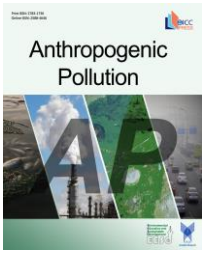

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Research Article

Traffic Air Pollution and Respiratory Health: A Route-Based Exposure-Symptom Study among Urban Taxi Drivers in Isfahan, Iran

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Abstract

Taxi drivers constitute one of the most at-risk subpopulations for road traffic air pollution within urban settings. In the polluted city of Isfahan, Central Iran, a cohort of 349 middle-aged male taxi drivers who were specifically exposed to road pollution was selected. Data collection involved assessing four respiratory symptoms (RSs)- coughing, dyspnea, wheezing, and chest tightness- using a 5-point Likert and a series of independent variables associated with the increase or abatement of air pollution along the routes that each driver took regularly during his working hours. A Generalized Additive Model ($0.372 < R^2 < 0.576$) was applied to determine the prevalence of RSs in relation to a small subset of independent variables identified using a Varimax-rotated PCA analysis. According to the findings, increasing roadside greenery, as measured through a Sentinel-2 NDVI layer, decreases the prevalence of RSs. Conversely, an increase in the number of bus stations, the mean average travel time spent by the taxi drivers on the road between two destinations, and the mean annual concentration of PM2.5 along the routes (with an average of 23.99 ± 6.00 μg/m³) exhibited a positive association with the onset of RSs. This research underscored the susceptibility of taxi drivers to road traffic air pollution while highlighting the alleviating role of road greenery in influencing the respiratory health of Isfahan taxi drivers.

Keywords: Particulate matter; Urban greenery; NDVI; Generalized Additive Model; Occupational exposure

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1. Introduction

The health of the urban population hinges upon a complex interplay of diverse factors. Beyond physiological and lifestyle attributes, urban residents often find themselves more susceptible to the adverse effects of urban environments, as compared to others (Faour et al., 2023). This is particularly because of air pollution, which is impacting numerous urban areas across the world (Moutinho et al., 2020, Piracha and Chaudhary, 2022). The significance of urban air pollution lies in its widespread impact on urban dwellers, with taxi drivers being

particularly vulnerable due to prolonged exposure to vehicular emissions in high-traffic settings (Adikaram, 2021). The primary culprit behind urban air pollution lies in the utilization of fossil fuels in the internal combustion engines that power urban transportation systems (Shafie and Mahmud, 2020, Özener and Özkan, 2020). As urban areas grow, the scope and scale of urban transportation expand to maintain urban efficiency. This expansion often necessitates substantial amounts of fossil fuel consumption in the urban territory, which is particularly evident in underdeveloped and developing nations (Zeng et al., 2021). Despite the strides made in advanced urban transportation designs and practices, prevailing evidence indicates that the rapid pace of urban growth, coupled with reliance on outdated and polluting modes of transportation in these countries have resulted in high air pollution levels and imperiled the health of their residents (Glazener et al., 2021).

One of the hazardous and pervasive air contaminants is particulate matter with diameters less than 2.5 and 10 μm (known as PM2.5 and PM10). These particles emanate from various sources, particularly from the incomplete combustion of fossil fuels within vehicles, which has rendered road traffic the primary factor exacerbating PM pollution (Hu et al., 2021). Consequently, individuals with substantial exposure to urban roadways, encompassing taxi and bus drivers, street cleaners (Adikaram, 2021, Pagdhune et al., 2023), and susceptible urban populations including children, the elderly, and patients (Zhang et al., 2020, Ghafoori et al., 2022) are anticipated to experience the most pronounced effects of PM-associated air pollution. Respiratory symptoms (RSs), including coughing, dyspnea (shortness of breath), wheezing, and chest tightness rank among the most prevalent types of health issues related to PM exposure in general urban populations (Voll-Aanerud et al., 2010, Heibati et al., 2021). With the inhalation of polluted air, PM (especially PM2.5) can penetrate deeply into the respiratory system, reaching the bronchioles and alveoli in the lungs. They can also trigger inflammatory responses and generate harmful reactive oxygen species that damage cells and tissues in the respiratory tract and manifest initially through RSs (Juan et al., 2021). Hence, understanding and addressing the ramifications of air pollutants, particularly those associated with vehicular emissions such as PM, takes on paramount importance in preserving the welfare of urban residents and the overall economic vitality.

Air pollutants are very dynamic at the urban level. Areas with higher traffic flow, intersections, and taxi and bus stations seem to emit higher levels of pollutants. According to Bikis and Pandey (2021), these areas serve as urban hotspots for pollution. Gao (2021) demonstrated that intersections equipped with traffic lights are highly polluted regions of an urban area. Stenson et al. (2021) also showed that the density of certain urban infrastructures, like road density, can have a significant impact on the emission of pollutants. Nonetheless, air pollutants are mobile and can be trapped or dispersed due to specific urban and climatic characteristics. For instance, Jiang et al. (2021) indicated that factors like building density and building height can play a determinant role in trapping pollutants. At the city scale and using spatial interpolation techniques, Kumar et al. (2020) found that urban areas might form different distribution patterns of air pollutants in which high-pollution areas exerted more harmful impacts on urban dwellers. Contrarily, the role of green coverage in reducing pollutant accumulation has also been highlighted in studies such as Eldeirawi et al. (2019) and Saenen et al. (2019). Additionally, bus stations contribute to pollution due to diesel emissions, as noted by Ngoc et al. (2018), while elevated PM2.5 levels correlate with health risks (Yunesian et al., 2019; Barzeghar et al., 2020). Traffic calming devices and intersections with long red lights increase exposure time, exacerbating respiratory issues (Ngoc et al., 2018). This body of research underscores the link between vehicular emissions, urban infrastructure, and respiratory health, while highlighting the potential of green spaces to mitigate pollution.

The diversity in influencing variables on pollutant dispersion within the city, as well as variations in climate, structure, and geography across different regions, has resulted in the absence of a uniform pattern of parameters affecting urban pollutant distribution and accumulation. Additionally, different urban resident groups and different racial backgrounds display varied responses to urban air pollutants (Kim et al., 2020).

Therefore, studies in this field should focus on specific social and infrastructural contexts unique to each city group to yield reliable results. Despite these insights, gaps remain in understanding the respiratory health impacts on specific occupational groups like taxi drivers, who face unique exposure patterns due to prolonged road time. The role of urban greenery in mitigating pollution for such groups in high-traffic settings is underexplored, and the interplay of local factors like bus stations and travel time in developing cities like Isfahan is poorly understood due to regional urban variability.

In this study, taxi drivers in the polluted city of Isfahan, central Iran were examined for RSs as a basis to identify the strong sensitivity of this group to various air pollution sources (mostly related to PM sources) and the parameters affecting their dispersion or absorption. By selecting several taxi routes in Isfahan, taxi drivers meeting certain physiological criteria were identified and their RSs were collected as independent factors. The characteristics of the driving routes and a set of pollutant-affecting

characteristics were also considered as dependent variables that might contribute to RSs. Ultimately, using PCA and nonlinear regression analysis, this study investigated 1) the most important variables affecting the respiratory health of taxi drivers and 2) the collective impact and statistical significance of these variables on the occurrence of each of these symptoms. This research aims to enhance the awareness of Isfahan city managers concerning the effects of urban planning and pollution on taxi drivers. This study addresses these gaps by employing a non-linear regression model to analyze RSs among Isfahan's taxi drivers, focusing on PM2.5, bus station density, travel time, and road-side greenery. While not a full-spectrum health risk assessment, this study provides a focused exposure-symptom analysis within a controlled occupational group to minimize confounding and identify modifiable spatial drivers. Its novelty lies in targeting a high-risk occupational group and integrating spatial and statistical modeling to assess pollution sources and mitigation strategies, with the objective of providing actionable insights for urban planning to reduce air pollution's health impacts

2. Material and methods

2.1. Study area

Isfahan is a semi-arid and dry city located in the Isfahan Urban Area and, with a population exceeding 2 million people, ranks as the third most populous urban core in Iran (Figure 1). The Isfahan Urban Area has undergone one of the most dispersed patterns of Iranian urban expansion, resulting in the development of three main cities and over 20 medium-sized cities (ranging from 100 to 300 ha) within a distance of less than 30 km from the Isfahan city center. At present, the Isfahan Urban Area encompasses 6 % of the province's geographical expanse and accommodates 70 % of its inhabitants (Rasouli et al., 2019). Although this strategic decentralization effort has effectively contributed to reducing the population pressure on Isfahan City, its central core remains amongst the most densely populated urban nuclei in Iran, experiencing an exceptional growth rate exceeding 70 % over 4 decades (Soffianian and Madanian, 2015). While road infrastructure covers more than 9 % of the city's total area, the historical layout of Isfahan and its streets have led to sluggish mobility within the city center and exacerbated Isfahan's air pollution challenges (Saghaei et al., 2016). Currently, road transportation, coupled with factors like the intense concentration of various national industries around the city, has transformed Isfahan into one of the most polluted cities in Iran. In recent years, the city endured polluted air for more than 70% of days of the year, with its adverse effects significantly impacting the health of Isfahan's residents (Jokar et al., 2020).

Despite the gradual expansion of Isfahan's metro lines, taxis continue to serve as a primary mode of transportation for city dwellers. The Isfahan taxi network boasts over 9,000 taxis, effectively connecting nearly every corner of the city. However, despite the importance of taxis in Isfahan's transportation system, approximately 7,200 taxis (roughly 80%) have become worn out and require replacement, and their drivers are significantly at severe health risks (Rasouli et al., 2019).

2.2. Selection of Isfahan taxi drivers

From the fixed taxi routes of Isfahan (Figure 2), we picked out 32 routes to gather information from their taxi drivers, all of whom were male. These routes were selected using stratified random sampling, ensuring representation across high, medium, and low traffic density zones and geographic regions (north, south, east, west, and central Isfahan) to capture urban variability. Data collection occurred in 2022 over a single stage, with respiratory symptom surveys conducted in July–August 2022. Initially, we excluded drivers who: had less than 5 years of experience on the specified route, were engaged in alternative occupations, resided beyond the city limits, were dealing with respiratory or related health issues, or were younger than 30 or older than 50 years old to mitigate potential biases in the findings. Drivers were randomly selected from each route, targeting 10–12 per route, with exclusion criteria applied to control for confounding health or exposure factors, yielding 350 eligible participants. In total, a group of 350 drivers met our criteria. As our study's primary objective centered around investigating respiratory issues, we specifically inquired with the drivers about their experiences with respiratory problems, including coughing, dyspnea (shortness of breath), wheezing, and chest tightness. This inquiry was conducted using a 5-point Likert scale (Joshi et al., 2015) with response options of rarely (1), occasionally (2), once a week (3), several times a week (4), and daily (5). During the process of collecting results, there was a minor delay and hesitation caused by some drivers' uncertainty in selecting the most accurate responses. To address this, we extended the questionnaire collection period by one week, and this extension proved to be beneficial as it instilled a heightened sense of confidence among the drivers, aiding them in providing more precise answers.

2.3. Explanatory variables

Drawing from the available literature, a range of explanatory variables that could potentially contribute to

the development of respiratory issues among taxi drivers. Travel time index (TTI) and travel distance index (TDI). These metrics quantify the time and distance covered by taxi drivers between their two destinations. They serve as indicators of exposure duration and distance, both of which can influence respiratory health outcomes. The inclusion of these matrices is based on the studies such as Lee and Sener (2019) who found that longer travel times on air-polluted roads increase the risk of health impacts for those exposed. Number of bus stations (NBS) along the driving route: This variable was included due to the fact that Iranian buses employ heavily polluting fuels. Additionally, buses spend considerable time at stations, leading to prolonged emissions and contributing to street-level air pollution. This aligns with the findings from Ngoc et al. (2018).

Mean annual concentration of PM2.5 (PMC) along the driving route: This variable was chosen because elevated PM2.5 concentrations have been correlated with increased health problems. Previous studies, such as those conducted by Yunesian et al. (2019) and Barzeghar et al. (2020), have demonstrated this association. This layer was produced using the Inverse Distance Weighting (IDW) interpolation based on the mean annual PM2.5 concentrations recorded by the Isfahan air quality monitoring stations (Figure 2). IDW used a power value of 2 and a search radius of 5 km, interpolating data from 10 monitoring stations across Isfahan to generate a 10-m resolution PM2.5 layer, capturing urban-scale variability.

Number of intersections with red traffic lights for over 30 seconds (NCS): This variable reflects the count of intersections where traffic signals remain red for a duration exceeding 30 seconds. As demonstrated by Paoin et al. (2022), longer waits at red lights can lead to extended exposure to air pollutants and potentially impact respiratory health.

Number of traffic calming devices (TCD): This variable accounts for the presence of devices designed to reduce vehicle speeds, which in turn might result in drivers spending more time on the road. This extended road time could correlate with heightened exposure to pollutants. This variable was also found to act as hotspots for environmental contamination in traffic-affected urban roads (Sahu and Elumalai, 2017). Percentage of road coverage within a 500-meter buffer from the taxi route (ROD): This variable was selected due to the dense network of roads around certain taxi routes, which often experience high traffic volumes and subsequent pollution emissions. Percentage coverage of green parks (UGP): This variable was included to account for the proportion of the route covered by green parks. Green spaces have the potential to act as pollution-mitigating factors (Figure 2). Density of vegetation along each route (NDVI): This variable captures the amount of vegetation cover along the taxi routes. Higher NDVI values can indicate better green coverage, potentially contributing to pollution mitigation. To calculate the NDVI of road pixels, we employed a mean filter on all NDVI layers derived from Sentinel-2 satellite images taken in 2022, using the Google Earth Engine platform (Figure 2).

Land Surface Temperature (LST): LST indirectly influences the movement and stability of air, along with the pollutants it carries within the urban atmosphere (Fuladlu and Altan, 2021). We extracted the LST from a Landsat-8 image using the Radiative Transfer Equation method as outlined by Sekertekin (2019).

Distance from the urban center (DCC): This variable is important because the urban center often experiences the highest levels of air pollution throughout the year due to concentrated sources. The farther the distance from the urban core, the greater the decrease in pollution levels.
Mean building height (MBH) within a 500-meter buffer from each route: Tall buildings have been associated with creating pollution hotspots and effectively trapping air pollutants (Zhang et al., 2021). This factor was considered using data from the Isfahan Municipality, which provided average building heights at 1-meter intervals (note: this layer is not presented in this study).

2.4. Statistical analysis

Following the collection of respiratory data, a one-way ANOVA test was conducted to analyze the potential relationship between the RSs and the age of the drivers. Our hypothesis posited that the symptoms might also be influenced by age, considering the longer exposure of older drivers to the urban atmosphere. Moreover, based on the Kolmogorov-Smirnov test for the normality of the data, a (Pearson/Spearman) correlation analysis was conducted to evaluate the relationships among both the dependent and independent variables. Considering the substantial number of independent variables, a Principal Component Analysis (PCA) was conducted to identify the most significant variables that account for the greatest variability within our dataset, thus selecting a narrower number of independent variables for the modeling. To achieve a simpler and more interpretable data structure, the Varimax method was used. Among the components with Eigenvalues greater than 1, the variables with the highest loading values were ultimately chosen as independent explanatory factors.

The association between each respiratory symptom and the PCA-derived variables was established using the Generalized Additive Model (GAM), implemented through the "mgcv" package within the R environment (Wood and Wood, 2015). In simple words, GAM extends the traditional linear regression model by allowing for non-linear relationships between predictors and the response

variable using smooth functions. GAMs were preferred over mixed-effects models due to their flexibility in capturing non-linear effects of variables like TTI and NDVI, with limited clustering by driver or route reducing the need for random effects. Residual diagnostics, including normality tests and residual plots, confirmed no significant deviations. Considering the number of freedom problems in this research, we employed a conservative approach with K = 3 smooth terms while maintaining the flexibility to explore non-linear effects and ensuring model interpretability and reliability. Moreover, the smoothing parameters were estimated using the Restricted (or Residual) Maximum Likelihood method. Ultimately, the statistical rigor and interpretability of the GAM results were assessed using the coefficient of determination and F-test analysis. The simple representation of the GAM is shown in Equation 1 where $PCA\_Variable\_i$ is the ith independent variable selected by PCA, k is the number of degrees of freedom chosen for the smoothing term and ϵ is the error term.

$$Respiratory\ symptom \sim s(PCA\_Variable\_1, k = 3) + s(PCA\_Variable\_2, k = 3) + \cdots + s(PCA\_Variable\_n, k = 3) + \epsilon \quad (1)$$

3. Results

The selected drivers totaled 349 individuals who engaged in daily driving for a minimum of 6 hours, excluding holidays. These drivers predominantly reside in close proximity to the passenger routes within the city. The mean age of the taxi drivers was 39.18 ± 3.48 years. Among them, 21 individuals were drivers of the busiest route, while only 2 drivers were selected from the least congested route. The mean number of drivers per route was 11.66 ± 5.91. Each of the drivers exhibited a high level of confidence in assigning ranks to various symptoms. The average ranks assigned to coughing, dyspnea, wheezing, and chest tightness were 2.79 ± 1.44, 2.32 ± 1.62, 2.13 ± 0.91, and 1.62 ± 0.61, respectively (Figure 3). Accordingly, it was determined that occurrences of coughing, dyspnea, and wheezing happen occasionally, even up to once a week, while chest tightness is reported to be exceedingly rare—most commonly during the winter months. Among the four RSs examined, only coughing exhibited a clear age-dependent pattern, while the other symptoms showed no discernible age-related trends (Figure 3). To ensure there was no systematic age-based bias in route exposure, we reviewed the distribution of drivers across the 32 selected routes and found that drivers from different age groups were homogeneously distributed across these routes. This design approach reduced the likelihood that older or younger drivers were assigned to routes with different pollution levels.

Furthermore, the distribution of the symptoms did not conform to a normal distribution, as demonstrated in Table 1. Coughing displayed significant positive correlations with the other three symptoms ($0.228 < r < 0.346$, p-value < 0.01) while the only significant relationship among the other three symptoms was observed between wheezing and chest tightness, marked by a notably low coefficient of 0.15 (p-value < 0.05).

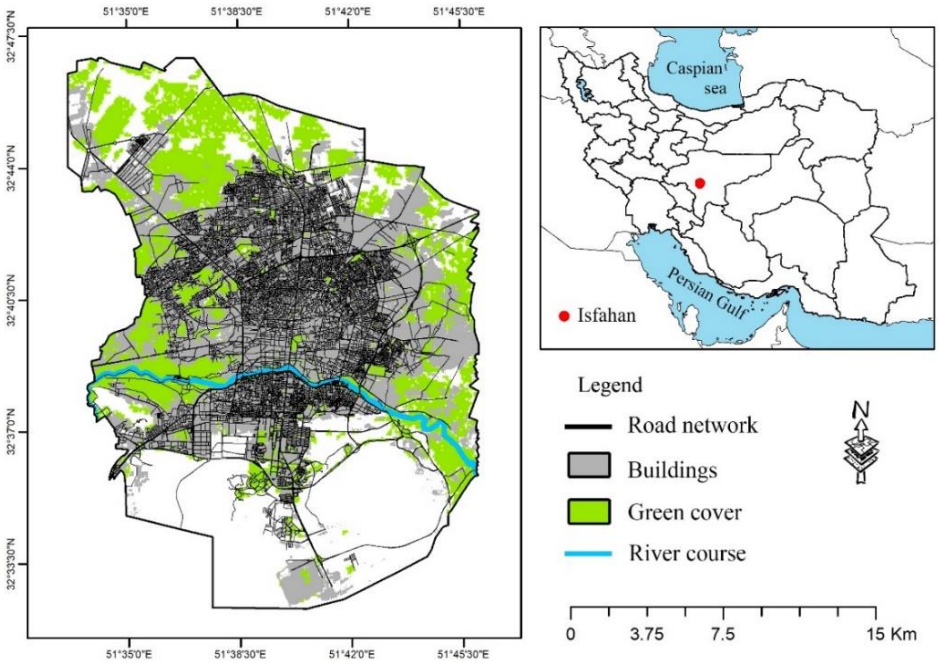

Figure 1. Central core of Isfahan urban area in Isfahan Province, Iran

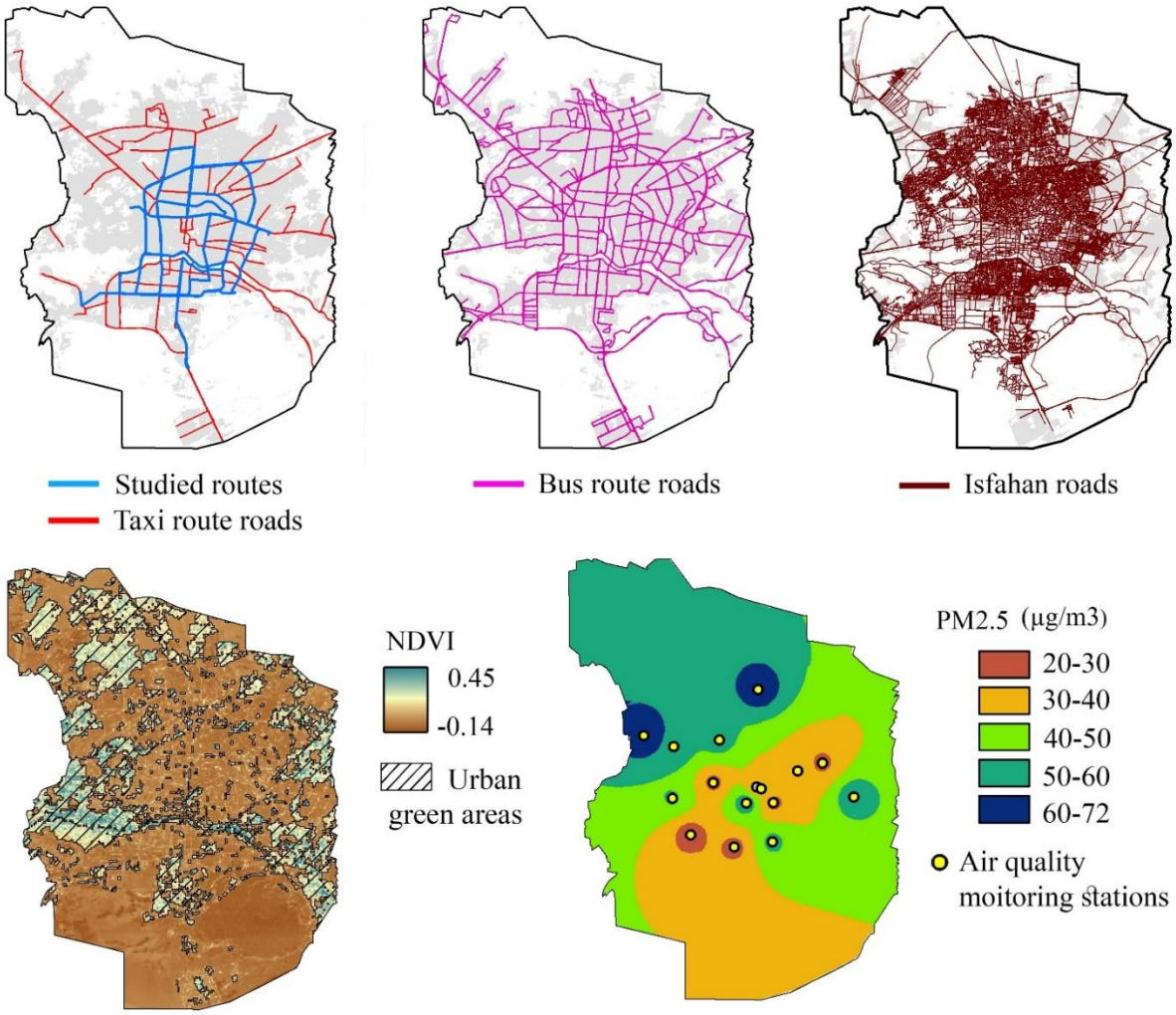

Figure 2. Road network of Isfahan Urban Area for specific uses (taxi and bus), studied taxi routes, NDVI and green areas of the region and annual PM2.5 layer interpolated using data from monitoring stations

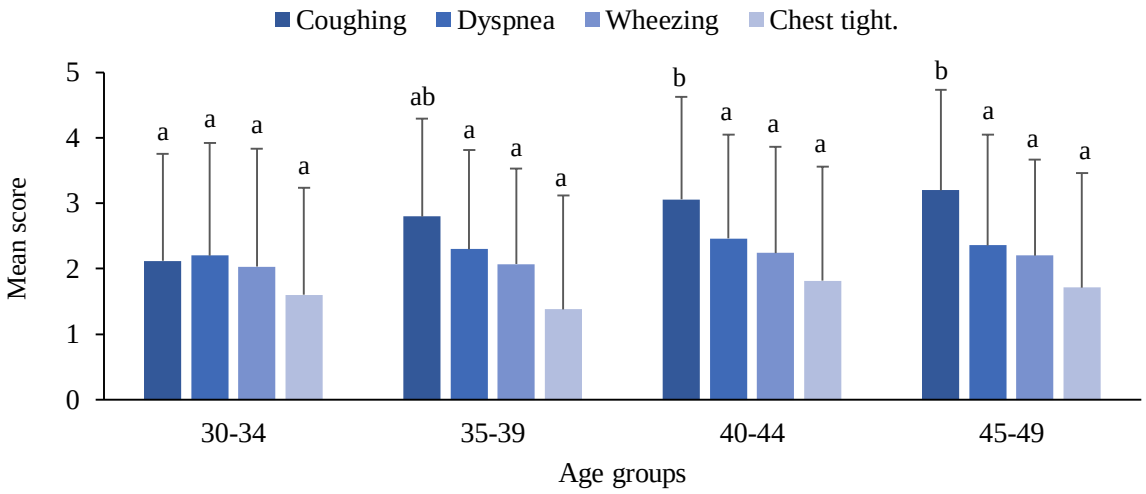

Figure 3. Mean values of the scores given by the selected taxi drivers of different age groups

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The taxi routes were converted from vector to raster format with a cell size of 10 m in order to calculate the means of PMC, DCC, ROD, LST, MBH, UGP, and NDVI variables for each route using overlay techniques. On average, a distance of 6.26 ± 1.81 km and a travel time of 18.73 ± 4.07 min were observed between the taxi stations. The mean concentration of PM2.5 along the taxi routes was determined to be 23.99 ± 6.00 µg/m³, with the highest concentration recorded on a taxi route passing through the city center and the northern part of the city (34.52 µg/m³). Despite Isfahan city being located in a semi-arid region with a mean NDVI not exceeding 0.05, the average NDVI value for the routes reached 0.194 ± 0.77 (maximum 0.241), attributed to the presence of dense trees and vegetation cover along some routes (Figure 4).

Along the selected routes, drivers encounter an average of 6.26 ± 1.52 bus stations, 4.23 ± 1.81 intersections, and 7.66 ± 2.50 traffic calming devices on their passenger routes. The percentage of green cover and road cover within a 500-m buffer along the routes averaged 7.43 ± 1.12 and 11.78 ± 2.39, respectively, corresponding to the central and western green parts of the city (Figure 4). Despite efforts to collect non-interrelated independent variables, significant meaningful relationships were found between certain variables, including NBS and NCS (r= 0.67, p-value < 0.01), TTI with three parameters TDI (r= 0.45, p-value < 0.05), MBH (r= 0.44, p-value < 0.05), and NCS (r= 0.37, p-value < 0.05). A significant negative relationship was also found between LST and DCC (r= -0.39, p-value < 0.05) (Table 2).

The Varimax-rotated PCA analysis resulted in four components with Eigenvalues of greater than 1.0 which collectively explained more than 96% of the data variance (Table 3). In the most important component, TDI and TTI exhibited the highest contribution and due to the significant correlation between the two variables, only TTI with the highest loading value (0.78) was selected as the first explanatory variable. NBS, NDVI and PMC were selected from the other three components with the corresponding loading values of 0.84, 0.90 and 0.76 (Table 3).

The GAM model was employed to analyze each respiratory symptom. The smooth term plots representing the relationship between each variable and the respiratory symptom are displayed in Figure 5 and the model statistics are provided in Table 4. The significance of the intercept across all models was observed at the 0.01 level. Among the four input variables in the model, the smooth term plot associated with NDVI exhibited a significant downward trend in relation to coughing (F=1.102, p-value=0.084), dyspnea (F=7.182, p-value=0.012), and wheezing (F=2.403, p-value=0.090), suggesting that a reduction in the road green coverage is likely to correspond to an increase in these RSs. This indicates NDVI's protective effect, with stronger significance for dyspnea (F=7.182, p=0.012). In contrast, the other three variables demonstrated a positive correlation with RSs. In the context of the coughing model, both TTI (F=5.698, p-value=0.025) and MPC (F=4.413, p-value=0.041) exhibited a notable nonlinear relationship with this respiratory symptom. Meanwhile, the model for dyspnea established this relationship with NBS (F=5.488, p-value=0.027).The parameter TTI similarly established a significant positive relationship in both wheezing (F=3.270, p-value=0.050) and chest tightness (F=4.578, p-value=0.042) models. Among the model performances, the coughing model demonstrated the most robust performance, boasting an R^2 of 0.576 and elucidating 65.3% of the deviance. On the other hand, the chest tightness model, which solely established a significant relationship with the parameter TTI, could only account for 47.6% of the deviance, yielding an R^2 of 0.372.

4. Discussion

According to Burdon (2015), the prevalence of RSs in adults is particularly linked to their working environment. In this context, taxi drivers are consistently identified as one of the most at-risk and vulnerable groups to air pollution on city roads. The present research was therefore carried out to seek a meaningful connection between asthma-related RSs among taxi drivers of Isfahan and air pollution sources and their associated dispersion/ mitigation factors. Urban air pollution, driven by vehicular emissions, poses a significant respiratory health risk globally, particularly for occupational groups like taxi drivers who face prolonged exposure (Moutinho et al., 2020). This study's findings confirm that Isfahan's taxi drivers experience frequent RSs, with coughing being most prevalent, especially among older drivers. In this study, the cumulative effects of air pollution exposure were found to be clearly evident in the increase of coughing symptoms as tested by the one-way ANOVA analysis. Notably, individuals aged over 40 significantly reported a higher number of coughing instances compared to younger drivers. This suggests stronger pollutant effects in the upper age group (40–50) compared to the lower (30–39), though clinical indicators were not assessed. This is in line with a large pool of studies, for example, see Satia et al. (2021), in which advancing age was found to play a pivotal role in the onset of chronic coughing in adults. However, the results of this study did not show a clear age association with dyspnea, wheezing, and chest tightness symptoms. In contrast to this finding, a study carried out by Fazlollahi et al. (2018) in Tehran, a neighboring City in central Iran, provided evidence of an increased occurrence of these symptoms with advancing age.

Table 1. Results of the normality test and correlation coefficients for respiratory symptoms

Respiratory symptom	K-S normality results		Spearman Correlation Coefficient			
	Statistic	Sig.	Coughing	Chest tigh.	Wheezing	Dyspnea
Coughing	0.174	0.000	1	0.228	0.320	0.346
Wheezing	0.203	0.000	**	1	0.054	0.076
Chest tigh.	0.175	0.000	**	0.054	1	0.15
Dyspnea	0.169	0.000	**	0.076	*	1

Table 2. Correlation coefficients between the explanatory variables.

NDVI	-0.04	-0.03	0.11	-0.23	0.20	0.15	0.40	0.16	-0.01	0.29	0.08
	UGP	-0.08	-0.18	-0.08	-0.03	0.13	0.03	-0.08	-0.19	0.12	0.23
		MBH	0.42	0.44	-0.11	0.22	0.18	-0.12	-0.22	0.10	0.21
		*	TDI	0.45	0.23	0.11	0.05	-0.17	0.20	0.21	0.18
		*	*	TTI	-0.09	0.37	-0.02	-0.36	0.01	-0.06	0.14
					TCD	-0.35	-0.25	0.00	-0.14	0.04	-0.16
				*		NCS	0.67	-0.27	-0.20	0.15	0.01
						**	NBS	-0.01	-0.10	0.03	0.16
								LST	0.03	-0.39	-0.10
									ROD	-0.22	0.24
								*		DCC	0.09
											PMC

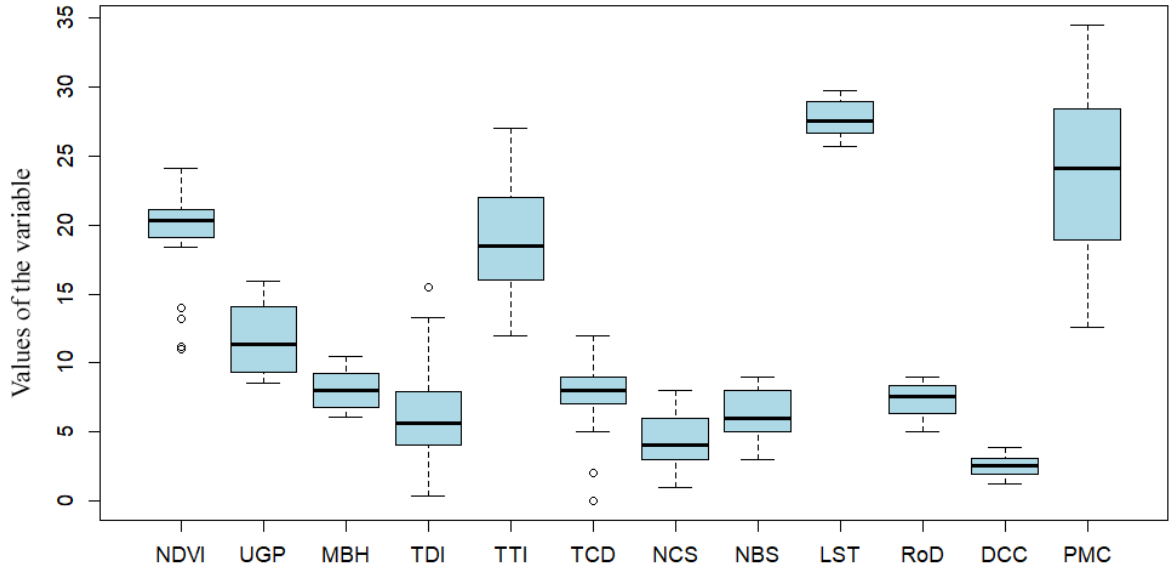

Figure 4. Boxplot of the initial explanatory variables (Note that the NDVI values are multiplied by 10 for better representation in the figure)

This discrepancy might be attributed to the broader scope of their study which included respiratory patients and the thorough screening of participants in this study which focused on exactly similar lifestyle behaviors and characteristics, such as complete smoking cessation, to decrease age-dependent biases. Furthermore, we identified a non-normal distribution in the scores assigned to RSs. This indicates that the responses are not centered around a specific intermediate score; instead, highly disparate scores were observed which reflect the high spatial variability of sources inducing RSs, particularly air pollution, as well as the associated dispersion and absorption attributes of the urban landscape. These findings align with Kelly et al. (2021), who note that congested urban roads exacerbate respiratory issues, supporting our observation that increased TTI correlates with RSs. The significant role of NBS in dyspnea aligns with Ngoc et al. (2018), highlighting diesel bus emissions as pollution hotspots in Iranian cities. The negative association between NDVI and RSs corroborates Eldeirawi et al. (2019) and Squillacioti et al. (2020), emphasizing greenery's protective effect. PM2.5's impact on coughing supports Nourouzi and Chamani (2021), though its limited effect on other RSs may reflect urban-scale variability. While we limited the sample to a defined age range (30–50 years) to control for lifestyle heterogeneity, we also stratified the symptom data into four age bands to explore potential intra-group variability. Coughing was notably more prevalent in the upper age band (40–50). However, we did not stratify environmental exposure variables by age group. It should be noted that older drivers were not disproportionately present on specific routes; their distribution across routes was uniform. Nonetheless, we acknowledge that age-stratified exposure modeling would enhance the depth of the analysis, and we recommend this as an important future direction.

Since statistical modeling with a large number of variables results in overfitting and sometimes leads to uninterpretable results for urban management, the Varimax-rotated PCA analysis was conducted to identify four key variables influencing RSs. The primary variable with the highest loading in the first PCA component was travel time (TTI). In the GAM models, TTI was found to be a positive function of three of RSs (coughing, wheezing and chest tightness). It seems that an increase in TTI refers to longer durations that taxi drivers spend between their destinations and possibly exposes them to higher traffic-related air pollution.

Table 3. Results of Varimax-rotated PCA analysis for selecting the most relevant predictive variables for respiratory symptoms

Variable	Component			
	1	2	3	4
Eigenvalue	2.54	1.81	1.53	1.23
% of variance	23.18	17.10	14.81	13.93
NDVI	-0.04	0.09	0.90*	0.03
UGP	-0.20	0.04	-0.08	0.14
MBH	0.40	0.15	0.00	-0.08
TDI	0.71	-0.16	0.24	0.21
TTI	0.78*	0.20	-0.38	0.19
TCD	0.12	-0.71	0.33	0.08
NCS	0.22	0.77	0.10	0.24
NBS	0.09	0.84*	0.48	-0.07
LST	-0.17	-0.13	0.24	-0.84
ROD	-0.04	-0.04	-0.02	-0.07
PMC	0.01	-0.05	0.36	0.76*
DCC	0.28	0.08	0.12	0.00

* The selected variable from each component for modeling

Table 4. Performance of the selected variables in the prediction of respiratory symptoms

Symptom	Statistic	Variable				R-sq.(adj)	Deviance explained (%)
		NDVI	NBS	TTI	PMC		
Coughing	F	1.102	3.331	5.698	4.413	0.576	65.3
	p-value	0.084*	0.115	0.025**	0.041**		
Dyspnea	F	7.182	5.488	0.321	0.495	0.461	54.3
	p-value	0.012**	0.027**	0.578	0.504		
Wheezing	F	2.403	0.100	3.27	1.311	0.458	57.6
	p-value	0.090*	0.754	0.050*	0.312		
Chest T.	F	2.568	1.205	4.578	0.658	0.372	47.6
	p-value	0.122	0.341	0.042**	0.425		

Signif. codes: 0.01 '**', 0.05 '*'

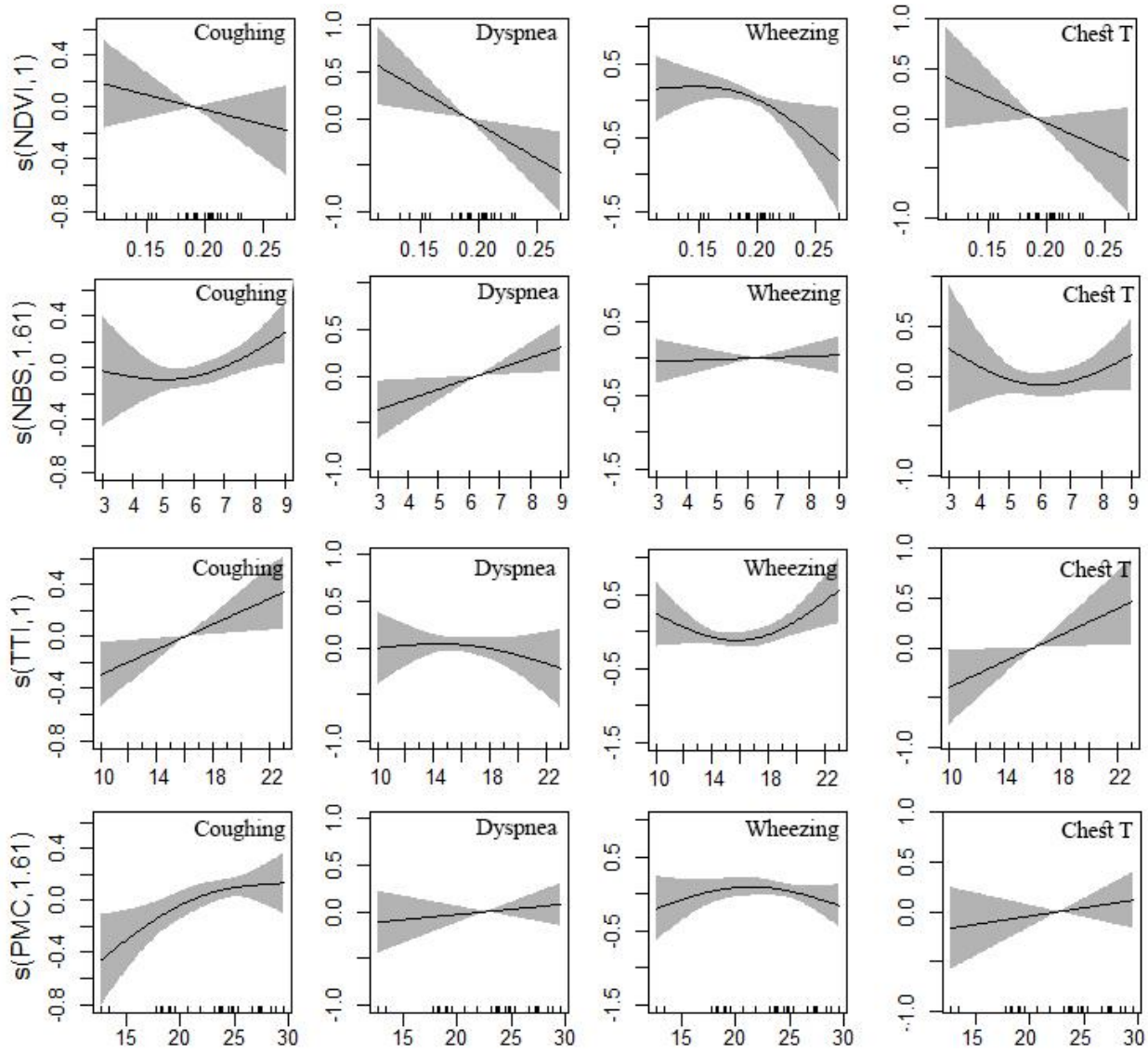

Figure 5. Smooth fitting curves of the GAM model. Solid lines represent the smooth fitting curves and gray areas show the upper and lower limits of the confidence intervals of the fitting additive functions

This observation is in line with studies such as Kelly et al. (2021) which suggest that respiratory problems continue to be a significant challenge in areas with congested urban roads. The sole high importance of NBS in the second PCA component reveals the significant role of buses in the onset of RSs in Isfahan. Although the respiratory effects of bus stations have been a focal point in recent studies (refer to the review article by Ngoc et al. (2018), this issue presents an even more challenging dilemma in Iranian cities because diesel fuel used by vehicles in Iran is highly polluting, leading to strict regulations that prohibit most diesel vehicles from entering city borders expect for buses whose presence is inevitable for the viability of Iranian large cities like Isfahan. Despite the high importance of NBS in recent studies (Ngoc et al., 2018) and its increasing trend as indicated in all smooth-term plots, it was found to be a significant predictor only for dyspnea in the GAM models. One plausible explanation for this might stem from the low variability of NBS in the central core of the city, compelling us to decrease the number of degrees of freedom for its smoothing term to 3. Hence, to better recognize the importance of NBS, it seems necessary to involve a broader range of taxi routes that encompass varying levels of bus traffic and bus station density in the modeling process.

NDVI refers to the amount of green biomass which increases as the density of vegetation cover increases. In our study, NDVI also served as a surrogate for assessing the number of trees and evergreen bushes linearly planted along urban roads, whether in the middle or on the sides. In Iranian cities, this practice is a common strategy used to enhance the natural elements of the urban environment, in conjunction with creating green parks. Remarkably, NDVI not only contributed significantly to one of the PCA

components but was also negatively associated with all RSs. This negative association was particularly significant for the models related to coughing, dyspnea, and wheezing. The GAM models showed NDVI's strongest effect on dyspnea (F=7.182, p=0.012), suggesting a notable reduction in RS prevalence with higher greenery. Recent studies such as Cilluffo et al. (2018), Eldeirawi et al. (2019) and Squillacioti et al. (2020) pointed out that NDVI is an excellent index of urban greenness and is inversely associated with the prevalence of asthma and PRs among urban residents. Building upon their findings, our study demonstrated that the impact of NDVI extends not only to the entire urban landscape but also to linear stretches of green vegetation along urban roads. These findings suggest that both the overall NDVI of an urban area and the NDVI associated with linear green features along roads can significantly lower the prevalence of RSs in an urban environment.

The IDW-generated PM2.5 layer exhibited significance solely in predicting coughing (Table 3) and did not exert any statistical influence on the occurrence of other RSs (Figure 4). It is important to recognize that the PMC layer is created at an urban level, and its distribution is subject to a wide array of highly dynamic and variable factors, including climate conditions and air currents. This variable contrasts starkly with the other explanatory variables, which were confined to a local (road-scale) level and primarily dictated by the characteristics of the roads themselves. Resource constraints prevented the use of mobile measurements or finer-resolution satellite products (e.g., MODIS), which could capture micro-spatial $PM_{2.5}$ variability. This urban-scale resolution limits precision for route-specific exposure. This distinction underscores the complexity of studying air pollution's impact on respiratory health, highlighting the need to consider both macro-level urban dynamics and micro-level road characteristics to comprehensively understand the contributing factors to respiratory health problems. This conclusion, even though it pertains to highly mobile individuals, aligns with a prior study conducted in Isfahan City by Nourouzi and Chamani (2021). Their study similarly highlighted that Isfahan's PM concentration, along with other related factors such as bus stations, impacts the health of pregnant women even in stationary scenarios. The consistency between our findings and theirs emphasizes the robustness of the associations discovered between air pollution variables and respiratory health outcomes, reinforcing the significance of these factors across various demographic groups and circumstances. Theoretically, these results support exposure-response models, where prolonged pollutant exposure (TTI, NBS) increases health risks, while mitigating factors (NDVI) reduce exposure intensity. The GAM's nonlinear approach effectively captured these relationships, highlighting the role of localized urban factors.

Based on the findings, it becomes evident that common air pollution sources and variables related to dispersion and mitigation significantly impact the health of urban residents, particularly sensitive subpopulations and individuals who are directly exposed to street environments. Alongside the continuation of individual- or subpopulation-level studies in this field, there is an urgent need for immediate action to update the urban transportation infrastructure. This update should focus on both improving the quality and diversity of transportation options, favoring more environmentally friendly modes of transportation. Spatial modeling investigations, which can identify areas with low vegetation and high traffic concentrations, hold the potential to be highly effective in addressing this issue. By pinpointing hotspots characterized by insufficient greenery and high traffic intensity, these models can offer valuable insights to Isfahan City managers. This information is particularly pertinent given their active pursuit of implementing low-emission zones over the past 5 years. The integration of research findings with tangible policy actions can contribute to improving air quality and overall respiratory health for the city's inhabitants. For urban policymakers in Isfahan, these findings advocate expanding green infrastructure along taxi routes to leverage NDVI's protective effect (e.g., F=7.182, p=0.012 for dyspnea) and optimizing traffic flow to reduce TTI, thereby lowering RS prevalence. Regulating diesel bus emissions near bus stations can further mitigate risks, aligning with low-emission zone initiatives. Practically, these findings urge Isfahan's planners to expand green infrastructure along taxi routes and regulate diesel bus emissions. Optimizing traffic flow to reduce TTI and enhancing low-emission zones can mitigate RSs among taxi drivers.

This study has limitations. The sample included only male drivers aged 30–50, limiting generalizability to female drivers or other age groups. The 32 selected routes may not capture Isfahan's full urban variability. PM2.5 data, derived from urban-scale interpolation, may lack road-level precision. The observational, non-clinical measurement of RSs without baseline clinical data or health risk assessments limits validity. The study also did not differentiate PM2.5 sources (e.g., diesel vs. gasoline), which may influence respiratory outcomes. The lack of clinical age-group analysis limits understanding of differential pollutant effects. In addition, while we explored age-related variation in symptoms, we did not conduct an analysis of whether exposure variables (such as travel time, PM2.5, or bus station density) differed by age group. Although the drivers were evenly distributed across routes regardless of age, such an analysis would provide

greater insight into age-dependent exposure-response relationships. Future studies should consider incorporating this stratified modeling, ideally with access to clinical diagnostics and a wider demographic base. Future research should include female drivers, broader route coverage, and longitudinal studies to assess long-term exposure effects. Investigating additional pollutants (e.g., NO_2, O_3) and real-time monitoring could enhance RS understanding, incorporating clinical examinations and health risk metrics.

5. Conclusion

This study aimed to evaluate the occurrence of RSs among a selected group of taxi drivers with similar lifestyles and physiological characteristics in Isfahan. The study explored the relationship between these symptoms and air pollution sources, as well as mitigation strategies. Despite the rigorous selection process of taxi drivers, our results revealed that coughing is an age-dependent respiratory issue, intensifying with prolonged occupation in this profession.

The PCA-derived factors emerged as noteworthy predictors of RSs. The implementation of green structures along taxi routes, quantified using NDVI, was linked to a reduction in the likelihood of experiencing these symptoms. Conversely, an increase in the number of bus stations and extended travel time between taxi destinations was associated with a higher prevalence of coughing, dyspnea, wheezing, and chest tightness. Additionally, the overall distribution of PM2.5 over an extended period significantly contributed to RSs among taxi drivers. This study advances urban air pollution research by providing novel insights into the respiratory health of taxi drivers, a high-risk group, through the integration of Generalized Additive Modeling and NDVI-based greenery assessment. It contributes to the field by demonstrating the protective role of urban greenery and the adverse effects of localized factors like bus stations and travel time, offering a framework for occupational health studies in polluted cities. Self-reported RSs via a Likert scale lacked clinical validation or calibration (e.g., double sampling or physician confirmation), risking recall bias. Future research should include clinical assessments, such as spirometry, to validate symptoms.

In light of these findings, there's a compelling need for a comprehensive reevaluation and enhancement of the urban transportation infrastructure. This is crucial to effectively mitigate the adverse effects of air pollution on vulnerable and high-risk subpopulations within the city. Taking these insights into account, urban planners and policymakers can develop targeted strategies to create a healthier urban environment for both residents and taxi drivers. For Isfahan and similar cities, the findings advocate expanding green infrastructure, optimizing traffic flow, and regulating emissions to reduce health risks. These contributions support evidence-based urban planning and public health policies to foster healthier environments for vulnerable populations. Lastly, we emphasize that while our study sheds light on symptom-exposure relationships within a specific occupational cohort, it does not encompass stratified exposure-risk modeling across age or broader population groups. Our findings should therefore be interpreted as internally valid but not fully generalizable across all urban residents or demographic categories. Expanding future studies to include age-stratified exposure analysis and clinically validated health outcomes will strengthen the evidence base for risk-based health planning.

Authors Contribution

Formal analysis and Investigation: S. M., and M. A. Methodology; S. M., M. A. Software: S. M.; Supervision: M. A.; Validation: S. M., M. A.; Writing: S. M., M. A.; Writing-review & editing: M.A.

Availability of data and materials

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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