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Analysis of Air Contamination from Sulfur Dioxide in Bogotá

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Abstract— *The present article discusses the air contamination in Bogotá and its connection to sulfur dioxide emissions. The study centers on analyzing the evolution of SO2 contamination over the last decade using data gathered from the Air Quality Monitoring Network in Bogotá. As in many large cities, air contamination in the Colombian capital is a serious problem both for public health and the environment that affects millions of people and causes health risks, especially for children, senior citizens, and people with respiratory conditions. The analysis focuses on presenting and examining data regarding the annual concentrations of SO2 at different monitoring stations located throughout the city. In general, said concentrations have remained below the authorized limit. However, there has been an increase in some specific areas, such as the southwestern region of the capital, where the stations of Puente Aranda and Carvajal-Sevillana are located. These areas are characterized by considerable traffic and the settlement of industries, which contribute to the emission of contaminants. Regarding public health, the article also presents an analysis of the connection between this scenario and the mortality rates derived from acute respiratory infection (ARI) and pneumonia, as well as the symptoms in children under the age of 5 and their geographical location.*

Keywords— *Bogotá; air contamination; sulfur dioxide; NIH; WHO; public health.*

I. INTRODUCTION

According to data from the World Health Organization (WHO), almost the entire global population (99%) breathes air that surpasses the limits recommended by the WHO and contains high levels of contaminants. The highest exposure is seen in countries with medium and low levels of income. Manyof the sources of atmospheric contamination (such as fossil fuel combustion) also emit greenhouse gases. Hence, policies aimed at cutting back contamination are doubly beneficial since they reduce morbidity rates and help mitigate climate change [2].

Air pollution is an environmental problem that affects people all over the globe, and Colombia is no exception. As the population grows and the economy of the country keeps developing, the emissions of atmospheric contaminants also increase. Air contamination can have negative effects on human health, the environment, and climate change.

Currently, one of the major environmental risks for human health is air contamination, which is the leading cause of death and disease all over the world. 77% of Colombians live in the main cities of the country, where higher emissions take place and there are numerous sources of contamination. This scenario, in addition to higher emissions from fuel combustion, represents a permanent risk caused by the respiration of polluted air [3].

Over 78% of emissions that cause climate change come from 15 million vehicles that move about, such as cars, buses, trucks, and motorcycles. Colombia is the second-worst country in the world in terms of the worst traffic and a concerning roads quality index (QRI) of 3.4 out of 7 [3]. Furthermore, the vehicles that circulate in the Colombian territory are on average 17.2 years old as of 2020, making them obsolete over time and without features that help protect the environment [4].

Air pollution is a problem that dates back several decades. Currently, different activities are in place to tackle this problem as much as possible. Nonetheless, despite the efforts of governments, organizations, and environmental institutions, the situation grows worse in highly populated areas with constant growth, such as Bogotá. In fact, common citizens are ill-informed on this matter since the information is scarce and poorly spread, rendering the policies promoted by local authorities ineffective and minimizing their impact.

William Thomson Kelvin once said, "What is not defined cannot be measured. What is not measured cannot be improved. What is not improved is always degraded". This reveals the need to develop research that allows citizens to easily learn about the evolution of air pollution in Bogotá overthe past 10 years, specifically in terms of SO2 emissions.

In this sense, the goal of this work is to present an analysis of the evolution of SO2-related contamination in the city of Bogotá. Hence, a graphical analysis is carried out based on annual reports obtained from the air quality monitoring network of Bogotá (RMCAB) between 2013 and 2021, which is comprised of 20 monitoring stations located throughout the city.

This article includes the following sections: Section 2 discusses some theoretical concepts and work. Section 3 describes the chosen methodology. Section 4 presents the results obtained through research. Section 5 lists some recommendations that can help citizens lower the impact of sulfur dioxide on their health. Lastly, Section 6 presents a set of conclusions on the overall work.

II. CONCEPTS

A. *Sulfur Dioxide*

Sulfur dioxide is produced as a combination of sulfur and oxygen (SO2). It is a colorless gas with a strong and pervasive smell that causes irritation in the eyes and respiratory channels. SO2 is the main cause of acid rain and an essential contaminant in acidification processes [5].

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Sulfur dioxide is generated in two ways: (1) naturally, from volcanic activity and wildfires; or (2) anthropogenically, as a product of transportation systems based on fossil fuels and industrial activity linked to factories and energy plants [6].

B. Public Health in Bogotá

Bogotá (the capital of Colombia), with over 8 million inhabitants, has considerably poor air quality, which has a direct impact on public health and the welfare of its citizens. According to a study performed by the Colombian Ministry of Environment and Sustainable Development [7], the capital is marked by high levels of atmospheric contamination, especially in terms of particle materials and SO2. Prolonged exposure to these contaminants can cause respiratory and cardiovascular diseases, eye irritation, and even worsen the symptoms of asthma and bronchitis of children and elderly people [7].

As of 2021, 3400 premature deaths are attributable to exposure to particle materials. This mortality rate is comparable.

To the tobacco death rates and higher than the mortality rates derived from homicide or drug use in Colombia [8]. Mobility is the main cause of pollution, given that 60% is generated by motorcycles, cars, buses, and trucks. Many of these contaminants are those that people breathe while moving through the city [8].

The impact of the contamination from particle materials and SO2 not only has a negative effect on health but can also strongly affect the national and regional economies since the expenses from lung and cardiopulmonary diseases from inhaling these contaminants are largely covered by government entities.

A study by the National Institute of Health (NIH) attributes 17549 deaths to environmental-related risk factors, with 15681 deaths linked to poor air quality, mostly due to ischemic heart disease (IHD) and chronic obstructive pulmonary disease (COPD) [9].

The national planning department states that just in Bogotá, it is estimated that close to 10.5% of deaths as of 2015 are attributable to urban air pollution, which translated into 4.2 billion pesos, which is equivalent to 2.5% of the city's GDP [10].

According to data from 2020, WHO recorded SO2 levels above the authorized limits in some parts of the city, such as Kennedy and Fontibón. This implies that the population in these areas is exposed to SO2 levels that can be harmful for thehealth of local citizens [11].

According to the Institute of Hydrology, Meteorology, and Environmental Studies (known by its Spanish acronym (IDEAM), 176096 tons of SO2 were produced in 2014, mostly by manufacturing, construction, energy, and transportation facilities [12].

SO2 causes environmental damage that mainly affects trees and plants, destroying foliage and hampering their growth [13].

SO2 does not only affects the environment, but also has consequences for the human body, including [14]:

- Wheezing, chest tightness, difficulty breathing.
- Reduction of lung capacity
- Impact on the lower respiratory tract during exercise
- Increased risk of hospitalization, especially inchildren, elderly people, and asthmatic patients.

C. Normativity

In terms of normativity, two policies were set in place to determine the maximum levels of SO2 that can be permitted within the city of Bogotá: (1) Resolution 610 of 2010 from the Ministry of Environment, Housing, and Territorial Development; and (2) Resolution 2254 of 2017 from the Ministry of Environment and Sustainable Development.

Regarding Resolution 610 of 2010, the maximum permitted levels are described in Table I.

TABLE I. Maximum SO2 levels according to resolution 610 of 2010

Contaminant	Maximum allowed level(μg/m3)	Exposure time	Calculation method
SO2	80	Yearly	Arithmetic mean of daily concentrations over 365 days
	250	24 hours	Average concentration in24 hours
	750	3 hours	Hourly average concentration for 3 hours

Resolution 610 of 2010 was in force between 2010 and 2017, and starting in 2018, Resolution 2254 of 2017 is in effect, thus changing the maximum permitted levels. Regarding Resolution 2254 of 2017, the maximum permitted levels are described in Table II.

TABLE II. Maximum SO2 levels according to resolution 2254 of 2017

Contaminant	Maximum permitted level (μg/m3)	Exposure time	Calculation method
SO2	50	24 hours	Average concentration in 24 hours
	100	1 hour	Average concentration in 24 hours

Although Resolution 2254 of 2017 is still in force, the previous resolution 610 of 2010 is still used as a reference for yearly exposure rates, given that the new resolution does not define a maximum permitted level per year.

III. METODOLOGY

The purpose of this study is to analyze the evolution of sulfur dioxide (SO2) contamination in the city of Bogotá throughout the last decade. A retrospective approach was chosen based on the data from the Air Quality Monitoring Network of Bogotá (RMCAB). This approach enabled us to examine a time series of data and extract conclusions about the evolution of urban contamination throughout a 10-year period. The target population of the study was comprised of the entire city. The data collection process involved air monitoring stations, strategically located throughout different areas of the city. 18 of the stations were fixed and 2 were mobile, as shown in Figure 1.

Figure 1 confirms that all the stations do not measure SO2 levels. Table III lists all the stations that measure pollutants, including SO2, as of 2021. Furthermore, the acronyms assigned to each station and their locality (neighborhood) are included.

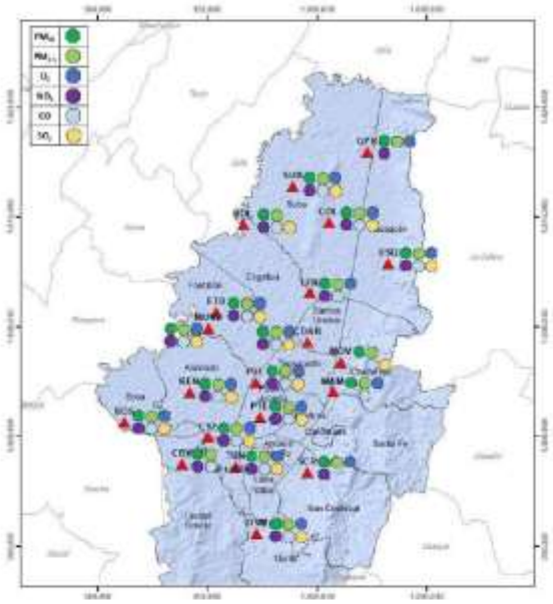

Fig. 1. Location of monitorin network stations in 2021.(yearly report from 2021).

TABLE III. SO2 monitoring network stations.

Station name	Acronym	Neighborhood
Usaquén	USQ	Usaquén
Suba	SUB	Suba
Bolivia	BOL	Engativá
Centro de alto rendimiento	CDAR	Barrios Unidos
Mobile station - Calle 7a	MOV	Chapinero
Fontibón	FTB	Fontibón
Puente Aranda	PTE	Puente Aranda
Kennedy	KEN	Kennedy
Carvajal-Sevillana	CSE	Kennedy
Tunal	TUN	Tunjuelito
El Jazmín	JAZ	Puente Aranda
Usme	USM	Usme
Bosa	BOS	Bosa
Colina	COL	Suba
Mobile station - Fontibón	MOV2	Fontibón

The selection process of the variables for the analysis defined the daily concentration of SO2 as the main variable, measured in micrograms per cubic meter (µg/m³). Furthermore, additional data was collected, such as the location of the monitoring station and the mortality rates caused by respiratory infections and morbidities. The annual rates of SO2 concentrations were derived from the stations detailed in Table

The data was collected over a period of 10 years and recorded in a database for subsequent analysis.

The analysis of the transient trend in SO2 contamination was based on statistical techniques. Descriptive metrics were calculated, such as the mean, standard deviation, and range, for each year encompassed by the study. Additionally, possible stationary patterns and fluctuations over time were also examined.

It is noteworthy to mention that the monitoring stations use standard methods, which are established in Title 40 of the Code of Federal Regulations (CFR) and approved by the Environmental Protection Agency (EPA) of the United States. The pulse ultraviolet fluorescence method was used to measure the SO2, which is based on the capacity of the sulfur dioxide molecules to emit light when stimulated by a UV light source.

A. *Correlation Analysis*

To determine the effect of SO2 contamination on respiratory health, a correlation analysis was performed through the Goodman-Kruskal and Spearman methods, which are more suitable to confirm the correlation between these variables.

In the measurement process, two different scenarios were considered: one that excludes the data from the 2020-2021 period due to the influence of COVID-19 and another that focuses on the effects of COVID-19.

Aiming to ensure higher accuracy of the results, annual concentrations of SO2 were collected with a span of 8 hours between measurements. The data were obtained through the air quality monitoring network in Bogotá.

B. *Goodman and Kruskal method*

The Goodman-Kruskal method reveals the matching of two pairs of data. The purpose of the test is to predict the classification of new values and the relationship between the two variables. This method analyzes continuous variables (weight, height) and discrete variables (warm, warmer). This is useful when atypical values are detected since it does not affect the results considerably [15].

The range of the gamma coefficient is interpreted as follows: A value of ‘1’ means that there is a perfect positive correlation. If one value increases, the other one behaves in the same manner. A value of ‘-1’ means that there is a perfect inverse correlation: when one value increases, the other value decreases. A value of ‘0’ means that there is no connection between the variables.

C. *Spearman method*

The Spearman method is a non-parametric test thatmeasures the degree of association between two variables. It measures the strength and direction of the association between two variables. The range of the correlation coefficient varies between ‘1’ and ‘-1’, with values closer to 0 representing a weak correlation between the variables [16].

Range of the correlation coefficient (ρ):

- $\rho > 0$ implies a positive agreement between ranges.
- $\rho < 0$ implies a negative agreement (or agreement inthe reverse direction).
- $\rho = 0$ implies that there is no agreement.

III. Results

This section shows the results obtained based on the statistical analysis of the collected information. The first part shows the annual SO2 concentration rates. The second part describes the mortality related to pneumonia and respiratory infections in children under the age of 5. The third part presents the analysis and correlation between cough symptoms in children under the age of 5 and their geographic location based on the monitoring stations.

A. *Annual records of SO2 in Bogotá*

Fig. 2 shows the yearly concentrations of SO2 between 2013 and 2017 for the city of Bogotá. In 2013, the behavior of SO2 was more prevalent than in the following years. Nonetheless, a concentration of approximately 6 µg/m3 was registered in 2017, marking one of the highest rates compared to 2014, 2015, and 2016. This can be explained by the fact that the levels measured at the Carvajal-Sevillana station were included in the mean calculation process and were the highest SO2 concentrations of the year.

Fig. 2 also shows that the concentration of SO2 in the city remained below the maximum limit of 80 µg/m3 throughout the analyzed period. However, there has been an increase in the concentration of the contaminant since 2015, which can be explained by the increase in freight car traffic in the vicinity of the Carvajal-Sevillana station. This area is a major highway for Bogotá and has also seen an increase in the number of factories and industrial facilities over the years.

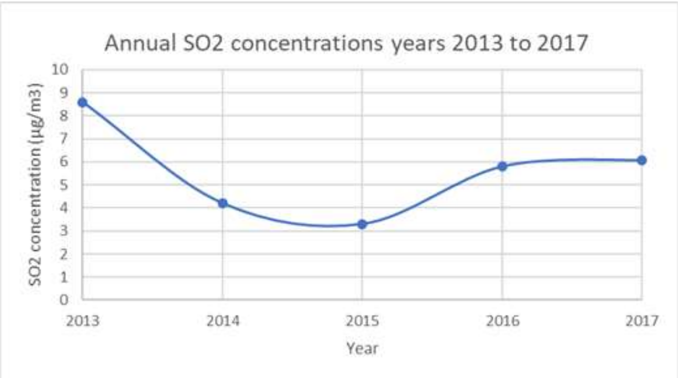

Fig. 2. Annual concentrations of SO2 between 2013 and 2017.(Compilation of annual reports.)

As previously stated, Resolution 2254 of 2014 has been in place since 2018. This resolution establishes the new maximum permitted levels of SO2 concentrations. As a result, the annual graphic-based analysis has been in place since that same year, using the monitoring station network data. Furthermore, Resolution 610 of 2010 was analyzed since the normativity in force does not contemplate a permitted maximum level per year.

Fig. 3 encompasses the most relevant data obtained from the monitoring stations between 2013 and 2021. The Sevillana station has the highest concentrations of SO2 compared to other stations.

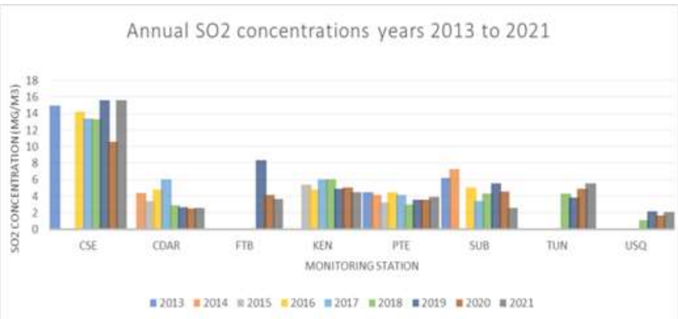

Fig. 3. Annual concentrations of SO2 between 2013 and 2021.

Although the annual and daily regulation levels have not been exceeded over the last decade, there have been some temporary threshold breaches since 2018. Hence, the RMCAB performed a monthly analysis in 2020 that revealed that higher SO2 concentrations were registered in October and November at the stations located in the southern part of the city. Meanwhile, the highest concentrations were observed in the western area in the months of January and February. These results showed a possible influence of increased activity from contaminant emission sources during the second semester of the year, after some COVID-19 pandemic restrictions were lifted.

In general, the highest concentrations of SO2 have been consistent in the southwestern region of the city, where diesel vehicles and factories have been identified as the main contributors to the matter. Moreover, a detailed statistical analysis was carried out at two of the most relevant monitoring stations to study the behavior of SO2 during the past decade. However, it is noteworthy to mention that a general analysis is not feasible for the 19 stations since the gas concentrations may vary largely according to geographical location (see Table IV).

TABLE IV. Annual average SO2 concentrations for each morning station

	Average [µg/m3]							
Station Year	**CSE**	**CDAR**	**KEN**	**PTE**	**SUB**	**USQ**	**FTB**	**TUN**
2013	15			4.5	6.2			
2014		4.4		4.2	7.3			
2015		3.4	5.4	3.3				
2016	14.2	4.3	4.8	4.5	5.1			
2017	13.4	3.3	6.1	4.2	3.4			
2018	13.3	2.9	6.1	3	4.3	1.1		4.3
2019	15.6	2.7	4.9	3.6	5.6	2.2	8.4	3.8

	Average [µg/m3]							
Station Year	**CSE**	**CDAR**	**KEN**	**PTE**	**SUB**	**USQ**	**FTB**	**TUN**
2020	10.6	2.5	5.1	3.6	4.6	1.7	4.2	4.9
2021	15.6	2.6	4.5	3.9	2.6	2.1	3.7	5.6

The stations of Carvajal Sevillana (CSE) and Puente Aranda (PTE) were selected given that, according to Table IV,Puente Aranda includes data collected between 2013 and 2021,while the Carvajal station has shown the highest indexes over the past 6 years. The data is measured in [µg/m3].

Tables V and VI represent a statistical summary of the data that is delivered annually by the Environment Secretary.

TABLE V. Descriptive analysis of SO2 rate in Carvajal- sevillana station

Carvajal Sevillana	
Media	13.95
Moda	15.6
Desviación estándar	1.75
Rango	5
Mínimo	10.6
Máximo	15.6
Suma	97.7
Cuenta	7

[a] *Source: Authors*

Tables 5 and 6 were built to provide a statistical point of view regarding the data delivered every year by the environment agency. Although there is enough data to carry out this analysis for all 19 monitoring stations, the study only included the stations of Carvajal-Sevillana (having the highest SO2 rates of the city) and Puente Aranda (having the highest volume of data collected over the past nine years).

TABLE VI. Descriptive analysis of SO2 rate in puente aranda station

Puente Aranda	
Media	3.86
Moda	4.5
Desviación estándar	0.52
Rango	1.5
Mínimo	3
Máximo	4.5
Suma	34.8
Cuenta	9

a. *Source: Authors*

A comparative analysis of the monitoring stations shows that the Carvajal-Sevillana facility has the highest SO2 mean over the last 9 years (13.95 [µg/m3]) compared to the other stations since it is in an area with significant vehicle traffic. The Puente Aranda station encompasses a considerable numberof industrial facilities in Bogotá and the equivalent of a quarterof the Carvajal rate with 3.8 [µg/m3].

As seen in Table IV, the monitoring station data is not characterized by significant changes; hence, the standard deviation of Tables 5 and 6 exhibits relatively small values given that the data is grouped within a specific range. The patterns shown by the measurement devices are worrying, especially for the health of the local population since the highest values tend to appear more often. The mode for PuenteAranda is 4.5 [µg/m3] and the mode for Carvajal-Sevillana is 15.6 [µg/m3] which represent peak values for both stations. The difference between the highest and lowest values over the past 9 years in Carvajal is close to 5 [µg/m3] while the same difference stands at 1.5 [µg/m3] for Puente Aranda.

Lastly, a person who frequently lived in Puente Aranda between 2013 and 2021 has inhaled approximately 0.013 tons of SO2, while Carvajal-Sevillana outputs an equivalent of 0.037 tons of sulfur dioxide over the same period. This revealsthe notorious danger to which the local inhabitants are exposed.

B. Mortality caused by Acute Respiratory Infections (ARIs)and pneumonia

A graphic analysis was performed regarding the mortality rates derived from acute respiratory infection (ARI) and pneumonia in children under the age of 5 over the past decade. Furthermore, the cough symptom rates for children under the age of 5 were also included, labeled for each neighborhood. The analysis centers mostly on the neighborhoods of Puente Aranda, Kennedy, and Tunjuelito, since the previously analyzed monitoring stations of Carvajal-Sevillana and PuenteAranda are in said areas.

It is important to point out that acute respiratory infection (ARI) can lead to certain diseases in the respiratory system, such as the aggravation of chronic affections or broncho-obstructive syndrome. These infections may have bacterial or viral causes and last less than 15 days. Similarly, they represent one of the main reasons for medical care all over the world, both in ambulatory consultations and hospitalizations, which are among the main causes of mortality.

The most vulnerable population to these infections is comprised of children under the age of 5 and elderly people. According to the World Health Organization, exposure to air contamination contributed to 7.9% of the global disease burden [17-18].

Fig. 4 and 5 depict the deaths in the city of Bogotá over the past 10 years due to ARIs and pneumonia, respectively, in a population below the age of 5.

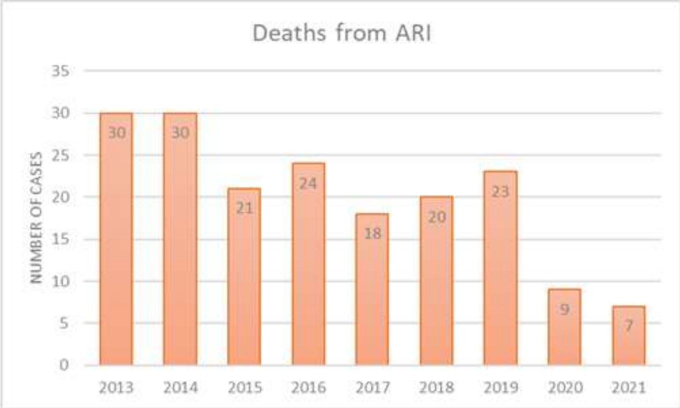

Fig. 4. Annual deaths from acute respiratory infection.

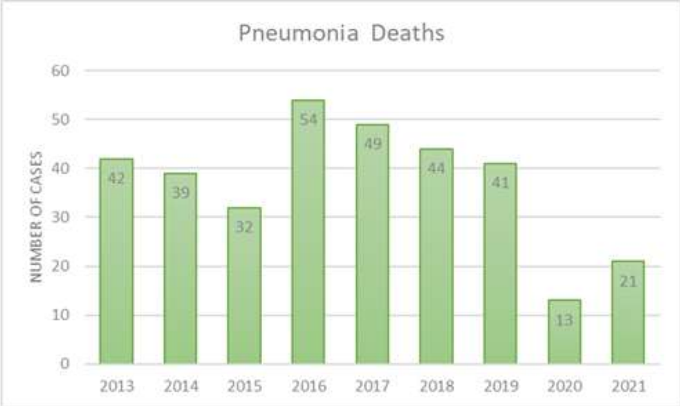

Fig. 5. Annual deaths from pneumonia.

Fig. 5 shows that there was an increased number of deaths between 2013 and 2019, with an average of 20 deaths from ARI and 37 from pneumonia, with the latter being the most dangerous for children under 5 years old.

Both deaths from respiratory infections and pneumoniahave decreased in 2020 and 2021 compared to the 2013-2019 period, mainly due to the COVID-19 pandemic. The health emergency forced the population to take measures such as confinement and significantly cut back on daily road traffic andindustrial activity.

a) Correlation analysis of pneumonia rate

Fig. 6 describes the relationship between the mortality rates linked to pneumonia and their correspondence with annual concentrations of SO2 in Bogotá, taking into account the effects of COVID-19.

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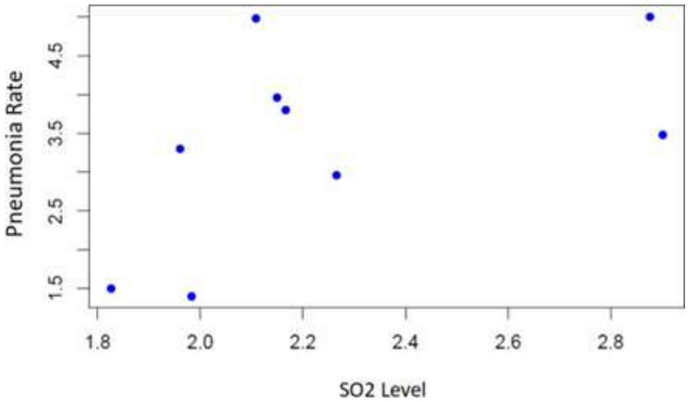

Fig. 6. Annual mortality rates from pneumonia vs annual concetrations of SO2 in Bogotá, considering the effects of COVID-19

In the scenario that contemplates the effects of COVID-19, the Goodman-Kruskal and Spearman tests delivered values of $\rho = 0.195$ and $\rho = 0.2001$, respectively. This implies a weak statistical correlation between the SO2 levels and death rates from pneumonia in Bogotá. In other words, the concentrations of SO2 are not responsible for deaths from pneumonia in children under the age of 5.

On the other hand, Fig. 7 presents the relationship between the mortality rates linked to pneumonia and their correspondence with annual concentrations of SO2 in Bogotá without considering the effects of COVID-19.

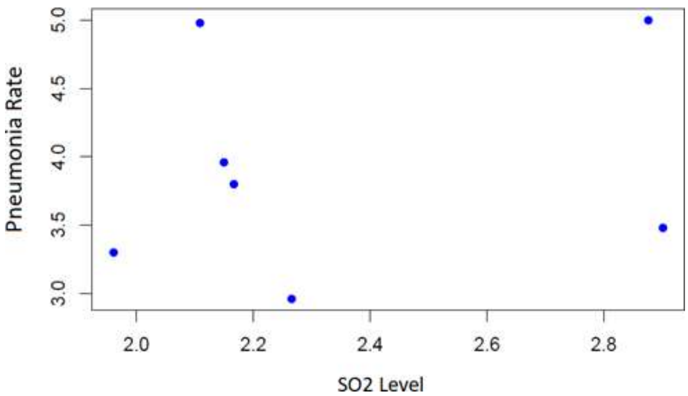

Fig. 7. Annual mortality rates from pneumonia vs annual concentrationsof SO2 in Bogotá, without considering the effects of COVID-19.

By excluding the data from 2020 and 2021, marked by the COVID-19 pandemic, the resulting test values were $\rho = 0.8891$ and $\rho = 0.9635$, respectively. These results translate into a potential statistical correlation between SO2 levels and mortality rates from pneumonia in Bogotá. This suggests that there could be a connection between SO2 concentrations and pneumonia-related deaths in children under the age of 5.

b) Correlation analysis of the ARIs rates

Fig. 8 presents a correlation between the mortality rates linked to ARI and their correspondence with annual concentrations of SO2 in Bogotá, taking into account the effects of COVID-19.

In the scenario that considers the effects of COVID-19, the application of Goodman-Kruskal and Spearman testing resulted in respective values of $\rho=0.4568$ and $\rho=0.4461$. These results indicate a weak statistical correlation between SO2 levels and the mortality rates linked to ARI in Bogotá. In this scenario, SO2 concentrations are not linked to deaths under the age of 5.

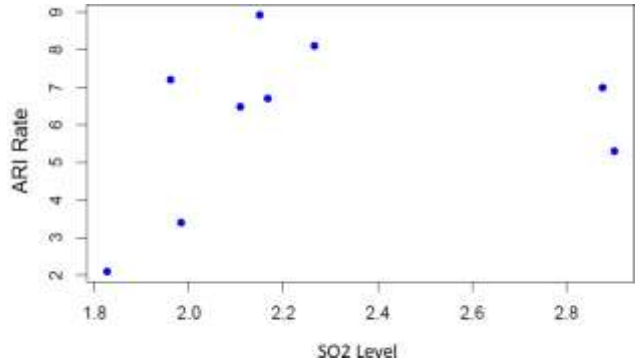

Fig. 8. Annual mortality rates from ARIs vs annual concentrationsof SO2 in Bogotá, considering the effects of COVID-19.

Fig. 9 shows a relationship between mortality rates linked to ARI and their correspondence with annual concentrations of SO2 in Bogotá, without considering the effects of COVID-19.

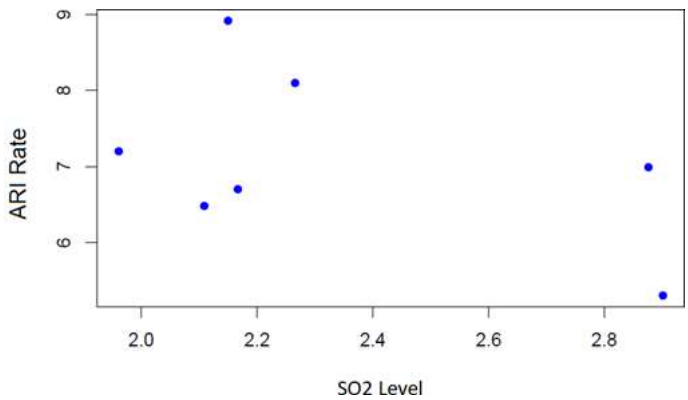

Fig. 9. Mortality rates from pneumonia VS annual concentrations of SO2 in Bogotá, without considering the effects of COVID-19

By excluding the data from 2020 and 2021, marked by the COVID-19 pandemic, the resulting test values were $\rho = 0.8891$ and $\rho = 0.9635$, respectively. These results translate into a potential statistical correlation between SO2 levels and mortality rates from ARI. This suggests that there could be a connection between SO2 concentrations and ARI-related deaths in children under the age of 5.

C. Cough symptoms in children under the age of five

Fig. 10 plots the symptom rates divided into the neighborhoods of Kennedy and Tunjuelito, since they are located within the monitoring range of the Carvajal-Sevillana station (CSE).

It is concluded that 2013, 2016, and 2018 were the periods marked by a higher presence of cough symptoms in children under the age of 5 in neighborhoods of the city. This is consistent with Fig. 3, which plotted high SO2 concentrations at the monitoring station in Carvajal-Sevillana.

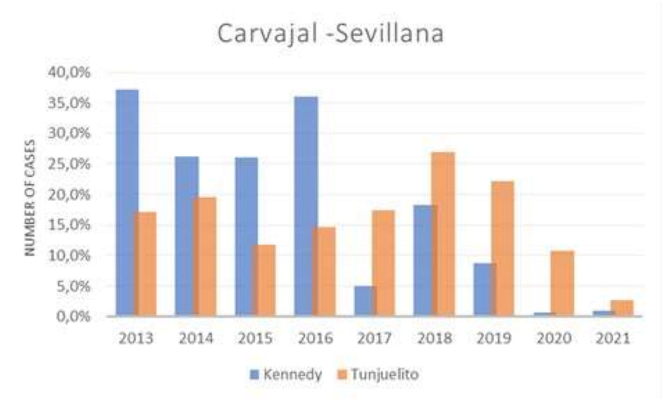

Fig. 10. Cough symptoms in children under the age of 5 inKennedy and Tunjuelito neighborhoods.

Fig. 11 reveals that 2013, 2014, and 2015 were the periods marked by the most symptoms among children under the age of 5 in Puente Aranda. Comparing the data with Fig. 3 showsa match in the periods with the highest concentrations of SO2 in the station of Puente Aranda.

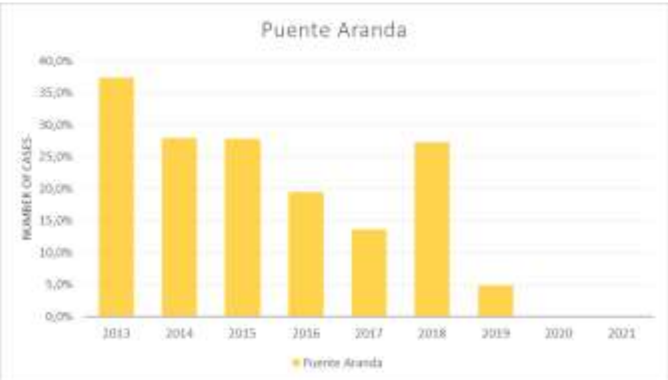

Fig. 11. Cough symptoms in children under the age of 5 in thePuente Aranda neighborhood.

TABLE VII. Correlation between cough symptoms and SO2 concentration levels

Neighborhood	Scenario	P-Value Goodman-Kruskal	P-Value Spearman	Level of correlation
Sevillana and Puente Aranda (cough)	with COVID-19	0.5695	0.6239	Moderate
	without COVID-19	0.8887	0.9446	Casualty
Bogotá (pneumonia)	with COVID-19	0.1950	0.2001	High
	without COVID-19	0.8891	0.9635	Casualty
Bogotá (IRA)	with COVID-19	0.4568	0.4460	Moderate
	without COVID-19	0.4155	0.5052	Moderate

The analysis of Fig. 3, 4, and 5 shows that the highest mortality rates regarding acute respiratory infections and pneumonia are consistent with the periods with the highest SO2 concentrations recorded in the stations of Carvajal- Sevillana and Puente Aranda. These findings suggest that cough symptoms and mortality rates could be related to the increase in SO2 concentrations in these parts of the city, whichare highly industrialized or represent important traffic roadways. A correlation analysis based on the Goodman- Kruskal and Spearman methods leads to the results presented in Table VII.

These results highlight the importance of monitoring and regulating SO2 emissions in Bogotá to protect the air quality and the health of the local inhabitants, especially in the most affected areas. It is essential to implement policies to reduce the concentrations of this contaminant and promote a healthier environment for all citizens

IV. RECOMMENDATIONS

After collecting relevant information on sulfur dioxide and its effects on the human body, it is appropriate to give a series of recommendations to the reader in case there is an impending exposure to this gas:

- Direct exposure to sulfur dioxide sources must be limited as much as possible. The use of masks is recommended to avoid inhalation of the particles. According to the National Institute for Occupational Safety and Health (NIOSH) in the United States, N95masks are highly recommended since these can filter 95% of the particles.
- In places with high concentrations of SO2, physical activity should be avoided until the concentrations arelower since the respiratory tracts can suffer from inflammation.
- Eye irritation is another health problem caused by SO2. In the event of feeling this symptom, the user should use protection goggles until the presence of gases is reduced.
- In the case of living near carbon dioxide sources, all water storage units (recipients, ponds) should be covered to avoid the creation of the mineral acidknown as thiosulphuric acid, which is harmful to human health.
- It is essential to take preventive measures to protect our health. The use of masks, frequent hand washing and the reduction of exposure to mobile and stationarySO2 sources are some of these measures. Although the studied areas have not exceeded the established limits, there is a progressive increase in the presence of the gas in the environment. This scenario could have a negative impact on the health of the population, both in the medium and long terms. The welfare of the inhabitants should be prioritized, and adequate precautions should be taken to maintain a healthy environment.

V. CONCLUSIONS

It is concluded that the statistical correlations can vary depending on the context, considering scenarios both with and without the impact of COVID-19. The analysis based on Goodman-Kruskal and Spearman tests revealed a significant relationship between the mortality rates from pneumonia and SO2 emissions. This supports the hypothesis that the contamination from SO2 has a considerable impact on the health of people under the age of 5.

After the analysis, it was also confirmed that the reduction of mortality rates from acute respiratory infections (ARIs) and pneumonia in 2020 and 2021 could be attributed, at least partially, to the restrictions imposed during the COVID-19 pandemic, such as confinement of the general population and reduction of industrial activity and vehicle traffic. As a result, a correlation between the concentrations of sulfur dioxide (SO2) and cough symptoms was established through the analysis of data excluding 2020 and 2021, which were strongly influenced by the pandemic. This suggests that the atmospheric contamination, especially derived from SO2, may have an influence on the prevalence of symptoms in children under the age of five in specific neighborhoods.

The results based on the different analyses highlight the relevance of implementing regulatory measures and local control of emissions to protect the health of children and other residents. Although some actions have been set in motion to mitigate the emissions of SO2 from fossil fuel vehicles, there is an increasing number of vehicles that produce this gas, which is why an environmental policy is needed to regulate these transportation systems, fostering electric vehicles as an alternative.

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