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Analyzing Urban Air Quality Perceptions: Integrating Socio-Demographic Patterns with Sensor-Based Measurements Using Regression Model and Multidimensional Scaling

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Abstract: In this study, the urban air quality perceptions are explored in the metropolitan area of Târgu Mureș, Romania, emphasizing the interaction between socio-demographic factors, air quality measures, and industrial activity. The research addresses the need to understand how public perceptions align with objective air quality data and industrial influences, aiming to support sustainable urban planning. Data were gathered through a structured survey of 321 respondents and complemented by air quality measurements, including $PM_{2.5}$ and PM_{10}, and industrial production data. Statistical analyses, such as regression models and multidimensional scaling (PROXSCAL), were applied to identify patterns and relationships between socio-demographic characteristics, perceived air quality, and environmental factors. The results reveal significant links between demographic factors (e.g., age, awareness of local initiatives) and perceptions of air quality, alongside a nuanced interaction between air quality indicators and industrial activity. Respondents frequently identified traffic and industrial emissions as major contributors to air pollution, which was corroborated by sensor data trends. The findings underline the importance of integrating public perceptions with empirical data to design targeted policies and foster community engagement. This comprehensive approach provides actionable insights for improving urban air quality and advancing sustainable practices in mid-sized cities like Târgu Mureș.

Keywords: urban air quality; socio-demographic analysis; multidimensional scaling; perceptions of pollution; industrial activity

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1. Introduction

Air quality has a profound impact on people's lives, particularly in both developed and developing countries, where urban environments with bustling industries and heavy traffic contribute to a diverse range of pollutants [1]. The effects of poor air quality extend beyond environmental degradation; they pose significant health risks that underscore the importance of adopting sustainable practices to reduce emissions [2,3]. In the context of the global transition towards sustainability, air quality stands as a crucial marker of urban

health and the effectiveness of environmental policies. Recent studies have emphasized the importance of integrating socio-demographic data with objective measurements to better inform public policies focused on environmental and health outcomes [4–6].

According to the World Health Organization, outdoor air pollution is responsible for approximately 4.2 million premature deaths each year, highlighting the urgent need for sustainable policies to mitigate pollution [7,8].

Research has consistently linked air pollution to a spectrum of illnesses, including respiratory and cardiovascular diseases and reduced life expectancy [9–11]. Pollutants like nitrogen dioxide (NO_2) and particulate matter (PM) worsen conditions such as asthma and chronic obstructive pulmonary disease (COPD), underscoring the need for sustainable approaches that tackle emissions at their source through urban planning and renewable energy development [12,13]. In urban contexts, sustainable transportation options and clean energy sources have become essential for reducing emissions from traffic and power generation, thereby enhancing public health and air quality [14].

The economic burden of respiratory diseases tied to air pollution is considerable [15]. Li et al. found evidence that higher $PM_{2.5}$ levels drive up healthcare expenses, particularly in low-income areas where awareness of air quality issues may be limited [16,17]. This underscores the need for sustainable communication strategies to increase public awareness that are accessible to all social categories [18]. Tompkins et al. and D'Antoni et al. emphasized the importance of using diverse communication channels to reach affected populations and improve public understanding of air quality issues [19,20].

Air pollution also poses significant risks to cardiovascular health. Studies by Miller and Newby indicated that urban air pollution from diesel exhaust and fine particulate matter is linked to increased cardiovascular mortality [21]. These findings stress the importance of policy interventions and urban planning that reduce emissions from vehicles and industries. Borrego et al. discussed how urban planning can significantly impact air quality, suggesting that sustainable urban development can mitigate pollution levels and improve public health outcomes [22,23].

Seasonal variations in air pollution further complicate its health impacts. Researchers found that the impact of ambient air pollution on respiratory outpatient visits was significantly higher during transitional seasons [24,25]. Similarly, the role of indoor air quality in respiratory health is increasingly recognized as integral to sustainable health outcomes [26]. Mkorombindo et al. highlighted that indoor pollutants, including those from fuel combustion, significantly contribute to respiratory morbidity, particularly in individuals with COPD [27]. Sustainable air quality management must therefore address not only outdoor pollution but also indoor sources, advocating for cleaner energy options in residential and industrial settings [28].

In Romania, the National Sustainable Development Strategy aligns with the 2030 Agenda, prioritizing environmental protection and public health, emphasizing a sustainable approach to air quality improvement [29,30].

In Târgu Mureș, where industrial activities and traffic emissions contribute to air pollution, local authorities have implemented various initiatives to enhance air quality, such as monitoring pollutants, promoting green urban spaces, and encouraging the use of public transportation to reduce emissions.

Air quality challenges in Târgu Mureș arise from multiple sources, including emissions from industrial activities, vehicular traffic, construction sites, and residential heating systems. Traffic emissions are particularly concerning, as they release nitrogen oxides (NOx) and particulate matter (PM) into the atmosphere, further underscoring the need for sustainable transportation and emission-reduction policies [31,32].

Understanding the public perception of air quality is essential for fostering community-driven sustainability efforts. To this end, we conducted a study to assess the Mureș community's perceptions of air quality. Using a structured questionnaire, we gathered insights into residents' experiences and attitudes towards air pollution, identifying commonly recognized pollution sources, such as vehicle and industrial emissions and evaluating the community's awareness of air quality issues. The findings aim to bridge the gap between public awareness and environmental realities by integrating socio-demographic factors with sensor-based measurements, offering a comprehensive understanding of urban air quality dynamics.

Prior research underscores the importance of community engagement in building awareness and promoting sustainable practices that can contribute to improved air quality outcomes [33,34]. The link between air quality and community well-being is evident [2]. Polluted air poses significant health risks, but proactive community engagement in sustainability initiatives can lead to better health outcomes [35]. A recent study by Ahamad et al. (2023) demonstrates the effectiveness of community-based initiatives and policy changes in enhancing air quality and public health, ultimately contributing to the resilience and sustainability of urban communities [36].

While prior research highlights the health and economic impacts of air pollution [28,31,32], there is a lack of studies that integrate socio-demographic factors with sensor-based measurements to provide a comprehensive understanding of urban air quality dynamics.

2. Materials and Methods

In this study, the aim was to evaluate air quality perceptions in the metropolitan area of Târgu Mureș through a combination of survey-based socio-demographic analysis and sensor-based environmental measurements. Two research phases were implemented, namely, survey analysis and environmental monitoring.

The survey analysis was completed through a structured questionnaire, designed to evaluate socio-demographic influences, awareness of air quality issues, and perceptions of pollution sources.

The questionnaire was pre-tested with a small sample of 20 respondents to ensure clarity and relevance of questions. Feedback was used to refine the survey before wider distribution. The data were collected in October 2024 through an online platform to maximize reach and ensure accessibility. The survey was distributed via an internal university platform using the student database, as well as on LinkedIn, targeting a diverse demographic. A total of 321 respondents participated.

The sample structure from the primary data is as follows:

- from the total number of respondents (321), 51% were female and 49% were male;
- according to the age, 60% were in age group 18–23 years old (192 respondents), 10% 24–29 years old (33 people), 9% between 30 and 39 years old (28 people), 12% between 40 and 49 years old (37 people), 8% between 50 and 59 years old (24 people), 2% between 60 and 69 years old and only 0.6% (2 people) over 69 years old;
- a total of 93% of respondents lived in Târgu Mureș or a surrounding area;
- a total of 77% were residents (248 respondents), 23% were foreign visitors (70 respondents), or other (3 persons).

Participants were queried about their awareness of local initiatives aimed at improving air quality. Their perceptions were captured using a Likert scale ranging from "very poor" to "very good", alongside identifying key contributors to pollution, such as traffic emissions, industrial activities, and waste management challenges.

For the second part of the research the secondary data were used.

The environmental data analysis relied on sensor-based measurements and industrial activity reports. In this study, several methods were incorporated to collect and analyze environmental data. Air quality monitoring focused on $PM_{2.5}$ and PM_{10} levels, using data from "Strop de Aer" sensors [37] installed in different residential areas within Târgu Mureș. The sensors were positioned at a height of approximately 3 m above ground level to capture ambient air quality. These locations were strategically selected to represent diverse residential environments across the city. The sensors remained stationary throughout the study period, ensuring consistent data collection. These sensors captured readings every two minutes, which were then aggregated into daily averages for the period between August 2021 and November 2024.

The air quality monitoring in this study utilized Strop de Aer sensors, manufactured by Strop de Aer. These sensors are equipped with the Nova Fitness SDS011 Optical Particle Counter, which measures particulate matter concentrations ($PM_{2.5}$ and PM_{10}) using a light scattering method. The model used was the SDS011 Sensor.

The Strop de Aer sensors were evaluated against Federal Equivalent Method (FEM) instruments, such as the GRIMM EDM 180 and the Teledyne API T640. For $PM_{2.5}$, strong correlations with reference instruments were observed, with coefficients of determination (R^2) ranging from 0.77 to 0.83 for hourly averages. However, correlations for PM_{10} were weaker, with R^2 values between 0.14 and 0.30.

The sensors demonstrated consistent performance, with low intra-model variability. For $PM_{2.5}$, the absolute variability was ~0.44 $\mu g/m^3$ (8.8% relative variability), while for PM_{10}, it was ~0.93 $\mu g/m^3$ (7.1% relative variability). These metrics highlight the reliability of the sensors in tracking air quality variations.

To assess the impact of industrial activities, data on production schedules and downtimes from a key industrial contributor in Târgu Mureș were obtained from local records. These data were coded into binary variables, where "1" indicated active production and "2" represented periods of downtime of the main chemical plant producing fertilizers. This approach facilitated an analysis of how industrial activity influenced pollution levels.

Additionally, in this study, the structure and age of the local vehicle fleet were examined, relying on automotive registration data for Mureș County from 2019 to 2023. This analysis included metrics such as the proportion of vehicles over 20 years old and the distribution of engine types, including diesel, gasoline, hybrid, and electric vehicles. These data points provided valuable insights into the contribution of traffic to local air pollution.

The analysis involved a combination of descriptive, inferential, and multivariate statistical techniques to ensure a comprehensive examination of the data.

First, descriptive statistics were used to summarize the demographic characteristics of the respondents and their responses to survey questions. This included measures such as means, medians, and frequency distributions, which provided an overview of public perceptions and behaviors related to air quality according to the type of data, continuous or categorial.

To explore relationships between variables, correlation analysis was conducted, with Kendall's tau coefficients used to assess the strength and direction of associations between socio-demographic factors and perceived pollution sources. These correlations were visualized through heat maps and/or correlation matrix, highlighting significant patterns in the data.

Regression analysis formed the backbone of the inferential approach, helping to identify predictors of air quality perceptions and their rating. Two separate models were applied, with one focusing on pollution sources as independent variables and the other on socio-demographic characteristics. Both models used a stepwise approach to isolate significant predictors, allowing for a nuanced understanding of the factors influencing

perceptions and behaviors. The rating of air quality was chosen as dependent variable of the model.

For examining dissimilarities and similarities among respondent groups, the PROXSCAL multidimensional scaling (MDS) technique was applied. These procedures generated perceptual maps that illustrated how respondents were grouped based on their socio-demographic profiles and air quality perceptions, providing a deeper visual insight into patterns of agreement or divergence.

Lastly, non-parametrical tests, including the Chi-square test and independent samples Kruskal–Wallis test, were used to detect statistically significant differences across socio-demographic groups regarding their perceptions and actions related to air quality. These tests offered insights, especially for ordinal or categorical variables, ensuring that the findings were not biased by assumptions of normality.

In our study, we used SPSS, GEODA, and Excel to analyze and visually represent the data, each tool contributing uniquely to the process. SPSS helped us explore the connections between socio-demographic factors and perceptions of air quality through regression analysis, correlation test, descriptive, and inferential statistics. GEODA allowed us to graphically represent and visually emphasize the similarities, dissimilarities, and some particularities of the research data. Also, Microsoft Excel was used for some graphical representation providing an accessible and efficient way to organize, visualize, and summarize the data, making it easier to identify trends, structures, and insights. By combining these tools, we ensured a comprehensive and well-rounded approach to the analysis.

Regression analysis was a cornerstone of this study. The following two models were developed: one focusing on how pollution sources (e.g., traffic, industrial activity) influenced air quality perceptions, and the other exploring the impact of socio-demographic characteristics. A stepwise approach was used to isolate the most significant predictors, enabling us to understand which factors played the most critical role in shaping perceptions.

To explore differences between groups, we used non-parametric tests, such as the Chi-square test and the Kruskal–Wallis test. These tests allowed us to examine how factors like age, gender, or residential status influenced perceptions and actions related to air quality.

Multidimensional scaling (MDS), implemented through PROXSCAL, was used to map how respondents with similar socio-demographic profiles were clustered based on their perceptions of air quality.

To assess the impact of industrial production on air quality, Kendall's tau correlation coefficients were calculated between $PM_{2.5}/PM_{10}$ levels and periods of industrial activity. Additionally, data were visualized through heatmaps and box plots, offering a clear comparison of pollution levels during operational and non-operational phases of the key industrial plant.

Multidimensional scaling (MDS) addresses the problems of positioning objects in perceptual space [38] and exists in the following variants [39]: fully metric (derived distances are linear or multiple functions of proximities); completely non-metric [40]; and non-metric (the rank of the derived distance between objects corresponds to a rank of proximity data). What differentiates it from the other descriptive methods is the criterion used to choose the number of factor axes, namely Kruskal's stress with the following formulas [41]. Along with this criterion, we can also use Cattell's scree-plot criterion, the variance index explained by analysis, and Shepard's diagram.

$$S = \sqrt{\frac{\sum \left(d_{ij} - \overline{d}_{ij}\right)^2}{\sum d_{ij}^2}} \quad (1)$$

$$S = \sqrt{\frac{\sum (d_{ij} - \hat{d}_{ij})^2}{\sum (d_{ij}^2 - \overline{d})^2}} \quad (2)$$

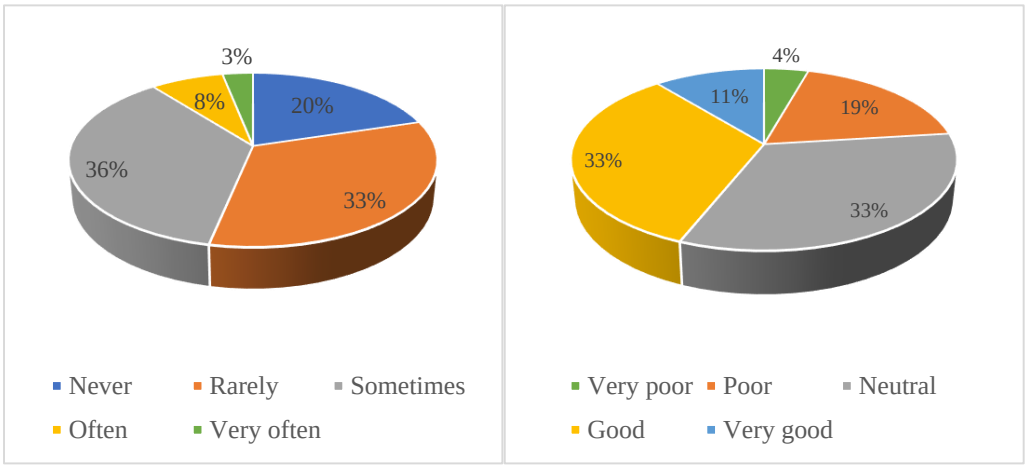
where $\begin{cases} d_{ij} = \text{observed distance between objects } i \text{ and } j \\ \hat{d}_{ij} = \text{predicted distance through modelling and derived from the judgments of similarities} \\ \overline{d} = \text{arithmetic means of distances } d_{ij} \end{cases}$

The inputs of the method are given by attitudes, similarities, and preferences and the outputs provide the location of the object in a limited number of dimensions (this is the main disadvantage of the method).

3. Results

3.1. Results of the Questionnaire

Referring to the rate of the air quality in the metropolitan area of Târgu Mureș, Romania, the structure of the responses is presented in Figure 1a. The mean of 3.27 calculated on a Likert scale, where 1 represents "very poor" and 5 represents "very good", indicates that on average, most respondents are neutral to slightly positive; additionally, 33% rated as "good" and 11% as "very good". In Figure 1b, the results are presented for how often they experienced problems related to air quality. The mean of 2.4, calculated on a Likert scale where 1 represents "never" and 5 represents "very often", indicates that, on average, respondents rarely encounter issues with air quality in the metropolitan area of Târgu Mureș; specifically, 20% responded "never", 33% "rarely", and 36% "sometimes". In total, only 11% experienced problems with air quality in metropolitan area of Târgu Mureș. Only 31% of respondents were aware of any initiatives in their area aimed at improving air quality.



(**a**) (**b**)

Figure 1. Respondents' perceptions: (**a**) the rate of the air quality in the metropolitan area of Târgu Mureș; (**b**) how often they experienced problems related to air quality.

In Figure 2, the main factors affecting air quality in the respondents' area are presented. Traffic ranked first, identified by 274 respondents (85.4%), followed by industrial activity with 166 respondents (51.7%), waste management with 127 respondents (39.6%), and construction work with 87 respondents (27.1%). The least selected factor, indicated by only 11.5% of respondents, was the heating systems as an element affecting air quality.

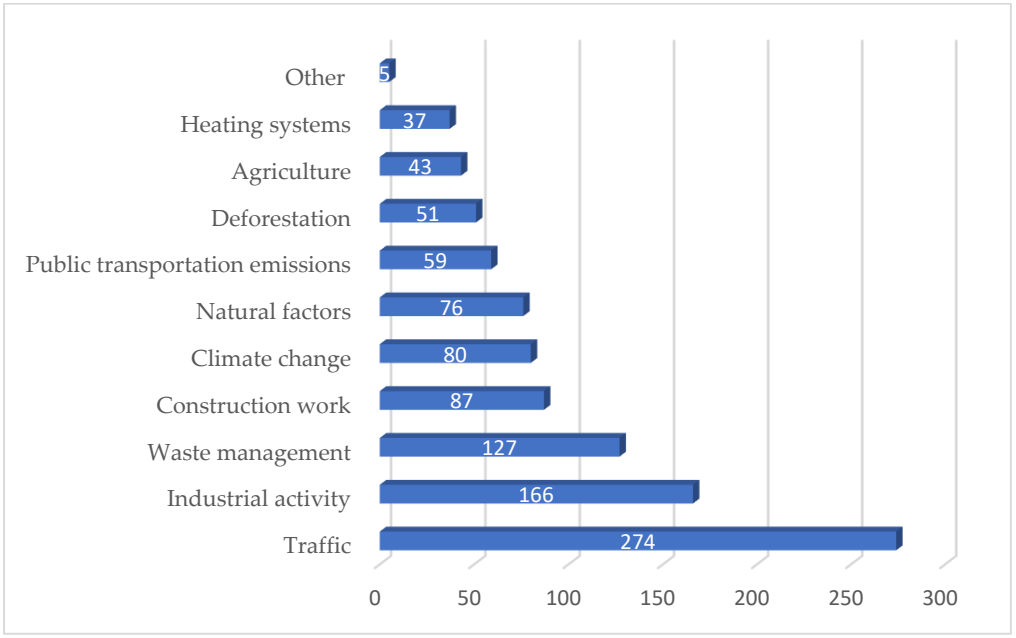


Figure 2. The main factors that affected the air quality in the respondents' area.

Regarding the actions that respondents personally take to reduce air pollution, the hierarchy extracted from a multiple choice question presented in Figure 3 shows that the most common action is recycling and properly disposing of waste, reported by 145 respondents (45.2%). This is followed by walking or biking instead of driving, cited by 142 respondents (44.2%), and using public transport instead of driving, mentioned by 106 respondents (33.0%). Reducing energy consumption at home was identified by 104 respondents (32.4%), avoiding single-use plastics by 89 respondents (27.7%), and planting trees or maintaining green spaces by 78 respondents (24.3%).

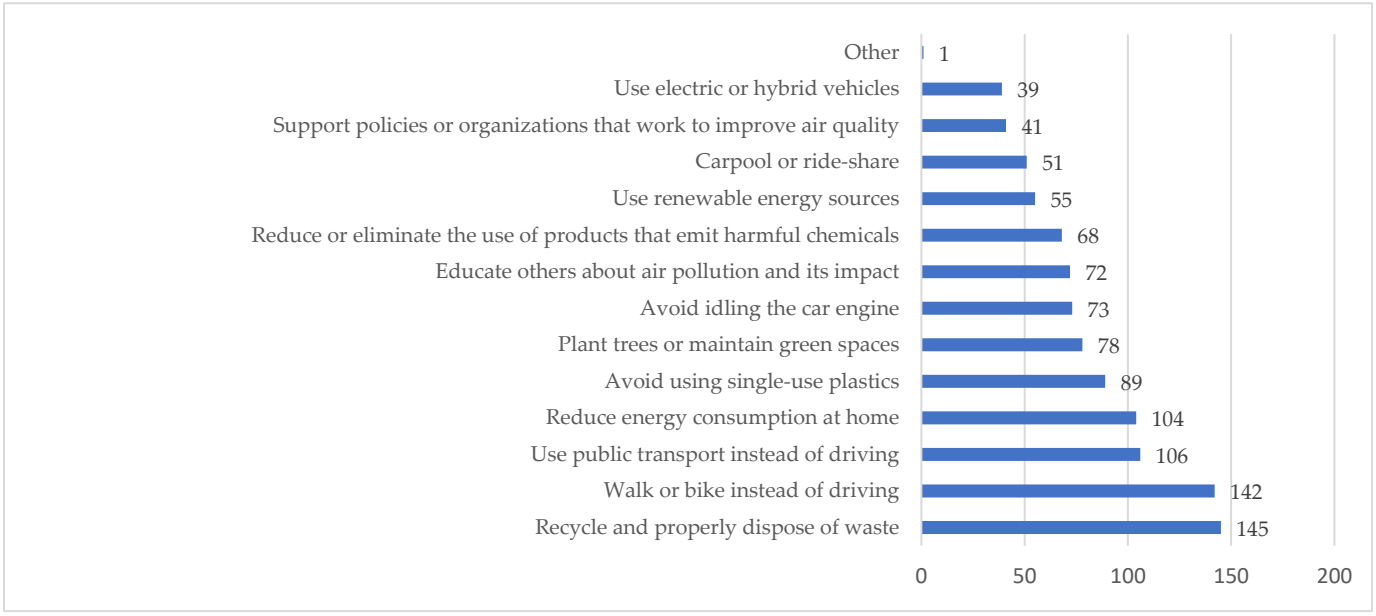


Figure 3. Actions that respondents personally take to reduce air pollution.

To identify correlations, for both residents and non-residents from the metropolitan area of Târgu Mureș, the Kendall correlation coefficients were applied, the results being presented in the heat map in Table 1. Even at the overall level of sample, there are only a

few positive, statistically significant correlations, of low intensity, as follows: deforestation and climate change (+0.262), deforestation and waste management (+0.223), climate change and natural factors (+0.221), and agriculture and construction work (+0.172). When the details were provided of the correlation analysis at the resident and non-resident level, some particularities were identified, as follows: a negative correlation between traffic and agriculture (−0.070), and a positive correlation between traffic and public transport emissions (+0.106) and traffic and construction work (+0.094). For non-residents, industrial activity and traffic (+0.076), an inverse correlation between the factors of climate change and traffic (−0.026) and a positive correlation between the factors of climate change and industrial activity (+0.023), natural factors and agriculture (+0.168), industrial activity and climate change (+0.023), and climate change and deforestation (+0.262).

Table 1. Heat map of Kendall correlation coefficients for factors affecting air quality.

	Traffic	Industrial Activity	Construction Work	Agriculture	Heating Systems	Natural Factors	Waste Management	Public Transportation Emissions	Deforestation	Climate Change	Other
Traffic	--										
Industrial activity	0.076	--									
Construction work	0.094	0.084	--								
Agriculture	−0.070	−0.078	0.172	--							
Heating systems	0.039	−0.042	0.153	0.116	--						
Natural factors	0.023	−0.019	0.089	0.168	0.143	--					
Waste management	−0.007	0.055	0.109	0.131	0.087	0.074	--				
Public transportation emissions	0.106	0.040	0.073	−0.069	0.081	0.095	0.060	--			
Deforestation	−0.013	−0.006	0.080	0.104	0.137	0.099	0.223	0.124	--		
Climate change	−0.026	0.023	0.086	0.006	0.13	0.221	0.152	0.061	0.262	--	
Other	−0.019	−0.029	−0.020	−0.049	−0.045	−0.070	0.053	0.135	−0.055	−0.072	--

The background colors indicate the strength and direction of Kendall correlation coefficients: green for strong positive, yellow for weak/negligible, and red for strong negative relationships.

A regression model was used to identify the best predictors for air quality ratings in the metropolitan area, with the air quality ratings serving as the dependent variable. While the model was statistically significant according to the ANOVA test, the identified factors accounted for only 13% of the total variance in the ratings. The results of this linear regression analysis are presented in Table 2. The most influential predictors, based on standardized Beta coefficients, were waste management, industrial activity, other factors, deforestation, and agriculture.

Based on results from Table 2 the regression equation is as follows:

$$\begin{aligned} \text{Rate of air quality in the metropolitan area} = {} & -1.046 - 0.001 \text{ traffic} \\ & - 0.358 \text{ industrial activity} - 0.074 \text{ construction work} - 0.300 \text{ agriculture} \\ & - 0.117 \text{ heating systems} - 0.080 \text{ natural factors}, - 0.429 \text{ waste management} \\ & - 0.035 \text{ public transport emissions} - 0.280 \text{ deforestation} + 0.183 \text{ climate change} \\ & - 0.905 \text{ other}, \end{aligned} \quad (3)$$

Table 2. Results of linear regression analysis for predictors of air quality ratings in the metropolitan area [a].

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	3.742	0.211		17.706	<0.001
Traffic	−0.001	0.157	0.000	−0.008	0.994
Industrial activity	−0.358	0.111	−0.174	−3.237	0.001
Construction work	−0.074	0.128	−0.032	−0.579	0.563
Agriculture	−0.300	0.169	−0.100	−1.780	0.076
Heating systems	−0.117	0.177	−0.037	−0.664	0.507
Natural factors	−0.080	0.135	−0.033	−0.590	0.556
Waste management	−0.429	0.117	−0.205	−3.685	<0.001
Public transportation emissions	−0.035	0.146	−0.013	−0.237	0.813
Deforestation	−0.280	0.160	−0.100	−1.754	0.080
Climate change	0.183	0.135	0.077	1.357	0.176
Other	−0.905	0.449	−0.109	−2.014	0.045

(Note: [a] Dependent Variable: How would you rate the air quality in the metropolitan area of Târgu Mureș?)

With the significance of these results (only for the best predictors) we calculated the following: on increasing by 1 unit of waste management (from 0 = no to 1 = yes) the rate awarded decreased by 0.429 from 5–very good to 1–very good); on increasing by 1 unit of industrial activity (from 0 = no to 1 = yes) the rate decreased by 0.358; by increasing by 1 unit for other factors, the rate decreased by 0.905; on increasing by 1 unit of deforestations, the rate decreased by 0.280; and on increasing by 1 unit of agriculture, the rate decreased by 0.300.

Also, to analyze which socio-demographic characteristics influenced the rating of air quality, another regression analysis was applied. The resulting model is statistically significant, the independent variables (the socio-demographic characteristics) explain 33.7% of the total variance in the dependent variable. The results are presented in Table 3. Therefore, only the frequency of experiencing problems related to air quality and the awareness of initiatives in their area aimed at improving air quality are the best socio-demographic characteristics with the significance, as follows: on increasing by 1 unit of frequency from 1—never to 5—very often, the rate decreased by 0.514 and with an increase by 1 unit of awareness from 0–no to 1–yes, the rate increased by 0.350.

Table 3. Regression analysis of socio-demographic predictors for air quality ratings.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	4.132	0.320		12.915	<0.001
Do you live in Târgu Mureș or a surrounding area?	−0.010	0.199	−0.003	−0.051	0.959
Do you live in the metropolitan area of Târgu Mureș, or are you a foreign visitor?	0.164	0.117	0.071	1.400	0.163
How often do you experience problems related to air quality?	−0.541	0.049	−0.523	−11.120	<0.001
Are you aware of any initiatives in your area aimed at improving air quality?	0.350	0.103	0.158	3.384	<0.001
Age	−0.009	0.033	−0.013	−0.270	0.788
Gender	0.114	0.097	0.056	1.181	0.238

(Note: Dependent Variable: how would you rate the air quality in the metropolitan area of Târgu Mureș?)

We detailed for each affecting factor of air quality place on the first three places, with the same independent variables as those mentioned in the previous table. So, for traffic (as the dependent variable), the model is not statistically significant. For industrial activity (as a dependent variable), the model is statistically significant (p-value = 0.043), but the independent variables only explain 4% of the total variance for traffic as an affecting factor

for air quality in the metropolitan area and the predictor is age (especially the age group of 30–39 years old according to the binary regression) and the awareness of initiatives for improving air quality in their area.

To test if there are statistically significant differences according to socio-demographic characteristics regarding the main affecting factors of air quality in the metropolitan area, the non-parametrical tests were applied according to each type of socio-demographic characteristics, bivariate Chi-square test and Kruskal–Wallis test with multiple comparisons to identify the exactly similar or different groups of respondents. These results are presented in Table 4.

Table 4. Results of statistical inference for factors affecting air quality.

Factor	Gender [a]	Age [b]	Resident /Visitor [a]	Live in Tg Mureș/not [a]	Rate Air Quality [b]	Experience Problems Related to Air Quality [b]	Awareness of Initiative [a]
Traffic (1)	0.495	0.615	0.074	0.890	0.350	0.577	0.576
Industrial activity (2)	0.880	0.006	0.812	0.135	0.022	<.001	0.036
Construction work (4)	0.020	0.393	0.536	0.632	0.212	0.034	0.765
Agriculture	0.024	0.429	0.400	0.973	0.004	0.116	0.009
Heating systems	0.297	0.649	0.335	0.711	0.432	0.365	0.858
Natural factors	0.037	0.498	0.195	0.914	0.013	0.047	0.297
Waste management (3)	0.046	0.769	0.575	0.441	<.001	0.018	0.170
Public transportation emissions	0.054	0.655	0.670	0.265	0.834	0.576	0.847
Deforestation	0.077	0.792	0.661	0.132	0.067	0.016	0.200
Climate change	0.628	0.289	0.146	0.205	0.210	0.613	0.416
Other	0.698	0.886	0.474	0.541	0.273	0.959	0.130

(Note: [a] Chi—square test, [b] Kruskal–Wallis test).

Starting with the results from Table 4, we can observe that:

- There are statistically significant differences between female and male respondents regarding the factors that affect air quality for construction work, agriculture, natural factors, waste management, and public transportation emissions according to results of the Chi-square test.
- There are statistically significant differences between the age groups regarding the factors that affect air quality only for industrial activity according to the results of the Kruskal–Wallis test but only between the group aged between 50 and 59, all the respondents younger than 50 years old (p-value < 0.05), and those over 69 years old (p-value = 0.018).
- There are no statistically significant differences between residents and visitors regarding the factors that affect air quality in metropolitan area of Târgu Mureș according to results of the Chi-square test.
- There are no statistically significant differences depending on where I live (Târgu Mureș or surrounding) regarding the factors that affect air quality in the metropolitan area of Târgu Mureș according to results of the Chi-square test.
- There are statistically significant differences depending on the rating awarded by respondents regarding the factors that affect air quality for industrial activity, agriculture, natural factors, and waste management according to results of the Kruskal–Wallis test;
- There are statistically significant differences depending on the respondents' experience of problems related to air quality regarding the factors that affect air quality for industrial activity, construction work, natural factors, waste management, and deforestation according to results of the Kruskal–Wallis test.
- There are statistically significant differences between the existence or not of awareness of initiatives regarding the factors that affect air quality only for industrial activity according to results of the Chi-square test.

To test if there are statistically significant differences according to socio-demographic characteristics regarding the awareness of initiatives regarding the factors that affect air quality, the non-parametrical tests were applied according to each type of socio-demographic characteristics, namely, the bivariate Chi-square test and Kruskal–Wallis test with multiple comparisons to identify the exactly similar or different group of respondents. These results are presented in Table 5.

Table 5. Results of statistical inference for personal initiatives to increase the air quality.

Personal Initiative to Increase the Air Quality	Gender [a]	Age [b]	Resident/ Visitor [a]	Live in Tg Mureș/not [a]	Rate Air Quality [b]	Experience Problems Related to Air Quality [b]	Awareness of Initiative [a]
Use public transport instead of driving	0.551	0.575	0.378	0.415	0.509	0.999	0.793
Walk or bike instead of driving	0.013	0.405	<0.001	0.905	0.342	0.833	0.954
Carpool or ride-share	0.711	0.502	0.721	0.035	0.269	0.678	0.971
Use electric or hybrid vehicles	0.016	0.126	0.492	0.258	0.008	0.383	0.428
Avoid idling the car engine	0.141	0.004	0.392	0.113	0.209	0.479	0.099
Plant trees or maintain green spaces	0.286	0.028	0.894	0.736	0.109	0.524	0.448
Reduce energy consumption at home	0.544	0.024	0.402	0.595	0.200	0.634	0.099
Use renewable energy sources (e.g., solar panels, wind energy)	0.031	0.083	0.156	0.892	0.370	0.495	0.216
Recycle and properly dispose of waste	0.220	0.065	0.359	0.677	0.841	0.125	0.599
Avoid using single-use plastics	0.021	0.009	0.555	0.587	<0.001	0.470	0.019
Reduce or eliminate the use of products that emit harmful chemicals (e.g., certain cleaning products, aerosols)	0.794	0.012	0.531	0.369	0.037	0.095	0.520
Support policies or organizations that work to improve air quality	0.090	0.171	0.801	0.592	0.468	0.724	0.658
Educate others about air pollution and its impact	0.180	0.001	0.645	0.972	0.005	0.443	0.458
Other	0.303	0.995	0.786	-	0.361	0.015	

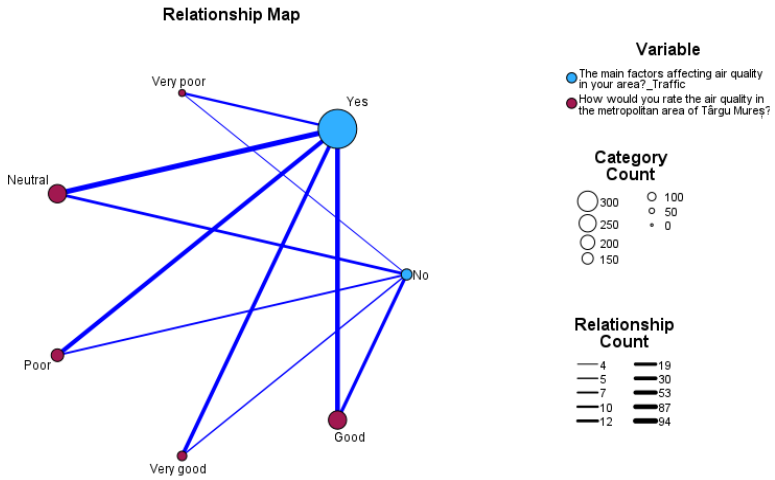
(Note: [a] Chi-square test, [b] Kruskal–Wallis test).

Starting with the results from Table 5, we can observe that:

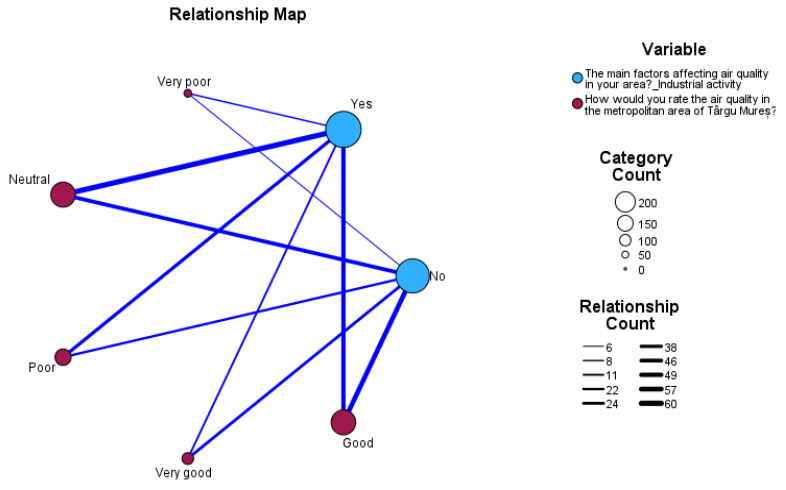
- There are statistically significant differences between the female and male respondents regarding personal initiatives to increase the air quality as follows: walk or bike instead of driving, use electric or hybrid vehicles, use renewable energy sources (e.g., solar panels, wind energy), and avoid using single-use plastics, according to the results of the Chi-square test.
- There are statistically significant differences between the age groups regarding personal initiatives to increase the air quality for the following: avoid idling the car engine (especially in the age group between 18 and 23 and the groups aged 30–39, 40–49, and 50–59 years old, 24–29 with 30–39 years old), plant trees or maintain green spaces, reduce energy consumption at home, avoid using single-use plastics, reduce or eliminate the use of products that emit harmful chemicals (e.g., certain cleaning products, aerosols), and educate others about air pollution and its impact (especially those aged between 30 and 39 with 18–23 and 24–29) according to the results of the Kruskal–Wallis test.
- There are statistically significant differences between the residents and visitors regarding personal initiatives to increase the air quality only for walk or bike instead of driving according to the results of the Chi-square test.
- There are statistically significant differences depending on where I live (Târgu Mureș or surrounding) regarding personal initiatives to increase the air quality only for carpool or ride-share according to the results of the Chi-square test.

- There are statistically significant differences depending on the rating awarded by respondents regarding personal initiatives to increase the air quality for the following: use electric or hybrid vehicles, avoid using single-use plastics, reduce or eliminate the use of products that emit harmful chemicals (e.g., certain cleaning products, aerosols), and educate others about air pollution and its impact according to the results of the Kruskal–Wallis test.
- There are statistically significant differences depending on the respondents' experience of problems related to air quality regarding personal initiatives to increase the air quality only for other personal initiatives according to the results of the Kruskal–Wallis test.
- There are statistically significant differences between the existence or not of awareness of personal initiatives to increase the air quality for the following: avoid idling the car engine, reduce energy consumption at home, and avoid using single-use plastics according to the results of the Chi-square test.

The relationship maps from Figure 4 show the intensity of the relationship between opinions based on ratings referring to the main four factors that affect the air quality in metropolitan area of Târgu Mureș. So, for the traffic factor, those respondents who indicated the traffic as one of the factors that affected the air quality, opted also for neutral and good. For industrial activity, the same options can be observed as for traffic. For waste management and construction work, the opinions are different from those which indicate traffic and industrial activity as the main factors that affect air quality.

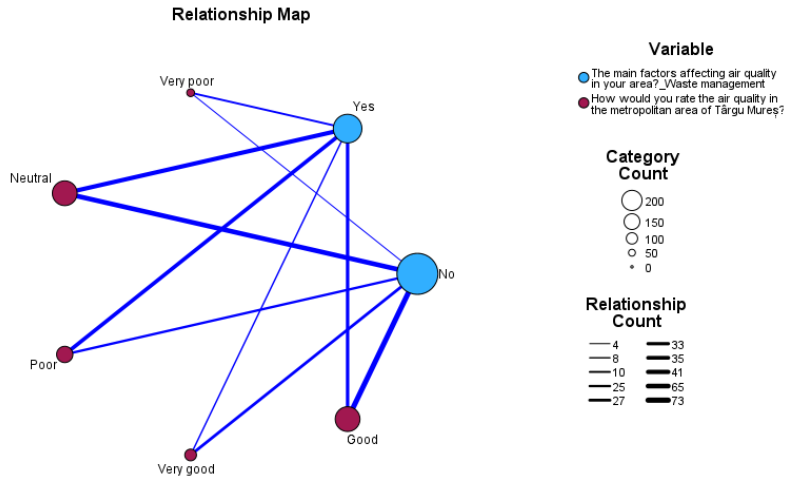


(**a**)

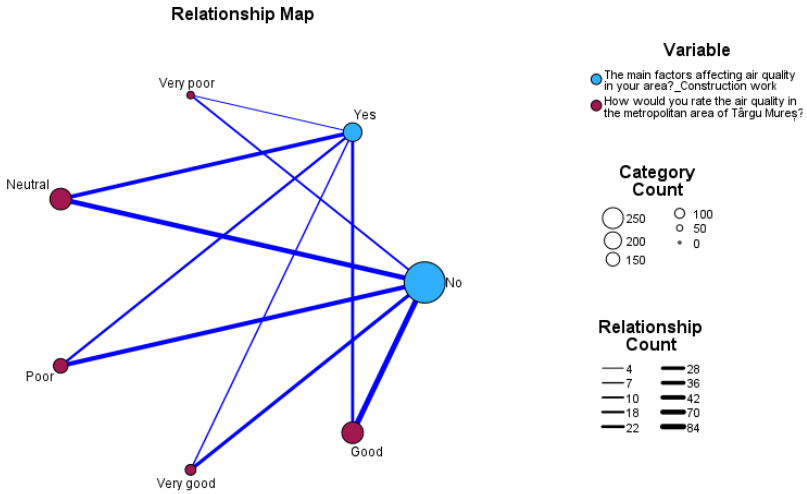


(**b**)

Figure 4. *Cont.*



(**c**)



(**d**)

Figure 4. Intensity of relationship between opinions based on ratings referring to the main four factors that affect the air quality in Târgu Mureș metropolitan area: (**a**) traffic; (**b**) industrial activity; (**c**) waste management; (**d**) construction works.

For all the socio-demographic characteristics, the perceptual maps were applied to identify the profile of the citizens (residents or not, age, gender, etc.) for each important variable from the research, as follows: the rate of air quality, the experiencing of problems related to air quality, and the first four factors that—in respondents' opinions from this study—affect the air quality in the metropolitan area of Târgu Mureș. So, for age and the ratings awarded for the air quality, and for age and the experiencing of problems related to air quality, the perceptual map analysis returned some results (marked with yellow in the tables), but these were not statistically significant for p-value < 0.05 and had low values for Cramer's V symmetric measures (Tables 6 and 7).

But for perceptual maps of quality of resident/visitor/other and the experience problem related to air quality (Table 8), and for age and the second affecting factor, industrial activity (Table 9), the perceptual maps analysis return the following results: for other categories which opted for "very often" a significant (p-value = 0.002) but low association (Cramer's V value = 0.194) and for age and industrial activity as factor which affect the air quality for group o age 50–59 years old, statistically significant (p-value = 0.006) but low intensity association (Cramer's V value = 0.237). Also, we performed the correspondence analysis, and these results confirm a non-significant statistical association between age and

experiencing problems related to air quality (Figure 5a) with p-value = 0.784 and also, for quality of resident/visitor/other and the rating of air quality (p-value = 0.293) (Figure 5b).

Table 6. Results of perceptual maps for rate of air quality in the metropolitan area and age.

			Age							Total
			18–23	24–29	30–39	40–49	50–59	60–69	>69	
How would you rate the air quality in the metropolitan area of Târgu Mureș?	Very poor	Count	5	3	2	3	1	0	0	14
		Standardized Residual	−1.2	1.3	0.7	1.1	0.0	−0.5	−0.3	
	Poor	Count	33	6	5	7	5	2	2	60
		Standardized Residual	−0.5	−0.1	−0.1	0.0	0.2	1.1	2.7	
	Neutral	Count	71	13	7	10	5	0	0	106
		Standardized Residual	1.0	0.6	−0.7	−0.6	−1.0	−1.3	−0.8	
	Good	Count	63	9	11	10	10	3	0	106
		Standardized Residual	−0.1	−0.6	0.6	−0.6	0.7	1.0	−0.8	
	Very good	Count	20	2	3	7	3	0	0	35
		Standardized Residual	−0.2	−0.8	0.0	1.5	0.2	−0.7	−0.5	
Total		Count	192	33	28	37	24	5	2	321

Table 7. Results of perceptual maps for experiencing problems related to air quality in the metropolitan area and age.

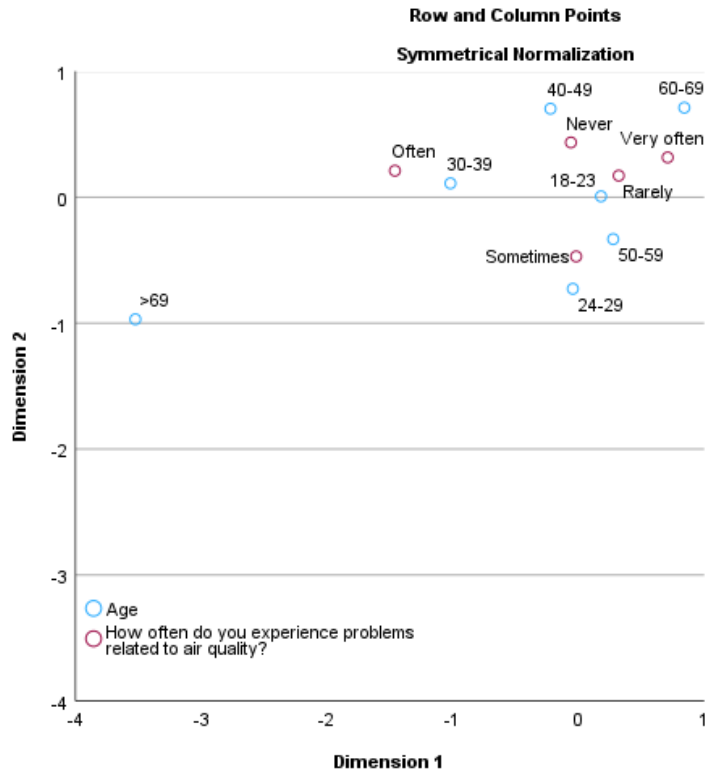
			Age							Total
			18–23	24–29	30–39	40–49	50–59	60–69	>69	
How often do you experience problems related to air quality?	Never	Count	38	5	7	10	4	1	0	65
		Standardized Residual	−0.1	−0.7	0.6	0.9	−0.4	0.0	−0.6	
	Rarely	Count	66	10	6	13	8	3	0	106
		Standardized Residual	0.3	−0.3	−1.1	0.2	0.0	1.0	−0.8	
	Sometimes	Count	69	16	10	9	10	1	1	116
		Standardized Residual	0.0	1.2	0.0	−1.2	0.5	−0.6	0.3	
	Often	Count	11	2	5	4	1	0	1	24
		Standardized Residual	−0.9	−0.3	2.0	0.7	−0.6	−0.6	2.2	
	Very often	Count	8	0	0	1	1	0	0	10
		Standardized Residual	0.8	−1.0	−0.9	−0.1	0.3	−0.4	−0.2	
Total		Count	192	33	28	37	24	5	2	321

Table 8. Results of perceptual maps for experiencing problems related to air quality in the metropolitan area and resident/visitor/other.

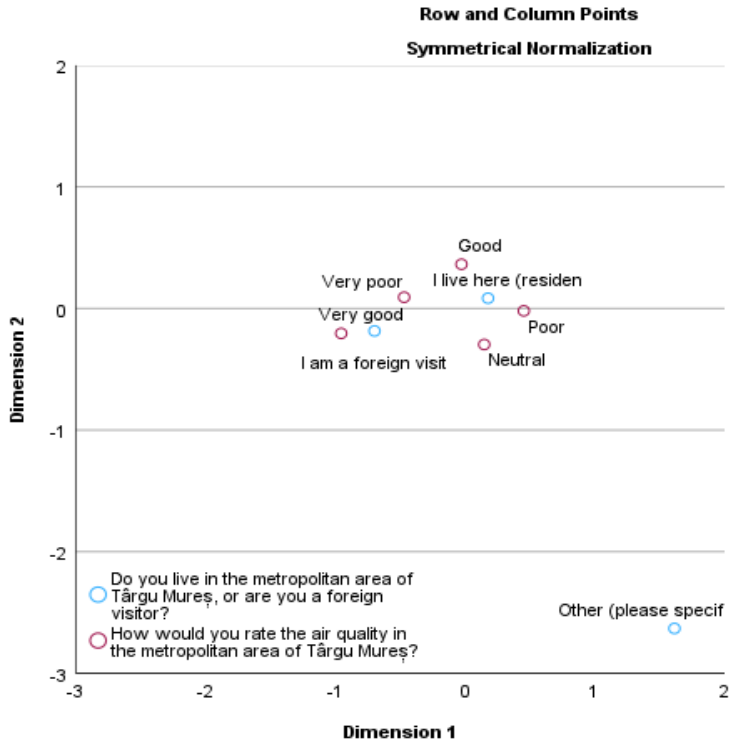
			Do You Live in the Metropolitan Area of Târgu Mureș, or Are You a Foreign Visitor?			Total
			I Live Here (Resident)	I Am a Foreign Visitor	Other (Please Specify)	
How often do you experience problems related to air quality?	Never	Count	50	15	0	65
		Standardized Residual	0.0	0.2	−0.8	
	Rarely	Count	80	25	1	106
		Standardized Residual	−0.2	0.4	0.0	
	Sometimes	Count	92	23	1	116
		Standardized Residual	0.3	−0.5	−0.1	
	Often	Count	23	1	0	24
		Standardized Residual	1.0	−1.9	−0.5	
	Very often	Count	3	6	1	10
		Standardized Residual	−1.7	2.6	3.0	
Total		Count	248	70	3	321

Table 9. Results of industrial activity as main factor affecting air quality and age.

			Age							Total
			18–23	24–29	30–39	40–49	50–59	60–69	>69	
The main factors affecting air quality in your area?_Industrial activity	No	Count	87	14	13	18	21	2	0	155
		Standardized Residual	−0.6	−0.5	−0.1	0.0	2.8	−0.3	−1.0	
	Yes	Count	105	19	15	19	3	3	2	166
		Standardized Residual	0.6	0.5	0.1	0.0	−2.7	0.3	0.9	
Total		Count	192	33	28	37	24	5	2	321



(**a**)



(**b**)

Figure 5. Correspondence analysis: (**a**) between age and experiencing problems related to air quality; (**b**) for quality of resident/visitor/other and the rating of air quality.

A detailed correspondence analysis (Figure 6) by transforming the variable age into generation age category (Generation Z/Y/X and baby boomers) showed and statistically confirmed that only the generation "baby boomers" have a poor perception of air quality

in Târgu Mureș metropolitan area, but no association with healthy experience of problems related to air quality.

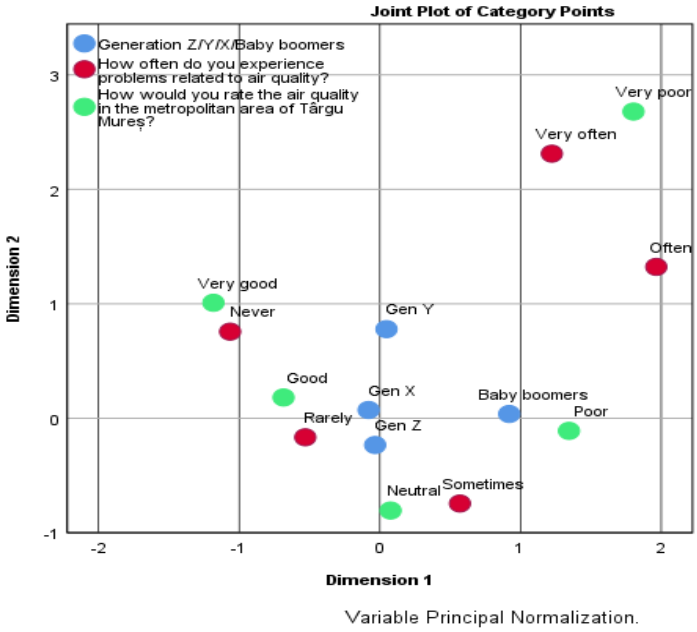
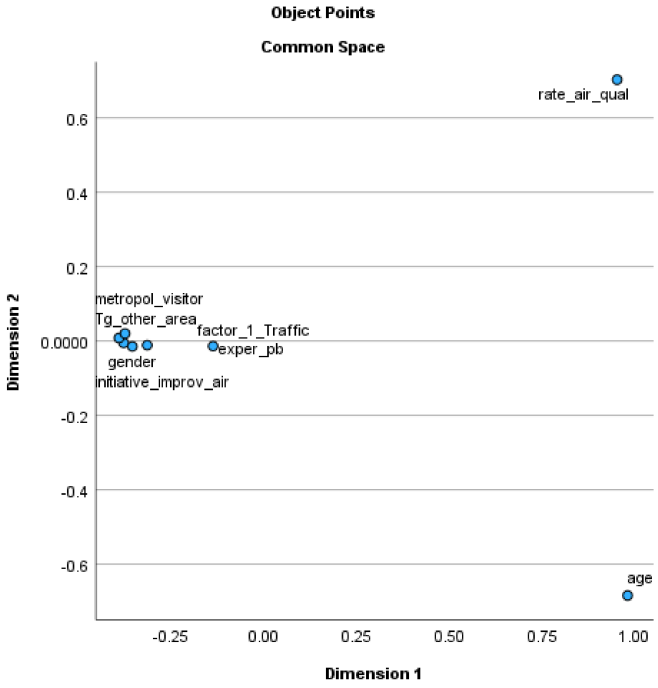


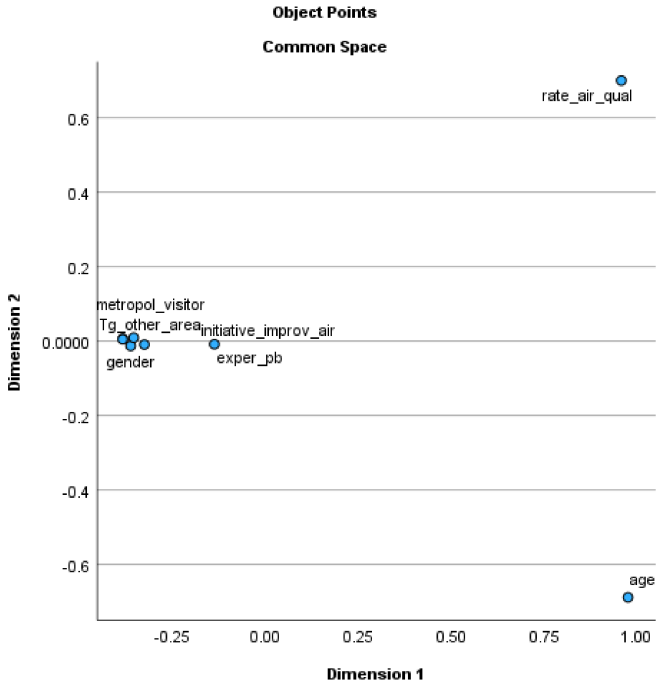
Figure 6. Correspondence analysis by generations.

By applying the Multidimensional Scaling (PROXSCAL), we identified those factors that are similar or dissimilar between the respondents according to their socio-demographic characteristics and opinions regarding the main affecting factors of air quality in the metropolitan area and according to the socio-demographic characteristics, the graphics presented below indicate that the ratings for air quality are negatively influenced by the age of the respondents for both the main affecting factors of traffic (Figure 7a) and industrial activity (Figure 7b).



(**a**)

Figure 7. *Cont.*



(**b**)

Figure 7. Multidimensional scaling (PROXSCAL): (**a**) representation of traffic as a main factor affecting air quality; (**b**) representation of industrial activity as a main factor affecting air quality.

These results are presented in the proximity matrices in Table 10.

Table 10. Proximity matrices.

	Traffic	Industrial Activity	Construction Work	Waste Management
Live in Târgu Mureș/surrounding	7.937	12.207	14.900	13.638
Live in the metropolitan area of Târgu Mureș/foreign visitor	9.849	12.689	14.142	13.565
Rating air quality in the metropolitan area of Târgu Mureș	42.767	37.296	33.764	35.043
Experience problems related to air quality	29.103	26.439	23.749	25.417
Awareness of initiatives to improve air quality	14.142	13.416	11.619	12.610
Age	43.920	38.923	35.749	37.815
Gender	12.369	12.610	12.000	12.000

3.2. Results for Mureș County—Analysis of Auto Park and Air Quality Sensors

Based on the research results from the questionnaire, which highlighted traffic and industrial activity as the key factors affecting air quality according to respondents, secondary data were utilized to conduct a more in-depth analysis and evaluate the extent to which these perceptions align with objective air quality measurements. Therefore, for our second part of the research, we built an interface between the following:

- data describing the automotive park in Mureș County, Romania, for the last five years (2019–2023), retrieved from the Romanian open data portal [42]. This dataset includes detailed information on the number of registered vehicles by type and fuel consumption category, providing valuable insights into the evolution of the local automotive fleet over time, collected at the end of each calendar year.
- data collected from the "Strop de Aer" sensor network [37], which measures $PM_{2.5}$ and PM_{10} concentrations at two-minute intervals. The raw data were aggregated into daily

mean values for analysis, covering the period from 20 August 2021 to 3 November 2024. These sensors were strategically placed in urban areas of Mureș County, providing high-resolution insights into air quality dynamics in a region influenced by diverse anthropogenic and climatic factors. The "Strop de Aer" sensors employ optical particle counting technology to monitor particulate matter and are equipped with additional modules for recording temperature [°C], relative humidity, further mentioned as humidity [%], and atmospheric pressure [hPa]. Their high temporal resolution and robust performance make them well-suited for analyzing seasonal and daily variations in pollution levels. The dataset, after quality checks, included 1091 effective days of measurement, offering a comprehensive view of air quality trends over three years.

- data about the production period and downtime of the main industrial producer, based on public information available online and internal data of the fertilizer producer.

Therefore, according to analysis about automotive parks for Mureș county, the data indicate (for the analyzed period 2019–2023) that 33.8% are cars older than 20 years, followed by (29.2%) of those between 16 and 20 years, 20.8% between 11 and 15 years, 6 and 10 years (9.7%), 4% between 3 and 5 years, 2.4% those cars between 0 and 2 years; all these details are presented in Figure 8.

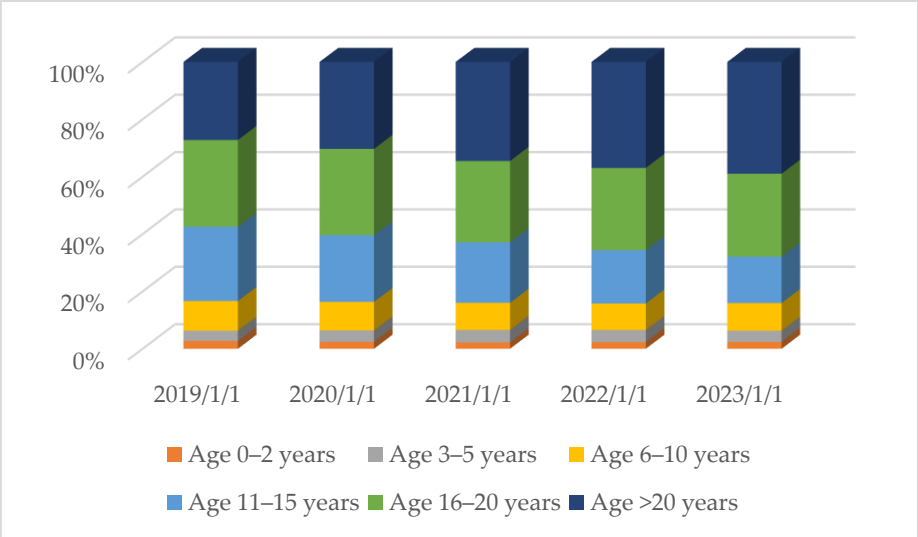


Figure 8. Age distribution of vehicles in Mureș County (2019–2023).

If we take into account another way of grouping the age of cars, for the same period, according to the reported data, 77.6% of cars are older than 12 years, 10.9% are between 9 and 12 years, 6.6% are between 6 and 8 years, and only 4.9% are between 0 and 4 years. Regarding the structure of cars according to type of engine (Figure 9), the mean for the last five years show a percentage of 53% for diesel, 39.6% for gasoline, only 0.6% for hybrid vehicles, and 0.1% for electric vehicles.

The trends of cars in relation to fuel source are presented in Figure 9, with an exponential increase for the electric and hybrid types of engine, starting from 2020, the moment when the Romanian Government applied an attractive buying program for these type of cars.

Regarding the collected data about the air quality indicators collected from sensors and the data about the descriptive statistics, these are presented for $PM_{2.5}$, PM_{10} (daily mean calculated by the authors from initial collected data), temperature, humidity, and pressure in Table 11. In Figure 10a–e, the box plots are illustrated for these variables. According to the one sample from the Kolmogorov–Smirnov test, none of these continuous variables have a normal distribution of values for the analyzed time period.

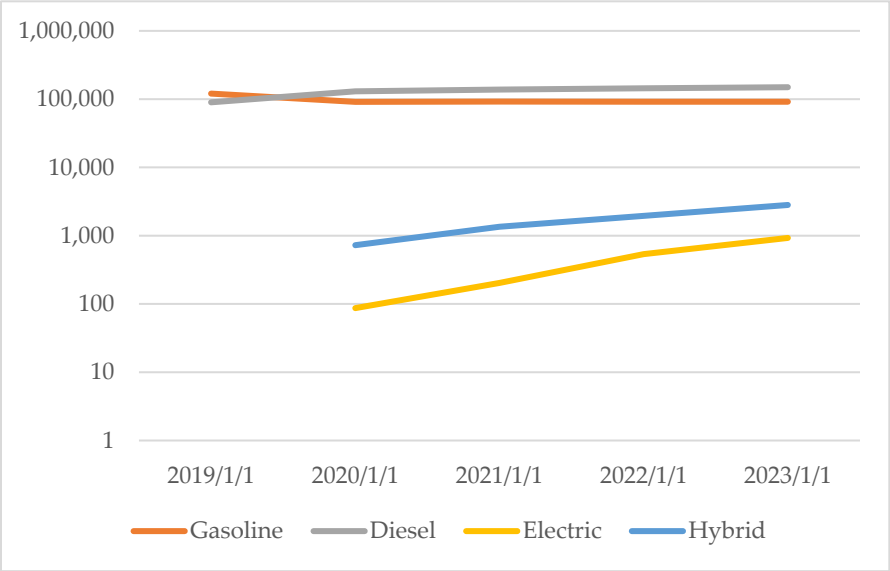


Figure 9. Evolution of cars by fuel source.

Table 11. Descriptive statistics for air quality indicators and weather.

		$PM_{2.5}$ (Daily Mean)	PM_{10} (Daily Mean)	Temperature	Humidity	Pressure
N	Valid	980	980	1048	1049	1049
	Missing	111	111	43	42	42
Mean		9.7143	15.6215	11.9245	66.1911	975.2589
Median		7.0007	10.4965	11.4583	66.8017	975.9577
Mode		8.94	2.26 [a]	−9.94 [a]	100.00	952.79 [a]
Std. Deviation		7.73102	12.74131	8.49532	15.58536	7.58575
Minimum		1.22	2.26	−9.94	19.20	952.79
Maximum		54.77	88.30	32.49	100.00	1002.41
Percentiles	25	4.4770	7.1059	53.8917	971.2244	970.8234
	50	7.0007	10.4965	66.8017	975.9615	975.8037
	75	12.8147	20.4208	76.7642	980.7356	980.6656

[a]. Multiple modes exist. The smallest value is shown.

If we compare the mean values for $PM_{2.5}$ and PM_{10} with the European Union standard [43], we can observe that for the analyzed period, the mean for $PM_{2.5}$ is under the EU cut-off for annual data of 25 $\mu g/m^3$ and the same for PM_{10} which is under the annual mean of EU 50 $\mu g/m^3$. If we detail these descriptive statistical indicators for each year, especially for $PM_{2.5}$ and PM_{10}, a decreasing annual mean of these indicators can be observed. A distribution of the values of $PM_{2.5}$ and PM_{10} on the bidimensional spatial of temperature and humidity are presented in Figure 11a for $PM_{2.5}$ and Figure 11b for PM_{10}. The increasing number over the EU limit for the daily mean of PM_{10} and annual mean for $PM_{2.5}$ are related to low temperatures and high humidity, as is well known.

To provide details of the quartiles and complete these observations for our research data, we completed some graphical representations based on a scatter plot matrix (Figure 12). The inverse (negative) correlations of medium intensity, statistically significant, is shown between $PM_{2.5}$ and temperature (−0.549); the direct correlation of low intensity, statistically significant, between $PM_{2.5}$ and humidity (+0.223); the direct correlation of low intensity, statistically significant, between $PM_{2.5}$ and pressure (+0.196); the inverse (negative) correlations of high intensity, statistically significant is shown between PM_{10} and temperature (−0.937); the direct correlation of low intensity, statistically significant, between PM_{10} and humidity (+0.348); and the direct correlation of low intensity, statistically significant, between PM_{10} and pressure (+0.390).

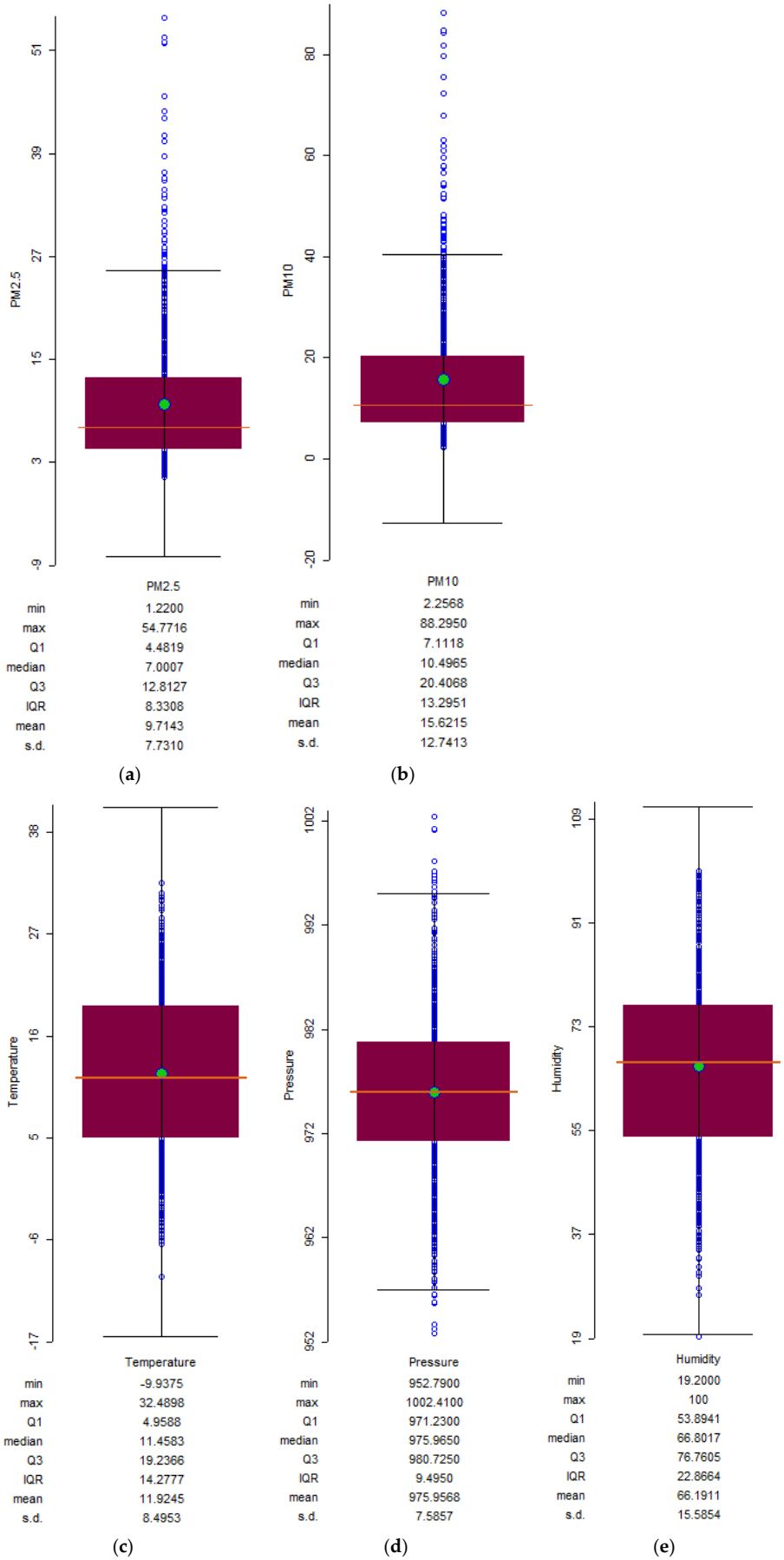
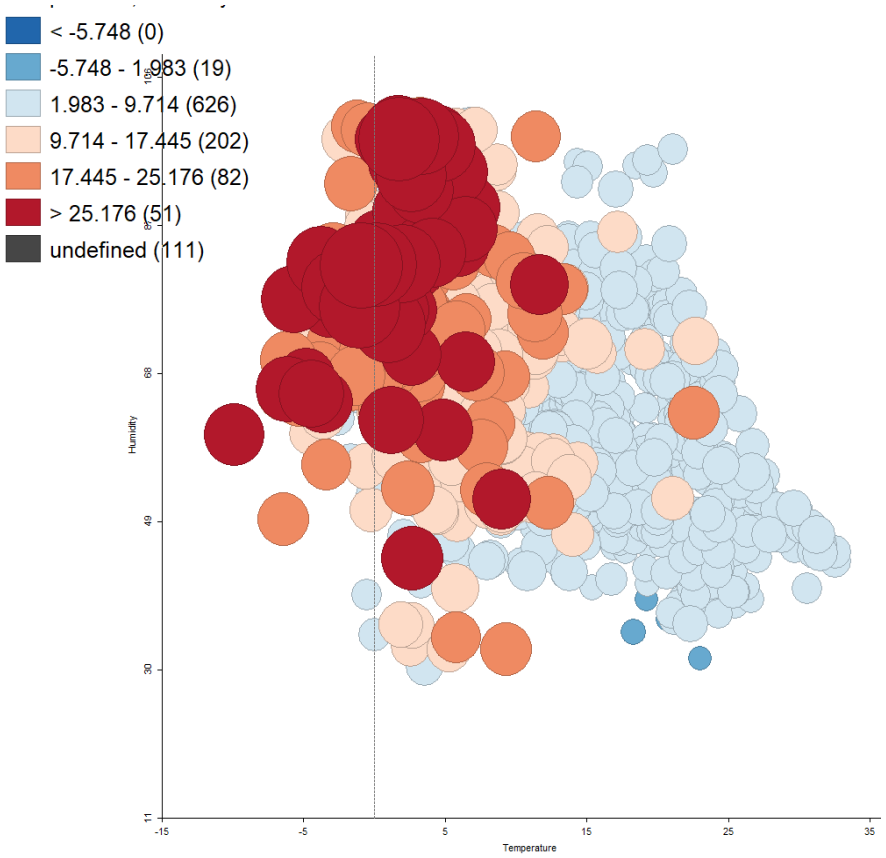
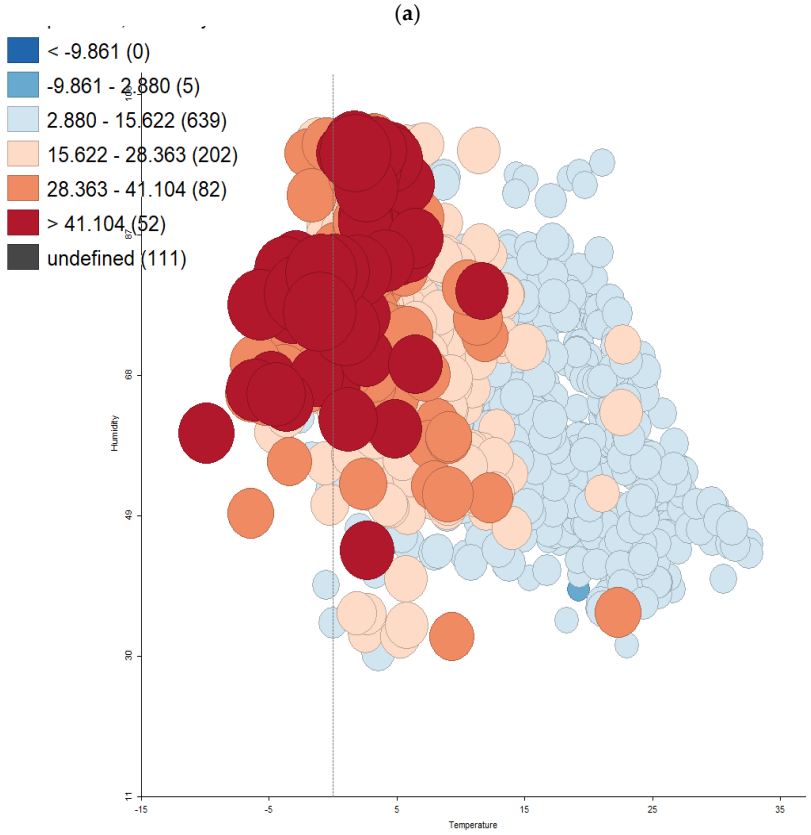


Figure 10. Box plots for continuous variables: (**a**) $PM_{2.5}$ [$\mu g/m^3$]; (**b**) PM_{10} [$\mu g/m^3$]; (**c**) temperature [°C]; (**d**) pressure [hPa]; (**e**) humidity [%].



(**a**)



(**b**)

Figure 11. Distribution of the values on bidimensional spatial of temperature (*X*-axis) and humidity (*Y*-axis): (**a**) $PM_{2.5}$ [$\mu g/m^3$]; (**b**) PM_{10} [$\mu g/m^3$].

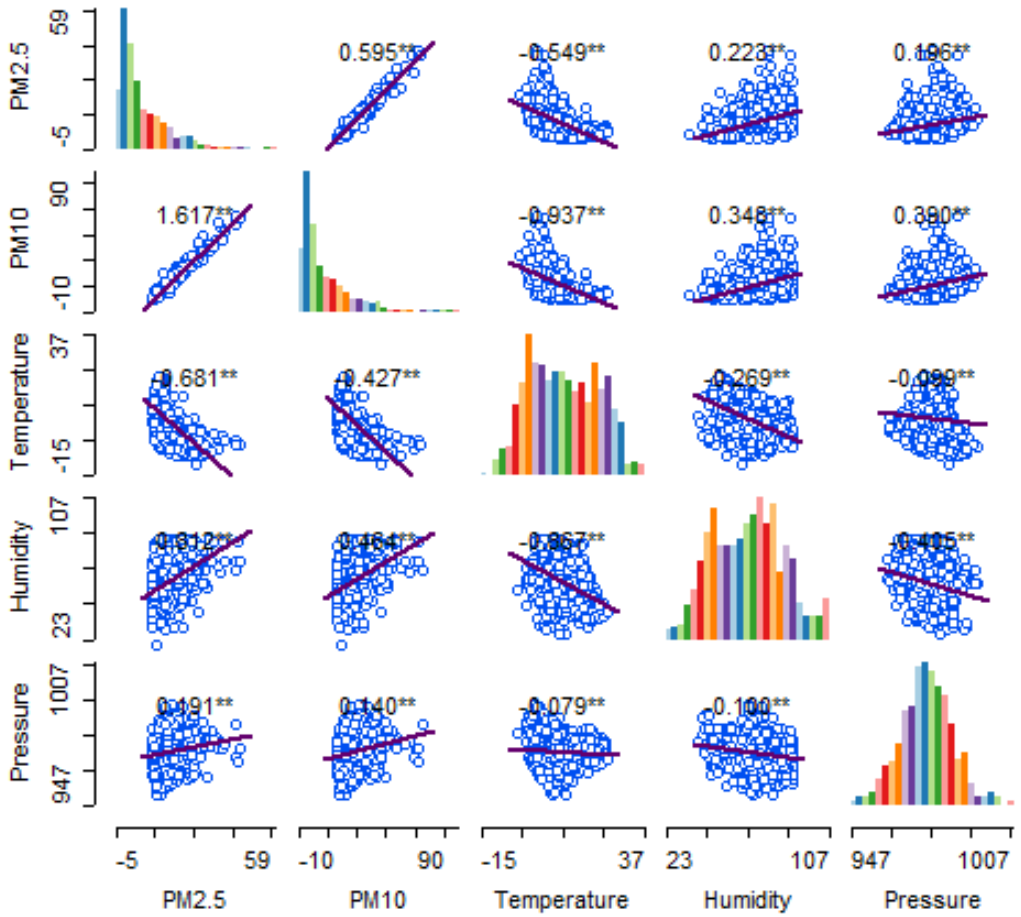


Figure 12. Scatter plot matrices for $PM_{2.5}$ [μg/m^3] and PM_{10} [μg/m^3] according to weather characteristics: temperature [°C], pressure [hPa], and humidity [%]. ** means Statistically significant for p_value < 0.05.

Because one of the affecting factors indicated by the respondents was industrial activity, we applied the Kendall correlation coefficients for the air quality indicators of $PM_{2.5}$ and PM_{10} and the periods when the main producer in the Mureș county was or not industrially active with an SPSS codification as 1 = with industrial activity and 2 = no industrial activity (stops). The results are presented in Table 12. We found out that there are direct correlations of low intensity, statistically significant between $PM_{2.5}$ and chemical plant production (+0.105) and between PM_{10} and chemical plant production (+0.105) with a significance that when the code for chemical plant production is increased from 1 (production) to 2 (stops), the values of $PM_{2.5}$ and PM_{10} increase, with the main conclusion being that those high values are due to other pollution factors in the metropolitan area of Târgu Mureș.

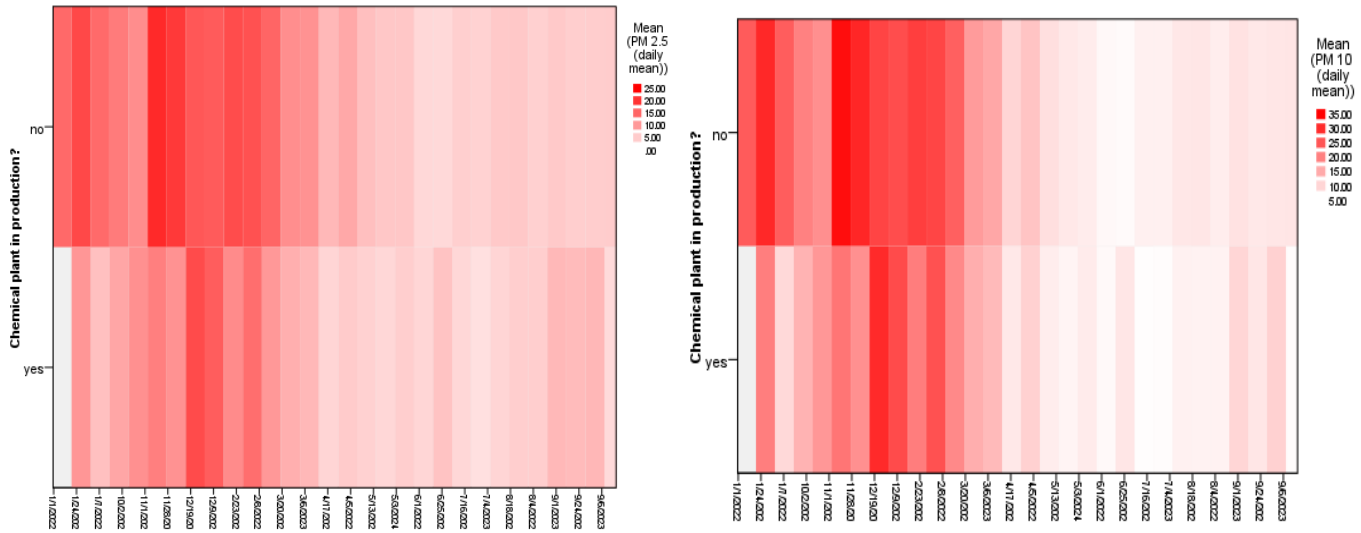
To more effectively emphasize this aspect, we made a graphical representation of the $PM_{2.5}$ and PM_{10} values during the production and stop periods as heat maps (Figure 13a,b), but also as sequence charts by marking the EU limited values for these air quality indicators (Figure 14). It was easy therefore to observe that during the stops of the chemical plant, the value of these air quality indicators were bigger compared to production time.

According to the box-plots from Figure 14, during the production of the chemical plant, the values for the indicators of $PM_{2.5}$ are under the EU annual limits of 25 μg/m^3, these aspects also being shown by the descriptive statistics from Table 13.

Table 12. Correlation coefficients between air quality indicators ($PM_{2.5}$ and PM_{10}) and the main chemical plant activity.

			$PM_{2.5}$ (Daily Mean)	**PM_{10} (Daily Mean)**	**Chemical Plant in Production?**
Kendall's tau_b	$PM_{2.5}$ (daily mean)	Correlation Coefficient	--		
		Sig. (2-tailed)	.		
		N	980		
	PM_{10} (daily mean)	Correlation Coefficient	0.855 **	--	
		Sig. (2-tailed)	<0.001	.	
		N	980	980	
	Chemical plant in production?	Correlation Coefficient	0.105 **	0.070 **	--
		Sig. (2-tailed)	<0.001	0.008	.
		N	980	980	1091

**. Correlation is significant at the 0.01 level (2-tailed).



(**a**) (**b**)

Figure 13. Heat map: (**a**) $PM_{2.5}$ values [$\mu g/m^3$] during chemical plant production and stop periods; (**b**) PM_{10} values [$\mu g/m^3$] during chemical plant production and stop periods.

The results suggest that the industrial activity of the chemical plant does not have a significant impact on air quality, contrary to initial expectations. This conclusion highlights the need to explore other major sources of pollution, such as heavy traffic or residential heating systems, which appear to have a more pronounced effect on PM2.5 and PM10 particle levels.

It is important to note that the newly adopted Directive 2024/2881 [44] sets stricter limits for particulate matter, reducing the annual limit for $PM_{2.5}$ from 25 $\mu g/m^3$ to 10 $\mu g/m^3$. Although the values observed in Figure 14 remain below the limits established by the 2008 directive, they would not fully comply with the updated standards of the 2024 directive. This highlights the need for ongoing evaluation of emissions and monitoring practices to ensure alignment with evolving regulatory requirements and stricter environmental goals.

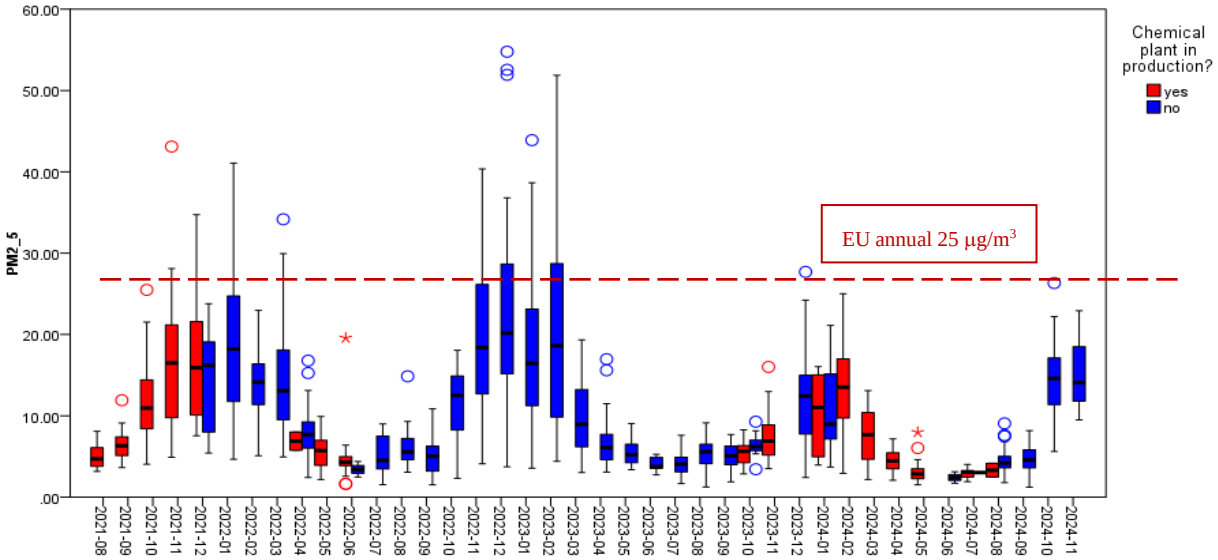


Figure 14. Box plots for $PM_{2.5}$ comparatively for production and stops of the chemical plant and EU standard.

Table 13. Descriptive statistics comparatively for production and stops of the chemical plant.

Chemical Plant in Production?		Yes		No	
		$PM_{2.5}$ (daily mean)	PM_{10} (daily mean)	$PM_{2.5}$ (daily mean)	PM_{10} (daily mean)
N	Valid	343	343	637	637
	Missing	23	23	88	88
Mean		8.2215	13.7339	10.5182	16.6379
Median		6.2145	9.9902	7.3415	10.8258
Mode		1.52 [a]	2.61 [a]	1.22 [a]	2.26 [a]
Std. Deviation		6.02518	10.23974	8.40429	13.80412
Minimum		1.52	2.61	1.22	2.26
Maximum		43.11	75.45	54.77	88.30
Percentiles	25	3.9393	6.7060	4.7588	7.3190
	50	6.2145	9.9902	7.3415	10.8258
	75	10.2148	17.3563	14.4034	22.7225

[a]. Multiple modes exist. The smallest value is shown.

4. Discussion

The findings of our study reflect a nuanced interplay between public perceptions, socio-demographic factors, and objective environmental indicators in understanding urban air quality. Respondents consistently identified traffic and industrial activity as the primary contributors to air pollution, a perception that aligns with the sensor data showing elevated levels of $PM_{2.5}$ and PM_{10} in these areas. However, the statistical analyses revealed variations in how different demographic groups experience and interpret these issues. For instance, younger respondents demonstrated greater awareness of sustainable practices, while older participants were more likely to report health concerns related to air quality. This divergence highlights the importance of tailoring public communication and policies to the specific needs and behaviors of diverse community groups.

Spatial analysis through GEODA provided further depth, uncovering geographic clusters where perceptions of poor air quality coincided with industrial zones or high-traffic corridors. These spatial insights emphasize the value of localized interventions, such as promoting green infrastructure in industrial neighborhoods or enhancing public transport networks in areas dominated by vehicle emissions. While the regression models offered significant predictors, such as awareness of initiatives and frequency of experiencing air quality issues, they also pointed to gaps in public knowledge, with only a third of

respondents aware of the existing programs aimed at improving air quality. This indicates an opportunity to strengthen community engagement and make air quality improvement efforts more visible and inclusive.

Positive correlations between awareness of local initiatives and higher air quality ratings suggest that better communication and visibility of these programs could improve public perception of pollution-related issues. Therefore, local authorities should invest in making these initiatives more visible and accessible to the public.

The perceptual maps indicate that perceptions of air quality are influenced by factors such as place of residence and the perceived source of pollution. For example, respondents from residential areas tend to underestimate the impact of traffic compared to those from industrial zones. These differences highlight the importance of tailored approaches in planning urban interventions.

Despite the robustness of the methodologies employed, in this study, there were limitations that warrant consideration. The survey sample, while representative of certain demographic groups, could benefit from broader diversity to better capture the experiences of the entire population in Târgu Mureș. Additionally, while statistical tools like SPSS and GEODA provided valuable insights, the reliance on self-reported data introduces the possibility of response bias. Future research could address these limitations by expanding the sample size and integrating real-time data from a wider range of sources, ensuring a more comprehensive understanding of air quality dynamics in mid-sized urban areas. This multidimensional approach not only enhances our grasp of environmental challenges but also provides a stronger foundation for sustainable urban planning.

5. Conclusions

In this study, how people perceive air quality in the metropolitan area of Târgu Mureș was explored, and these perceptions were connected with objective environmental data. Traffic and industrial activity emerged as the main contributors to pollution, a finding echoed by both survey responses and sensor measurements. Beyond identifying these factors, our research highlights the significant influence of demographic characteristics, such as age and awareness of local initiatives, on how individuals view and respond to air quality challenges. The analysis of differences between groups shows that the older respondents perceive industrial activity as a main source of pollution, while younger respondents are more aware of the impact of traffic. These results indicate the need for information campaigns tailored to each demographic category to increase general awareness of the real sources of pollution. In this study, sustainable solutions are highlighted by linking air quality challenges to targeted actions like greener transport, urban green spaces, and cleaner heating, fostering healthier, more sustainable urban living.

What stands out is the need for tailored solutions. For areas heavily affected by traffic or industrial emissions, promoting greener transportation options and investing in urban green spaces could bring tangible improvements. Raising awareness about existing air quality initiatives could also encourage broader public participation in sustainability efforts. The spatial analysis in this study further reveals that localized interventions, designed with the unique characteristics of each area in mind, can have a lasting impact on reducing pollution and improving quality of life.

By combining community perceptions with objective measurements, this research offers a well-rounded perspective on urban air quality. It not only helps us understand current challenges but also provides practical ideas for creating healthier, more sustainable urban environments.

The analysis revealed that the chemical plant's operational status had no significant impact on the two key air quality indicators, $PM_{2.5}$ and PM_{10}. While the initial assumption

was that industrial activity (the chemical plant being considered by the local population as the main polluter) would directly contribute to higher pollution levels, the data suggest otherwise. This finding points to other sources, such as traffic or residential heating, as the primary drivers of particulate matter in the region.

Although there were minor variations observed during production and downtime periods, these differences were statistically insignificant, reinforcing the conclusion that the plant may not be a major contributor to local air quality challenges. This insight shifts the focus to addressing other factors, such as emissions from older vehicles and inefficient heating systems, which could have a more pronounced impact on pollution levels.

One of the limitations in this study was the relatively small number of participants in the questionnaire, which, while representative of certain demographic groups in Târgu Mureș, may not fully capture the diversity of perspectives across the entire population. Future research could address this limitation by expanding the sample size and ensuring a more balanced representation of different age groups, socio-economic statuses, and geographic areas within the region. Another limitation is the potential for response bias in self-reported data and the exclusion of extreme daily sensor readings. Additionally, monthly automotive data trends were not available, limiting temporal precision in correlating vehicle emissions with air quality indicators. This comprehensive methodological framework allowed for a robust analysis of the interaction between public perceptions and measurable environmental factors, laying the groundwork for actionable insights into urban sustainability.

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