sciendo

DOI: 10.2478/rjti-2023-0007

ROMANIAN JOURNAL
OF TRANSPORT INFRASTRUCTURE

# A MODERATION EFFECT OF ATMOSPHERIC CONDITIONS ON $PM_{2.5}$ TRAFFIC RELATED CONCENTRATION

**Eugen Roșca,** Professor, University Politehnica of Bucharest, Romania, email: eugen.rosca@gmail.com
**Florin Ruscă,** Associated Professor, University Politehnica of Bucharest, Romania, email: florin.rusca@upb.ro
**Oana Dinu,** Associated Professor, University Politehnica of Bucharest, Romania, email: oana.dinu@upb.ro
**Ștefan Burciu,** Associated Professor, University Politehnica of Bucharest, Romania, email: stefan.burciu@upb.ro
**Cristina Oprea,** Lecturer, University Politehnica of Bucharest, Romania, email: cristina.oprea@upb.ro
**Anamaria Ilie,** Lecturer, University Politehnica of Bucharest, Romania, email: Anamaria.ilie.@upb.ro
**Cătălin Coman**, Ph.D. student, University Politehnica of Bucharest, Romania, email: catalin.coman@upb.ro

***Rezumat***

Lucrarea evidențiază contribuția traficului rutier la poluarea atmosferică cu $PM_{2,5}$, luând în considerare influența parametrilor atmosferici. Față de alte studii, temperatura și umiditatea relativă sunt considerate ca variabile moderatoare. Concentrația de particule în suspensie este, de asemenea, influențată de geografia locală, structura urbană și forma străzilor. Studiul de caz a fost realizat în București, într-o zonă deschisă. Seria de timp cu concentrațiile de $PM_{2.5}$ este staționară, modelele autoregresive de ordin unu și doi fiind relevante. În timp ce efectele directe ale traficului rutier și ale umidității sunt semnificative, temperatura nu are un efect liniar direct semnificativ. Dar ambii moderatori prezintă efecte de moderare semnificative. Efectele condiționate se diminuează odată cu creșterea temperaturii și umidității, din cauza schimbărilor în dinamica aerului și a precipitației la sol a particulelor.

**Cuvinte cheie: particule în suspensie ($PM_{2.5}$), trafic rutier, congestie urbană, condiții atmosferice, model de moderare**

***Abstract***

The paper highlights the contribution of the road traffic to $PM_{2.5}$ air pollution, taking in consideration the atmospheric parameters. But, despite other studies, temperature and relative humidity are considered as moderating variable. The concentration of particulate matter is also influenced by local geography, urban structure, and streets shape. The case study was done in

Bucharest, in an open area. The $PM_{2.5}$ air concentration time series is proved stationary, an autoregressive model with two lags being tested. While the main effects of road traffic and humidity are significant, temperature has not a significant direct effect. But both moderators show interactive effects. The conditional effects are getting down with increase in temperature and humidity, due to changes in air dynamics and precipitation phenomena.

**Keywords: particulate matter ($PM_{2.5}$), road traffic, urban congestion, atmospheric conditions, moderation model**

## 1. INTRODUCTION

Particulate matter is a collective name for fine solid or liquid particles added to the atmosphere by natural or anthropic process. $PM_{2.5}$ particulates have an aerodynamic equivalent diameter less than or equal to 2.5 microns. $PM_{2.5}$ are characterized by small size, long suspension time, long transmission distance, large surface areas allowing easy attachment of dangerous substances and microbes/viruses which can significantly damage air quality and human health. It can penetrate the lung barrier and enter the blood system, causing cardiovascular and respiratory disease and cancers, affecting more people than other pollutants even at very low concentrations [1, 2].

The European Union (EU) and the World Health Organization (WHO) have issued critical and target values that should not be exceeded in order to protect people from the hazardous effects of $PM_{2.5}$ on human health [3, 4]. The ultimate WHO guidelines state that annual average concentrations of $PM_{2.5}$ should not exceed 5 $\mu g/m^3$, while 24-hour average exposures should not exceed 15 $\mu g/m^3$ more than 3-4 days/year. In EU, the current annual concentration obligation is 20 $\mu g/m^3$. Depending on the value of average exposure indicator (AEI) in 2010, a percentage reduction requirement (0-20%) is set in the directive Directive 2008/50/EC to achieve 18 $\mu g/m^3$ by 2020.

In EU-27, the $PM_{2.5}$ monitoring and reporting started in 2000. The main sector contributors to $PM_{2.5}$ emissions in EU are residential, institutional, and commercial (54%), manufacturing and extractive industry (18%), road transport (11%), agriculture (7%), and non-road transport (2%) [5].

The regions in the EU are improving their $PM_{2.5}$ concentration, meeting the limits, but the richest regions are doing so from lower starting levels and significantly faster than the poorest ones. Although at regional level the standards are met, the large cities remain the major points where concentrations are overpassed, and due to population density, the risks of exposure are high. 96% of the EU urban population is exposed to $PM_{2.5}$ concentrations above WHO guidelines (Figure 1). The poorest situation is presented in northern Italy and in

Central and East Europe. The use of solid fuels, together with an older vehicle fleet is the main reason for the situation in Central and Eastern Europe. In northern Italy, the high concentrations are due to the combination of a high density of anthropogenic emissions and meteorological and geographical conditions that favor the accumulation of air pollutants in the atmosphere [6].

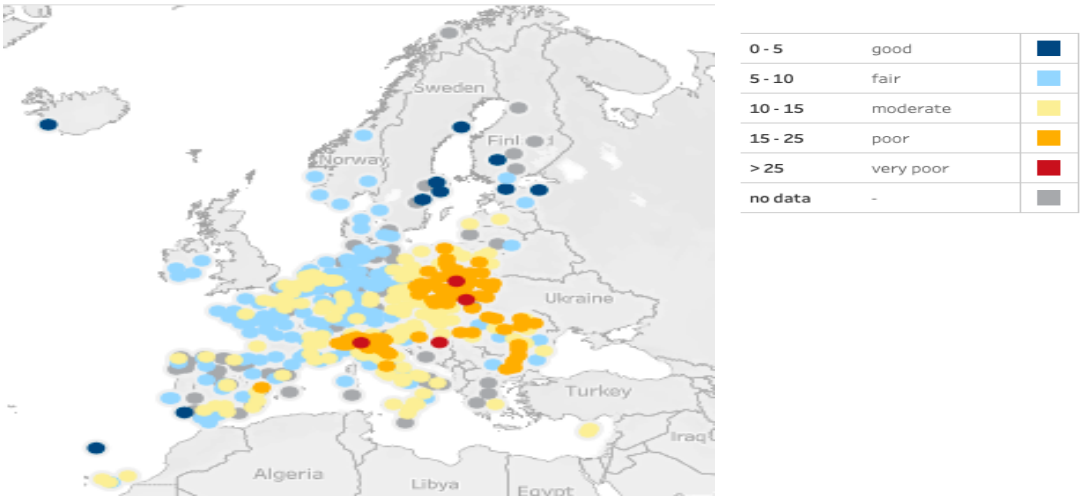



**Figure 1.** $PM_{2.5}$ annual mean concentration in EU cities (µg/m$^3$)
*Source*: Wilson et al. [6]

Emissions of $PM_{2.5}$ have decreased in the EU-27 during the last decades, because of policy efforts across several transport modes [5].

The present paper addresses the $PM_{2.5}$ pollution due to road traffic and the moderation effect induced by the atmospheric conditions (temperature and humidity) in urban areas. The study case is done in Bucharest, the capital city of Romania. With a population of 2.1 million estimated to be living in and 1.8 million cars, the city is burden with one of the most congested traffic in Europe. With a growing economy, as well as larger amounts of residential zones and urban infrastructure built in the last decades, there is a blow to the level of air quality. The annual average $PM_{2.5}$ concentration vary between 12.85 - 18.69 µg/m$^3$, exceeding the WHO limits, with hourly scores above 30 µg/m$^3$ in rush-hours [7].

## 2. $PM_{2.5}$ AIR CONCENTRATION FACTORS

### 2.1. $PM_{2.5}$ emission factors and traffic

Internal-combustion motor generates direct emission of $PM_{2.5}$ and the emission of precursor gases that form $PM_{2.5}$ through gas-to-particle conversion [8-10]. Influence of near-road $PM_{2.5}$ concentration due to traffic flow has been

outlined in literature [11-15]. Additional factors impact the traffic contribution to $PM_{2.5}$, including the traffic composition and volume, the age of fleet, travel speed, speed limit and speed calming methods, and typical driving mode [16-18]. At European level, EMEP/EEA technical guidance proposes three tiers for computing the emission levels [10]:

- *Tier I*

The Tier 1 approach for exhaust emissions uses the following general equation:

$$E_{PM2.5} = \sum_j \left( \sum_m \left( FC_{j,m} \times EF_{PM2.5,j,m} \right) \right) \quad (1)$$

where: $E_{PM2.5}$ = emission of $PM_{2.5}$, g;

$FC_{j,m}$ = fuel consumption of vehicle category *j* using fuel *m*, kg;

$EF_{PM2.5,j,m}$= fuel consumption-specific emission factor of $PM_{2.5}$ for vehicle category *j* and fuel *m*, g/kg.

The vehicle categories to be considered are passenger cars, light commercial vehicles, heavy-duty vehicles and L-category vehicles. The fuels to be considered include petrol, diesel, LPG and natural gas.

- *Tier II*

The Tier II approach considers the fuel used by different vehicle categories and their emission standards. The four broad vehicle categories used in the Tier I approach are sub-divided into different technologies according to emission-control legislation. The general exhaust emission equation is:

$$E_{PM2.5,j} = \sum_k \left( N_{j,k} \times M_{j,k} \times EF_{PM2.5,j,k} \right) \quad (2)$$

where: $E_{PM2.5,j}$ = emission of $PM_{2.5}$, g;

$N_{j,k}$ = number of vehicles in nation's fleet of category *j* and technology *k*;

$M_{j,k}$ = total annual distance driven by all vehicles of category *j* and technology *k*, veh×km;

$EF_{PM2.5,j,m}$= technology-specific emission factor of $PM_{2.5}$ for vehicle category *j* and technology *k*, g/veh×km.

- *Tier III*

The Tier III method computes exhaust emissions using a combination of technical data (e.g. emission factors) and activity data (e.g. total vehicle×km, road type). For $PM_{2.5}$ hot emission, the general formula is:

$$E_{PM2.5,k,r} = \sum_k \left( N_k \times M_{k,r} \times EF_{PM2.5,k,r} \right) \quad (3)$$

where: $E_{PM2.5,k,r}$ = emission of $PM_{2.5}$ produced in the period concerned by vehicles of technology *k* driven on roads of type *r*, g;

$N_k$ = number of vehicles in nation's fleet of technology *k*;

$M_{k,r}$ = mileage per vehicle driven on roads of type *r* by vehicles of

technology *k*, km/veh;

$EF_{PM2.5,k,r}$ = technology-specific emission factor of $PM_{2.5}$ for the vehicle technology *k*, operated on roads of type *r*, g/km.

Cold emissions are computed as a fraction of hot emissions.

## 2.2. Topography and urban structure

Large topography affects the particulate matter concentration through energy and mass exchanges in the atmosphere. The terrain geography can favorize air temperature inversion, changes in horizontal and vertical air flows, forcing a strong terrain trap effect [19, 20]. Industrial activity (steel industry, chemicals, and energy production), traditional technologies for domestic heating (wood-burning fireplaces and stoves), and traffic congestion in cities along mountain valleys and basins are the main factor for $PM_{2.5}$ high atmospheric concentration in China [21, 22] and northern Italy [23].

The urban structure, the built environment, side constructions, and the road design have also influence on $PM_{2.5}$ concentration. Regarding urban size, larger urban areas record increased air pollution due to high energy consumption and traffic emission [24]. As for urban form, compact cities can shorten commutes and other trips compared to sprawling cities, decreasing energy use and traffic emissions [25]. Also, a polycentric city, as a set of connected small compact urban areas, could reduce air pollution on condition that travel speed and/or the number of links directly connected with the city center are sufficiently high [26]. The spatial extension is still the critical aspect to curb transport-related urban pollution.

The $PM_{2.5}$ levels in the urban open areas are significantly affected by the street "canyon" structure [27]. The canyon street structure is described by the rise ratio between the heights of the building on the roadside and the road-width (H/W ratio). The particulate matter has increased levels at high-H/W ratio, compared to low ones. In covered/tunneling spaces a higher concentration of $PM_{2.5}$ is recorded, than in open areas [28].

## 2.3. Atmospheric conditions

Atmospheric conditions could provide variations of the level of $PM_{2.5}$ air concentration.

In the case of relative humidity, findings show strong negative correlation with $PM_{2.5}$ in urban areas. Relative humidity influences particulate matters to settle down on the ground, thus the more humidity goes up, the more

concentrations of air pollutants become lower [29-31]. However, in high altitude cities, with intense traffic, the rainfall should be factored when analyzing the effect of the relative humidity. If rains are not particularly strong, they do not result always in lower $PM_{2.5}$ concentrations [32].

Both negative and positive correlations between particulate matter and temperature are presented in literature [31-35], which might indicate a polynomial relationship between the two variables. A higher air temperature generates atmospheric turbulence, accelerating the dispersion, and dilution of pollutants. At the same time, a lower temperature requires more energy consumption through combustion, and hence more emissions, and the atmospheric stability on days of lower surface temperature leads to higher $PM_{2.5}$ concentrations.

Contrasted results are also found for wind speed and $PM_{2.5}$ concentration. [36-38], concluding that the relation wind speed – $PM_{2.5}$ is nonlinear (polynomial) over time. A lower wind speed does not favor the pollutants dispersion, while a moderate increase in wind speed allows their dispersion. A high wind speed with a dry environment brings dust spread. Also, seasonal effects can influence the wind speed – $PM_{2.5}$ relation [37].

## 3. MATERIALS AND METHODS

### 3.1. Sampling location

Bucharest is divided in four metropolitan concentric zones. The study area is situated in the second zone, connecting NE and SE regions of the city. The area is surrounded by University ”Politehnica” of Bucharest, an office building area, a thermal plant, and several green zone (Figure 2). There is a 4-lane road crossing the zone, with high traffic during the peak hours (7:00-10:00 and 15:00-18:00). The zone is classified as an open one, with small ratio H/W, and few near-road buildings in the extremities of the area.

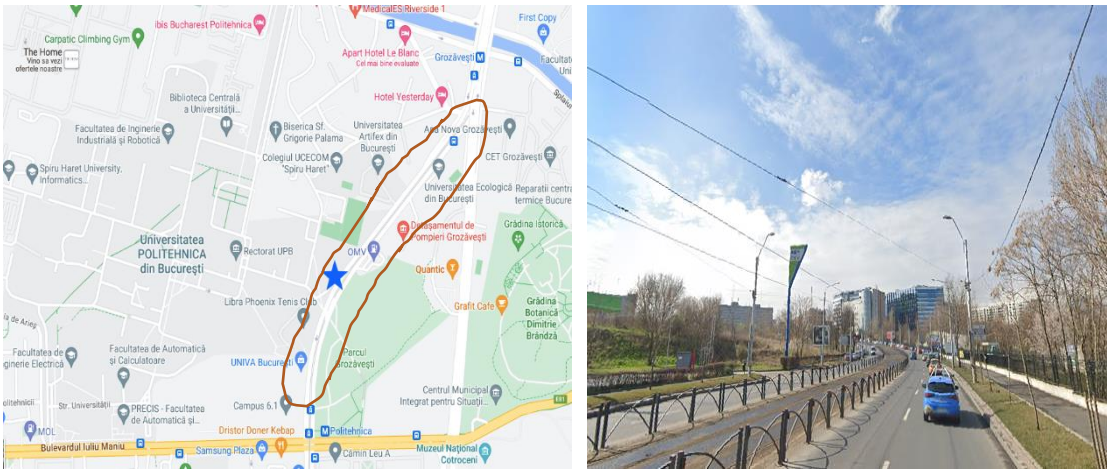



**Figure 2.** Location of the study area in Bucharest
*Source*: Google Maps

## 3.1. Air and traffic sampling data

The air sampling instruments were placed on a pilar at 1.8 m above the ground and 10 m distance from the road curb and other direct source. The device containing the instruments during the setting up is shown in Figure 3.

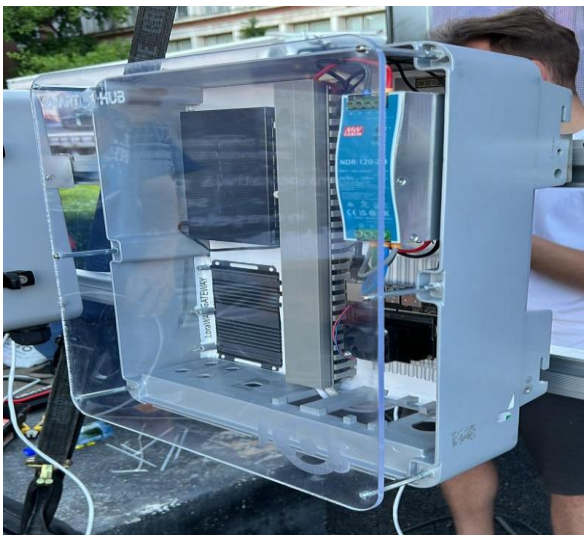


**Figure 3.** The device with air sampling instruments

$PM_{2.5}$ concentration and atmospheric parameters were collected using a sensor uRAD Smoggie, having the ranges: temperature (-40 – 85°C; accuracy ±1°C), relative humidity (0 – 100 %; accuracy ±2 %), $PM_{2.5}$ (0 – 1,000 μg/m³; accuracy ±5 %). Particulate matters are quantified using a laser scattering counter. The device is an IOT adapted, with Wifi connectivity to send the air quality

measurements to the uRADMonitor Cloud in real time. Data samples were collected continually, during March 14th - May 05th 2023, every 10 seconds. For traffic counting, a Hikvision DS-2CD2046G2-IU camera was used, with 1/3" Progressive Scan CMOS sensor, shutter speed 1/3 s to 1/100,000 s, illumination distance up to 40 m. From the data cloud, data are processed and the hourly means for $PM_{2.5}$ concentration, temperature, and relative humidity and the hourly traffic flow are stored in a database. All statistical analysis applied to data sampling were developed using R programming language and RStudio interface.

The descriptive statistics of data sampling are provided in Table 1.

**Table 1. Descriptive statistics of the data sample**

| **Parameter** | **Traffic Flow** [veh/h] | **Temperature** [°C] | **Relative humidity** [%] | **$PM_{2.5}$** [μg/m³] |
|---|---|---|---|---|
| Mean | 662 | 10.38 | 57.47 | 15.047 |
| Min. | 153 | 3.59 | 25.43 | 0.016 |
| Max. | 1675 | 25.74 | 91.64 | 77.531 |
| 1st Quartile | 445 | 6.35 | 45.04 | 7.093 |
| Median | 594 | 9.15 | 57.16 | 12.939 |
| 3rd Quartile | 839 | 14.22 | 70.36 | 21.516 |
| St. dev. | 294 | 6.02 | 15.39 | 10.120 |

The $PM_{2.5}$ average concentration in the study area is in accordance with the city statistic mean [7]. There are moments of high pollution (77.5 μg/m³), that are generated not only by road traffic, but the activity of the thermal energy plant located beside (gas evacuation procedures). The mean temperature of the data sample (10.38 °C) falls between the historical means of the months March – May (5.4 °C – 16.8 °C), but the mean relative humidity (57.47 %) is less than the means of the period (69 – 75 %).

## 4. RESULTS AND DISCUSSION

### 4.1. Autoregressive models of the $PM_{2.5}$ air concentration

The dispersion/dilution of the particulate matter occurs in time, and therefore spatial autocorrelation, temporal convergence, and lag-time autocorrelation in time series are present [39, 40].

An autoregressive model of order p – AR(p), can be written as:

$$Y_t = c + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \cdots + \phi_p Y_{t-p} + \varepsilon_t, \quad (4)$$

where: $Y_t$ = the time series value at moment t;
$\phi_i$ = coefficients of lag values;
$c$ = constant coefficient;
$\varepsilon_t$ = the white noise.

For an autoregressive model to be stationary, the following constraints on the values of the parameters must be satisfied [41]:

- For an AR(1) model: $-1 < \phi_1 < 1$. (5)
- For an AR(2) model: $-1 < \phi_2 < 1$, $\phi_1 + \phi_2 < 1$, $\phi_2 - \phi_1 < 1$. (6)

Applying the autoregressive analysis for p = 1, 2, 3, the AR(p) model parameters are shown in Table 2. All models are statistically significant ($R^2 >$ .80).

**Table 2. Autoregressive models parameters**

| Model | Coefficients | Estimate | Std. error | *T* | *P* | $R^2$ |
|---|---|---|---|---|---|---|
| AR(1) | *C* | 1.705 | 0.220 | 7.73 | < .001 | .802 |
| | $\phi_1$ | 0.883 | 0.012 | 72.67 | < .001 | |
| AR(2) | *C* | 1.564 | 0.207 | 7.54 | < .001 | .833 |
| | $\phi_1$ | 1.055 | 0.025 | 41.36 | < .001 | |
| | $\phi_2$ | -0.159 | 0.025 | -6.35 | < .001 | |
| AR(3) | *C* | 1.654 | 0.211 | 7.81 | < .001 | .834 |
| | $\phi_1$ | 1.060 | 0.027 | 38.24 | < .001 | |
| | $\phi_2$ | -0.126 | 0.038 | -3.26 | < .001 | |
| | $\phi_3$ | -0.044 | 0025 | -1.74 | 0.08 | |

For the AR(1) and AR(2) models, all coefficients are statistical significant ($p$ < .001), and both lag 1 and lag 2 time series terms are good predictors for the current value. In the AR(3) model, the coefficient $\phi_3$ is not statistical significant ($p$ > .05), thus $Y_{t-3}$ cannot be a good predictor for $Y_t$. The AR(1) and AR(2) models satisfy conditions (5) and (6) respectively, thus the $PM_{2.5}$ air concentration is a stationary time series, no trend or seasonality is found, reducing possible spurious correlations.

## 4.2. The moderation process of the $PM_{2.5}$ air concentration

A moderation model with two continuous moderators [42] for the atmospheric concentration of $PM_{2.5}$ is proposed (Figure 4).

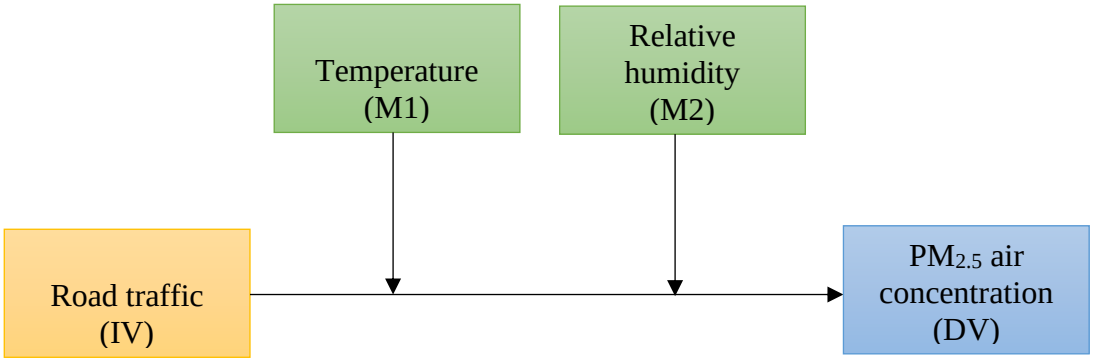



**Figure 4.** The moderation model for $PM_{2.5}$ atmospheric concentration

The road traffic is the independent variable (IV) that represents the main source of particulate matter emissions. Temperature (M1) and relative humidity (M2) plays as moderators; they do not represent sources of emission, but through their actions discussed in section 2.3, they could influence the dependent variable (DV) that is the atmospheric concentration of the $PM_{2.5}$.

A multiple linear regression analysis was conducted, in order to examine moderation effects between road traffic, temperature, and relative humidity on $PM_{2.5}$ concentration (Figure 5).

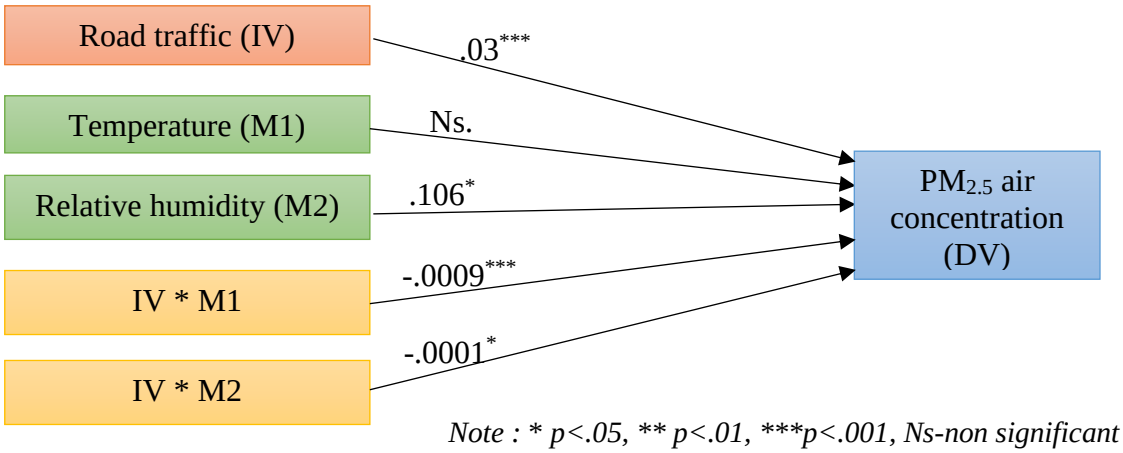



**Figure 5.** Main effects and significant moderator effects on $PM_{2.5}$ atmospheric concentration

The analysis indicates that about 30,1% of the variation in the $PM_{2.5}$ air concentration could be explained by the main effects and the interaction effects ($R^2$ = .3007, $F(5, 1296) = 111.45$, $p < .001$). The summary of the moderation model is shown in Table 3.

**Table 3. Moderation model summary**

| Variable and interaction | Estimate $\beta$ | $t$ | $P$ | 95% Confidence Interval | |
|---|---|---|---|---|---|
| | | | | LL | UL |
| Road traffic | .030 | 6.117 | < .001 | .02 | .04 |
| Temperature | -.108 | -.854 | .393 | -.357 | .14 |
| Relative humidity | .106 | 2.320 | .020 | .016 | .195 |
| Road traffic × Temperature | -.0009 | -4.894 | < .001 | -.0012 | -.0005 |
| Road traffic × Relative humidity | -.0001 | -2.077 | .038 | -.0003 | -.00005 |

The regression model containing the moderation effects is:

$$PM_{2.5} = .03 * Traffic + .106 * Humidity - .108 * Temperature - .0001 * Traffic * Humidity - .0009 * Traffic * Temperatute + \varepsilon \quad (7)$$

The predicted vs. the observed values are plotted in Figure 6.

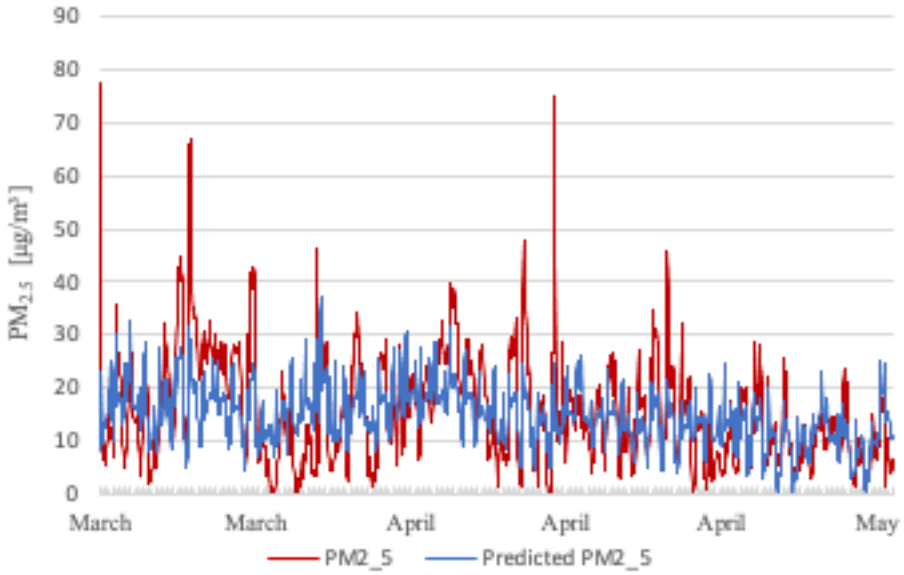



**Figure 6.** $PM_{2.5}$ air concentration observed vs. predicted (hourly mean)

Two of the main effects are significant and contribute to high levels of particulate matter concentration: road traffic flow ($\beta$ = .03, $t$ = 6.11, $p$ < .001) and relative humidity ($\beta$ =.106, $t$ = 2.32, $p$ = .02). Temperature has a negative estimate, but not statistically significant ($\beta$= -.108, $t$ =-.854, $p$ = .39). The results indicate that the two moderator effects (road traffic × temperature and road traffic

× relative humidity) are significant and negative in sign. The tests of highest order unconditional interactions (Table 4) prove that the moderation of temperature is responsible for 1.29 % of the variation in the $PM_{2.5}$ air concentration, while the moderation of relative humidity is responsible for .23 %. Both moderation effects count for 1.32 % of the variation in the $PM_{2.5}$ air concentration.

**Table 4. Test of interactions**

| Interaction | $R^2$ change | *p* |
|---|---|---|
| Road traffic × Temperature | .0129 | < .001 |
| Road traffic × Relative humidity | .0023 | .038 |
| Both | .0132 | < .001 |

Conditional effects of the road traffic at values of the moderators are shown in Table 5. The values of the moderators are for 16th, 50th, and 84th percentile, corresponding to median and ± one standard deviation.

**Table 5. Conditional effect of focal predictor at values of moderators**

| Temperature [°C] | Relative humidity [%] | Effect | *t* | *p* |
|---|---|---|---|---|
| 5.15 | 39.91 | 0.0209 | 10.46 | < .001 |
| 5.15 | 57.16 | 0.0186 | 14.93 | < .001 |
| 5.15 | 76.98 | 0.0160 | 12.20 | < .001 |
| 9.15 | 39.91 | 0.0174 | 11.56 | < .001 |
| 9.15 | 57.16 | 0.0151 | 18.07 | < .001 |
| 9.15 | 76.98 | 0.0125 | 9.10 | < .001 |
| 16.63 | 39.91 | 0.0107 | 7.93 | < .001 |
| 16.63 | 57.16 | 0.0084 | 6.09 | < .001 |
| 16.63 | 76.98 | 0.0058 | 2.60 | 0.009 |

As Figure 6 shows, the regression model cannot predict the highest values of the observed $PM_{2.5}$ concentrations. Stochastic events (e.g., power plant emissions, aged high duty vehicles circulation during the night) could determine high values of concentration during small periods when these values occur. No matter the level of the moderators (low, medium, or high), the effects are significant. As temperature and relative humidity increase, the conditional effect of road traffic is getting down. Thus, a higher temperature produces air movements that disperse the particulate matter, and a higher relative humidity brings precipitation of the particulate matter.

## 5. CONCLUSIONS

The present study highlights the effect of road traffic as a direct pollution source on $PM_{2.5}$ air concentration, depending on environmental temperature and relative humidity as moderators. In an open area study, the main effects of traffic flow and relative humidity are relevant, while temperature's is not, suggesting a possible polynomial dependence that should be explored farther. The moderation effects are relevant for both moderators, but the conditional effects are getting down with increase in temperature and humidity, due to changes in air mass movement and precipitation phenomena.

**Authors contribution:** conceptualization, statistical data processing, and writing – E. Roșca; atmospheric data collection, processing, and writing – F. Ruscă, C. Coman; traffic data collection and image processing – C. Oprea, S. Burciu; analysis of results – O. Dinu, A. Ilie. All authors reviewed the results and approved the final version of the manuscript.

**Acknowledgments:** The research work contained in this paper was supported within the frame of the project "Innovative platform for the provision and management of public services in smart cities - SMART HUB", Code SMIS 120419.

**REFERENCES**

[1]. World Health Organization: *"Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide"*, Tech. Rep. WHO **2003**.

[2]. C.A. Pope, R.T. Burnett, M.J. Thun: *"Lung Cancer, Cardiopulmonary Mortality, and Long-term Exposure to Fine Particulate Air Pollution", JAMA*, 287 (9): 1132–1141, **2006.**

[3]. European Union: *Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on Ambient Air Quality and Cleaner Air for Europe*, European Union: Brussels, Belgium, **2008**.

[4]. World Health Organization: *WHO Global Air Quality Guidelines: Particulate Matter (PM2.5 and PM10), Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide,* World Health Organization: Geneva, Switzerland, **2021**.

[5]. European Environment Agency: *Air quality in Europe — 2020 report*, **2020.**

[6]. J. Wilson, B. Bessagnet, E. Pisoni, et al.: "*Urban PM2.5 atlas: air quality in European cities : 2021 report"*, Publications Office of the European Union, **2021.**

[7]. Romanian Ministry of Environment: *"Air Quality Report – 2022"*, Bucharest, Romania, **2023.**

[8]. S. Brown, T. Lee, G.A. Norris, P.T. Roberts, J.L. Collett, P. Paatero, D.R. Worsnop: *"Receptor modeling of near-roadway aerosol mass spectrometer data in Las Vegas, Nevada, with EPA PMF"*, Atmospheric Chemistry and Physics, 12, 309-325, **2012**.

[9]. A.W. Gertler: *"Diesel vs. gasoline emissions: does PM from diesel or gasoline vehicles dominate in the US?"*, Atmospheric Environment, 39(13), 2349-2355 , **2005**.

[10]. European Environment Agency: *"EMEP/EEA air pollutant emission inventory guidebook 2019"*, Bruxelles, Belgium, **2020**.

[11]. Washington State Department of Transportation: *"Influence of Roadway Emissions on Near-Road PM2.5: Monitoring Data Analysis and Implications for Determining Transportation Projects of Local Air Quality Concern (POAQC)"*, Washington DC, **2019.**

[12]. C.D. Le, H.V. Pham, D.A. Pham, A.D. Le, & H.B. Vo: "*A PM2. 5 concentration prediction framework with vehicle tracking system: From cause to effect"*, RIVF International Conference on Computing and Communication Technologies (RIVF), 714-719, IEEE, **2022.**

[13]. S. Heydari, M. Tainio, J. Woodcock, & A. de Nazelle: *"Estimating traffic contribution to particulate matter concentration in urban areas using a multilevel Bayesian meta-regression approach"*, Environment international, 141, **2020**.

[14]. B. Bessagnet, N. Allemand, J.P. Putaud, F. Couvidat, J.M. André, D. Simpson, E. Pisoni, B.N. Murphy, P. Thunis: "*Emissions of Carbonaceous Particulate Matter and Ultrafine Particles from Vehicles—A Scientific Review in a Cross-Cutting Context of Air Pollution and Climate Change",* Appl. Sci., 12, 3623, **2022**.

[15]. X. Wang, X. Yang, X. Wang, J. Zhao, S. Hu, J. Lu: *"Effect of reversible lanes on the concentration field of road-traffic-generated fine particulate matter (PM2.5)",* Sustainable Cities and Society, 62, **2020**.

[16]. H. Pérez-Acebo, R. Ziolkowski, & H. Gonzalo-Orden: *"Evaluation of the radar speed cameras and panels indicating the vehicles' speed as traffic calming measures (TCM) in short length urban areas located along rural roads"*, Energies, 14(23), 8146, **2021**.

[17]. S.A. Obregón-Biosca: *"Speed humps and speed tables: Externalities on vehicle speed, pollutant emissions and fuel consumption"*, Results in Engineering, 5, 100089, **2020**.

[18]. F.N. Da Silva, R.A.L. Custódio, & H. Martins (2014): *"Low Emission Zone: Lisbon's Experience"*, Journal of Traffic and Logistics Engineering, 2(2), 133-139, **2014**.

[19]. X.C. Wang, J.J. Klemeš, X. Dong, W. Fan, Z. Xu, Y. Wang, P.S. Varbanov: *"Air pollution terrain nexus: A review considering energy generation and consumption"*, Renewable and Sustainable Energy Reviews, 105, 71-85, **2019**.

[20]. L. Zhang, X. Guo, T. Zhao, X. Xu, X. Zheng, Y. Li, L. Luo, K. Gui, Y. Zheng, Z. Shu: *"Effect of large topography on atmospheric environment in Sichuan Basin: A climate analysis based on changes in atmospheric visibility"*, Frontiers in Earth Science, 10, **2022**.

[21]. Z. Shu, T. Zhao, Y. Liu, L. Zhang, X. Ma, X. Kuang, Y. Li, Z. Huo, Q. Ding, X. Sun, L. Shen: *"Impact of deep basin terrain on PM2.5 distribution and its seasonality over the Sichuan Basin, Southwest China",* Environmental Pollution, 300, **2022**.

[22]. Y. Wen, J. Xiao, J. Yang, S. Cai, M. Liang, P. Zhou: *"Quantitatively Disentangling the Geographical Impacts of Topography on PM2.5 Pollution in China"*, Remote Sens, 14, **2022.**

[23]. L. Giovannini, L. Laiti, S. Serafin, and D. Zardi: *"The thermally driven diurnal wind system of the Adige Valley in the Italian Alps"*, *Q. J. R. Meteorol. Soc.* 143, 2389–2402, **2017**.

[24]. J.G. Zivin, M. Neidell: *"Environment, Health, and Human Capital"*, Journal of Economic Literature, 51(3), **2013**.

[25]. M.C. Rodríguez, L. Dupont-Courtade, W. Oueslati : *"Air pollution and urban structure linkages: Evidence from European cities"*, Renewable and Sustainable Energy Reviews, 53, 1-9, **2016**.

[26]. L. Denant-Boemont, C. Gaigné, R. Gaté : *"Urban spatial structure, transport-related emissions and welfare"*, Journal of Environmental Economics and Management, 89, 29-45, **2018**.

[27]. C. Miao, S. Yu, Y. Hu, M. Liu, J. Yao, Y. Zhang, X. He, W. Chen: *"Seasonal effects of street trees on particulate matter concentration in an urban street canyon"*, Sustainable Cities and Society, 73, **2021**.

[28]. N. Sahanavin, K. Tantrakarnapa, T. Prueksasit: *"Ambient PM 10 and PM 2.5 concentrations at different high traffic,-related street configurations in Bangkok, Thailand"*, Southeast Asian Journal of Tropical Medicine and Public Health, 47, **2016**.

[29]. I. Kayes, S.A. Shahriar, K. Hasan, M. Akhter, M. Kabir, M.A. Salam: *"The relationships between meteorological parameters and air pollutants in an urban environment"*, Global Journal of Environmental Science and Management, 5(3), 265–278, **2019**.

[30]. Q. Yang, Q. Yuan, T. Li, H. Shen, L. Zhang: *"The relationships between PM2.5 and meteorological factors in China: Seasonal and regional variations"*, International Journal of Environmental Research and Public Health, 14(12), 1510, **2017**.

[31]. D. Sirithian, P. Thanatrakolsri: "*Relationships between Meteorological and Particulate Matter Concentrations (PM2.5 and PM10) during the Haze Period in Urban and Rural Areas, Northern Thailand*", Air, Soil and Water Research, 15, 1–15, **2022**.

[32]. R. Zalakeviciute, J. López-Villada, Y. Rybarczyk: *"Contrasted Effects of Relative Humidity and Precipitation on Urban $PM_{2.5}$ Pollution in High Elevation Urban Areas"*, Sustainability, *10*, 2064, **2018**.

[33]. O.K. Owoade, P.O. Abiodun, O.R. Omokungbe, O.G. Fawole, F.S. Olise, O. Popoola, R. Jones, P.K. Hopke: *"Spatial-temporal variation and local source identification of air pollutants in a semi-urban settlement in Nigeria using low-cost sensors"*, Aerosol Air Qual Res, 21, 200598, **2021**.

[34]. H. Zhao, Y. Liu, T. Gu, H. Zheng, Z. Wang, D. Yang: *"Identifying spatiotemporal heterogeneity of PM2. 5 concentrations and the key influencing factors in the middle and lower reaches of the yellow river"*, Remote Sens, 14(11), 2643, **2022**.

[35]. Z. Chen, D. Chen, C. Zhao, M.P. Kwan, J. Cai, Y. Zhuang, B. Zhao, X. Wang, B. Chen, J. Yang, R. Li, B. He, B. Gao, K. Wang, B. Xu: *"Influence of meteorological conditions on PM2. 5 concentrations across China: a review of methodology and mechanism",* Environment International, 139, 105558, **2020**.

[36]. C. Deng, C. Qin, Z. Li, K. Li: *"Spatiotemporal variations of PM2. 5 pollution and its dynamic relationships with meteorological conditions in Beijing-Tianjin-Hebei region"*, Chemosphere, 301, 134640, **2022**.

[37]. T. You, R. Wu, G. Huang, G. Fan: *"Regional meteorological patterns for heavy pollution events in Beijing"*, J. Meteorol. Res., 31, (3), 597–611, **2017.**

[38]. G. Rincon, G. Morantes, H. Roa-López, M. Cornejo-Rodriguez, B. Jones, L.V. Cremades: *"Spatio-temporal statistical analysis of PM1 and PM2.5 concentrations*

*andtheir key influencing factors at Guayaquil city, Ecuador"*, Stochastic Environmental Research and Risk Assessment, 37, 1093–1117, **2023**.

[39]. H. Wang, Z. Chen, P. Zhang: *"Spatial Autocorrelation and Temporal Convergence of $PM_{2.5}$ Concentrations in Chinese Cities"*, Int. J. Environ. Res. Public. Health., 19(21), 13942, **2022**.

[40]. I. Wardana, J.W. Gardner, S. Fahmy: *"Optimising Deep Learning at the Edge for Accurate Hourly Air Quality Prediction"*, Sensors, 21(4), **2021**.

[41]. R.J. Hyndman, G. Athanasopoulos: *Forecasting: principles and practice*, 3rd edition, OTexts: Melbourne, Australia. OTexts.com/fpp3, **2021**.

[42]. A.F. Hayes: Introduction to Mediation, Moderation, and Conditional Process Analysis, Third Edition, Guilford Press, **2022**.