VOL. 17, NO. 14, JULY 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

DETERMINATION OF AN ENVIRONMENTAL JUSTICE INDEX ASSOCIATED WITH AIR QUALITY IN THE CITY OF BOGOTA

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ABSTRACT

The main characteristics in the distribution of the territory are due to economic, social, cultural, sanitary and health factors and the availability of natural resources; throughout the research carried out on environmental goods in the territory, it has been identified that such distribution is not carried out in an equitable manner, which contradicts the principle of environmental justice. Particularly, in terms of air quality, being an intangible good, the level of perception and environmental management processes to have access to better quality air is difficult, behavior that is reflected in the quality of life of people, specifically in terms of public health. this work develops an index of environmental justice associated with air quality that allows identifying equity or inequity in the access and quality of the resource by the population, taking as a basis for this study, the composition of the air in the city of Bogotá (Colombia).

Keywords: air quality, equity, index, environmental justice and territory.

INTRODUCTION

Environmental Justice refers to the disproportionate distribution of environmental "goods" and "bads", a situation that falls mainly on racial and ethnic minorities, low-income populations and other vulnerable groups, due to the burden of the bads and the scarcity of the goods.) [1]; Currently, according to WHO [2], inequality is identified in terms of access, quality, and availability of natural resources such as water, air and soil throughout the world's territory, an aspect that raises concerns about how the environment impacts people's lives in different magnitudes [3].

Regarding air quality, at the global level, the case of China is identified, which is considered one of the countries with the largest total ecological footprint [4], highlighting a high affectation by Particulate Matter below 2.5 micrometers ($PM_{2.5}$), which is associated with coal combustion, motor vehicle emissions and industrial sources mainly, evidencing that this behavior is associated with the highest risk of morbidity and mortality from cardiovascular and respiratory diseases [5]. For its part, at the local level, in the city of Bogotá heterogeneity is identified in the composition of the air throughout the localities that compose it, highlighting that in the locality of Puente Aranda the permissible limit of particulate matter less than 10 micrometers (PM_{10}) is exceeded in 75% of the measurements; in contrast, the lowest levels of pollution in the city are presented in the locality of Barrios Unidos. According to the above, the two sectors present significant differences in terms of land use, number of inhabitants and socioeconomic stratum, which in turn generates inequality between the exposure to pollution of the inhabitants in each sector.

In terms of public health, air pollution presents an important health risk, generating implications in cerebrovascular accidents, lung cancer, chronic and acute pneumopathies, inflammation in the pulmonary interstitium and coagulation factors in the blood [5]. For the local case, in Bogotá, a positive relationship is found between PM_{10} concentrations and the number of consultations for respiratory diseases in the locality of Puente Aranda, according to the study conducted [6]. Similarly, if we analyze its opposite, the urban, we will have a distractor of rural development that, through the agglomeration of population, has concentrated development in industrialization and access to services, which has not been in harmony with the source of resources where the country's main income and providers of environmental goods and services originate.

Due to the importance of the implications in terms of health caused by exposure to air pollutants, it is necessary to determine the extent to which the composition of the air influences the quality of life of the population and the inequalities that this problem entails. In accordance with the above, this study develops an index to measure the Environmental Justice associated with air quality in the city of Bogota, to determine the environmental inequalities associated with exposure to air pollutants.

MATERIAL AND METHODS

The study is conducted in the city of Bogotá, Colombia; the climate is moderately cold with an average temperature of 14°C. Particularly, the monitoring points corresponding to the Air Quality Monitoring Network (RMCAB) are analyzed, which in total are thirteen (13) and are located in the localities of Suba, Usaquén, Engativá, Barrios Unidos, Santa Fe, Fontibón, Puente Aranda, Kennedy, Tunjuelito and San Cristóbal (See Figure-1); each of which determines Wind Speed and Direction, Temperature, Precipitation, Solar Radiation, Relative Humidity, Atmospheric Pressure, PM_{10}, $PM_{2.5}$, PST, O_3, NO_X, CO and SO_X.

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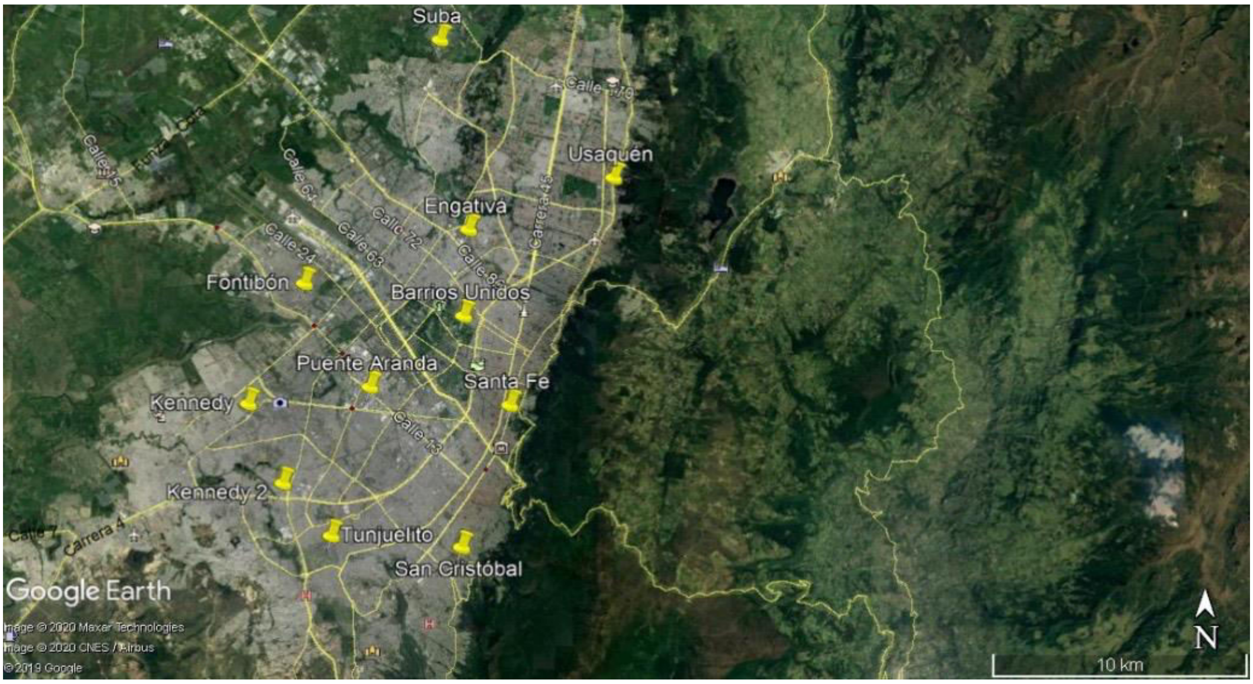

Figure-1. Monitoring points.

The research is composed of 4 phases, as identified in Figure-2; in Phase 1 the systematic search of information is performed through databases such as Google Scholar and Science Direct, which, based on previous studies allows identifying the variables involved in the determination of Environmental Justice associated with air quality in urban areas [7]. Subsequently, the selection and categorization of variables is carried out following the methodology of Dunnete [8] [10] and the collection of information, which corresponds to a space of time between the years 2007 to 2017, belongs to the RMCAB and entities such as the Environmental Observatory of Bogotá, Secretariat of Planning of Bogotá, DANE, Health Observatory of Bogotá, Special Unit of District Cadastre, Secretariat of Mobility and IDU.

In Phase 2, the subindex for each parameter is determined, starting with a principal components analysis, implementing the Varimax method [7]; subsequently, following the methodology presented by Fernández and Solano (2005), the curves are made based on mathematical equations, using the SPSS Version 23 software. Once the subindexes for each parameter are obtained, in Phase 3 the environmental justice index associated with air quality is formulated by means of the aggregation of subindexes [7]; in Phase 4, the index is applied to the case study of the city of Bogotá, graphically representing and analyzing each of the factors obtained.

RESULTS AND DISCUSSIONS

Selection of parameters or variables. Through the systematic search for information, 154 research studies were obtained, of which 20.1% were discarded because they were carried out in rural areas; in this sense, there is a total of 123 research studies, of which 37% correspond to replicas, because the search was carried out in two databases. Once the variables worked on in these investigations are identified, the categorization is carried out according to the Dunnete methodology [10] the resulting categories with their respective variables are: Health (ERA in children under 14 years of age, Mortality by ERA in children under 70 years of age and Low gestational age weight), Geography (Sources of Contamination, Rural Land, Urban Land, Average commercial land area, Average industrial land area, Average area in services, trees per locality, tree coverage and slope), Population (inhabitants per locality, inhabitants under 5 years of age per locality, inhabitants over 70 years of age per locality), inhabitants over 70 years old per locality), Pollutants (PM_{10} and $PM_{2.5}$), Meteorology (wind speed, wind direction and precipitation), Education (primary school enrollment and education coverage), Economy (Gini coefficient, housing tenure, land prices, Multidimensional Poverty Index, socioeconomic stratum and occupancy rate) and Transportation (road network).

Determination of the sub-index for each parameter. This phase begins with the principal components analysis performed in SPSS Version 23 software, selecting a factorial model, according to the methodology presented by Samboní [7]; as a product of this process, the reduction of dimensions is obtained, in descending order, the variables with the greatest variation throughout the period analyzed (years 2007 to 2017) are the price of land for each of the uses (service, commercial and industrial), inhabitants per locality, number of trees, students enrolled in the education sector, inhabitants under 5 years of age, inhabitants over 70 years of age and cases of respiratory diseases. In contrast, the lowest variation is found among the Gini coefficient, wind speed, precipitation, slope and the multidimensional poverty index.

With respect to the behavior between variables, it is highlighted that for the variables of the health group, a direct relationship is presented with the sources of pollution, number of trees, tree cover, number of inhabitants, concentrations of $PM_{2.5}$ and PM_{10}, students enrolled, land price and road network [8]; in contrast, an inverse behavior is highlighted with respect to commercial land use and wind direction and speed. Additionally, particulate matter (both $PM_{2.5}$ and PM_{10}) refers a direct relationship with industrial and service land use, urbanized area, wind direction and speed, and road network; in contrast, the relationship is inverse with respect to stratum 4 population [9].

By means of the Total Variance Explained, in the SPSS Version 23 Software, the number of components formed is established, which are 8, considering that one of the conditions to perform the extraction of this information corresponds to eigenvalues greater than 1, an aspect that was initially defined in the factor analysis. Subsequently, to define the variables corresponding to each component, the information provided by the Component Matrix is considered, by means of which the variables are grouped according to the highest variance value found (in absolute value). In this sense, the following groupings are obtained [10]

- Component 1: Inhabitants/Locality, Inhabitants under 5 years old, Primary School Enrolled, Road Network, Trees/Locality, Tree Cover, Inhabitants over 70 years old, Low Weight Gestational Age, Cases of Respiratory Diseases, Mortality due to Respiratory Diseases, Commercial Land Area, Stratum 5.
- Component 2: Service Land Area, Urbanized Areas, Rural Areas, Stratum 1, Wind Direction, PM10, $PM_{2.5}$, Stratum 3, Gini Coefficient, Stratum 6.
- Component 3: Stratum 2, Stratum 4, Industrial Land, Service Land, Slope, Commercial Land, Housing Tenure.
- Component 4: Wind Speed, Multidimensional Poverty Index, Education Coverage.
- Component 5: Pollution Sources and Industrial Land.
- Component 6: Values are too low to determine relationship.
- Component 7: Values are too low to determine relationship.
- Component 8: Precipitation and Occupancy Rate

The determination of subindices is performed by means of curves based on mathematical equations, so that once the scatter plots are obtained, it is pertinent to identify the regression model to be implemented. Consistent with the above:

Null hypothesis: $H_0: X_i = Y_i$
Alternative hypothesis: $H_1: X_i \neq Y_i$

In this sense, according to the T-test performed by means of the SPSS Version 23 software, the significance level for each variable is obtained, which is greater than 0.05 in all the variables analyzed, so the null hypothesis is accepted, indicating that the distribution of the data is normal and fits a linear model

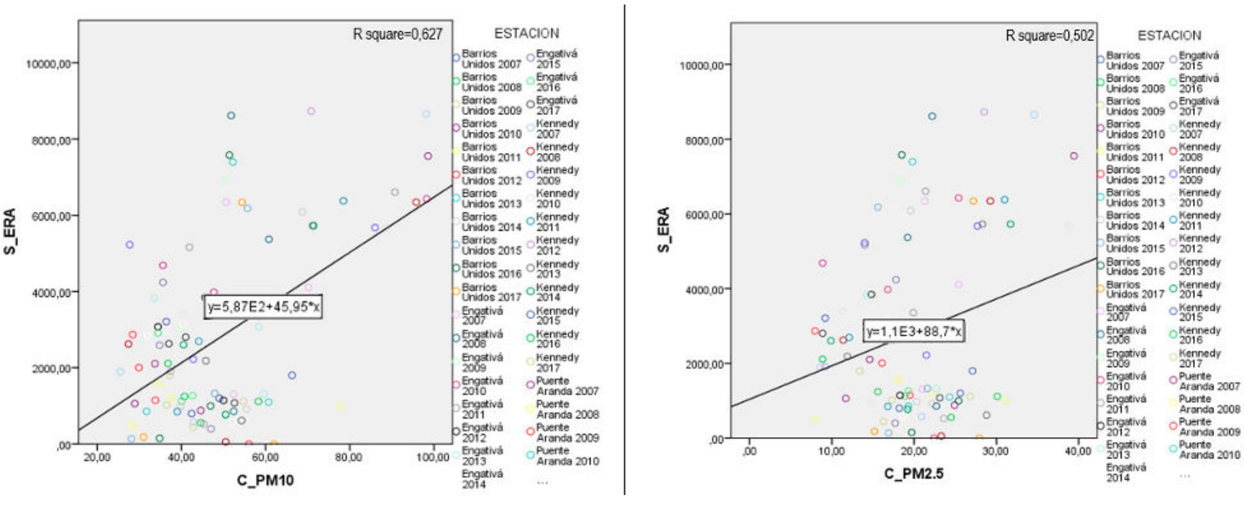

Figure-2. Cases of respiratory diseases.

Due to the number of variables and components, a sample calculation for obtaining the mathematical equations is presented below, pointing out the case of respiratory diseases:

$$Y_{ERA-PM10} = 5,87 * 10^2 + 45,95X$$
$$Y_{ERA-PM2,5} = 1,1 * 10^3 + 88,7X$$

subsequently, Table-1 presents the consolidated equations, which correspond to the subindices organized by principal components.

Formulation of the environmental justice index associated with air quality by aggregation of sub-indices. The index was formulated by aggregating sub-indices according to the methodology established by Helmond [11], implementing the weighted average method for each of the factors obtained:

ARPN Journal of Engineering and Applied Sciences

$$IC = \frac{1}{n}\sum_{i=1}^{n} q_i$$

In total, 6 factors are obtained, of which the analysis can be performed based on PM_{10} and $PM_{2.5}$ concentrations; Table-2 shows the environmental justice index associated with air quality, considering each of its components (6). To perform the calculation, the subscripts of Table-2 are replaced by the equations presented in Table-1, leaving PM_{10} and $PM_{2.5}$ concentrations as independent variables.

To define the quality ranges, is considered, where the normative limits are considered, as well as the records of historical behavior for previously conducted studies (Table-3)

ARPN Journal of Engineering and Applied Sciences

Table-1. Sub indexes organized by principal components.

FACTOR	**COMPONENT**	**ECUATION PM_{10}**	**R^2Equation PM_{10}**
1	Inhabitants	$Y_{H-PM10} = 1{,}63E5 + 7{,}26E3X$	0,531
	Inhabitants under 5 years old	$Y_{H5a-PM10} = 3{,}08E3 + 6{,}26E2X$	0,506
	Students enrolled	$Y_{EM-PM10} = 5{,}21E3 + 6{,}84E2X$	0,534
	Road network	$Y_{MV-PM10} = 1{,}68E2 + 6{,}73X$	0,494
	Trees	$Y_{A-PM10} = 9{,}4E4 - 5{,}77E2X$	0,586
	Tree coverage	$Y_{CA-PM10} = 89{,}72 - 0{,}68X$	0,563
	Inhabitants over 70 years old	$Y_{H70A-PM10} = 1{,}66E4 + 61{,}43X$	0,609
	Low Gestational Weight	$Y_{BP-PM10} = -58{,}18 + 4{,}65X$	0,672
	Cases of Respiratory Diseases	$Y_{ERA-PM10} = 5{,}87E2 + 45{,}95X$	0,627
	Cases Mortality due to respiratory diseases	$Y_{MORT-PM10} = 6{,}28 + 0{,}14X$	0,509
	Average commercial land area	$Y_{UC-PM10} = 1{,}05E2 + 0{,}15X$	0,519
	Stratum 5	$Y_{E5-PM10} = 4{,}73 - 0{,}04X$	0,500
2	Average floor area services	$Y_{US-PM10} = 1{,}83E2 + 1{,}97X$	0,559
	Urban Areas	$Y_{URB-PM10} = 41{,}31 + 0{,}66X$	0,464
	Rural Areas	$Y_{SR-PM10} = 58{,}69 - 0{,}66X$	0,464
	Stratum 1	$Y_{E1-PM10} = 5{,}25 - 0{,}05X$	0,400
	Wind direction	$Y_{DV-PM10} = 1{,}06E2 + 1{,}29X$	0,595
	Stratum 3	$Y_{E3-PM10} = -0{,}68 + 0{,}89X$	0,703
	Gini Coefficient	$Y_{CG-PM10} = 0{,}49 - 4{,}13E - 4X$	0,661
	Stratum 6	$Y_{E6-PM10} = 5{,}29 - 0{,}07X$	0,506
3	Stratum 2	$Y_{E2-PM10} = 11{,}18 + 0{,}97X$	0,696
	Stratum 4	$Y_{E4-PM10} = 21{,}09 - 0{,}26X$	0,515
	Industrial Land Price	$Y_{\$I-PM10} = 1{,}49E6 - 1{,}12E4X$	0,537
	Land Price Services	$Y_{\$S-PM10} = 1{,}95E6 - 1{,}67E4X$	0,578
	Commercial Land Price	$Y_{\$C-PM10} = 1{,}76E6 - 1{,}41E4X$	0,575
	Land Slope	$Y_{P-PM10} = 3{,}64 - 0{,}02X$	0,642
	Housing tenure	$Y_{TV-PM10} = 43{,}32 - 0{,}13X$	0,635
4	Wind Speed	$Y_{VV-PM10} = 1{,}07 + 0{,}01X$	0,489
	Multidimensional Poverty Index	$Y_{IPM-PM10} = 6{,}73 - 0{,}02X$	0,708
	Education coverage	$Y_{CE-PM10} = 62{,}09 + 0{,}82X$	0,786
5	Contamination Sources	$Y_{FC-PM10} = 5{,}58E2 - 2{,}09X$	0,576
	Average industrial land area	$Y_{UI-PM10} = 1{,}07E2 + 8{,}65X$	0,428
6	Precipitation	$Y_{PRECP-PM10} = 2{,}6 - 5{,}12E - 3X$	0,511
	Occupancy Rate	$Y_{TOC-PM10} = 60{,}18 - 0{,}09X$	0,504
FACTOR	COMPONENT	ECUATION $PM_{2.5}$	R^2Equation $PM_{2.5}$
1	Inhabitants	$Y_{H-PM2.5} = 2{,}28E5 + 1{,}48E4X$	0,465
	Inhabitants under 5 years old	$Y_{H5a-PM2.5} = 9{,}76E3 + 1{,}22E3X$	0,411
	Students enrolled	$Y_{EM-PM2.5} = 1{,}66E4 + 1{,}13E3X$	0,481
	Road network	$Y_{MV-PM2.5} = 2{,}54E2 + 12{,}5X$	0,486
	Trees	$Y_{A-PM2.5} = 1{,}03E5 - 2{,}01E3X$	0,639
	Tree coverage	$Y_{CA-PM2.5} = 98{,}15 - 2{,}26X$	0,588
	Inhabitants over 70 years old	$Y_{H70A-PM2.5} = 1{,}73E4 + 1{,}16E2X$	0,576
	Low Gestational Weight	$Y_{BP-PM2,5} = 23{,}23 + 7{,}48X$	0,462
	Cases of Respiratory Diseases	$Y_{ERA-PM2,5} = 1{,}1E3 + 88{,}7X$	0,502
	Cases Mortality due to respiratory diseases	$Y_{MORT-PM2,5} = 8{,}79 + 0{,}23X$	0,495
	Average commercial land area	$Y_{UC-PM2.5} = 97{,}61 + 0{,}74X$	0,454
	Stratum 5	$Y_{E5-PM2.5} = 6{,}76 - 0{,}2X$	0,523
2	Average floor area services	$Y_{US-PM2.5} = 1{,}77E2 + 5{,}18X$	0,574
	Urban Areas	$Y_{URB-PM2,5} = 37{,}04 + 1{,}87X$	0,502
	Rural Areas	$Y_{SR-PM2,5} = 62{,}96 - 1{,}87X$	0,502

ARPN Journal of Engineering and Applied Sciences

FACTOR	COMPONENT	ECUATION PM_{10}	R^2Equation PM_{10}
	Stratum 1	$Y_{E1-PM2.5} = 6{,}11 - 0{,}18X$	0,489
	Wind direction	$Y_{DV-PM2.5} = 97{,}05 + 3{,}68X$	0,655
	Stratum 3	$Y_{E3-PM2.5} = 1{,}29 + 2{,}12X$	0,663
	Gini Coefficient	$Y_{CG-PM2.5} = 0{,}48 - 8{,}82E - 4X$	0,600
	Stratum 6	$Y_{E6-PM2.5} = 8{,}7 - 0{,}34X$	0,581
3	Stratum 2	$Y_{E2-PM2{,}5} = -0{,}37 + 1{,}87X$	0,552
	Stratum 4	$Y_{E4-PM2.5} = 18{,}98 - 0{,}55X$	0,440
	Industrial Land Price	$Y_{\$I-PM2.5} = 1{,}24E6 - 1{,}52E4X$	0,432
	Land Price Services	$Y_{\$S-PM2.5} = 1{,}95E6 - 1{,}67E4X$	0,465
	Commercial Land Price	$Y_{\$C-PM2{,}5} = 1{,}48E6 - 2{,}11E4X$	0,479
	Land Slope	$Y_{P-PM2.5} = 3{,}62 - 0{,}06X$	0,525
	Housing tenure	$Y_{TV-PM2.5} = 44{,}01 - 0{,}37X$	0,503
4	Wind Speed	$Y_{VV-PM2.5} = 0{,}99 + 0{,}03X$	0,535
	Multidimensional Poverty Index	$Y_{IPM-PM2.5} = 6{,}19 - 0{,}01X$	0,633
	Education coverage	$Y_{CE-PM2.5} = 69{,}02 + 1{,}69X$	0,656
5	Contamination Sources	$Y_{FC-PM2.5} = 7{,}15E2 - 14{,}41X$	0,422
	Average industrial land area	$Y_{UI-PM2.5} = 2{,}88E2 + 12{,}46X$	0,486
6	Precipitation	$Y_{PRECP-PM2.5} = 2{,}41 - 3{,}19E - 3X$	0,481
	Occupancy Rate	$Y_{TOC-PM2.5} = 56{,}44 - 0{,}04X$	0,497

Table-2. Environmental justice index formula associated with air quality.

FACTOR	Environmental Justice Index Formula Associated with Air Quality by means of the PM_{10}
1	$IJA_{PM10-FACTOR1} = \left(\begin{matrix} Y_{H-PM10} + Y_{H5a-PM10} + Y_{EM-PM10} \\ + Y_{MV-PM10} + Y_{A-PM10} + Y_{CA-PM10} \\ + Y_{H70A-PM10} + Y_{BP-PM10} + Y_{MORT-PM10} \\ + Y_{ERA-PM10} + Y_{UC-PM10} + Y_{E5-PM10} \end{matrix}\right)/12$
2	$IJA_{PM10-FACTOR2} = (Y_{US-PM10} + Y_{URB-PM10} + Y_{SR-PM10} + Y_{E1-PM10} + Y_{DV-PM10} + Y_{E3-PM10} + Y_{CG-PM10} + Y_{E6-PM10})/8$
3	$IJA_{PM10-FACTOR3} = (Y_{E2-PM10} + Y_{E4-PM10} + Y_{\$I-PM10} + Y_{\$S-PM10} + Y_{\$C-PM10} + Y_{P-PM10} + Y_{TV-PM10})/7$
4	$IJA_{PM10-FACTOR\ 4} = (Y_{VV-PM10} + Y_{IPM-PM10} + Y_{CE-PM10})/3$
5	$IJA_{PM10-FACTOR5} = (Y_{FC-PM10} + Y_{UI-PM10})/2$
6	$IJA_{PM10-FACTOR6} = (Y_{PRECP-PM10} + Y_{TOC-PM10})/2$
Factor	Environmental Justice Index Formula Associated with Air Quality by means of the $PM_{2,5}$
1	$IJA_{PM10-FACTOR1} = \left(\begin{matrix} Y_{H-PM2,5} + Y_{H5a-PM2,5} + Y_{EM-PM2,5} \\ + Y_{MV-2,5} + Y_{A-PM2,5} + Y_{CA-PM2,5} \\ + Y_{H70A-PM2,5} + Y_{BP-PM2,5} + Y_{MORT-PM2,5} \\ + Y_{ERA-PM2,5} + Y_{UC-PM2,5} + Y_{E5-PM2,5} \end{matrix}\right)/12$
2	$IJA_{PM2,5-FACTOR2} = \left(Y_{US-PM2.5} + Y_{URB-PM2.5} + Y_{SR-PM2.5} + Y_{E1-PM2.5} + Y_{DV-PM2.5} + Y_{E3-PM2.5} + Y_{CG-PM2,5} + Y_{E6-PM2.5}\right)/8$
3	$IJA_{PM2,5-FACTOR3} = (Y_{E2-PM2.5} + Y_{E4-PM2.5} + Y_{\$I-PM2.5} + Y_{\$S-PM2.5} + Y_{\$C-PM2.5} + Y_{P-PM2.5} + Y_{TV-PM2.5})/7$
4	$IJA_{PM2,5-FACTOR\ 4} = (Y_{VV-PM2.5} + Y_{IPM-PM2.5} + Y_{CE-PM2.5})/3$
5	$IJA_{PM2,5-FACTOR5} = (Y_{FC-PM2.5} + Y_{UI-PM2.5})/2$
6	$IJA_{PM2,5-FACTOR6} = (Y_{PRECP-PM2.5} + Y_{TOC-PM2.5})/2$

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Table-3. Environmental justice index formula associated with air quality.

LEVEL	CALCULATION BASIS	RANGE		OBSERVATION
		PM_{10}	$PM_{2,5}$	
1	0 µg/m³for the PM_{10} y $PM_{2.5}$	FACTOR 1: less than 23566	FACTOR 1: less than 31354	ENVIRONMENTAL FAIRNESS: Corresponds to the absence of impact by pollutants, which indicates that there is no environmental injustice.
		FACTOR 2: less than 50	FACTOR 2: less than 49	
		FACTOR 3: mayor a 742868	FACTOR 3: mayor a 667152	
		FACTOR 4: less than 23	FACTOR 4: less than 25	
		FACTOR 5: less than 333	FACTOR 5:greater than 502	
		FACTOR 6: greater than 31	FACTOR 6: greater than 29	
2	Permissible limits [2]: 10 µg/m³ para el $PM_{2,5}$ y 20 µg/m³ PM_{10}	FACTOR 1: 23567 a 37085	FACTOR 1: 31355 - 44157	SLIGHT ENVIRONMENTAL INJURY: No short-term human health impact recorded [2]
		FACTOR 2: 51 a 60	FACTOR 2: 50 a 62	
		FACTOR 3: 622870 a 742867	FACTOR 3: 591439 a 667151	
		FACTOR 4: 22 a 29	FACTOR 4: 26 a 31	
		FACTOR 5: 334 a 398	FACTOR 5:492 a 501	
		FACTOR 6: 30 a 31	FACTOR 6: 29	
3	Permissible limits forResolution 2254 de 2017: 25 µg/m³ para el $PM_{2,5}$ y 40 µg/m³ PM_{10}	FACTOR 1: 37086 - 50604	FACTOR 1: 44158 -63361	ENVIRONMENTAL INJUSTICE FACTORS: For the levels mentioned above, there are conditions that affect human health.
		FACTOR 2: 61 a 70	FACTOR 2: 63 a 82	
		FACTOR 3:502872 a 622869	FACTOR 3: 477870 a 591438	
		FACTOR 4: 30 a 34	FACTOR 4: 32 a 40	
		FACTOR 5: 399 a 464	FACTOR 5:477 a 491	
		FACTOR 6: 29 a 30	FACTOR 6: 28	
4	Highest concentrations reported at the level of Bogotá: 40 µg/m³ para el $PM_{2,5}$ y 99 µg/m³ PM_{10}	FACTOR 1: 50605-90485	FACTOR 1: 63362-82565	MAXIMUM ENVIRONMENTAL INJUSTICE: Representation of the conditions in which the greatest inequity in access to air quality is evident.
		FACTOR 2: 71 a 100	FACTOR 2: 83 a 101	
		FACTOR 3: 148876 a 502871	FACTOR 3: 364300 a 477869	
		FACTOR 4: 35 a 50	FACTOR 4: greater than 48	
		FACTOR 5: 465 a 657	FACTOR 5: less than476	
		FACTOR 6: 27 a 29	FACTOR 6: less than28	

Application of the environmental justice index associated with air quality - Bogotá Case Study. The application is performed in the city of Bogota, taking as a reference the state of air quality for November 18, 2021, in terms of $PM_{2.5}$ and PM_{10} concentrations, collecting data from the Air Quality Monitoring Network which are presented in Table-4.

Table-4. Conditions case study - November 18, 2021.

Parámetro	PM_{10}	$PM_{2,5}$
Unidades	µg/m³	µg/m³
Usaquén	28,45	7,966
Santa Fe	29,9	16,1
San Cristóbal	27,7	14,0
Tunjuelito	42,8	21,5
Kennedy	70,2	25,4
Engativá	40	18,9
Suba	50,3	18,4
Barrios Unidos	31	15,2
Puente Aranda	46,5	18,1

For the case study, the results are presented graphically in Figures 3 and 4, which correspond to the Environmental Justice Index associated with Air Quality in Bogota with respect to PM_{10} and $PM_{2.5}$ respectively; the graphical representation shows the consolidated behavior described for the six (6) factors analyzed.

In the locality of Usaquén, a behavior of "slight environmental injustice" predominates with respect to the factors that describe $PM_{2.5}$, indicating that an inverse relationship is presented between the concentrations of particulate matter and population density [12], with respect to road mesh, number of trees and tree cover is confirmed, where an inverse trend is presented with respect to $PM_{2.5}$. With respect to land use and socioeconomic stratum, in the locality of Usaquén the population of stratum 3 and 6 predominates, behavior that is associated with the studies conducted by Ribeiro *et al.* (2019); on the other hand, an inverse behavior is evidenced between particulate matter and housing tenure and the population belonging to stratum 4.

For the case of "maximum environmental injustice", this behavior is presented with respect to $PM_{2.5}$in the locality of Kennedy, while with respect to PM_{10}, such condition is presented in the localities of Suba, Puente

Aranda, Kennedy and Tunjuelito, sectors that present the highest concentrations for particulate matter in the city and in turn, a direct relationship is identified with respect to population density, according to the environmental injustice factors [13]; Likewise, the areas of Kennedy and Suba have the highest number of students enrolled, cases of health problems and the greatest length of the road network, confirming the findings of Morelli [8]. On the other hand, an inverse behavior is identified between particulate matter with respect to the number of trees and tree cover.

The conditions of maximum environmental injustice coincide with the areas of greater urbanization, highlighting the localities of Tunjuelito, Kennedy and Puente Aranda, where 100% of the area is urban; In turn, for the areas of "maximum environmental injustice", stratum 3 prevails with respect to 1 and 6; on the other hand, the Gini coefficient is lower for the stations with the highest incidence of air pollution

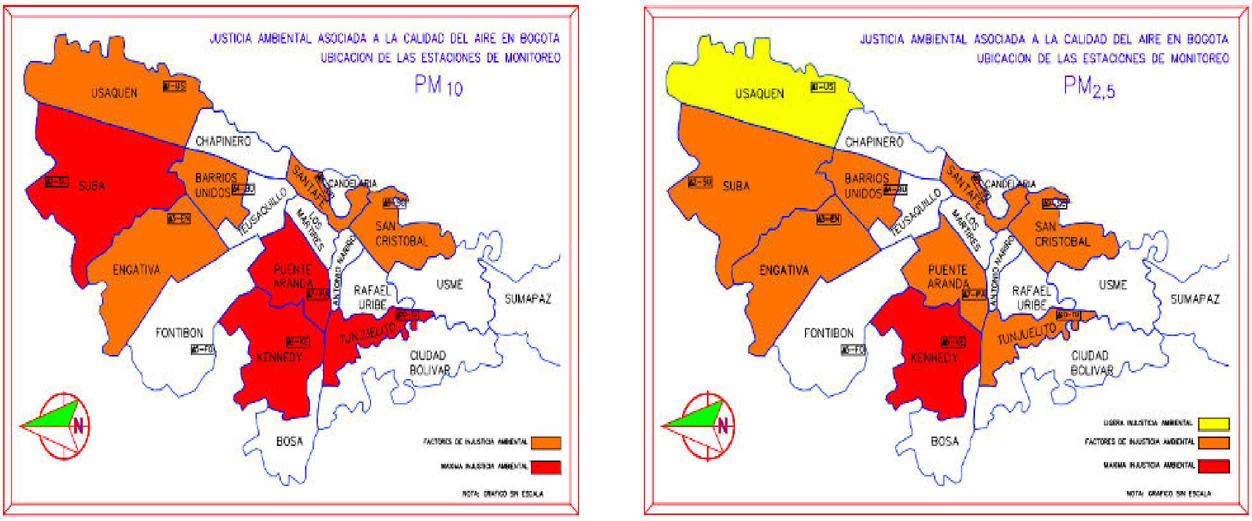

Figure-3. Results of the Environmental Justice Index associated with air quality in the city of Bogota (PM_{10}) and ($PM_{2.5}$).

4. CONCLUSIONS

Through the systematic review of the academic production worldwide, the variables through which environmental justice is determined are classified in Health (Mortality rate due to chronic respiratory disease in people over 70 years old, Low weight according to gestational age and Respiratory Diseases in children under 14 years old), Geography (percentage of urban space, land use by productive activity, number of trees per locality, (percentage of urban space, land use by productive activity, number of trees per locality, tree cover and land slope), population (population density, inhabitants under 5 years old and inhabitants over 70 years old), pollutants (particulate matter under 10 microns and 2.5 microns), meteorology (wind speed and wind direction), education (illiteracy), economy (household income, housing tenure, land prices, multidimensional poverty index, socioeconomic stratum and occupancy rate) and transportation (road network). According to the number of citations in scientific productions, the variables with the highest relevance are: Family Income (8%), PM10 (6%), PM2.5 (6%), Socioeconomic Stratum (5%), Road Grid (5%), Multidimensional Poverty Index (4%), Number of Trees per locality (4%) and Respiratory Diseases (4%).

The analysis of the information collected shows that the greatest relationship between the data corresponding to the same variable (according to the different sites evaluated) is found in the Gini coefficient, wind speed, precipitation, slope and the multidimensional poverty index; subsequently, the correlation between variables indicates that there is a direct relationship between health effects and the sources of contamination,

VOL. 17, NO. 14, JULY 2022 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

the number of trees, tree coverage per locality, number of inhabitants and particulate matter in the air (PM_{10} and $PM_{2.5}$). On the other hand, there is an inverse relationship between the area of land used for service activities and the Gini coefficient; likewise, the same behavior is maintained between particulate matter and sources of contamination, rural space, number of trees, precipitation,and housing tenure. By means of the principal components analysis, it is identified that the selected variables are grouped into six (6) components, which are called "Factors".

The formulation of the environmental justice index associated with air quality is done by means of a linear regression model and the aggregation of sub-indices by the weighted average method, which allows obtaining an index for each factor. Once applied to the case study in the city of Bogotá, it is obtained that the localities of Kennedy, Suba, Puente Aranda and Tunjuelito present the conditions of "maximum environmental injustice", both for PM_{10} and $PM_{2.5}$, behavior that is mainly related to the areas with the highest concentration of particulate matter population, high length of road network, cases of health affectations; in contrast, a low number of trees is identified. Additionally, with respect to land use, it is evident that the areas destined for commercial activities and services are exposed to particulate matter in the same proportion with respect to the areas destined for industrial use; on the other hand, the areas most marked by environmental injustice are associated with the population in stratum 2 and 3.

The localities of Usaquén, San Cristóbal, Santa Fe, Engativá and Barrios Unidos are classified as "Environmental Injustice Factors", for which the localities of Usaquén and San Cristóbal are favored by the eastern hills of the city and the rural area, despite the length of its road network, while in Barrios Unidos influence is identified by the land destined for service activities; On the other hand, Engativá reports that the environmental injustice factors are associated with the size of the population, finding that the student population is exposed to a greater proportion of particulate matter in the air, as well as a high length of road network and cases of health affectation. In general terms, wind direction has a direct relationship with respect to the presence of particulate matter in the air, while the relationship with the Gini coefficient is inverse.

However, with respect to the analysis of results, an exception is presented in the locality of Usaquén associated with the application of the Environmental Justice Index by means of $PM_{2.5}$, where a condition of Slight Environmental Injustice is identified, which is favored by the eastern hills, finding that in this zone the population belonging to stratum 5 and 6 predominates. Likewise, analysis factor 6 associated to $PM_{2.5}$, shows that in the study area there is a predominance of "Environmental Justice" and "Slight Environmental Injustice" conditions.

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