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Evaluation of air quality and health perception in the urban area of La Ceja (Antioquia, Colombia) through a community participation strategy

Evaluación de la calidad del aire y la percepción de la salud en la zona urbana de La Ceja (Antioquia, Colombia) mediante una estrategia de participación comunitaria

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RESUMEN

El monitoreo de la calidad del aire favorece la planificación urbana y la implementación de políticas que garanticen la salud pública. Buena parte de los municipios de Colombia carecen de redes de monitoreo de la calidad del aire. Es el caso de La Ceja (Antioquia), que ha presentado en los últimos años un acelerado crecimiento demográfico y urbanístico asociado con el incremento del parque automotor y sus posibles efectos de contaminación atmosférica. Para asumir esta situación investigamos sobre la calidad del aire y conocimos la percepción de la salud entre la población. En diferentes sectores de la zona urbana del municipio se instalaron siete dispositivos de bajo costo, que midieron la concentración de material particulado de hasta 2.5 μg ($PM_{2.5}$) durante 5 meses consecutivos. De la percepción ciudadana sobre el estado de salud se encargaron los responsables de los sensores, quienes diligenciaron encuestas semanales. Con los datos medidos se realizaron análisis temporales y espaciales. Los resultados sugieren que, de acuerdo con la normatividad colombiana, la categoría ICA resultó apropiada en 83 % de los días de monitoreo. Sin embargo, en algunos eventos puntuales como las fiestas de fin de año (2021) se observaron las mayores concentraciones de $PM_{2.5}$, asociadas con el uso extendido de pólvora. La percepción del estado de salud de los participantes en el estudio sobresale (91 %). Estos resultados plantean la posibilidad de que este tipo de redes ciudadanas puedan utilizarse como apoyo para la gestión ambiental y la salud pública en municipios intermedios.

PALABRAS CLAVE: contaminación atmosférica, percepción en salud, salud pública

ABSTRACT

Air quality monitoring favors adequate urban planning and policy implementation to ensure public health. Most Colombian municipalities lack air quality measurement networks. It is the case of La Ceja (Antioquia), which in recent years has experienced accelerated demographic and urban growth associated with an upsurge in the number of vehicles and the consequences for air pollution. To face this situation, we compiled information about air quality to learn from its inhabitants' health perceptions. Seven low-cost devices were placed in sectors of the urban area of the municipality to measure the concentrations of particular matter up to 2.5 μg ($PM_{2.5}$) for 5 consecutive months. The sensors completed weekly surveys to ascertain public perception of the state of health. Temporal and spatial analyses were performed with the data. Results suggest that, according to Colombian regulations, the AQI was appropriate on 83% of the monitoring days. However, the highest concentrations of $PM_{2.5}$, associated with the widespread use of gunpowder, were observed on specific occasions, such as the year-end holidays. The perception of the health status of the participants stands out (91%). These results raise the possibility that citizen networks can be used to support environmental management and public health in intermediate municipalities.

KEYWORDS: air pollution, health perception, public health

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Introduction

Nowadays, air pollution challenges environmental health worldwide (Newell et al., 2017). Poor air quality threatens human health, social well-being, ecosystem integrity, and, as a consequence, economic development (Languille et al., 2020; Muñoz-Pizza et al., 2020). More than 150 million people in Latin America live in cities whose air pollution levels surpass the maximum limits established by the World Health Organization, WHO. In this region, inhalation of pollutants (Pan American Health Organization, PAHO, and WHO, 2021) causes 50% of deaths from lower respiratory tract infections. In Colombia, acute respiratory diseases caused 52% of overall mortality and 15% of deaths in children under 5 years from 2011-2017 (Ministry of Health & Social Protection, 2020). The department of Antioquia recorded 33.2 deaths per 100 000 inhabitants caused by lower respiratory tract diseases in 2019 (Secretaría Seccional de Salud y Protección Social-Gobernación de Antioquia, 2021)

The small size of particulate matter eases its entry and permanence in human tissues, leading to varied health effects (Coronel & Marzo, 2017). Therefore, it is necessary to set up ways of measuring and monitoring the multiple sources of emissions, which will allows to promote proposals for urban planning and effective public health policies (Escobar Jiménez & Vivas Moreno, 2019; Gálvez Serna et al., 2020). The Colombian air quality strategy recommends implementing measures to update regulations and encourage research, education, and citizen participation to advance the air governance agenda (Ministry of Environment & Sustainable Development, 2019). Likewise, it is necessary to link pollutant monitoring data with the wellness of the population; thus, the perception of health status, risk, and well-being is a widely used indicator to assess population health and life satisfaction (Assari & Lankarani, 2015; Muñoz-Pizza et al., 2020; Razo González et al., 2018).

Even though health perception is not considered a conventional methodology for assessing environmental problems, different research has shown that it is valuable for guiding decision-making by public institutions and promoting changes in citizen behavior (Clayton et al., 2015; Mendoza et al., 2019; Rodríguez Hernández et al., 2018; Ruiz-Ballesteros & Valcuende del Río, 2020). Research developed in Latin America has identified the existence of differences in the perception of health among age groups (Razo González et al., 2018). As such, it has been evidenced in communities with high social vulnerability the influence of living in proximity to permanent sources of pollution and the scarce knowledge observed on the chronic health effects of poor air quality (Mayorga et al., 2020; Muñoz-Pizza et al., 2020; Ramírez et al., 2017; Razo González et al., 2018).

The Institute of Hydrology, Meteorology and Environmental Studies, IDEAM (2019) reports that in 2018, 27 air quality surveillance systems operated in the country with 203 monitoring stations; likewise, it highlights that it is imperative the measurement of emissions and the establishment and strengthening of air monitoring in all Colombian cities. Despite these efforts, most municipalities still lack air quality monitoring systems, among them La Ceja (MiOriente, 2018; Tobón Ramírez, 2020), the second intermediate city of the eastern subregion of the department of Antioquia and where 4.5% of the fixed sources of atmospheric pollutants in the jurisdiction of CORNARE (Corporación Autónoma Regional de las Cuencas de los Ríos Negro y Nare) are located (Valencia Zapata, 2019). In recent years, La Ceja has undergone accelerated urban and population growth, from 46 268 inhabitants in 2005 to 64 889 in 2020, with an associated increase in the vehicle fleet (20 969 vehicles registered as of December 31, 2019) and possible consequences on air quality (Alcaldía de La Ceja del Tambo, 2020; Secretaría de Protección Social La Ceja, 2019).

In recent years, several citizen science initiatives of environmental monitoring have been successful and allowed obtaining data on various biological and atmospheric processes. Local links prove it, such as the Citizen Scientist Network driven by the Early Warning System of Medellín and the Aburrá Valley (Sistema de Alerta Temprana de Medellín y el Valle de Aburrá, SIATA, 2021), and international ones, such as the Citizen Air Quality Monitoring Network, which has sensors in Colombia, Ecuador and Perú (Aire Ciudadano, 2022). As well as

Mosquito Alert in Barcelona and Europe (Palmer et al., 2017). The outcomes obtained by these and other citizen networks have shown that the community can contribute to monitoring environmental conditions (Aceves-Bueno et al., 2017; English et al., 2018; Forrest et al., 2019).

Given the air quality problem and the absence of a measurement system in La Ceja, a first approach to air pollution conditions in the municipality is proposed, aiming to collect indices on particulate matter and know the health perception of the population through a citizen network that features low-cost sensors to simultaneously monitor $PM_{2.5}$ concentrations in different sectors of the urban area of the municipality.

Methodology

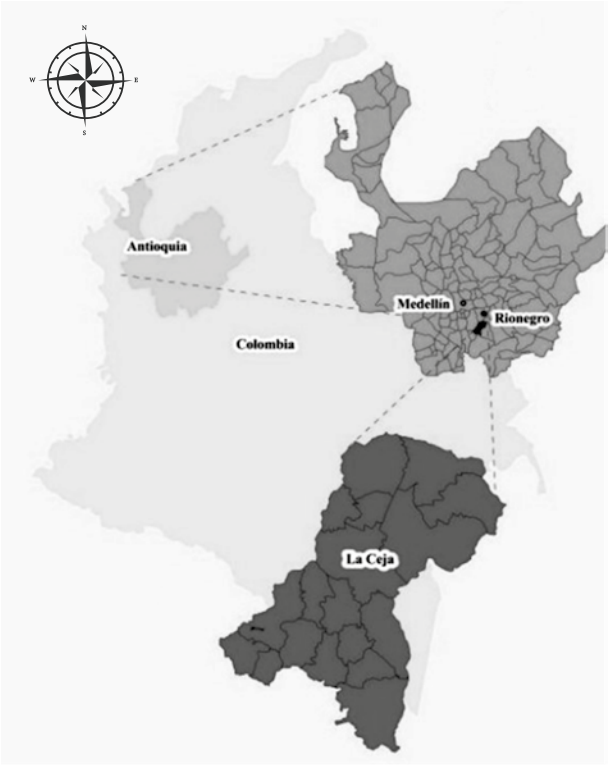
Study area

La Ceja is a municipality in the department of Antioquia located in the eastern subregion, 50 kilometers from Medellín (Figure 1). Eighty-four percent of the inhabitants live in urban areas, with a population density of 484 inhabitants/km^2. Twenty-one percent of the population is under five and over 60 years old, corresponding with the age groups with prevalent vulnerability to acute respiratory diseases (Secretaría de Protección Social La Ceja, 2019). For 20 years, the town's primary economic activity has been large-scale floriculture. Other occupations settled in the territory include wood processing companies, locksmiths, tile and paper producers, as well as garment workshops (Alcaldía de La Ceja del Tambo, 2020).

In the last decade, its vicinity of Medellín has led to an unusual population increase and accelerated urban growth reflected in the high pressure for public services, access to health care, education, and housing (Tobón Ramírez, 2020). As a result of the expansion, the unbridled population, industrial, and commercial growth in La Ceja has increased the number of vehicles and traffic associated with the possible deterioration of air quality.

La Ceja has a road network of 77 480 linear meters; approximately 2.43% is in poor condition, contributing to an increase in air pollution (Alcaldía de La Ceja del Tambo, 2020; MiOriente, 2018; H., 2019). Besides and especially during December and January, there is an intensification in air pollution levels associated with the extensive use of traditional pyrotechnic material during Christmas and New Year's Eve celebrations.

Figure 1. Geographical location of Antioquia and the municipality of La Ceja



Note. Source: CORNARE (2012).

Collection of information

An environmental science study was developed with an interdisciplinary approach and ethnographic emphasis, in which community participation provided the grounds for the knowledge of health perception and data management, with the consequent implementation of air quality monitoring and its continuity during the 5 consecutive months of observation, between December 2021 and May 2022.

Citizen monitoring of $PM_{2.5}$ with low-cost devices. Low-cost sensors are a good alternative for monitoring air quality; they offer dimensional advantages and are usable as fixed or mobile instruments due to their ease of installation and transport.

Their price makes it possible to deploy a good number of units, facilitating the simultaneous and detailed control of significant areas of the territory.

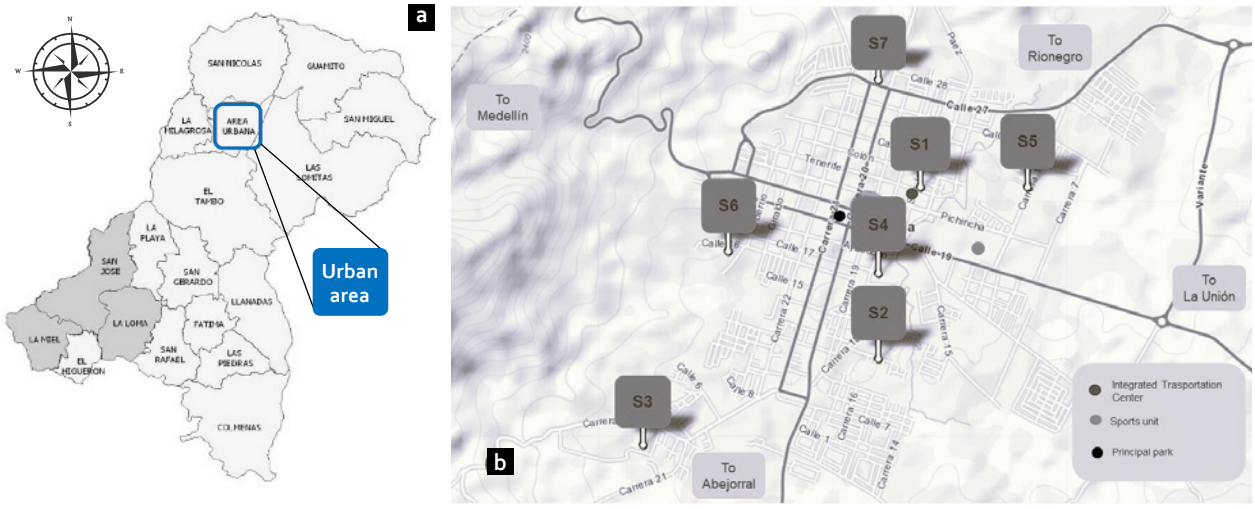
In this study, seven low-cost fixed devices were used for $PM_{2.5}$ monitoring. They were assembled in Colombia by the Aire Ciudadano initiative: a citizen science project that builds mobile and permanent devices for measuring particulate matter concentrations ($PM_{2.5}$, $\mu g/m^3$) using Sensirion sensors (SPS30), which include MCERTS certification and operate as optical particle counters based on laser scattering (Aire Ciudadano, 2022; Sensirion, 2020, 2022). The devices are open source, with a Wi-Fi module through which they connect to the Aire Ciudadano website, providing real-time data enabled for download with ranges over 1 minute, 31 minutes, and 1 hour. However, these sensors collect indicative data and would not replace the information from the robust stations but complement it.

Considering that the density of vehicular flow influences $PM_{2.5}$ levels, industrial and commercial activities, meteorological and topographic conditions, and land use, among other factors, seven monitoring sites were chosen in the urban area of the municipality. They were selected based on the presence of residential zones and their proximity to main roads (Figure 2). The monitors were installed outdoors at heights between 2 and 3 meters and remained connected to electric power and the Wi-Fi network since their installation during the entire study period. The hourly time series of $PM_{2.5}$ measured by the seven devices were downloaded from the Citizen Air web portal and compiled into a database for temporal analysis.

Citizen perception of health status and air quality. Seven people over 18 years were in charge of the monitoring devices and accompanying the conditions and perception of health related to air quality via two survey-type information-gathering instruments. These were created in a Google form and filled out by the participants. The initial survey included some data that allowed for demographic and health situation characterization, including gender, age, educational level, occupation, sector of residence, habits, chronic and current health conditions, medication consumption, and frequency of medical consultation attendance. Subsequently, weekly health perception surveys were conducted emphasizing respiratory symptoms and air quality during the time the research progressed. The survey responses were consolidated in a database for subsequent analysis.

A group of volunteers — who applied after learning about the objectives and scope of the study — selected the seven participants. The call was disseminated through the social networks Instagram and WhatsApp. All persons confirmed their participation, filling out an informed consent form that guaranteed the confidentiality of the data under the

Figure 2. Political map of the municipality of La Ceja (a) and location of sensors in the study area (b)



Note. Source: (a) Molina Saénz (2011); the box indicates the location of the study. (b) AQICN (2022).

ethical principles of research in Colombia (Castañeda Ruiz et al., 2020).

Statistical analysis

$PM_{2.5}$ data were analyzed using statistical, descriptive, univariate, and multivariate methods. As a starting point, the data measured by the sensors were explored to identify outliers, thus ensuring their quality. Then the minimum and maximum values were recognized, and the figures of central tendency and variability (mean, median, mode, and standard deviation) were calculated. Additionally, the linear correlation coefficient between stations was calculated.

Daily and weekly statistics were generated for each of the monitoring points and, as defined for Colombia by Resolution 2254 (2017) of the Ministry of Environment and Sustainable Development, the Air Quality Index (AQI) was calculated. Likewise, the relative frequencies for each of the AQI categories were established, and the daily averages were compared with national and international standards on air quality as follows: maximum permissible levels of 37 μg/m^3 according to Colombian regulations and 15 μg/m^3 according to WHO guidelines, which allowed evaluating the risk level for the exposed population (Table 1). The temporalities were also established to locate the periods in which the data showed usual behaviors.

Table 1. Air Quality Index (AQI) for $PM_{2.5}$

Category	AQI	$PM_{2.5}$ μg/m^3 24 hours
Good	0-50	0-12
Acceptable	51-100	13-37
Harmful to health-sensitive groups	101-150	38-55
Harmful to health	151-200	56-150
Very harmful to health	201-300	151-250
Dangerous	301-500	251-500

Note. Source: Ministry of Environment and Sustainable Development (Ministerio de Ambiente y Desarrollo Sostenible, 2019).

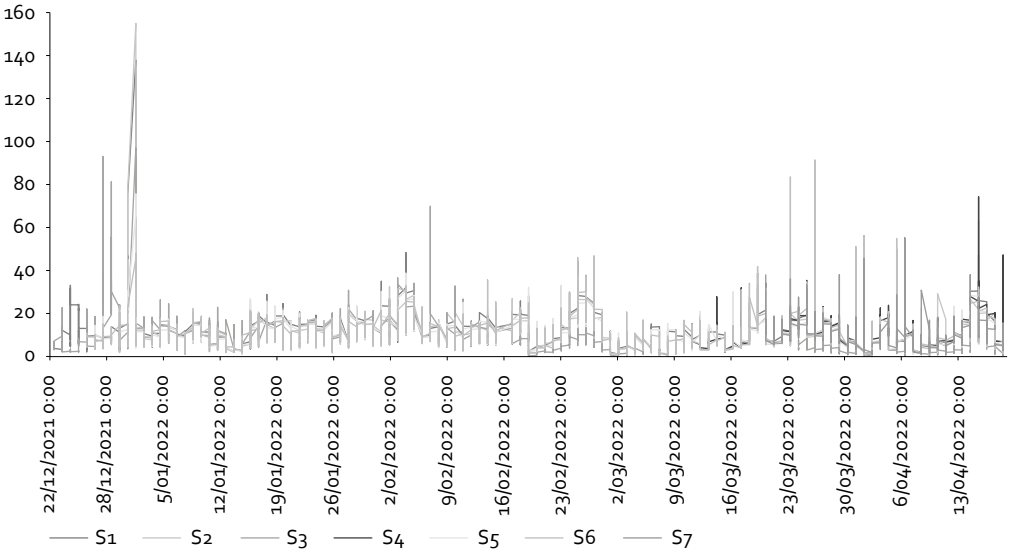
With the results of the initial surveys, descriptive statistics were analyzed, characterizing the demographic conditions, risk behaviors, and populations' health status. In turn, the data from the weekly surveys on health perception and air quality helped to identify the presence of symptoms, medical consultation attendance, and the rating given to air quality.

Results

Statistical analysis

The seven installed sensors provided hourly $PM_{2.5}$ data, as shown in Figure 3. In general, the instruments yielded average values of 8.5 μg/m^3. However, it should be noted that high values

Figure 3. Time series of hourly $PM_{2.5}$ data in μg/m^3 (municipality of La Ceja, December 2021- April 2022).

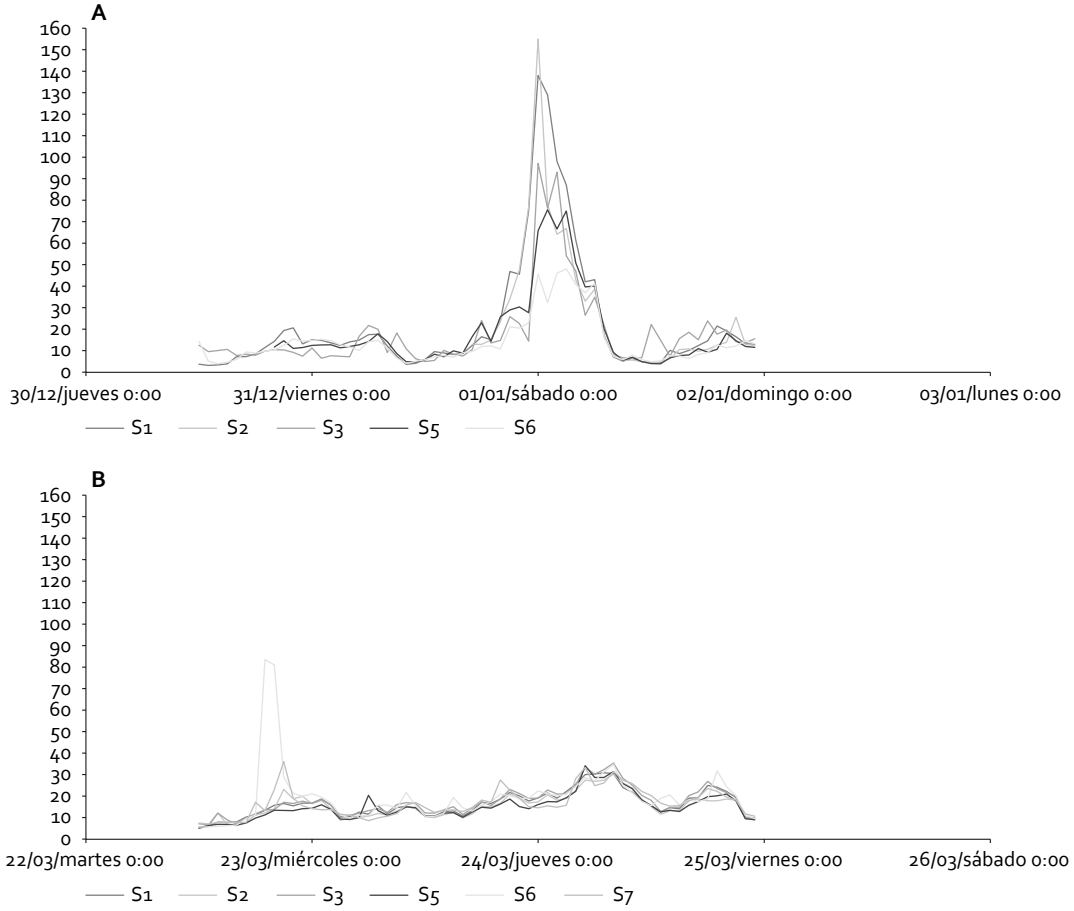


were recorded three times during the observation: December 31, 2021 and January 1, 2022; March 18 to 26, and April 13 to 15, 2022.

Figure 4 illustrates the time series between December 30, 2021 and January 1, 2022, and between March 22 and March 24, 2022. Values for the two lapses are observed to exceed 70 and 30 µg/m^3 in most sensors. The December event completed 24 hours and is associated with the widespread use of traditional pyrotechnic material during year-end celebrations. In March, above-average concentrations were presented, coinciding with the critical air quality during this time of the year in Medellín and its metropolitan area.

As shown in Table 2, the maximum hourly concentration during the five monitoring months was 155 µg/m^3 measured by sensor 2, and the minimum concentration was 0.01µg/m^3 measured by sensor 1.

Figure 4. Time series and periods



Note. (a) December 31, 2021-January 1, 2022. (b) March 18-26, 2022.

Table 2. Hourly measurements of $PM_{2.5}$ between December 2021 and May 2022 (µg/m³)

Statistical*	S1	S2	S3	S4	S5	S6	S7
Number of hourly data	3,715	3,196	2,867	1,854	3,595	3,693	1,599
Minimum	0,01	0,18	0,10	0,10	0,18	0,16	0,07
Maximum	138	155	30,80	74,30	75,60	91,40	89,80
Medium	8,00	6,48	6,10	6,70	9,18	8,50	6,40
Average	9,80	8,50	7,60	8,30	10,30	10,00	8,60
Standard deviation	8,20	8,10	5,60	6,10	6,70	7,00	9,60

Note. (*) Descriptive statistical summary of 23 weeks of observation with seven sensors.

It is noteworthy that sensor 2 is in a residential area. The highest concentrations were observed during the night of December 31, 2021, and the early morning of January 1, 2022.

Daily averages of $PM_{2.5}$ and AQI were calculated, as established by Resolution 2254 (2017) previously cited. The results show that the AQI category 'good' predominated with 83% and, in second place, the 'acceptable' level with 17%. There were no concentrations of 'harmful' to the health of sensitive groups. According to the standards defined by WHO, 6.5% of the 24-hour average concentrations exceed the suggested 15 μg/m^3 (PAHO, Organización Panamericana de la Salud & WHO, Organización Mundial de la Salud, 2021). As proposed in this study, to evaluate the weekly exposure levels, the relative frequencies of the AQI during the 7 days of all monitoring weeks were calculated: in 87%, the category was 'good', and in the remaining 13%, 'acceptable'.

The correlation coefficient reveals a positive linear relationship between the monitoring points. According to the values obtained, there is a strong correlation between sensor 1 and sensors 2, 4, and 5, and between sensor 2 and sensors 4 and 5, all located in urbanized sectors. For sensor 7, coefficients lower than 0.60 are observed, indicating a weak to moderate correlation with the other monitoring points; this sensor, unlike the others, is located in an area of an urban expansion near the Circunvalar road, which facilitates transit from Medellín to Rionegro and vice versa (Table 3).

Survey results

Characterization of the population. The analysis of the seven initial surveys identified that 86% of the participants are between 26 and 40 years old while the remaining 14% are between 18 and 25; 57% are men and 43%, women. A maximum of four people inhabit the households with installed sensors. When evaluating the age groups at risk, it was found that only two residences were home to people over 60, and none were home to anyone under 5. On background and habits, medical conditions and behaviors were identified that may increase individual susceptibility to poor air quality. Thus, 67% of those surveyed reported suffering from allergic rhinitis; they also mentioned a history of respiratory disease and medication allergy. Eighty-six percent of those surveyed assured that they engage in physical activity; a higher percentage outdoors. None of the respondents are smokers (Table 4).

Perception of health status and air quality. According to the 80 weekly surveys completed, 90.66% of the participants rated their health as good and only 9.33% as medium. In the latter case, they report associated symptoms, including sore throat, rhinitis, headache, burning eyes, and anxiety. A 78.37% of the responses indicate that the participants perceive the air quality in the municipality to be good. Seventy percent believe that the time of day with the best air quality is the morning, 14% believe it is the afternoon, and 16% believe it is the evening (Table 4).

It should be noted that during the study implementation, some participants did not fill out all the weekly surveys. After collecting the information, nine surveys were counted for participant one; 11 for participant two; 23 for participant four; 16 for participant five; 15 for participant six, and 10 for participant seven. The person in charge of sensor 3 did not complete the weekly surveys.

Table 3. Correlation coefficients between monitoring stations

	S1	S2	S3	S4	S5	S6	S7
S1	1						
S2	0,94	1					
S3	0,61	0,74	1				
S4	0,89	0,91	0,74	1			
S5	0,92	0,89	0,62	0,83	1		
S6	0,77	0,77	0,52	0,66	0,79	1	
S7	0,53	0,51	0,42	0,52	0,55	0,43	1

Table 4. Frequency distribution

Demographic characteristics*	% (n)
Sex	
Female	43 (3)
Male	57 (4)
Age	
18-25	14 (1)
26-40	86 (6)
Persons at risk in the household	
> 60	28 (2)
Medical history and habits	
Allergies	
Rhinitis	67 (4)
Other allergies	17 (2)
Respiratory disease	16 (1)
Physical activity	
Physical activity	86 (6)
Physical activity outdoors	67 (4)
Indoor physical activity	33 (2)
No physical activity	14 (1)
Perception of health status**	
Good	90,66 ± 0,01%
Medium	9,33 ± 0,01%
Poor	-
Perception of air quality**	
Good	78,37 ± 0,04%
Medium	21,62 ± 0,03%
Poor	-

Note. ** 95% confidence interval.

Discussion

Main findings

The monitoring points were installed in seven sectors of the municipality, prioritizing those considered critical due to their location near roads with high vehicular flow. On the one hand, the highest averaged values during the measurement belong to sensors 1, 5, and 6. The zones with sensors 5 and 6 are residential and close to the principal roads; on the other hand, sensor 1 is near the Integrated Transportation Center. These results resemble the conclusions of the Report on the State of Air Quality in Colombia 2018, which points out that the largest source of $PM_{2.5}$ in the country comes from vehicles (IDEAM, 2019). Accelerated urban expansion is associated with an increase in the vehicle fleet, resulting in environmental consequences such as rising concentrations of air pollutants (Anenberg et al., 2019; Calasans Souza, 2019; Quirama-Aguilar et al., 2021).

In Colombia, cities such as Bogotá register the highest amounts of $PM_{2.5}$ in sectors with high vehicular traffic (Molina-Gómez et al., 2021); in the Metropolitan Area of the Aburrá Valley, it has been identified that the vehicle fleet emits 79% of the $PM_{2.5}$ in the atmosphere (Aguiar Gil & Correa Ochoa, 2020). $PM_{2.5}$ particulate matter from vehicle emissions and diesel combustion causes the worst impact on public health (Hernández López & Baloco Vega, 2019). It has been observed that the highest levels of emissions occur when vehicles are stopped or move forward in an irregular manner: braking, turning, or abrupt stop (Rojas et al., 2019), usual conditions during vehicular congestion near industrial, commercial or central transportation areas and in sectors with deterioration or poor condition of the road network.

One of the dates with intensive use of pyrotechnics on the planet is New Year's Eve (Singh et al., 2019). Data collected during year-end festivities in La Ceja expose the impact of the widespread use of gunpowder on $PM_{2.5}$ concentrations and warn about the importance for public health of implementing control measures on these and other dates when pyrotechnic objects are traditionally used. Fireworks are an anthropogenic source that generates local and short-term effects of air quality deterioration. The sudden production of high concentrations of pollutants — mainly particulate matter — is associated with up to 92% decrease in visibility, adverse health effects such as asthmatic crises, respiratory allergies and coughing, high noise levels affecting wildlife, and release of polluting chemicals from surface water sources (Yao et al., 2019). Figures have been found to double and quadruple average PM_{10} and $PM_{2.5}$ concentrations during events involving gunpowder; generally, particulate matter levels decrease and stabilize within 24 hours afterward (Garaga & Kota, 2018; Masiol et al., 2014; Oroji et al., 2020; Singh et al., 2019).

In La Ceja, $PM_{2.5}$ concentrations during the New Year's celebration reached 155 μg/m^3, even when the phenomenon of particulate matter decreased gradually, since the values recorded by all sensors on January 2 showed concentrations between 5 and 9 μg/m^3, 24 hours after the peak (December 31).

In the Aburrá Valley Metropolitan Area, there are two episodes of air quality alerts over the year. The first, in March, and the second, in October, associated with meteorological conditions that include the shift towards the rainy season and the presence of a low-altitude cloud layer (Aguiar Gil et al., 2017; González Gutiérrez, 2021).

Colombian regulations assess daily averages of $PM_{2.5}$, which may conceal events such as those observed in La Ceja in the week of March 21, 2022. In that period, hourly concentrations above 30 μg/m^3 were found at several sampling points. As already indicated, March is one of the periods of the year when a critical air quality episode occurs in Medellín and its metropolitan area (Aguiar Gil et al., 2017; *El Tiempo*, 2022; González Gutiérrez, 2021). This situation inclines to be associated with the stress of particulate matter concentrations in La Ceja for the period in question.

For environmental anthropology, perception is a fundamental tool of analysis that allows the understanding of the relationships humans build in and with their environment. Perception is diverse and adopts a cultural and social component more akin to experience than theory (Ruiz-Ballesteros & Valcuende del Río, 2020). Likewise, when considering environmental risks, perception can shape behaviors and decisions leading to actions that affect health status (Esquivel-Ferriño et al., 2018). In this research, there were no remarkable differences in health perception among participants; in most cases, this was rated as 'good'. However, collaborators recognized many of the symptoms: anxiety, rhinitis, sore throat, and burning eyes, which are associated with deteriorating air quality (Díaz Garrido et al., 2019; Li et al., 2020; Mandell et al., 2020; Oyarzún & Valdivia, 2021; Yolton et al., 2019). Since participants could access the data measured by the sensors in real-time, the continuity of the perception of their health status and air quality during periods with higher $PM_{2.5}$ values is highlighted.

The connection between perceptions of environmental risks and health hazards is overt (Esquivel-Ferriño et al., 2018), and this can be a starting point to involve communities in their prevention and management, as well as to guide the design and deployment of communication and vulnerability reduction strategies (Icedo-Palacios et al., 2022).

Furthermore, research that evaluated citizen perception of air quality and associated health risks in countries and cities with notable air quality deterioration, such as China (Dong et al., 2019), South Korea (Kim et al., 2019), United States (Reames & Bravo, 2019), Mexico (Muñoz-Pizza et al., 2020), Chile (Mendoza et al., 2019), and Bogotá (Fischer & Beltrán, 2021; Fonseca Mantilla et al., 2021) document that high levels of air pollution and proximity to fixed sources of pollution such as industries decrease citizens' perception of well-being.

Since the municipality was hosting first-time monitoring stations and networks that provide access to information on air quality, it is possible that the periods in which the concentrations of atmospheric pollutants increased became irrelevant or unnoticed by the citizens, and, perhaps, they dismissed the presence of pollution. It is worth noting that citizen science can serve as a strategy for advanced community participation by favoring the spread of related information and accompanying collective decisions on human health, even when there is a lack of appropriation of the data and information gathered by the sensors, which shows the need to strengthen these innovative participation exercises guided by educational and communicative actions (Alfonso et al., 2022; Forrest et al., 2019).

For some years now, changes have been witnessed in decision-making to address environmental problems according to the complexity of their dynamics. A participatory approach that involves new social participants and strengthens the relationship between citizens and their environment has been promoted (Giannuzzo, 2010). At this juncture, community participation in health represents an articulating element between environmental sciences and public health, facilitating the empowerment of individuals and their active involvement in tackling pressing environmental health needs (WHO, 2021).

Strengths and limitations

This is a pioneering study in Antioquia. With its implementation, La Ceja became the first municipality in the department with less than 65 000 inhabitants to have a citizen strategy monitoring air quality. It is necessary to continue joining efforts to consolidate the network, expanding its scope and favoring its sustainability, strengthening community commitment and knowledge appropriation.

Among this research's limitations, it is worth detailing the absence of monitoring points in rural areas, permitting the comparison of air quality with urban areas. Likewise, and despite the strategies to guarantee the filling out of the surveys, it was not possible to obtain (in the majority of the participants) a weekly response.

This study's results indicate the relevance of improving the mechanisms to approach the community and promote interdisciplinary work towards addressing difficulties of this type and to formulate, propose and implement territorial planning that considers the lessening of health risks related to environmental issues and consolidates citizen science as a helpful and relevant instrument for community surveillance in public and environmental health in the country.

Social and political implications

The citizen and community participation approach has made it possible to launch a pioneering network of indicative measurements of particulate matter in this municipality; its continuity will promote access to information on environmental conditions in the territory among the population in the short and medium term and will guide land use planning and monitoring of events of public health interest linked to decision-making.

Although indicative, the information collected by the sensors allows inferring that, in the sectors studied, $PM_{2.5}$ concentrations maintain the limits considered safe for human health by Colombian regulations and the intervals defined in this study. However, some of the daily averages occasionally exceed the standard value suggested by the WHO. Some emission sources should be listed, given their overt influence on the deterioration of air quality in the municipality, such as the vehicle fleet and the uncontrolled use of gunpowder and pyrotechnic material.

This study finds that citizen monitoring of environmental conditions would enhance collective awareness of problematic situations, as well as strengthen the follow-up of their spatial and temporal behavior with impacts on social welfare. Moreover, it highlights the convenience of reinforcing the population's capacity to recognize the effects of air quality on their health and to conduct territorial planning actions, considering the risks to public health from environmental conflicts.

Recommendations for future studies

This report suggests continuing with the implementation of monitoring and follow-up actions in municipalities of Antioquia with similar characteristics, as well as expanding the monitoring coverage of La Ceja, where it is recommended to include measurements in rural areas near the principal park and its multiple commercial premises and service infrastructure, and in the sectors of El Tambo, Las Lomitas and San Nicolás, where there are educational centers and through which cargo vehicles circulate with agricultural products from the town of San José and some villages with ample productive potential.

We recommend involving both the Secretariat of Health and the responsibles of Environment in these initiatives when analyzing epidemiological data and climatic variables such as wind speed, wind direction, temperature, and precipitation; it would allow directing public health and environmental regulatory decisions under the findings of air quality conditions like those associated with gunpowder during the Christmas and New Year holidays.

Conclusions

Citizen participation in this project has led to an innovative network indicating figures of particulate matter in a municipality with less than 65 000 inhabitants. The information collected by the sensors shows that $PM_{2.5}$ concentrations do not exceed the limits considered safe for human health by Colombian regulations, whose laxity exceeds the values suggested by the WHO. In this study, there

were no significant differences in health perception among participants, which would reflect aspects such as (a) a low appropriation of the measured values by the citizens; (b) inadequate dissemination of the data consultation tool, and (c) the absence of citizen awareness of the effects of air quality on health in intermediate municipalities such as La Ceja.

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Author contributions

Sandra María Echeverri-García: preparation of the initial version of the proposal. Participation in the methodological design. Design and supervision of the monitoring network installation. Collection and analysis of data measured by sensors and survey results. Contributions to the initial drafting and the consolidation and revision of the final version.

Vladimir G. Toro: review and update of the proposal. Support in data analysis through the sensors, in designing the methodology and the monitoring network, and in the discussion of results. Contributions in the initial drafting and in the revision of the final version.

Eliana Martínez-Herrera: review of the proposal and adjustments. Support in the analysis of data obtained from the surveys, in designing the methodology, and the discussion of results. Contributions to the manuscript draft and the revision of the final version.

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