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Air Pollution and Climate Change Risk Perception among Residents in Three Cities of the Mexico Megalopolis

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Abstract: Recent reports of the criteria pollutants in the Megalopolis, located in the central part of Mexico, consistently show air quality standard exceedances in most of the cities that make it up, since it is a large concentration where approximately 17% of the national population resides and because it has significant commercial and industrial development. To investigate the similarities and disparities in risk perception concerning air pollution and climate change among residents living in Central Mexico, a cross-sectional survey study was carried out within three metropolitan areas encompassed by the Megalopolis. A total of 1750 questionnaire surveys were conducted across 21 municipalities within the Mexico City Metropolitan Area (MCMA), 16 municipalities within the Toluca Valley Metropolitan Area (TVMA), and 8 municipalities within the Cuernavaca Metropolitan Area. The three metropolitan areas showed significant differences in terms of air quality perception, risk perception, attitudes, and causal attribution perception, but health-related perception did not have significant differences among the areas. The MCMA exhibited higher knowledge about air pollution, although it associated the causes with urban activities such as car usage, while the Toluca and Cuernavaca areas linked this issue to the burning of garbage, coal, wood, and agricultural activities. Although residents expressed concern about air pollution, climate change, and their effects, they do not know how to act to contribute to the solution.

Keywords: risk perception; air pollution; climate change; attitudes; causal attributions

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1. Introduction

Currently, air pollution is considered the world's largest environmental public health issue, accounting for 7 million deaths worldwide and causing a significant reduction in healthy life years; since 2015, the World Health Organization (WHO) has acknowledged that air pollution is a causal factor in premature death or chronic illnesses including ischemic heart disease, stroke, chronic obstructive pulmonary disease, asthma, neurogenerative conditions, and cancer, whereas in the case of children, diseases might include reduced lung growth and function, respiratory infections and aggravated asthma, mainly in low-income and middle-income countries [1]. Climate change, in conjunction with air pollution, presents an additional formidable threat to human health and well-being, while concurrently exerting a substantial economic strain on nations; as these two challenges share common underlying factors, recent research has indicated that policies aimed at mitigating and adapting to greenhouse gases (GHG) can also yield reductions in air pollution; conversely, strategies designed to combat air pollution can lead to co-benefits in addressing climate change, ultimately resulting in significant improvements in public health [2,3].

To ensure the successful design, communication, execution, and evaluation of strategies for reducing air pollution and adapting to and mitigating climate change, it is crucial to understand and comprehend the perceptions, attitudes, beliefs, and feelings, of citizens; this understanding is essential to achieve the desired level of participation and encourage residents to undertake recommended protective actions, thereby reducing health or integrity risks [4–6] including perception, depending on the used words [7].

On one hand, various studies demonstrate that risk perception plays a significant role in influencing individual behavioral responses to risk-related issues [8]. Most findings indicate that risk perception is a positive predictor of people's adaptive behaviors concerning air pollution, such as reducing the use of automobiles and other types of engines, paint, and aerosols [9]. On the other hand, human behavior is influenced by causal attribution; it is considered internal when the individual believes they are the cause and external when they attribute it to other factors or people [10,11]. Finally, people's perceptions are greatly influenced by circumstances such as age, gender, economic status, place of residence, occupation, information received, and education, as well as economic and political contexts, among other factors; consequently, their willingness to engage in actions related to environmental risks may vary [12]. However, there have been relatively few studies on perception related to air pollution, particularly in low and middle-income countries. Saksena studied the perception of people in urban European cities [13]; Oltra and Sala [14] conducted a study in four Spanish cities; Mor et al. surveyed people in Indian cities and found that sociodemographic factors were associated with an awareness of air pollution, health effects, and people's attitudes [15]. In Africa, where information about atmospheric pollution is very limited, some air pollution perception studies have been performed in Kenya in a rural area close to a polluting industry [16]; in South Africa, in a mining district [17]; and in a poor neighborhood in Nairobi [18]. The number of investigations is higher regarding perception studies in climate change: several studies have been published in the United States for six Americas categories [19–21]; in Latin America, Vignola et al. [22] compared the perception of Costa Rican citizens with American residents.

Over the past 20 years in Mexico, some local studies have been conducted regarding the public perception of air pollution risks [23–25] and global change in Mexico by Landeros-Mugica [26] and González-Hernández et al. [27] in Nuevo Leon, Mexico. Mobility, climatic, and environmental events in Mexico City were explored by Urbina-Soria et al. [28] and Bee [29] in Guanajuato, Mexico. Landeros-Mugica et al. [30] related risk perception with exposure and commitment. However, considering that people transit between different cities due to commerce, work, or studies, such as the case of the central Megalopolis, it is important to carry out regional studies about the social perception of residents related to air pollution and climate change, since individual feelings and behaviors could be altered due to the daily or frequent transportation among nearby metropolitan areas.

Under the hypothesis that people's risk perceptions, causal attributions, beliefs, and attitudes associated with air pollution and climate change vary across different sites and regions, the primary objective of this study was to identify these variations in three metropolitan areas of the Megalopolis: the Mexico City Metropolitan Area, the Toluca Valley Metropolitan Area, and the Cuernavaca Metropolitan Area. This will allow policymakers to establish communication strategies tailored to each area, providing essential information for making informed judgments and adopting appropriate decisions and behaviors related to health, safety, and the environment.

2. Materials and Methods

2.1. Study Zone Description

This is a cross-sectional study performed with a questionnaire survey applied in three metropolitan areas of the central Megalopolis in Mexico from March to May 2022, because this Megalopolis concentrates more than 17% of the population in seven states located in the central part of Mexico; moreover, this is the most important economic zone of the country. The selected metropolitan areas where residents were surveyed are the Mexico City Metropolitan Area (MCMA), the Toluca Valley Metropolitan Area (TVMA), and finally the Cuernavaca Metropolitan Area (CMA) (Figure 1). This selection is related to the

Environmental Megalopolis Council (CAMe, its Spanish acronym) which indicated that, in these areas, at least one monitoring station in each site fails to meet both the annual and the 24-h standards for respirable and fine particles (PM_{10} and $PM_{2.5}$), and they do not comply with the 1-h and 8-h limits for ozone [31]; additionally, a recent research study reported the $PM_{2.5}$ mass exchange among these three metropolitan areas, based on meteorological conditions, as part of a comprehensive study of particle characterization [32], showing that the $PM_{2.5}$ imported mass to CMA and TVMA is greater than the exported masses. The characteristics of these sites are briefly described in the following sections.

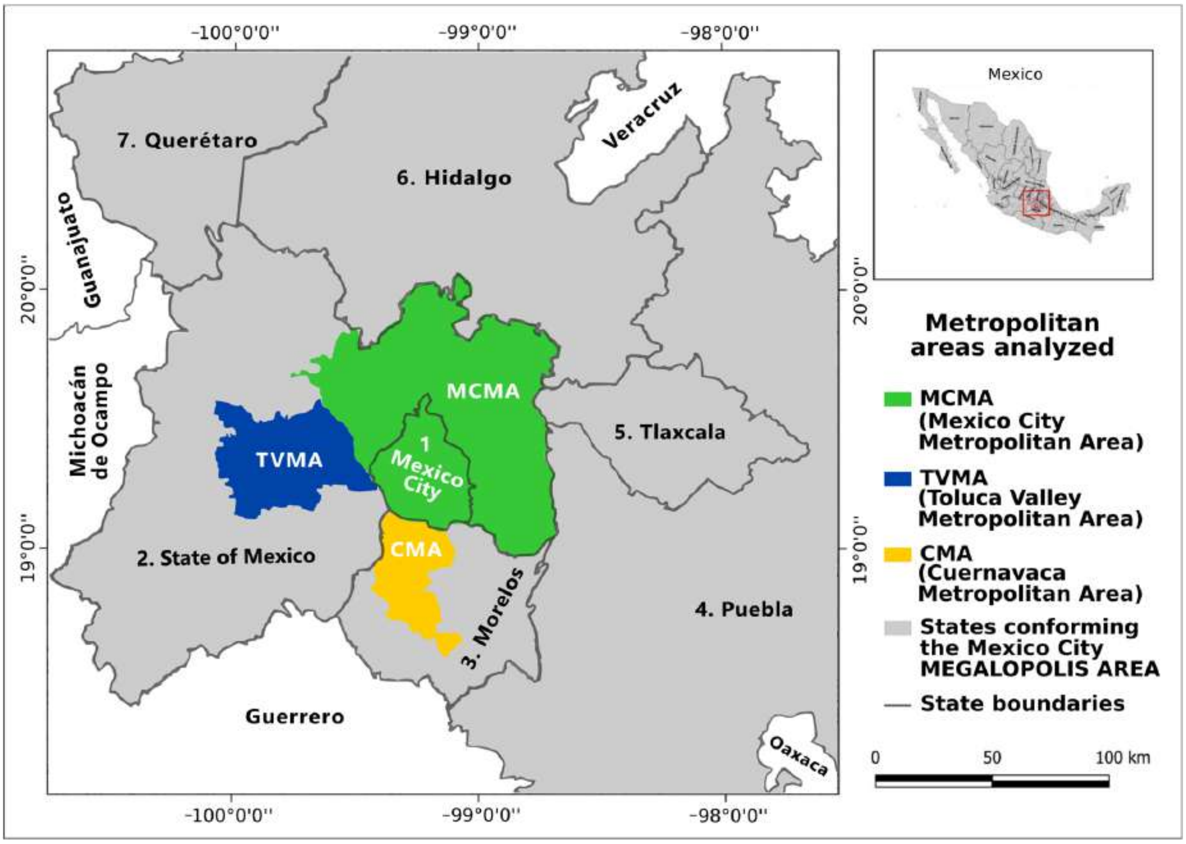

Figure 1. The Megalopolis and the three studied metropolitan areas.

2.1.1. Mexico City Metropolitan Area

The MCMA is the largest urban concentration in the country, situated at an average altitude of 2240 masl (meters above sea level), comprising around 22 million people in 2020 and over 5,565,000 vehicles in circulation; it encompasses 16 municipalities of Mexico City, 59 municipalities of Mexico State, and also the Tizayuca municipality of Hidalgo State, and it is surrounded by mountains that hinder air dispersion; in the early 90s, it was classified by the World Health Organization as the city with the worst air quality globally [33,34]. For that reason, numerous studies were performed, and control policies were implemented to limit emissions from both mobile and stationary sources through improvements in control technologies, transitioning to low-sulfur fuels, migration of industries to other states, and the enforcement of regulatory frameworks for these sources. From 1991 to 2012, the annual average levels of air pollutants showed significant reductions at monitoring stations: approximately 80%, 87%, 22%, 28%, 58%, and 96% for carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, respirable particles, and lead, respectively [34,35]. However, in the last decade, the reductions have been less pronounced, with an additional 10%, 4%, 2%, 2%, and 2%, respectively, with better conditions prevailing for more hours and days; additionally, the air quality standards for carbon monoxide, sulfur dioxide, nitrogen dioxide, and lead associated with particles have not been exceeded in almost two decades, although ozone and fine-particle air quality standards are exceeded 50% and 40% of the days in the year, respectively, which is a big concern for environmental authorities [35].

2.1.2. Toluca Valley Metropolitan Area

The TVMA ranks first in atmospheric pollutant emissions in the country and fourth in Latin America, attributed to high industrial and agricultural activities. The TVMA has a population of 2,202,886 inhabitants and comprises 16 municipalities in the State of Mexico; on average, the altitude is 2260 masl. The NO_2 concentration has sporadically exceeded limits, while SO_2 and CO have consistently stayed within the norm according to monitoring data; however, high concentrations of fine and respirable particulate matter have been observed since 2002, with approximately a 50% increase from 2000 to 2011, and until 2017, these pollutants remained constant, exceeding air quality standards around 47% of the days, whereas ozone concentrations decreased by approximately 17% between 2000 and 2011 and have remained similar until 2017, with a 12% air quality standard exceedance [36,37].

2.1.3. Cuernavaca Metropolitan Area

The CMA, with around one million inhabitants in eight municipalities, has doubled its population since 1990, along with a fleet of vehicles. The region exhibits a wide variation in altitudes and terrain slopes, with Cuernavaca Municipality having the highest altitude at 1768 m and Xochitepec the lowest at 381 m on average; economic development is tied to urban planning, services, transportation, and tourism. It also hosts an industrial zone with 230 hectares and over 150 companies. Due to the inconsistent performance of the monitoring network over the years, there are no validated historical air quality records due to insufficient, temporal, and statistically limited monitoring data, and it is difficult to know the trends of pollutant concentrations, although the intermittent campaigns since 1996 indicate standards compliance with sulfur dioxide, nitrogen dioxide, and carbon monoxide standards; on the contrary, suspended particulate matter and ozone often exceed air quality norms [38,39].

2.2. Sample and Respondent Characteristics

In order to gauge public opinion on air pollution and climate change, 1750 surveys were conducted across three metropolitan areas. Data were collected through electronic devices during door-to-door visits, with the intention of garnering participation from a diverse range of individuals across genders, age groups, and urban and peri-urban areas.

To gather data for this study, a non-probability quota sampling technique was utilized. Specifically, geographic areas known as AGEBS located within a 3 km radius of air quality monitoring stations were chosen, with two areas selected randomly. Participants were then selected to meet specific quotas in terms of gender (50% male and 50% female) and age (20% each group). Sample sizes for each metropolitan area were determined based on the proportion of residents, with a confidence interval of 95% and a 5% margin of error. In this study, only 21 municipalities were included within the MCMA, specifically those with air quality monitoring. The number of survey participants in each municipality ranged from 30 to 35 residents, except for Ecatepec, with three monitoring stations where 90 residents were surveyed, and Coyocan, Cuajimalpa, Iztapalapa, Nezahualcoyotl, and Tlalnepantla with two nearby stations where 60 people were surveyed. In the TVMA, 30 surveys were administered in each municipality, except Toluca, the largest one, where there are four monitoring stations; there, 20 people were surveyed within 4 km of each station. Finally, at CMA, the survey number in each municipality was between 30 and 40 except for Cuernavaca, which is the most populated municipality with 2 monitoring stations; 70 people were surveyed there. Table 1 displays the sample characteristics in the responses of the last section of the questionnaire.

Table 1. Sociodemographic characteristics.

	Total	MCMA	TVMA	CMA
Municipalities	45	21	16	8
Respondents	1750	900	530	320
Personal data				
Men	875	450	265	160
Women	875	450	265	160
18–25 years old	345	175	106	64
26–35 years old	345	174	107	64
36–45 years old	336	172	100	64
46–55 years old	376	204	111	106
56–70 years old	348	64	61	67
Highest education level				
Elementary school	176	36	88	52
Middle school or technical career	505	251	161	93
High school	582	327	156	99
Bachelor's degree	377	204	107	66
Graduate studies	60	32	18	10
Highest socioeconomic level	343	200	90	53
Middle-high socioeconomic level	366	220	89	57
Middle socioeconomic level	353	178	107	68
Middle-low socioeconomic level	296	132	105	59
Low socioeconomic level	213	100	68	45
Lowest socioeconomic level	189	70	71	38
Uses car frequently	443	235	100	108
Uses public transport frequently	1124	595	336	193
Uses bicycle frequently	183	70	94	19

2.3. Questionnaire

A qualitative approach was employed through the content analysis of programs, public policies, and prior research, as well as semi-structured interviews with experts from both academia and local and national environmental agencies specializing in air pollution and climate change, aimed to uncover the history, current status, and contextualization of air quality and climate change in the three metropolitan areas. By analyzing public programs and policies, we gained insight into the current measures being taken by the government and institutions to address air quality, as well as the state of air quality in different areas. Previous research helped us identify psychosocial variables that are relevant to studying air quality, such as risk perception, attributed causality, and perceived vulnerability. We also gathered information on the sources of contaminants and their health effects, as well as the populations most at risk. The initial questionnaire was developed based on findings from the qualitative phase, which was piloted in four municipalities. This pilot study tested the wording and relevance of the items, the functionality of response options; adjustments and modifications were made based on the data collected.

The same survey with 85 questions was used for the three metropolitan areas. The four-point Likert scale questions were used because respondents have different abilities to discriminate among various categories, and the use of face-to-face interviews poses challenges in incorporating a larger number of response categories; however, as these kind of questions could limit the capacity to capture different and complex details of risk perceptions, multiple-choice and ranking questions were also included in order to enrich the research by providing a more comprehensive and contextualized understanding [40].

For the questionnaire validation, a principal component analysis with Varimax rotation was employed to identify underlying components that enabled the evaluation of constructs based on the grouping of items in one or more dimensions for the Likert scales. The Cronbach alpha test was used to evaluate internal consistency, and an acceptable range between 0.65 and 0.9 was considered; the Cronbach alpha was calculated for each dimension and the full scale. (See Tables 2–6).

Table 2. Air quality perception.

Dependent Variable	Question	Response Categories
Air quality perception of the city/town	The air quality you breathe in the metropolitan area is:	Five answers from very bad to very good
	When compared to other cities in the country, the air in the metropolitan area is:	Three answers from much less polluted to more polluted
	When comparing the current situation to 10 years ago, the air in the metropolitan area was:	
	If we continue the same path, in 10 years, the air in the metropolitan area will be:	

Table 3. Risk perception, frequency, and beliefs.

Dependent Variable	Question	Response Categories
Level of risk perception	Thinking about the entire metropolitan area, air pollution is:	Four answers from Not at all risky to very risky
Frequency of risk perception	Thinking about the entire metropolitan area, air pollution is:	Not at all frequent to very frequent
Exposure to air pollution	In which month is there the greatest air pollution?	Multiple-choice answer with the 12 months of the year
Beliefs	Taking care of air quality is:	Four answers from Unnecessary to very necessary
	Taking care of air quality is:	Four answers from Unhelpful to very helpful
	Taking care of air quality is:	Four answers from Very difficult to very easy
	How much does it influence air quality? List of 7 environmental phenomena	Four answers from None to A lot

Table 4. Dimensions and reliability of attitudes toward air quality.

	Factorial Analysis	% Variance Explained	Alpha
Behavioral factor			
How much...			
can you protect yourself from climate change?	0.800	21.706%	0.739
can you protect yourself from air pollution?	0.754		
are you prepared to deal with climate change?	0.644		
are you prepared to deal with air pollution?	0.572		
Cognitive factor			
How much do you...			
have an awareness of air quality?	0.701	21.208%	0.663
identify areas with better and worse air quality?	0.668		
know what to do to face climate change?	0.635		
know what to you if air quality is bad?	0.634		

Table 4. *Cont.*

	Factorial Analysis	% Variance Explained	Alpha
Affective factor How much... are you concerned about air quality? are you concerned about climate change?	 0.845 0.838	14.973%	0.627
Total		57.888%	0.772

Table 5. Dimensions and reliability of causal attribution to different sources.

	Factorial Analysis	% Variance Explained	Alpha
Causal attribution to stationary sources How much do the following industrial activities pollute the air?		14.503%	0.889
Cement plant	0.855		
Brickyard	0.837		
Mine	0.815		
Factory	0.741		
Causal attribution to area sources How much do the following activities and services pollute the air?		13.291%	0.768
Construction	0.677		
Businesses	0.651		
Hotels and resorts	0.649		
Mechanical, carpentry, tinsmithing, and printing workshops	0.636		
Charcoal- or wood-fired restaurants	0.540		
Gas stations	0.537		
Agricultural sowing and harvest	0.498		
Dumpsters	0.383		
Causal attribution to natural sources How much do the following natural events pollute the air?		10.354%	0.813
Blowing dust	0.810		
Erosion	0.802		
Forest fires	0.691		
Causal attribution to mobile sources (public services) How much do the following vehicles pollute the air?		10.184%	0.722
Trailers and trucks	0.772		
Buses from other cities	0.714		
Public transport	0.606		
Delivery and service trucks (e.g., gas, garbage)	0.561		
Causal attribution to mobile sources (individual services) How much do the following vehicles pollute the air?		9.604%	0.647
Taxi, Uber, Didi	0.741		
Private cars and trucks	0.728		
Motorcycles	0.678		
Total		57.937%	0.870

Table 6. Dimensions and reliability of causal attribution to people.

	Factorial Analysis	% Variance Explained	Alpha
How much do the following people pollute the air?			
Causal attribution to people (in general)			
Inhabitants of Mexico City	0.918		
Inhabitants of the Mexico City metropolitan area	0.910	42.813%	0.817
Inhabitants of their municipality or city	0.606		
Causal attribution to people (in particular)			
You and your family	0.877	35.628%	0.679
Neighbors in your neighborhood	0.813		
Total		78.441%	0.780

The final questionnaire, constructed and validated, consisted of six sections:

Section 1. Introduction, filter questions, and participation consent.

Section 2. Air quality perception.

Section 3. Risk perception. Levels, frequency, beliefs, attitudes.

Section 4. Causal attribution perception. Responsible causes.

Section 5. Air quality and health. Consequences, symptoms, diseases, relationships.

Section 6. Sociodemographic data. Sex, age, education, socioeconomic level.

The three first questions of the survey in Section 1 were aimed at learning if respondents were adults, lived in that house, and if they agreed to participate after receiving the introductory information.

2.4. *Air Quality Perception*

The four multiple-choice questions included in Section 2, related to air quality perception, are organized in Table 2.

2.5. *Air Quality Risk Perception, Beliefs, and Attitudes*

This section comprises a total of thirteen multiple-choice questions that aim to evaluate risk perception (risk, frequency, and exposure) and beliefs surrounding the ease and necessity of taking care of air quality. Additionally, seven questions explore the various environmental phenomena that can impact air pollution, including temperature, wind speed, rain, drought, volcanic ashes, deforestation, and climate change (See Table 3).

Participants were surveyed using a 4-point Likert scale to assess their attitudes towards air pollution. The survey included 10 statements related to perceived knowledge and awareness of air quality (cognitive), concerns about air pollution and climate change (affective), and preparedness and feasibility of protective measures to address these environmental issues (behavioral).

2.6. *Air Pollution Causal Attributions*

Two scales were developed to assess causal attributions of air pollution. First, a 22-item, 4-point Likert scale was presented to residents to understand their perceptions of responsibility for pollution sources. The items are presented in Table 5.

Then, five items were evaluated with the same four-point response scale to identify participants' perceptions of the responsibility of different characteristics. The items can be seen in Table 6.

2.7. *Perceived Air Pollution Consequences and Health Relationships*

This section contains two scales that aim to assess participants' perceptions of the health and environmental consequences of poor air quality (seven items) and identify the individuals who are most likely to be affected (five items). See Tables 7 and 8.

Table 7. Dimensions and reliability of perceived air pollution consequences.

	Factorial Analysis	% Variance Explained	Alpha
Consequences on health and environment			
How much does air pollution. . .?			
Harm the quality of life	0.764		
Have effects on health	0.725		
Decrease life expectancy	0.702		
Damage plants, animals, and crops	0.687	45.420%	0.783
Affect mood and performance	0.684		
Contribute to climate change	0.627		
Deteriorate the constructions	0.494		

Table 8. Dimensions and reliability of perceived air pollution consequences on people.

	Factorial Analysis	% Variance Explained	Alpha
Consequences of air pollution on people			
How much do the following people suffer the consequences of air pollution?			
Neighbors in your neighborhood	0.873		
Inhabitants of their municipality or city	0.863		
You and your family	0.832	66.791%	0.875
Inhabitants of Mexico City	0.772		
Inhabitants of the Mexico City metropolitan area	0.738		

Participants were asked (yes or no questions) to report whether they had been diagnosed with diseases associated with exposure to air pollution (heart failure, heart attack, thrombosis, obstructive pulmonary disease, cerebral hemorrhage, pulmonary emphysema, chronic bronchitis, or allergic rhinitis) or whether they had presented associated symptoms during the last month (allergy, poor performance, headache, sore throat, stress, eye irritation—conjunctivitis—, shortness of breath, unusual fatigue, flu, chest tightness or pain, palpitations, cough, dryness, or skin irritation). Then, they were asked to identify the months in which they experienced more respiratory illness.

In the end, socioeconomic data were collected: sex, age, educational level, main transportation mode (car, public transportation, or bicycle), and socioeconomic level (calculated from six multiple-choice questions).

2.8. Statistical Analysis

Resident responses were analyzed using Statistical Package for Social Sciences (SPSS) version 28. Proportions (%) were used to report variables for air quality, risk perception, causal attributions, consequences, and health in descriptive statistics summaries. The Kruskal–Wallis with Bonferroni post hoc test was used to assess differences in perception across the three metropolitan areas. For the ranking question, chi squared was used. The significance level was set at 0.05 with the corresponding 95% confidence intervals. The report presents the significant differences among groups, as indicated by the H of KW and p values.

3. Results

3.1. Air Quality Perception

This section describes the perception of the air quality that residents breathe in their living areas, exploring how these perceptions vary across cities and have changed over time (Figure 2). The analysis revealed significant distinctions across all surveyed aspects, with the MCMA registering the poorest air quality.

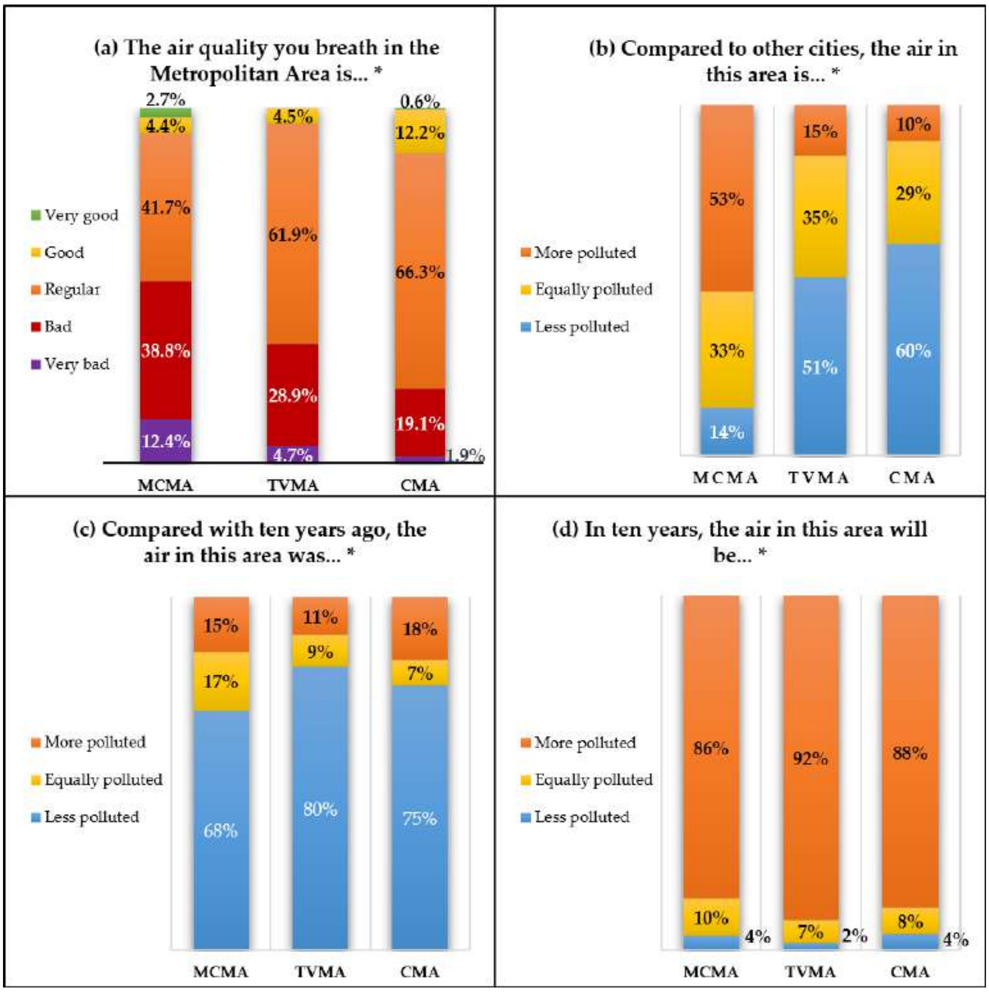

Figure 2. (**a**) Comparison of air quality perception among the three metropolitan areas. (**b**) Air quality perception of each metropolitan area in comparison with other cities. (**c**) Perception of the current air quality in the three metropolitan areas compared to that of ten years ago. (**d**) Perception of air quality in ten years (* $p \leq 0.05$).

Approximately half of the respondents from MCMA expressed the belief that the air they breathe is either bad or very bad. In contrast, around 60% of participants from TVMA and CMA characterized their air quality as regular. Significant differences were found between the three areas (H (2) = 101.50, $p = 0.000$). When comparing perceptions with other cities, nearly half of MCMA residents perceive their air as more polluted than elsewhere. Conversely, over half of those from TVMA and CMA believe their air is less polluted. Significant differences were found between MCMA and the other two areas (H (2) = 433.36, $p = 0.000$).

Participants from all three areas agree that the air was less polluted a decade ago. However, distinctions arise, notably with 32% of MCMA participants expressing that the air was either equally or more polluted a decade ago (H (2) = 24.053, $p = 0.000$). The air quality ten years ago was perceived as less polluted in TVMA than in MCMA (post hoc $p = 0.000$). Anticipating the future, more than 80% of respondents from all areas foresee increased pollution in the next decade. The analysis showed significant differences between two areas: in MCMA, 14% believe it will remain equally polluted or become less polluted, a perspective shared by only 7% in TVMA (H (2) = 11.225, $p = 0.004$; post-hoc $p = 0.002$).

3.2. Air Quality Risk Perception

To comprehensively analyze risk perception among residents in the three areas, different variables were taken into consideration. The examined variables for assessing risk perception encompassed the perceived level of risk, the perceived frequency, and the most commonly identified time of year for heightened pollution. The study also explored beliefs regarding the necessity, usefulness, and ease of caring for air quality. Furthermore, attitudes toward air pollution and climate change were assessed across three components: cognitive (perceived knowledge and awareness), affective (concern), and behavioral (preparation and the feasibility of protection).

At the outset, participants were queried about the frequency, perceived risk level, and timing of air pollution peaks. Noteworthy variations were identified based on the metropolitan area of residence. In the MCMA, participants perceived air pollution as a highly risky and frequent occurrence. In the TVMA, air pollution was viewed as somewhat risky and somewhat frequent, while in the CMA, 30% perceived it as not very risky, with only 15% considering it very risky or as something occurring infrequently. Significant differences between the three areas were found (H (2) = 111.162, $p = 0.000$). As can be seen in Figure 3a, across all areas, there was a higher perception of frequency compared to the level of perceived risk; consequently, a moderate correlation was found between frequency and risk perception (spearman r = 0.427, $p = 0.00$).

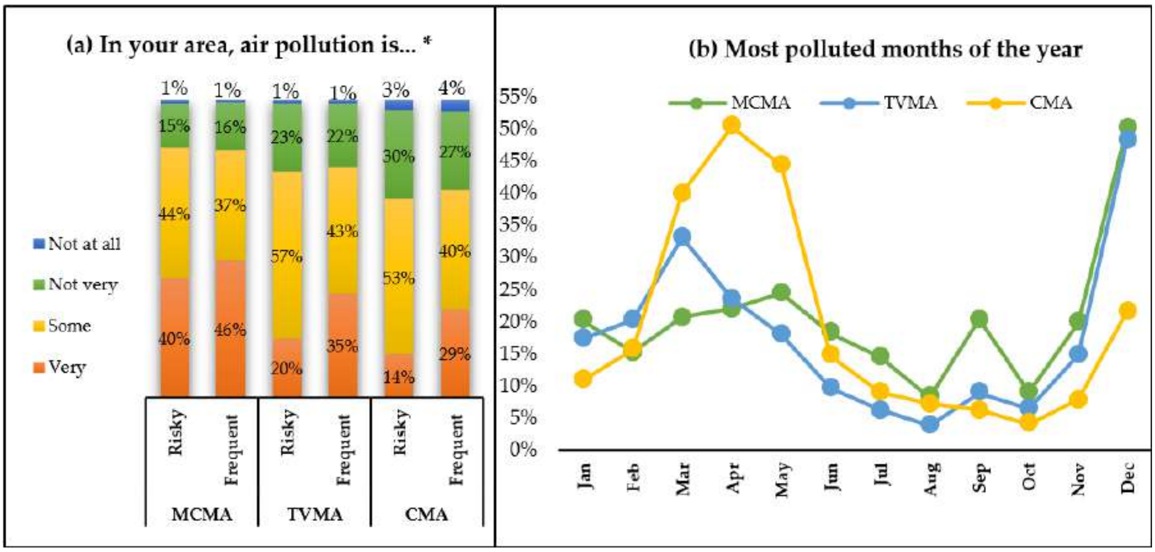

Figure 3. (**a**) Perception of risk and frequency in the three metropolitan areas. (**b**) Perception of the most air-polluted months in the three metropolitan areas (* $p \leq 0.05$).

The frequency perception aligns with how inhabitants perceive the months with more significant pollution levels. Figure 3b illustrates that pollution levels are perceived to be higher in December in all three areas; however, specific increases vary by city and likely correlate with geographical and climatic characteristics. In the MCMA, residents identified a period of air pollution increase starting in November, peaking in December, and subsiding in January and February. Another increase is noted from March to May before a subsequent decline; interestingly, an increase is also perceived in September. In the TVMA, a similar surge is observed in November and December, with a secondary peak in March; from May to October, a reduced perception of pollution is noted. Lastly, in the CMA, individuals perceive the highest pollution levels from March to May, with the other months indicating low pollution perception, except for a slight increase in December.

Figure 4 reveals distinctive patterns in beliefs, showing significant differences among the three areas regarding the usefulness (H (2) = 6.028, p = 0.048) and ease of caring for air quality (x^2 = 6.859, p = 0.032). Respondents generally agreed that this is very necessary, with more than 70% response.

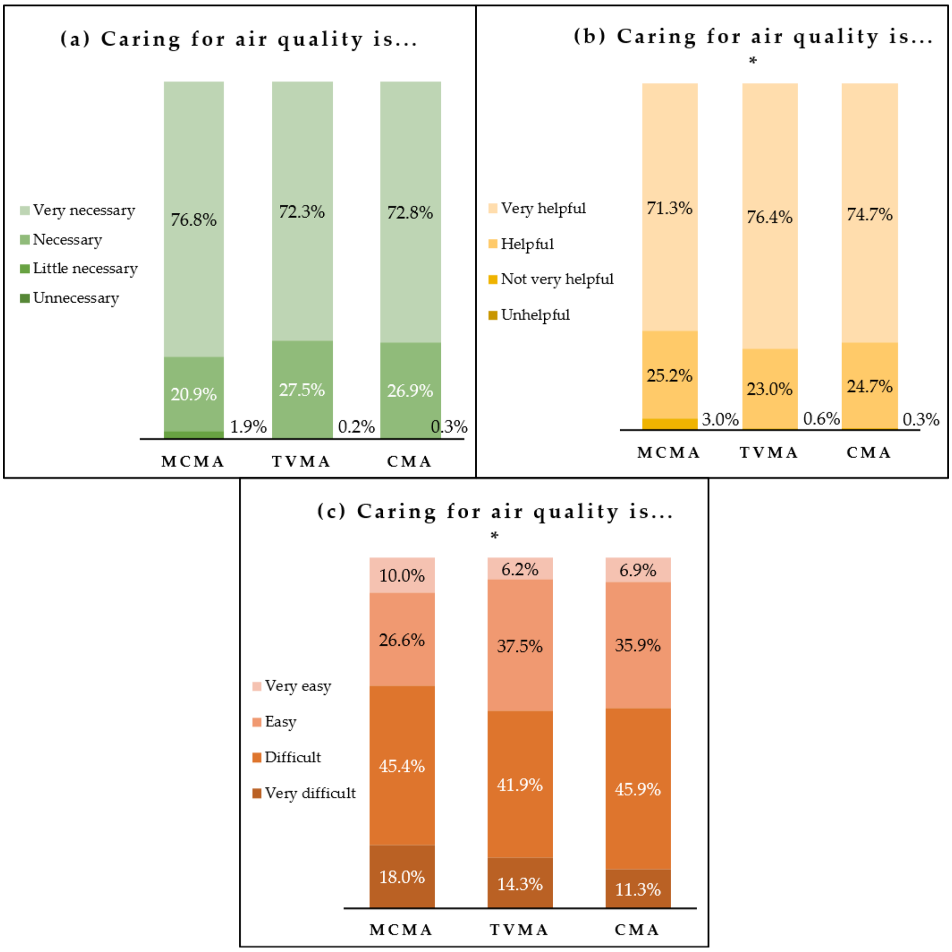

Figure 4. Perception of the need (**a**), usefulness (**b**), and difficulty in taking care of air pollution (**c**) (* $p \leq 0.05$).

In the people's beliefs regarding the interrelation of various environmental phenomena, the three study areas converge in their viewpoints. Three-quarters of the participants assert that climate change and volcanic ash wield significant influence over air quality. Approximately 60% believe that deforestation and rainfall play a role, and half of the respondents contend that droughts are closely linked. Conversely, extreme temperatures and winds, regardless of their strength, are perceived by 20% of the sample as having minimal or no impact. Significant disparities were identified in the perception of the impact of winds on air quality (H (2) = 10.475, p = 0.005). In the MCMA, a higher percentage of individuals (50%) believed that winds have a significant influence, compared to the CMA, where only 40% shared this view (post hoc p = 0.006). Similarly, there were notable differences in the perception of deforestation's impact (H (2) = 7.185, p = 0.028). Approximately 83% of respondents from TVMA asserted that deforestation has a substantial influence, while this percentage slightly decreased to 75% in the MCMA (post hoc p = 0.022). A detailed breakdown of responses for the entire sample can be found in Figure 5.

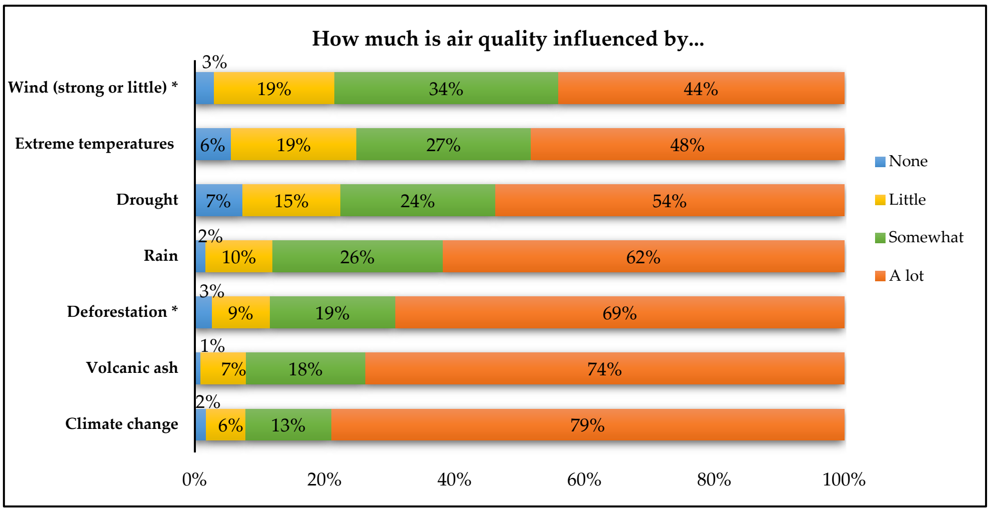

Figure 5. People's beliefs related to the influence of environmental phenomena on air quality (* $p \leq 0.05$).

To assess attitudes towards air pollution and climate change, a series of questions were employed to explore cognitive and perceived knowledge-based factors linked to both phenomena, as well as affective components related to concern when they occur. Additionally, the study looked at behavioral aspects, including individual sense of preparedness and the potential for protective measures.

Figure 6 displays findings on the public perceived knowledge and awareness of air quality. The results indicate that awareness of air quality varies between 51% and 55% among respondents in the three areas. However, just over 50% feel that they have little to no knowledge about addressing climate change. Notably, there are significant differences between the areas in terms of identifying zones with good or bad air quality (H (2) = 14.534, $p = 0.001$). Specifically, 60% of respondents in Cuernavaca mostly identify areas with good or bad air quality, while only 40% in Mexico City share the same perception (post hoc $p = 0.001$). Furthermore, significant differences are found in terms of knowing what to do (H (2) = 7.587, $p = 0.023$). Half of the MCMA inhabitants express having a lot or some perceived knowledge about addressing poor air quality, while only around 40% in Toluca feel the same (post hoc = 0.031).

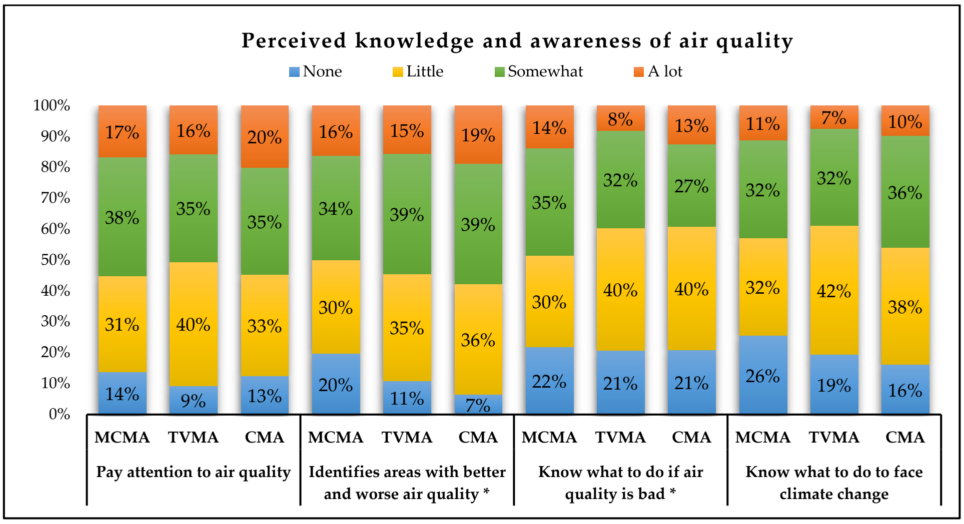

Figure 6. Attitudes towards climate change and air quality. Cognitive component (* $p \leq 0.05$).

The emotional dimension of attitudes toward air pollution and climate change is reflected in the concerns expressed by participants, as depicted in Figure 7, variations between the areas were evident in the level of concern for air pollution (H (2) = 19.629, $p = 0.000$) and climate change (H (2) = 30.385, $p = 0.000$). Significantly, responses from MCMA participants differed from those in the metropolitan areas of Toluca and Cuernavaca, demonstrating greater levels of concern for both air pollution (post hoc $p = 0.006$) and climate change (post hoc $p = 0.002$), respectively.

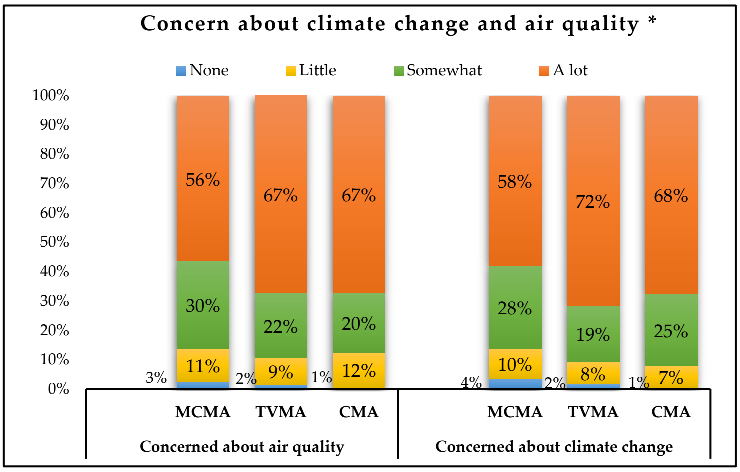

Figure 7. Attitudes towards climate change and air quality. Affective component (* $p \leq 0.05$).

The final aspect concerns behavior, specifically the ability to safeguard oneself and prepare for both poor air quality and climate change (Figure 8). Just over 60% of respondents across the three areas feel inadequately prepared to confront poor air quality, with half of them not perceiving the possibility of self-protection. Regarding climate change, significant differences emerged in perception of preparedness (H (2) = 8.362, $p = 0.015$) and the ability to protect oneself from it (H (2) = 9.185, $p = 0.010$). Residents of Mexico City feel more prepared than those from Toluca to face climate change ($p = 0.013$) and more able to safeguard themselves from this phenomenon than their counterpart from Cuernavaca ($p = 0.032$). A moderate correlation was found between the cognitive and behavioral components (Spearman r = 0.550, $p = 0.00$) These results suggest that those who perceive they have knowledge and awareness feel more prepared and able to protect themselves.

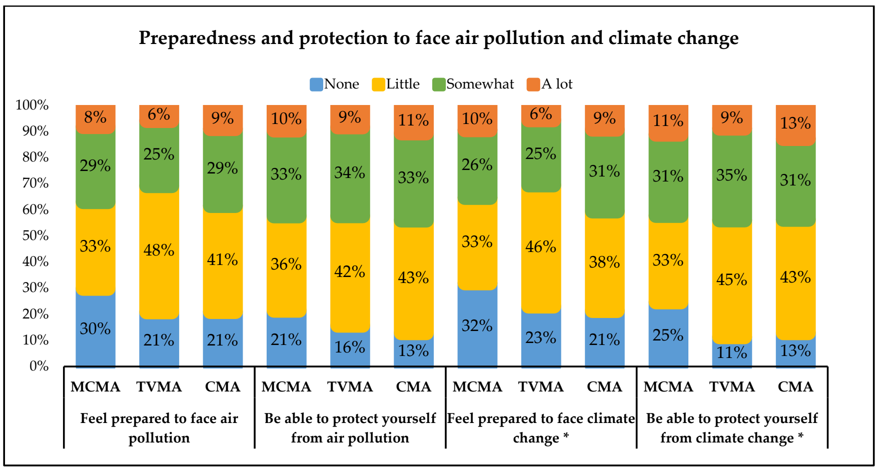

Figure 8. Attitudes towards climate change and air quality. Behavioral component (* $p \leq 0.05$).

3.3. Causal Attribution Perception

Causal attribution plays a crucial role in the examination of environmental risks. In classifying sources emitting atmospheric pollutants, we have identified four categories: mobile, area, stationary, and natural. Table 9 outlines the percentages of responses regarding the degree of air pollution attributed to different sources, including various vehicle types, activities and services, industrial activities, and natural events. Table 9 also shows the perception differences among the three metropolitan areas under analysis, emphasizing variations based on the type of emission source.

Table 9. Perception differences of the causal attribution to air pollution sources.

		MCMA	TVMA	CMA	H (2)	*p*
Mobile sources: Private vehicles						
Cars and Vans	Nothing	0.6%	0.4%	1.3%	73.94	0.000
	Little	14.7%	20.0%	29.1%		
	Something	31.2%	44.3%	39.1%		
	Much	53.6%	35.3%	30.6%		
Motorcycles	Nothing	2.4%	4.5%	5.3%	63.58	0.000
	Little	27.6%	39.4%	38.8%		
	Something	34.4%	37.4%	35.9%		
	Much	35.6%	18.7%	20.0%		
Taxis, Uber	Nothing	2.9%	4.0%	7.5%	43.02	0.000
	Little	27.0%	31.5%	32.8%		
	Something	32.3%	42.3%	40.0%		
	Much	37.8%	22.3%	19.7%		
Mobile sources: Service vehicles						
Foreign Buses	Nothing	12.6%	4.9%	6.3%	2.14	0.343
	Little	23.0%	21.7%	23.1%		
	Something	20.3%	33.0%	33.1%		
	Much	44.1%	40.4%	37.5%		
Delivery and service trucks	Nothing	1.7%	0.9%	1.3%	36.02	0.000
	Little	16.7%	18.9%	26.6%		
	Something	29.3%	42.1%	37.5%		
	Much	52.3%	38.1%	34.7%		
Trailers and cargo trucks	Nothing	4.1%	3.4%	8.8%	2.48	0.290
	Little	13.3%	13.2%	12.8%		
	Something	17.3%	18.9%	16.6%		
	Much	65.2%	64.5%	61.9%		
Public transportation	Nothing	1.9%	2.6%	3.8%	32.22	0.000
	Little	12.1%	11.3%	15.3%		
	Something	19.8%	29.6%	33.4%		
	Much	66.2%	56.4%	47.5%		

Table 9. *Cont.*

		MCMA	TVMA	CMA	H (2)	*p*
Area sources: Services						
Construction	Nothing	15.3%	13.4%	10.3%	6.539	0.038
	Little	32.1%	39.8%	35.6%		
	Something	31.0%	32.1%	34.4%		
	Much	21.6%	14.7%	19.7%		
Businesses	Nothing	8.9%	8.3%	12.2%	9.282	0.010
	Little	32.8%	40.4%	39.7%		
	Something	41.2%	36.2%	32.5%		
	Much	17.1%	15.1%	15.6%		
Gas stations	Nothing	6.4%	5.5%	10.9%	7.772	0.021
	Little	22.9%	23.2%	23.8%		
	Something	35.6%	31.9%	34.1%		
	Much	35.1%	39.4%	31.3%		
Hotels and resorts	Nothing	35.9%	34.7%	24.4%	25.338	0.000
	Little	33.0%	35.1%	33.1%		
	Something	20.7%	22.8%	23.4%		
	Much	10.4%	7.4%	19.1%		
Charcoal- or wood-fired restaurants	Nothing	10.4%	8.7%	12.2%	8.193	0.017
	Little	21.7%	24.5%	28.4%		
	Something	33.9%	35.5%	32.5%		
	Much	34.0%	31.3%	26.9%		
Mechanical, carpentry, tinsmithing, and printing workshops	Nothing	7.1%	7.0%	12.2%	14.665	0.001
	Little	29.2%	35.5%	33.1%		
	Something	37.8%	38.3%	35.3%		
	Much	25.9%	19.2%	19.4%		
Agricultural sowing and harvest	Nothing	56.9%	35.8%	30.3%	75.721	0.000
	Little	22.1%	36.6%	35.9%		
	Something	13.0%	18.3%	21.6%		
	Much	8.0%	9.2%	12.2%		
Dumpsters	Nothing	13.2%	5.1%	7.2%	58.533	0.000
	Little	14.4%	7.7%	9.4%		
	Something	16.8%	13.2%	16.9%		
	Much	55.6%	74.0%	66.6%		
Stationary sources:						
Cement plants	Nothing	54.7%	23.0%	22.8%	157.962	0.000
	Little	13.8%	18.3%	14.7%		
	Something	12.3%	29.6%	27.2%		
	Much	19.2%	29.1%	35.3%		

Table 9. *Cont.*

		MCMA	TVMA	CMA	H (2)	*p*
Factories	Nothing	36.2%	11.5%	23.1%	127.361	0.000
	Little	10.8%	8.9%	12.2%		
	Something	13.1%	12.1%	11.3%		
	Much	39.9%	67.5%	53.4%		
Brickyards	Nothing	56.3%	20.9%	27.2%	167.627	0.000
	Little	13.7%	21.1%	21.6%		
	Something	12.3%	24.9%	25.0%		
	Much	17.7%	33.0%	26.3%		
Mines	Nothing	67.9%	30.4%	31.9%	232.553	0.000
	Little	9.7%	16.0%	13.4%		
	Something	8.9%	22.6%	16.9%		
	Much	13.6%	30.9%	37.8%		
Natural sources						
Erosion	Nothing	26.0%	11.5%	9.7%	90.078	0.000
	Little	25.8%	19.1%	24.4%		
	Something	23.7%	27.9%	28.1%		
	Much	24.6%	41.5%	37.8%		
Forest fires	Nothing	31.7%	7.0%	5.3%	254.376	0.000
	Little	18.1%	8.9%	10.9%		
	Something	14.4%	15.5%	13.1%		
	Much	35.8%	68.7%	70.6%		
Blowing dust	Nothing	24.3%	8.3%	10.3%	51.979	0.000
	Little	24.9%	20.9%	25.9%		
	Something	22.4%	35.7%	30.3%		
	Much	28.3%	35.1%	33.4%		

In terms of mobile sources, there is a notable tendency to attribute higher pollution levels to service vehicles rather than private individuals. Across all three zones, trailers and cargo trucks emerge as the most significant contributors, accounting for more than 60% of responses categorized as "A lot". Additionally, there is a consensus that foreign buses also play a substantial role in air pollution. However, significant differences exist among the three cities. For instance, 60% of MCMA residents perceive public transport as a major contributor to air pollution, while 56% of TVMA residents share this view. In contrast, only 47% of CMA residents hold a similar opinion. Regarding delivery and service trucks, more than half of Mexico City participants believe that they cause a significant amount of pollution, whereas 42% of those in the Toluca Valley and 37% in Cuernavaca believe they contribute to pollution to some extent.

Significant differences in perceptions emerge across the three regions when considering private vehicles. Over 50% of respondents in the MCMA area believe that cars significantly contribute to pollution, whereas 42% of respondents in the TVMA and 40% in the CMA consider cars to be somewhat polluting. Furthermore, there are distinctions in the perceived impact of motorcycles and taxis/Uber/Didi, with the metropolitan area of Mexico City having the highest percentage of respondents who believe that these vehicles pollute somewhat or a lot. In the TVMA and the CMA, between 30% and 40% of respondents believe that these vehicles contribute somewhat or little to pollution.

Table 9 also illustrates significant differences in response percentages regarding causal attributions to area sources. Particularly noteworthy are the significant discrepancies in perceived pollution levels from businesses in the services sector. Approximately 58% of individuals in MCMA perceive them as somewhat or highly polluting, whereas 52% of those in CMA consider them to be minimally or not polluting. Regarding construction, differences were observed between Mexico City and Cuernavaca, with 15% of individuals in the former perceiving them as not polluting at all, while only 10% of those in the latter held the same view.

Perceptions of pollution vary among the three metropolitan areas, particularly concerning mechanical, carpentry, tinsmithing, and printing workshops. In the MCMA, 64% of individuals find them somewhat or very polluting, while in TVMA, 57% share a similar opinion, and in Cuernavaca, 54% express this view. The perceived level of pollution from gas stations also varies significantly, with a similar response tendency. Concerning charcoal- or wood-fired restaurants, MCMA believes that they are somewhat or very polluting (70%), in contrast to CMA, where only 59% hold the same perception. Finally, regarding hotels and spas, evident differences exist between the three areas, CMA attributing greater pollution (43%), while Toluca and Mexico City have lower attributions (31% and 32%, respectively), indicating little or no pollution.

Several activities are commonly identified as area sources of pollution, including garbage dumps, planting, and harvesting. However, it is crucial to note that these activities differ significantly regarding their perceived impact on air quality. Garbage dumps, planting, and harvesting are generally considered highly polluting in all three zones, with a majority of respondents in TVMA selecting "a lot" as their response. CMA and MCMA exhibit similar trends, although to a lesser extent. In the case of planting and harvesting in the metropolitan area of Cuernavaca, 33% of participants consider this activity to be somewhat or very polluting. On the other hand, only 20% of participants in the Mexico City metropolitan area believe that this activity contributes to the pollution of the area.

The results concerning stationary sources of air pollution revealed significant differences, with the MCMA having a lower percentage perceiving it as a major cause. In the CMA, a third of the inhabitants believe that mines cause a lot of pollution, contrasting with the MCMA, where almost 70% think it is not a significant cause of pollution in the area. Regarding cement plants, Cuernavaca shows a higher attribution of contamination causality (35% responding "A lot", followed by the Toluca (29%) and, finally, Mexico City (19%)). Prominent differences among the three areas are also observed regarding the perceived pollution level from factories and brickyards. It is believed that brick factories heavily or somewhat pollute the air in TVMA (60%) and Cuernavaca (50%), while 50% of the MCMA perceives them as little or non-polluting. Factories were perceived as an important source of pollution in TVMA (67%) and CMA (53%), but not as much in the MCMA, where only 40% hold the same view.

In addition to pollutants originating from human activities, natural phenomena can be sources of atmospheric pollutants. In MCMA, half of the participants believe that forest fires, blowing dust, and erosion have little or no impact on pollution levels, but in CMA and TVMA, forest fires are considered highly polluting (around 70%). Blowing dust and erosion are associated with the highest contamination levels in Toluca (approximately 70%), followed by the Cuernavaca area (65%).

The perception of causal attribution is closely linked to those deemed responsible for causing air pollution. As depicted in Figure 9, individuals in the three areas feel less accountable and tend to attribute more responsibility to their neighbors, fellow residents of their municipality, and, to some extent, people living in the city and metropolitan area. Data reveal significant differences at the personal level (H (2) = 9.562, p = 0.008) of responsibility perceived by people from MCMA compared to those from Toluca or Cuernavaca. Those in MCMA tend to attribute more responsibility to their neighbors (H (2) = 19.636, p = 0.000) and fellow residents of their municipality (H (2) = 16.925, p = 0.000) than individuals in the other two areas. While MCMA and TVMA assign similar percentages of responsibility to the inhabitants of their city (H (2) = 40.497, p = 0.000) and the metropolitan area (H (2) = 37.781, p = 0.000), the percentage is lower in the CMA.

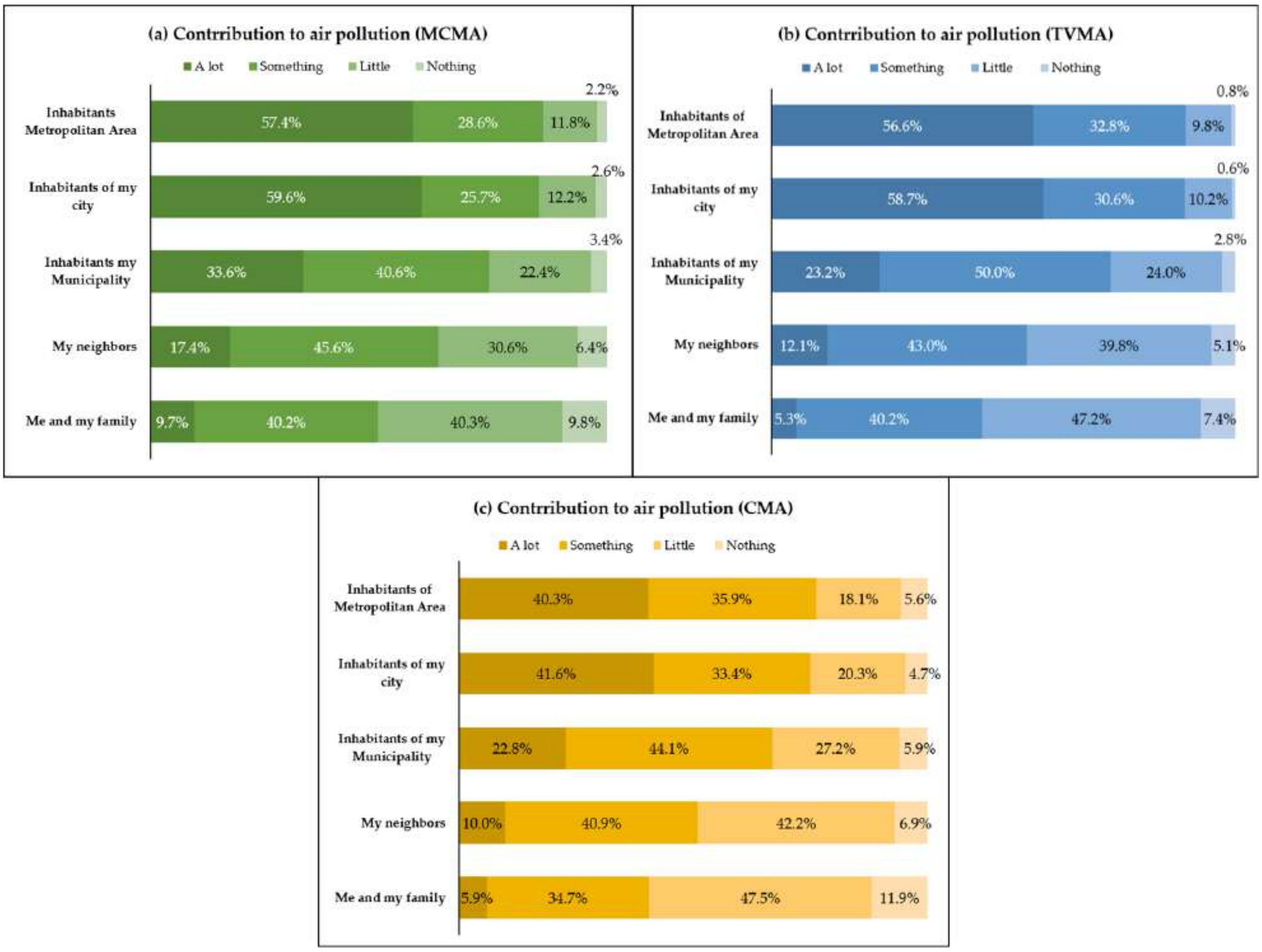

Figure 9. Personal attribution. Contribution of different characters to air pollution in MCMA (**a**), in TVMA (**b**) and in CMA (**c**).

In addition to the previously mentioned sources, it is crucial to consider daily activities that significantly influence air quality (Figure 10). When respondents were questioned about the top three behaviors contributing to pollution, substantial variations emerged regarding their ranking preferences in the three metropolitan areas. Significant differences were observed in the behaviors they ranked in first (x^2 = 77.040, p = 0.000), second (x^2 = 38.341, p = 0.000), and third place (x^2 = 42.576, p = 0.000). The most frequently mentioned behavior in the first position is burning garbage or engaging in bonfires, particularly noted in Cuernavaca and Toluca. The second most commonly cited activity involves using firewood, charcoal, or fireplaces for heating homes, with a lower proportion in the MCMA. Concerning environmental impact, those in the TVMA identify fireworks as highly pollutant. However, car usage has a more significant contribution to pollution in the MCMA.

3.4. Air Quality Consequences and Health

Figure 11 shows the survey results, focusing on the percentage of responses regarding the consequences of air pollution. A predominant agreement emerges among most respondents, indicating that air pollution significantly affects health and quality of life negatively. Further analysis reveals noteworthy differences between the three study areas; particularly, a high percentage of individuals from the MCMA (68% and 62%) believed that poor air quality can substantially reduce life expectancy (H (2) = 6.892, $p = 0.032$) and negatively affect attitude and performance (H (2) = 10.866, $p = 0.004$), respectively. It is noteworthy that participants were also asked about any potential connection to COVID, revealing significant variations between the metropolitan areas of TVMA (50%) and CMA (48%) versus the MCMA (35%).

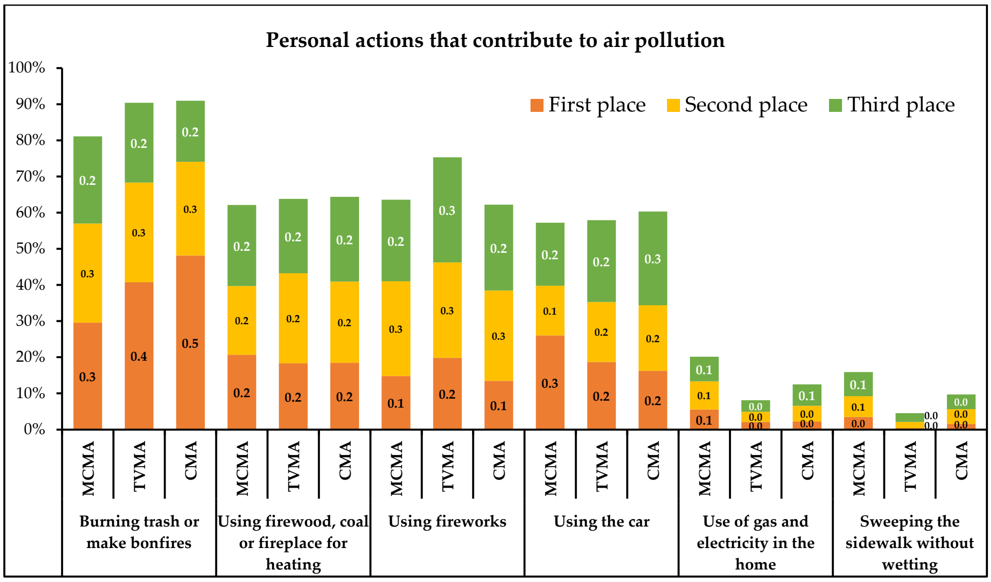

Figure 10. Contribution of personal actions to air pollution.

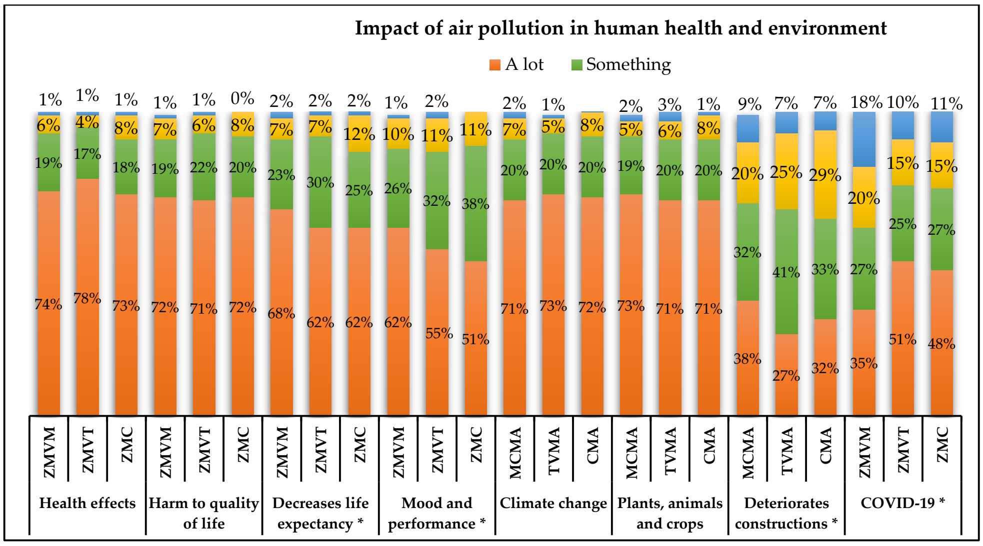

Figure 11. Different consequences due to air pollution on human health and environment (* $p \leq 0.05$).

According to the survey, a vast majority of respondents believe that air pollution significantly affects climate change, as well as the well-being of plants, animals, and crops. This perspective resonated with approximately 70% of the population in each surveyed group. Interestingly, the impact of air pollution on buildings yielded different results. Specifically, 70% of those in Mexico City indicate that pollution damages buildings, whereas this proportion dropped to 60% in the other two groups, and this observed difference proved to be statistically significant, (H (2) = 8.604, $p = 0.014$).

To identify which demographic is perceived as the most vulnerable to the effects of air quality, respondents were asked about the extent to which different groups of people suffer from the consequences of air pollution. Figure 12 provides a detailed breakdown of the percentages obtained from residents of the three metropolitan areas. The findings reveal a pattern where individuals perceive themselves and their neighbors as less vulnerable, while people residing in the city, municipality, or the metropolitan area have a greater probability of suffering damage.

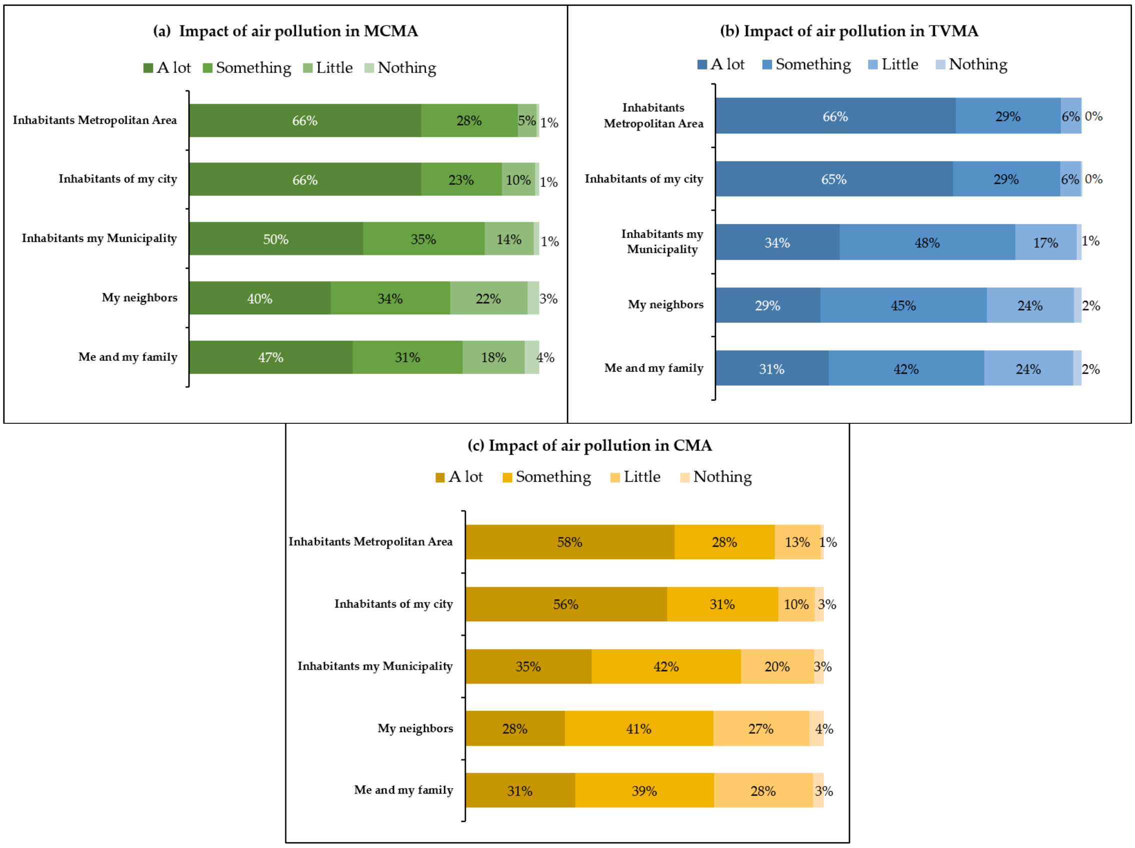

Figure 12. Impacts of air pollution on people. MCMA (**a**); TVMA (**b**); and CMA (**c**).

When examining perceptions based on the area of residence, significant disparities emerge regarding the extent to which individuals and their neighbors are affected by pollution (H (2) = 35.219, p = 0.000; x^2 = 16.610, p = 0.000). Intriguingly, the data suggest that residents of the MCMA exhibit a slightly higher perception of vulnerability compared to those in the other two cities. Furthermore, individuals in the TVMA and CMA perceive that the consequences of pollution are equally experienced by themselves, their families, and their neighbors, while those in the MCMA express a higher likelihood of the consequences affecting the entire population (H (2) = 35.048, p = 0.000). All three groups believe that residents of the city and metropolitan area will be the most impacted. Statistical differences also indicate that the CMA has a lower perceived likelihood of being affected compared to the other two (H (2) = 11.348, p = 0.003; H (2) = 10.670, p = 0.000).

The results of this research show the importance of carrying out this type of study in all metropolitan areas of the Megalopolis and in other regions of the country. It is interesting to note that in the megacity of the MCMA, people are more aware about air pollution and its risks because at least once a year the environmental authorities decree an environmental contingency situation where mobility is restricted and health damage is reported in all media; this population is aware and mainly perceive the pollution produced by mobile sources, but almost not by the industries, since a large part of them emigrated to other places due to strong regulations. It is presumed that this type of perception is similar to the other two large metropolitan areas in Mexico: Guadalajara and Monterrey, as well as big cities in the world. On the other hand, in the TVMA, although the concentrations are higher, people perceive less risk from air pollution and attribute it to industry, since they have a large industrial corridor visible to the entire population; so, the perception observed in this city could be similar to that experienced by medium-sized cities in the Megalopolis such as Hidalgo and Querétaro that have large industrial corridors, or in cities with important industrial zones. Finally, in the case of Cuernavaca, which is a small city with only a few years of air pollution monitoring, the perception of risk is lower, and air pollution is more related to natural sources and much less to vehicles and industries, since it has agricultural areas and many areas not yet built, which can happen in the smaller cities of this and other countries.

Since most people perceive a close relationship between air quality and health, the aim was to identify diagnosed diseases and experienced symptoms in the month prior to the survey. Allergic rhinitis and chronic bronchitis are notably reported more frequently than other diseases, particularly in the MCMA. As for symptoms, flu, stress, chest pain, and headaches are the most commonly reported, with some variations. The MCMA participants consistently report higher percentages of some symptoms, while participants from the CMA show lower percentages in some instances (See Figure 13).

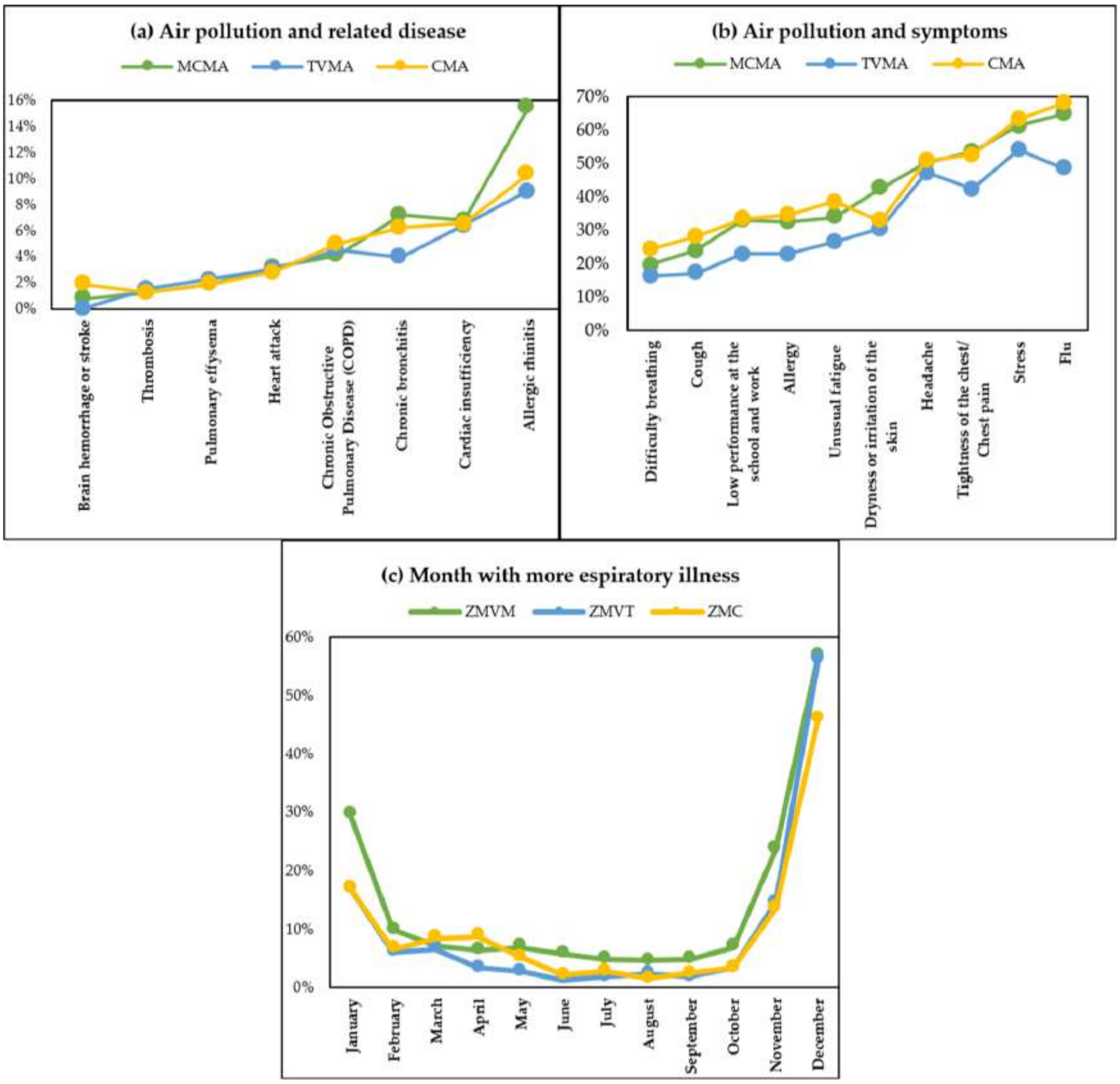

Figure 13. Health consequences: diseases (**a**); symptoms (**b**); and presence of respiratory illnesses (**c**) associated with exposure to air pollution.

There is a discernible correlation between the months in which respiratory diseases, primarily attributed to air pollution, require the most medical attention. Data from all three areas indicate that November, December, and January are the peak months for these types of illnesses. Additionally, Cuernavaca experiences a slight increase in cases during March and April, aligning with increased reports of poor air quality during those months. Table 10 summarizes all the Kruskal–Wallis results presented previously.

Table 10. Kruskal–Wallis report by dimension and by item.

Attitudes About Air Quality								
	City	C1	C2	C3	C4			
Cognitive factor	ZMVM	876.57	836.51	866.48	906.13			
	ZMVT	862.05	896.82	859.86	838.28			
	ZMC	894.78	949.84	926.77	851.02			
H-statistic		0.935	14.534 **	4.501	7.587 *			
		A1	A2					
Affective factor	ZMVM	830.61	821.05					
	ZMVT	925.48	942.87					
	ZMC	918.98	917.06					
H-statistic		19.629 ***	30.385 ***					
		B1	B2	B3	B4			
Behavioral factor	ZMVM	861.85	855.81	857.40	841.78			
	ZMVT	870.32	866.94	882.45	908.90			
	ZMC	922.46	945.04	914.90	915.03			
H-statistic		3.854	8.362 *	3.571	9.185 *			
Causal Attribution to Air Pollution								
		M1	M2	M3	M4	M5	M6	M7
Causal attribution to mobile sources	ZMVM	883.74	863.33	926.86	937.64	946.35	965.10	964.15
	ZMVT	882.15	900.75	852.99	833.07	820.59	811.71	780.06
	ZMC	841.31	867.91	768.34	771.01	767.20	729.14	784.24
H-statistic		2.478	2.139	32.222 ***	36.021 ***	43.016 ***	73.943 ***	63.576 *
		AS1	AS2	AS3	AS4	AS5	AS6	AS7
Causal attribution to area sources	ZMVM	888.47	907.39	850.46	916.66	896.64	877.12	782.51
	ZMVT	832.39	854.46	843.97	845.02	880.86	909.39	948.65
	ZMC	910.44	820.64	998.16	810.22	807.18	814.82	1015.88
H-statistic		6.539 *	9.282 *	25.338 ***	14.665 ***	8.193 *	0.021 *	58.533 ***
		N1	N2	N3				
Causal attribution to natural sources	ZMVM	795.42	768.40	703.42				
	ZMVT	978.17	999.09	1051.97				
	ZMC	930.68	972.01	1067.19				
H-statistic		51.979 ***	90.078 ***	254.374 ***				
		S1	S2	S3	S4			
Causal attribution to stationary sources	ZMVM	735.17	732.80	709.78	763.22			
	ZMVT	1009.87	1055.77	1044.52	1049.12			
	ZMC	1047.63	978.26	1061.65	903.75			
H-statistic		157.962 ***	167.727 ***	232.553 ***	127.361 ***			
		P1	P2	P3	P4	P5		
Causal attribution to people	ZMVM	903.90	903.83	917.98	904.11	921.53		
	ZMVT	914.76	912.53	848.43	865.34	844.07		
	ZMC	730.61	734.49	800.87	811.86	798.09		
H-statistic		40.497 ***	37.781 ***	16.925 ***	9.562 **	19.636 ***		
Perceived Air Pollution Consequences and Health								
		HE1	HE2	HE3	HE4	HE5	HE6	HE7
Consequences on health and environment	ZMVM	876.97	862.68	901.25	887.29	908.67	868.83	908.22
	ZMVT	873.60	907.70	852.21	863.13	849.34	890.10	838.79
	ZMC	874.50	858.23	841.66	862.84	825.54	870.07	844.29
H-statistic		0.026	5.441	6.892 *	1.638	10.866 **	1.030	8.604 *
		P1	P2	P3	P4	P5		
Consequences of air pollution on people	ZMVM	918.81	939.56	940.50	890.27	892.34		
	ZMVT	843.93	814.14	815.81	894.38	889.24		
	ZMC	805.99	796.96	791.56	802.70	805.39		
H-statistic		16.610 ***	35.048 ***	35.219 ***	11.348 **	10.670 **		

Significance level: * −0.05, ** −0.01, *** −0.001.

4. Discussion

The findings of this study emphasize significant differences in the perception of air quality, its causes, and consequences among residents in the three metropolitan areas, as anticipated at the onset of this research. However, in several cases, despite the differences between the three metropolitan areas, there were slight variations and even coincidences. Recognizing that individuals' perceptions on the topics explored in this study are shaped by context, personal experiences, and received information, the findings suggest that the observed differences are attributable to those factors, such as distinctive geographical features, diverse socioeconomic conditions, and distinct policies and programs that have been implemented in each region.

In MCMA, over 50% of respondents believe that the air quality is poor or very poor, with the majority considering their city the most polluted. This perception is likely influenced by a history of experiencing poor air quality since the 1980s. Additionally, residents have had access to real-time information through local environmental authorities' websites for over two decades, fostering a heightened awareness of the issue. Notably, despite monitoring data demonstrating a significant reduction in pollution levels during the three last decades, this improvement is not distinctly perceived by the residents. In contrast, in other metropolitan areas characterized by rural and peri-urban zones, the perception of pollution is influenced by factors such as burning, agricultural activities, forest fires, bonfires, and garbage dumps, rather than urban sources like cars or services.

In the CMA, where the industrial zone is relatively small, the monitoring network relies on occasional campaigns, leading to limited awareness among residents. Nearly 80% believe their city is less polluted, aligning with the measurements indicating regular or good air quality. The TVMA, known as the most polluted area in the country, has had an information system on air quality for two decades. Surprisingly, only 30% of respondents perceive the air quality as poor, with over half believing their residential area is less polluted than others, despite evidence to the contrary, showing that there is a low level of air quality information and that the communication strategy should be changed. However, residents accurately perceive an increase in pollution over the last decade, expressing confidence (99%) that it will improve in the next 10 years; this is possibly due to information about expanded air monitoring coverage performed the last three years, even though the pollutant concentration has not decreased

An interesting aspect is that, in the MCMA, a majority no longer perceives pollution from stationary sources, possibly because the information they receive does not emphasize these sources. This stands in contrast to other areas where residents remain cognizant of the risks posed by industrial activities. This contrasts with the other two areas, which was expected in TVMA because it has several industrial zones but not in CMA, where the industrial zone is small, although residents are aware of that risk. The literature mentions that the notion of pollution is flexible and depends on history and context [41]; it is constantly redefined and reinvented, and environmental scenarios and aspects can give rise to new meanings and uses, behaviors, which is also reported by Oltra and Salas, indicating that the subjective assessment of local air differs significantly between populations in cities with strong differences [14]. Environmental aspects or signals serve as references for participants to analyze their risk perception. People, in general, believe they can identify air quality with their senses, leading to biases when assessing risk. Another aspect is that cities that are not as large and are surrounded by natural areas give the false idea of being cleaner environments, as is evident in the Cuernavaca and Toluca perception.

The perception of air pollution risk is parallel, to some extent, with residents perceptions of air quality. Those residing in the MCMA are the most cognizant, followed by the Toluca Valley Metropolitan Area and the Cuernavaca Metropolitan Area. Across all three regions, the perception of pollution risk and frequency surpasses the recognition of poor air quality, with awareness ranging from 60% to 80% among residents. This contrasts with the findings of Oltra and Sala, who reported generally low levels of perceived severity. In the metropolitan areas of Mexico City and Toluca, the fall and winter months pose higher risks due to elevated altitude and increased pollution frequency, especially during these colder months, linked to lower temperatures that complicate and exacerbate respiratory diseases [14]. Conversely, for the CMA, warmer months are considered double the pollution compared to winter due to the warm climate and ongoing sugarcane harvest and burning.

The observed spike in risk occurs around March, corresponding to the ozone season with clear skies, making it challenging to associate it with specific environmental factors. Specific activities, such as sugarcane harvesting and tourism, not only impact air quality but also influence people's perceptions of it. While differences in pollution perception, risk, and frequency exist among the three zones, over 70% of residents across all areas clearly recognize the importance of caring for air quality. This indicates that they are sensitive residents who, with adequate information and education, could actively participate in reducing pollution-causing activities. However, the strategy for each location must be tailored, considering the varying causal attributions. Another signal that people need information is that 50–55% pay attention to air pollution and can identify areas with higher or lower contamination, yet over 50% find it challenging to do so.

Regarding the cognitive component of both air pollution and climate change, only 50% of MCMA participants know what to do when air quality is poor, showing higher awareness than the other areas where knowledge decreases to 40%. Concerning climate change, less than 45% of participants know what to do. Another finding reinforcing the need for effective communication about air pollution and climate change is that emotional concern ranges from 56 to 72% of participants, with the highest percentages in the less-informed areas (67–72%), while concern in the MCMA decreases to 56–58%. Consistent with other studies, over 60% of respondents do not feel adequately prepared to face or know what to do to protect themselves from air pollution or climate change, especially in the CMA and the TVMA. Rectifying misperceptions is thus essential to improving residents' views and attitudes [42].

Queries about personal actions contributing to air pollution are crucial for generating positive and sustainable responses. Recognizing the most important sources, MCMA residents acknowledge that car use is the leading cause of climate change and air pollution, while TVMA and CMA recognize waste burning, use of firewood, coal, and fire in general as highly polluting. However, more than 50% do not consider themselves or their families responsible, attributing responsibility to neighbors or inhabitants of the municipality, city, or metropolitan area. Consequently, they do not feel part of the problem and do not contribute to avoiding these actions. In this regard, Leiserowitz et al. [43] showed that minimizing the "self" for others is a complex phenomenon. There is a need for people to adopt these strategies through education and communication to achieve multiple targets [44]. Messages should be clear, awareness-raising, and not fear-inducing but encouraging, emphasizing that we are part of the solution.

Finally, regarding the negative impacts of air pollution on human health perception, there are no differences between the three areas. Between 62 and 74% are aware that pollution damages health, quality of life, and reduces life expectancy, in contrast to Benney et al. [45] who reported that most of Utah's residents are unaware of the short- and long-term health risks associated with air pollution. These are important findings since Orru et al. [46] suggested that air pollution and health risk perception play crucial roles in understanding and predicting health symptoms. Care must be taken while informing people about health effects to avoid inducing additional consequences such as stress-induced physiological responses and health symptoms. Policymakers should translate the population perceptions and the drivers of such perceptions into positive actions for the management of air pollution and climate change [47].

5. Conclusions

This is the first perception study conducted in the Megalopolis considering three zones of its metropolitan areas, which has shown that resident perceptions related to air pollution and climate change are influenced by the local context.

Regarding air quality, individuals in the MCMA demonstrate heightened sensitivity compared to those in Toluca and Cuernavaca. Participants display a comprehensive understanding of the issue, acknowledging that air pollution has worsened and is likely to continue, despite official reports indicating a decrease in pollution over the past two decades. This apparent contradiction is attributed to stringent environmental regulations and contingency measures.

Notably, distinctions emerge between the MCMA and the metropolitan areas of Toluca and Cuernavaca. The latter areas exhibit a greater risk and frequency of environmental concerns, accompanied by a higher level of awareness, concern, and a capacity for protection. Specifically, Mexico City faces a prevalence of mobile and area sources; Toluca, as an industrial zone, has more fixed sources; and Cuernavaca relies on natural sources due to agricultural activity. These variations align with the primary causes of environmental issues in each area, such as car usage in Mexico City, burning of garbage in Cuernavaca, and industries and the use of fireworks in Toluca.

A consistent finding is that individuals generally feel less accountable and personally exposed compared to others in their community, city, or metropolitan area. They tend to attribute greater responsibility to others and believe that others will bear the consequences. Moreover, people not only possess knowledge about the risks of poor air quality but also understand its potential impacts on health and quality of life. This awareness is particularly evident in the metropolitan area of Mexico City, where participants report a high frequency of respiratory diagnoses, likely attributed to increased exposure associated with urban living.

Studies related to the psychosocial dimensions of air quality and climate change should enable the population to identify health risks, address them, and sensitize them to getting involved in the challenges of improving air quality and addressing climate change. Moreover, it encourages the development and success of behavioral changes to achieve a more sustainable development model that will undoubtedly benefit all residents. Additionally, with the results obtained, policymakers can tailor specific measures or strategies for communities or areas with different issues.

Finally, regarding the limitations of this research, the use of non-probabilistic sampling and multiple-choice questions precludes the use of parametric statistics. Nonetheless, given the absence of prior perception studies conducted in the Megalopolis, it was deemed important to conduct a detailed exploration of resident perceptions. Selecting a sample near monitoring stations may limit the generalizability of data to the broader population, but this decision was made to enable future correlation analysis with pollution levels at these stations. Furthermore, while recognizing the need to include other variables for a more comprehensive understanding of the psychosocial dimensions of air pollution and climate change, the purpose of this document is to analyze valid and reliable scales to assess air pollution in three key areas of the megalopolis. Further analysis with additional variables will be conducted as part of a Megalopolis project.

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