for the dry season and the rainy season, with a value of 9.03μg/m^3 and 19.2 μg/m^3 respectively for Universidad Libre, and an average of 8.17 μg/m^3 and 20.2 μg/m^3 respectively for the Centro de Alto Rendimiento; data which are listed in Table 1.

A statistical analysis was carried out by means of the student's t-test using Minitab software for the values of the $PM_{2.5}$ concentration collected in the dry season (2018) and the rainy season (March-May 2019). The results are shown in Table 1.

Table 1. Student t-test of the two samples.

T and IC tests of the two samples: $PM_{2.5}$ U. Libre; $PM_{2.5}$ CDAR

Descriptive Statistics

Sample	N.	Mean	Standard Deviation	Standard error of the Mean
$PM_{2.5}$ U. Libre	10	9.31	4.69	1.5
$PM_{2.5}$ CDAR	30	19.22	5.99	1.1

Estimated Difference

Difference	95% IC for the Difference
-9.91	(-13.77; -6.05)

TEST

Null hypothesis	H0: µ1 - µ2	= 0
Alternate hypothesis	H1: µ1 - µ2	≠ 0

T Value	GL	P Value
-5.37	19	0

Source: own work

With a significance level of 5%, it can be established that the means of the data between the dry and rainy seasons are not equal, which is given by the analysis of the P value equal to 0, which indicates that there is reason to reject the null hypothesis, that is, the means of the data are different. Studies on the subject indicate the differences between the concentrations in both seasons; the most critical case being the dry season, since rainfall in rainy seasons contributes to improving the air quality due to particulate matter.

Table 2 presents the data obtained at the Universidad Libre and those from the monitoring station of the high-performance Air quality Center, which is located at an average distance of 2.4 kilometers from the sampling point.

Table 2. $PM_{2.5}$ concentration data for Universidad Libre and CDAR in the two sampling seasons.

	Dry Season 2018		**Rainy Season 2019**	
	[$PM_{2.5}$]	**[$PM_{2.5}$]**	**[$PM_{2.5}$]**	**[$PM_{2.5}$]**
	U Libre	**CDAR**	**U Libre**	**CDAR**
Average	9.03	8.17	19.2	20.2
Minimum	2.92	4.2	7.4	5.5
Maximum	17.62	13.2	30.2	43.7
S.D.	4.69	2.71	5.9	9.3

CDAR: Centro de Alto Rendimiento, S.D: Standard deviation.

Source: own work

3.1 Dry Season, year 2018

3.1.2. Descriptive statistics of Data.

Table 3 depicts the descriptive statistics of the variables analyzed in the dry season of the year 2018. It was found that the meteorological variables presented less deviations of the data compared to the concentration of particulate matter $PM_{2.5}$. This is due to the sampling method and determination of the concentration in semi-automatic equipment such as those used in this research.

Table 3. Descriptive Statistics of data obtained in the Dry Season, year 2018.

	Dry Season 2018					
	$[PM_{2.5}]$ U Libre	**$[PM_{2.5}]$ CDAR**	**Temperature**	**Precipitation**	**Wind speed**	**%HR**
Average	9.03	8.17	14.3	40.4	0.5-2.10	63.6
Minimum	2.92	4.2	13.2	0	0.8	55
Maximum	17.62	13.2	15.6	15.2	2.2	73
S.D.	4.69	2.71	0.58	3.06	0.28	4.40
Variance	22.03	7.38	0.33	9.39	0.08	19.40
Median	8.35	8.1	14.4	0.1	1.3	63.5
Mode	-	8.1	-	0	1.3	59

CDAR: Centro de Alto Rendimiento, S.D: Standard deviation

Source: own work

To support the previous results, box and whisker graphs made are presented in Figure 3. The data collected in Universidad Libre are compared with those of the Centro de Alto Rendimiento (CDAR) station. It shows that the former presents greater dispersion with respect to the second site. In Universidad Libre, the recordings were as follows: a minimum value of concentrations of 2.92 µ/m^3, a maximum value of 17.62 µg/m^3, without the presence of atypical values and an average of 9.03 µg/m^3. On the other hand, the data collected for the CDAR show a maximum value of 13.2 03µg/m^3; however, the data show a lower dispersion, with a mean of 8.17 µg/m^3.

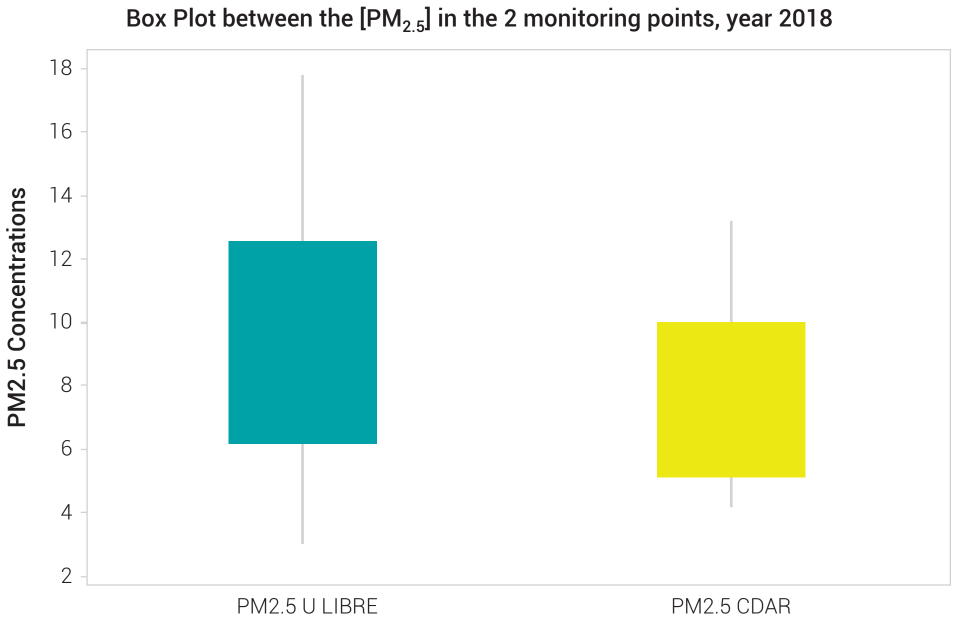

Figure 3. Box Plot between the [PM$_{2.5}$] in the 2 monitoring points, year 2018. Prepared with MiniTab software.

Source: own work

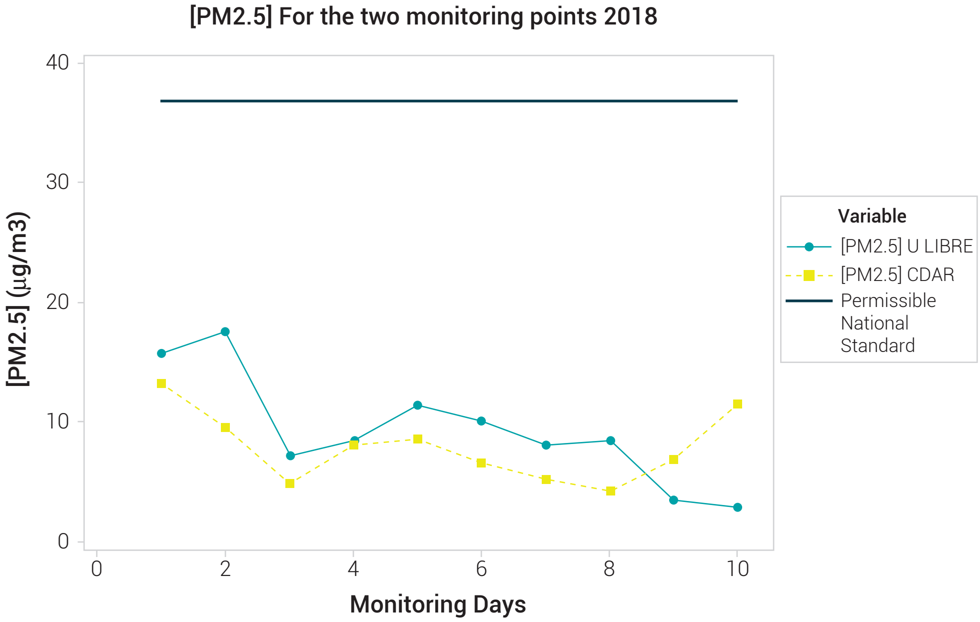

Figure 4. PM$_{2.5}$ concentrations for U. Libre and CDAR for the dry season. Drafted with the MiniTab free software.

Source: own work

Figure 4 shows the concentrations of $PM_{2.5}$ in the period studied (dry season 2018). It is observed that, according to the Air quality Standard, Resolution 2254 of 2017 in Article 2 Paragraph 1, which indicates that maximum permissible levels as of July 1st, 2018 for an exposure time of 24 hours are 37 (μg/m^3) [35]; the concentrations of $PM_{2.5}$ obtained at both monitoring points did not exceed the National Standard for Ambient Air Quality. Additionally, it is observed that the concentration trend between the sampling point and the CDAR station is similar.

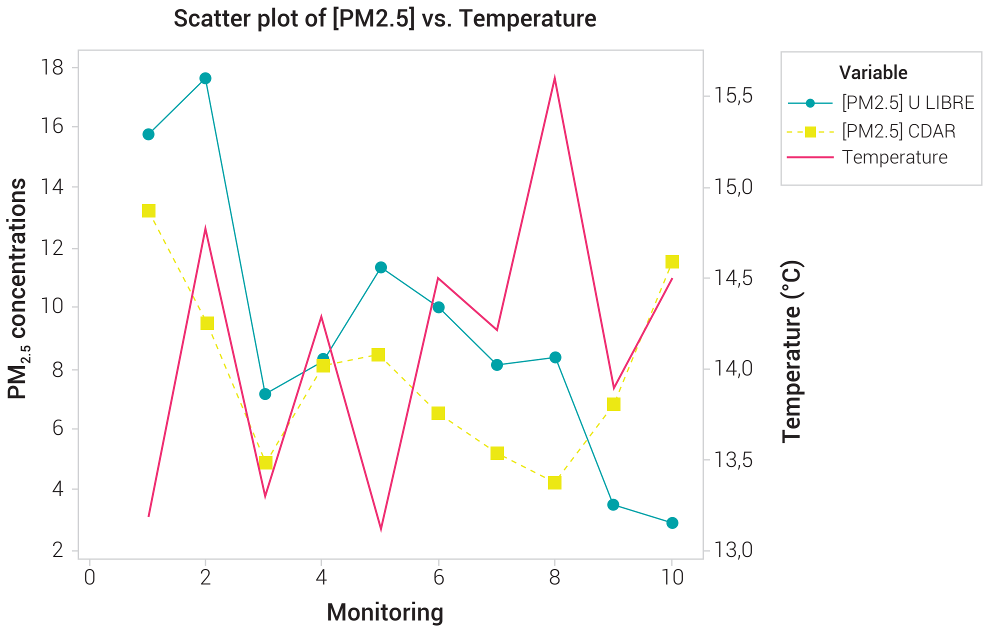

Figure 5. $PM_{2.5}$ concentration for U Libre & CDAR vs. Temperature for Dry season. Prepared with MiniTab software.

Source: own work

Figure 5 shows the influence of Temperature with $PM_{2.5}$ concentrations, where the temperature performance is directly proportional to concentrations of particulate matter and as mentioned later in the existing relationship according to the Pearson coefficient.

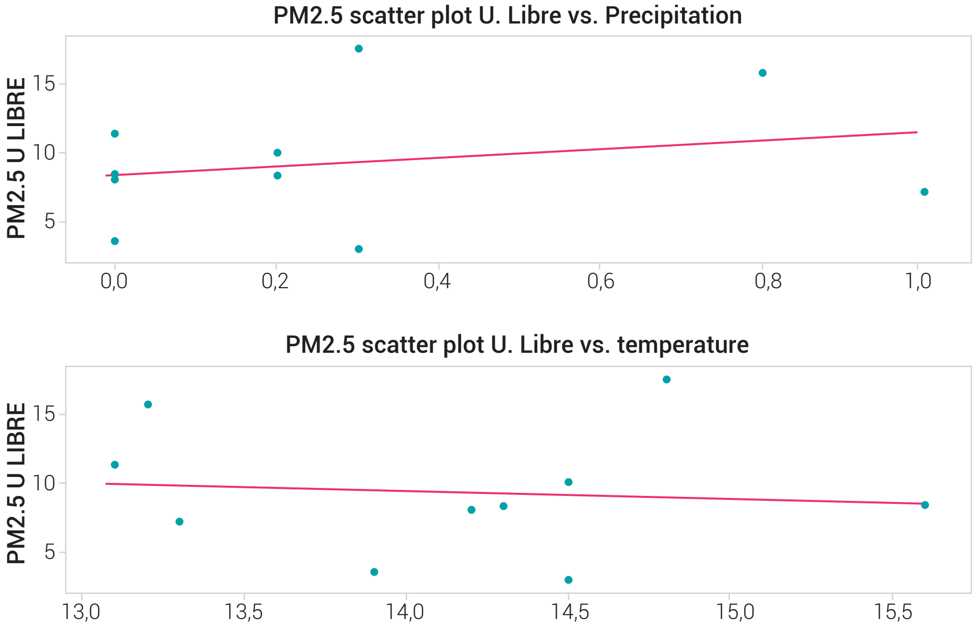

Figure 6. Scatter Plot between [$PM_{2.5}$] and meteorological variables. Prepared with MiniTab software.

Source: own work

From a statistical analysis using scatter graphs and the Pearson Coefficient, as shown in Figure 6, it was possible to establish that for the $PM_{2.5}$ concentration and temperature data, the Pearson coefficient is r = 0.46; a value within the moderate positive range, indicating that as the temperature increases, $PM_{2.5}$ concentration increases as well and its correlation strength is average.

Between precipitation (mm) and $PM_{2.5}$ concentrations, there is a Pearson coefficient of r = -0.03, meaning that it has a very low negative relationship, indicating that, in this dry season, the little precipitation that occurred moderately helped to diminish the concentrations of the $PM_{2.5}$ variable; results similar to those found in the literature.

A similar case to the previous one, the $PM_{2.5}$ variable has a negative correlation with the wind speed, since the value is r = -0.04, which is within the very low negative range, thus being that the concentrations of particulate matter data are inverse to those obtained with wind speed. On the other hand, there is a relationship between the very low negative range, between the variables and relative humidity, with a Pearson coefficient of r = -0.06, which signifies that the concentrations of the $PM_{2.5}$ variable are weakly influenced by Relative Humidity.

Another variable considered is the wind direction and speed, since it is through this means that the carrying capacity of the particulate matter can be determined and in general where the wind comes from [36], as shown in Figure 7. The Centro de Alto

Rendimiento station shows winds with average speeds coming in most of the eastern part of Bogotá; winds that enter through the eastern hills of the capital, with values between 2.1 and 3.6 m/s, with some possibility of entrainment of particulate matter towards monitoring points.

Figure 7. Wind Rose Dry season. Prepared with WRPLOT free software and exported to Google Earth
Source: own work

3.2 Rainy Season, year 2019

3.2.1. Descriptive statistics of Data.

Table 4. Descriptive statistics of data obtained during the Rainy Season, Year 2019.

	Rainy Season 2019					
	$[PM_{2.5}]$ U Libre	$[PM_{2.5}]$ CDAR	Temperature	Precipitation	Wind Speed	%HR
Average	19.22	20.18	15.32	373.6	0.5-2.10	68.8
Minimum	7.4	5.5	13.3	0	0.8	48
Maximum	30.16	43.7	17.4	46.6	2.4	83
S.D.	5.99	9.34	0.81	7.95	0.3	6.46
Variance	35.88	87.26	0.66	63.35	0.09	41.79
Median	18.23	19.05	15.4	0.4	1.2	69
Mode	23.58	-	15.4	0	1.2	72

CDAR: Centro de Alto Rendimiento, S.D.: Standard Deviation

Source: own work

Table 4 depicts the descriptive statistic of the variables analyzed in the rainy season of the year 2019, between the months of March and May, observing that the meteorological variables of wind speed and temperature data show a lower deviation, compared to the particulate matter concentration of $PM_{2.5}$. This could be determined thanks to the automatic equipment of the Air quality Monitoring Network of Bogotá.

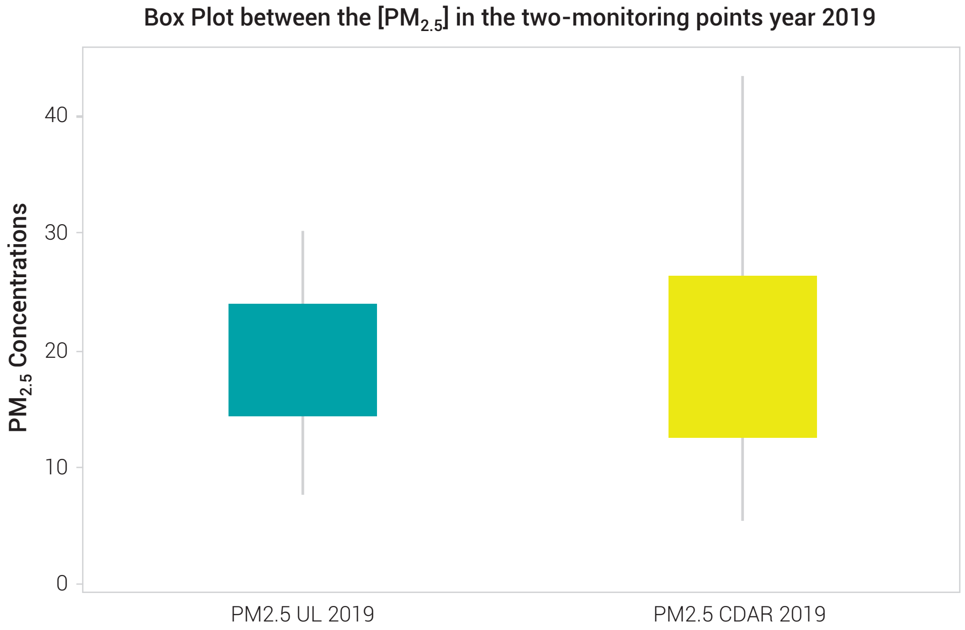

Figure 8. Box Plot between the [$PM_{2.5}$] in the two-monitoring points year 2019. Prepared with MiniTab software.

Source: own work

Figure 8 shows a box and whisker plot for the rainy season, making note that the Universidad Libre data have little dispersion without atypical data with a Maximum and Minimum value equidistant to the first and third quartiles, with a mean of 19.22 μg/m^3. On the other hand, it was noted that the data collected for CDAR have a greater dispersion compared to those of Universidad Libre, with a maximum value of 43.7 μg/m^3 and a mean of 20.18 μg/m^3, without outliers.

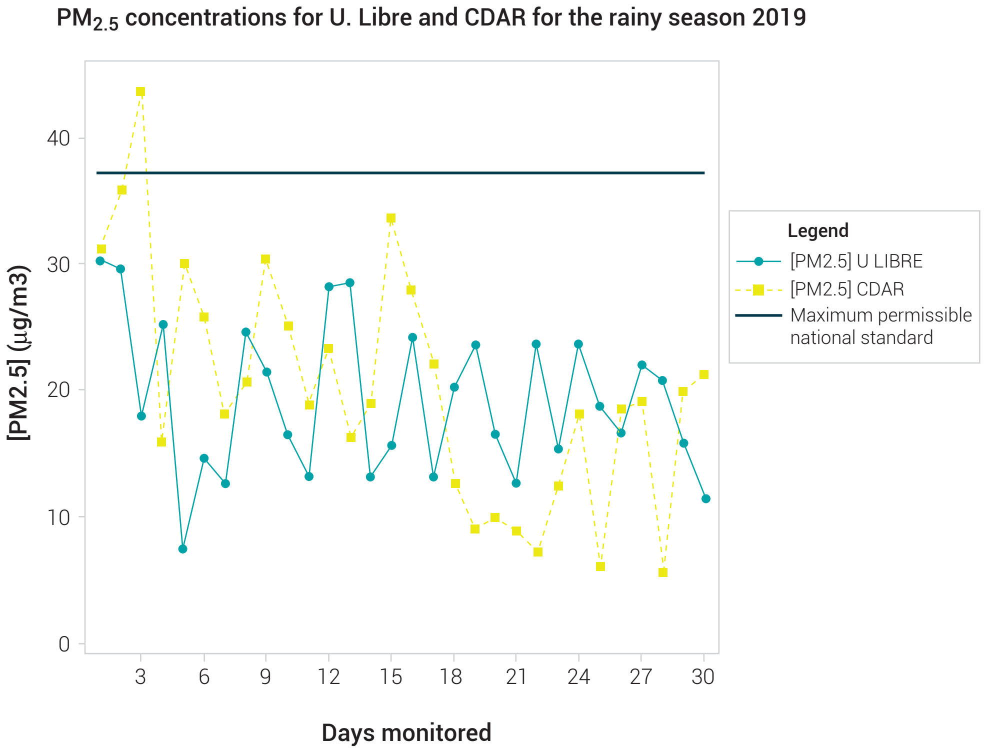

Figure 9. $PM_{2.5}$ concentrations for U. Libre and CDAR for the rainy season. Prepared with MiniTab software.
Source: own work

There is a trend similarity for both the rainy season as well as the dry season, regarding [$PM_{2.5}$] data in both monitoring points, as shown in Figure 9. Nonetheless it is noted that the CDAR concentrations exceeded the 3.3% standard, which represents the number of days that were outside the permissible limit. This indicates that both monitoring points are in an area with moderate air quality, since these are relatively low percentage exceedances in comparison to other stations of the Bogotá Air quality Monitoring Network (RMCAB), such as the Kennedy and Carvajal - Sevillana Stations, which had high concentrations mainly in the first week of April, with a total of exceedances of the Air quality Standard, for the second quarter of 2019 of 6% and 32%, respectively [37] [38][39][40].

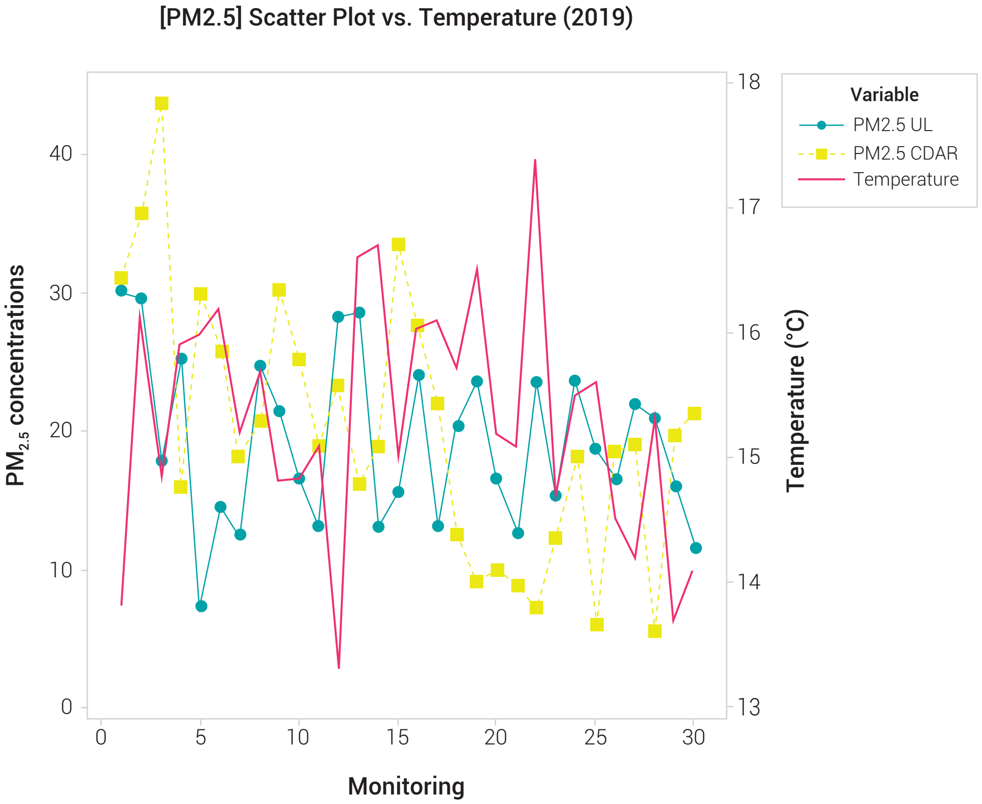

Figure 10. PM$_{2.5}$ concentrations for U Libre and CDAR vs. Temperature during the rainy season. Prepared with MiniTab software.

Source: own work

Clearly, in Figure 10, one can see the decrease in the concentrations of particulate matter as the months of the rainy season pass, as well as a slight decrease in temperature in the last days of monitoring; a directly proportional relationship, that is, while there is a decrease in temperature, the concentrations of particulate matter decrease as well.

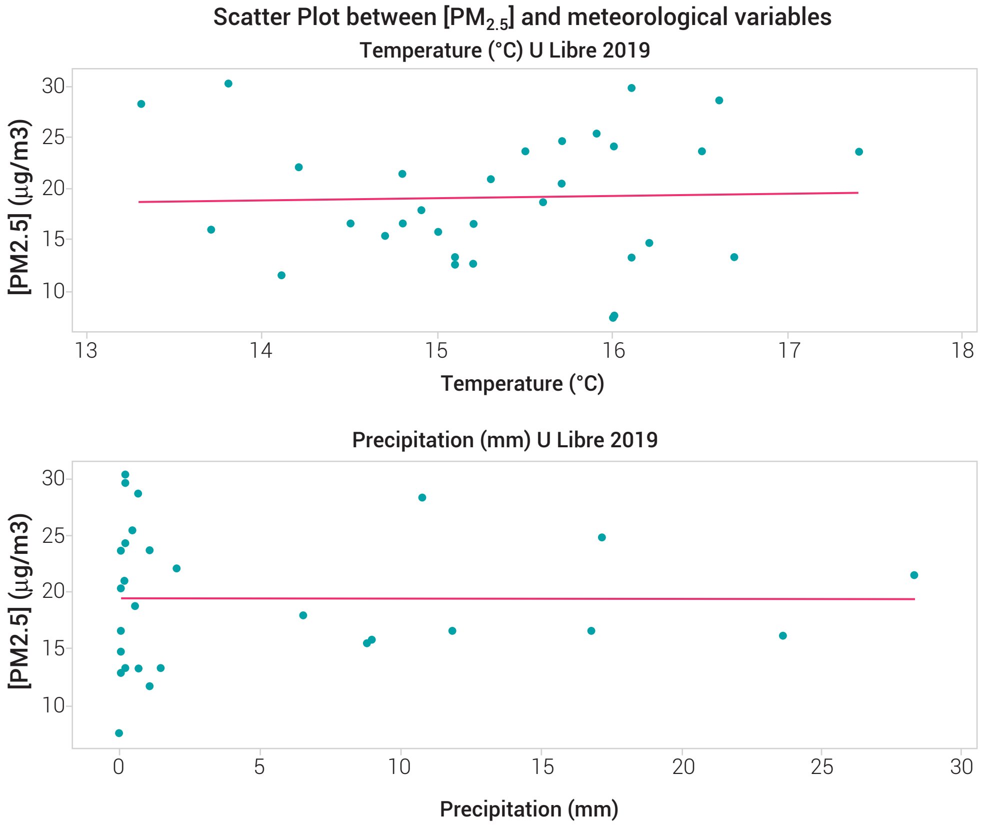

Figure 11. Scatter Plot between [$PM_{2.5}$] and meteorological variables. Prepared with MiniTab software.

Source: own work

According to the point distribution and the trend line between the two variables, as shown in Figure 11, for both precipitation and temperature, the Pearson coefficient was 0.014 and 0.030, respectively, which indicates that there is a very low positive relationship for both interpretations, that is, despite being a positive trend, it could not be taken for granted that the increase in temperature or precipitation directly impacts the $PM_{2.5}$ concentrations in the area. However, in the Precipitation Dispersion graph, a cloud of closely related points can be seen, indicating that most $PM_{2.5}$ concentrations are at an average precipitation between 0 and 3 mm. The correlations of the $PM_{2.5}$ variable with the wind speed, are in the range of very low positive, with a correlation of r = 0.09, while the relationship with Relative Humidity is very low negative, with a Pearson's coefficient of r = - 0.019.

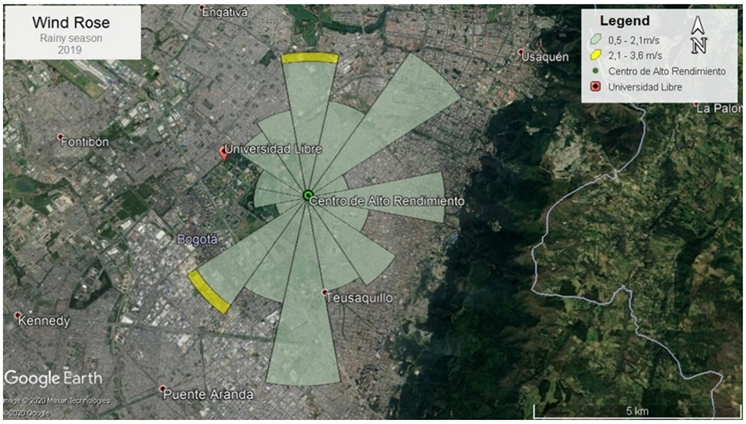

Figure 12. Wind Rose. Rainy season. Prepared with WRPLOT free software and exported to Google Earth
Source: own work

The Wind Rose, in Figure 12, for the rainy season, shows that the winds come mainly from the southeastern part of the capital, where the Puente Aranda zone is located, which has industrial, residential, commercial and heavy traffic activities. This leads to major environmental problems [41], with an average of wind speeds between 0.5 and 3.6 m/s, which can indicate the dragging of particulate matter towards the established monitoring points.

3.2.2. Influence of the Mobile and Fixed sources in the city of Bogotá.

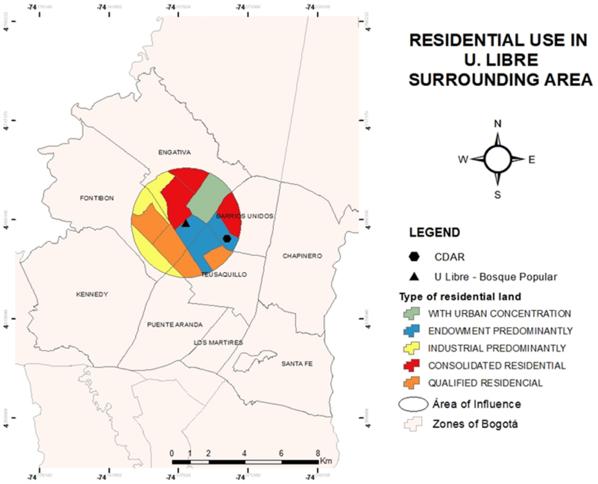

Figure 13. Soil utilization in Bogotá. Prepared in ArcMap
Source: own work

To have a clear context of how fixed and mobile sources contribute to the concentrations of particulate matter, a map of land use was made in the surroundings of the two monitoring points, so as to more clearly determine the fixed sources contributing to air pollution. In Figure 13, the green zone displays urban centrality [42]. This land use refers to parts of territory focused on services and equipment or provisioning at various scales. They depend directly on the number of persons demanding the services provided; in other words, in those urban centers the prevailing residential use has been displaced by commercial activities [43], an example of which is Las Ferias UPZ (4° 41'06.3" N 74 ° 05'07.7" W). The map shows all kinds of commercial shops, automotive workshops and industries in this land type. The blue color shows that the land is used predominantly for provision, where the two monitoring points are located. The large areas of this zone have been dedicated to the production of urban and metropolitan facilities, which are managed under special conditions [43]. It refers to the entire area shown in Figure 2, since they are areas adopted by the District for recreation and sport: the José Celestino Mutis Botanical Garden, the Metropolitan Park Simon Bolivar, the High- performance Center, Parque de los Novios and other similar areas. The yellow color refers to a predominantly industrial land use, where industrial activity prevails, as its name refers to. Elsewhere there is the consolidated residential land-type depicted in red color where the residential use for middle income populations prevails. Nonetheless, there have been changes in land use and unplanned increases in territorial occupation [43]. Finally, the orange section represents the Qualified Residential land for middle- and upper-class residential use, with a large infrastructure of public spaces, a suitable habitat and environmental conditions.

According to the above, the types of land that mostly predominate in the area adjacent to the two monitoring points are predominantly Provisioning and Qualified and Consolidated Residential, which considerably improves the area of influence. Being surrounded by residences and metropolitan areas generates a positive impact on air quality. To a lesser extent, we find a predominantly Industrial land use, with all kinds of industries that contribute towards throwing particulate matter into the environment.

In context, the fixed sources that could be found near the monitoring points are minimal, since they do not have a great bearing on the $PM_{2.5}$ concentration contribution.

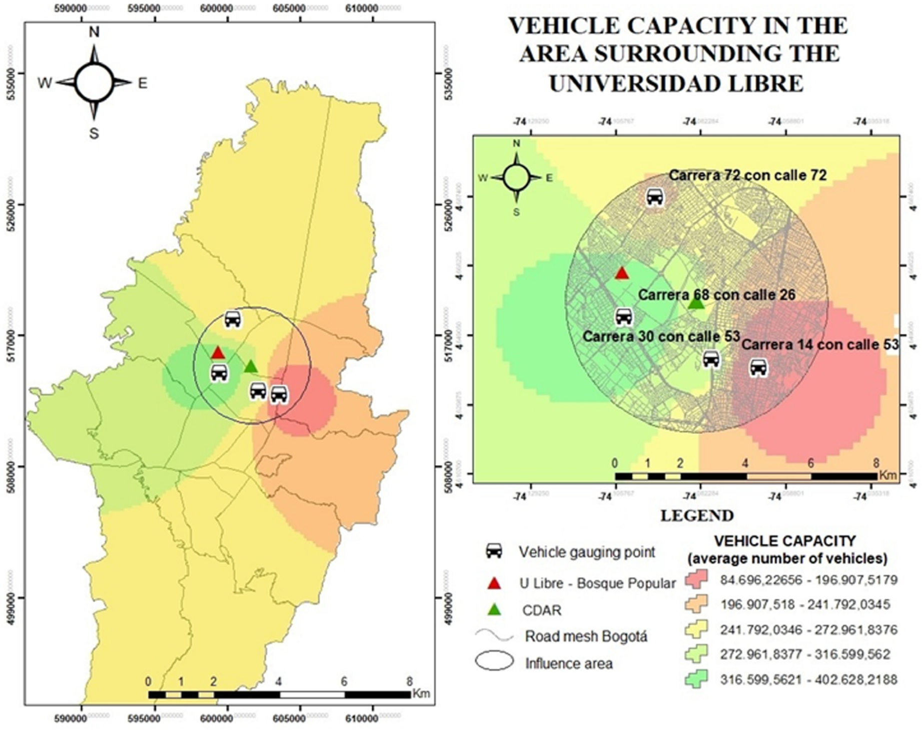

Figure 14. Vehicle capacity in the area surrounding the monitoring points. Prepared in ArcMap.
Source: own work, based on SDA data.

In a different perspective, using the Kriging method in ArcMap, Figure 14 shows the interpolation of vehicle capacity made by the Ministry of Mobility, with the 4 points closest to the area of influence of the monitoring points, such as Carrera 72 with 72 St., Carrera 68 with 26 St., Carrera 30 with 53 St. and finally Carrera 14 with 53St. You can clearly see on the map that the main monitoring point (U Libre) is within the area with the most influence and traffic of vehicles from all types, with a range of vehicles running in the area on a daily basis between 316,599 and 402,628. For the second monitoring point (CDAR), the number of vehicles ranges between 272,961 and 316,599. This could be considered as the source that contributes the most [$PM_{2.5}$] to the area of influence of the monitoring points.

4. DISCUSSION AND CONCLUSIONS

The concentrations of $PM_{2.5}$ Particulate Material were determined at the monitoring point for the dry and rainy season. The results were compared with the data of the air quality station High Performance Center for the same period, showing that the air quality in the area studied is favorable, with average concentrations between 9.03 µg/m^3 and 19.2 µg/m^3. while at the CDAR station averages were 8.17 µg/m^3 and 20.18 µg/m^3. In both cases, they follow the same trend both in the dry and the rainy season. The above is caused by the phenomenon in the first months of the year, during the transition from the dry to the rainy season, in which high concentrations of particulate material are present caused by meteorological phenomena that drag particles from forest fires in surrounding areas or due to thermal inversion of the phenomenon [44].

Based on the current study carried out at Bosque Popular campus- Universidad Libre, and the hypothesis that relates the meteorological variables, rainfall and temperature and $PM_{2.5}$ concentrations, it is found that there is a weak positive correlation between them, which was determined applying Pearson's coefficients. It could be stated that the increase in precipitation or temperature has a (minor) relation with the $PM_{2.5}$ concentrations found during the two sampling seasons, for the main monitoring point (U Libre) and the comparison with the CDAR station. This is the same performance result found in another study carried out in the city of Villavicencio, Colombia, where relationships were found between $PM_{2.5}$ concentrations and the temperature, that demonstrated a directly proportional trend, that is, if the temperature increases, the $PM_{2.5}$ concentrations increase [45].

For the sake of precision, we state that it is possible that the correlations found between $PM_{2.5}$ concentrations and the meteorological variables may be very low positive due to the terrain morphology and the local sampling conditions which may alter these variables [46].

According to the data obtained from the vehicle capacity, carried out by the Secretariat of Mobility, it is evident that one of the main sources of Particulate Material lower than 2.5 microns, for both monitoring points corresponds to the vehicular circulation on the main roads of the sector. However, despite the fact that the number of vehicles that passes by the area adjacent to Universidad Libre is greater compared to the CDAR, a lower $PM_{2.5}$ concentration is reported versus the last site. This is due to the fact that the sampling point of the University is farther to the roads with high traffic flow and, in addition, it is a strategic point of the city, close to all types of ecosystems and full-of-trees zones [39].

Regarding the land use, we did not find a number of zones contributing towards the poor air quality; while they are based on commercial and residential areas, most of the areas are covered by plenty of trees as stated. Another factor contributing to particulate material concentrations at the monitoring point is the material dragged from the Puente Aranda zone, where the $PM_{2.5}$ concentrations are higher as a result of the number of industries present therein.

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