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[Ioana Tanasa](#) , [Marius Cazacu](#) ^{*} , [Dumitru Botan](#) , [John Atkinson](#) , [Viktor Sebestyén](#) , [Brindusa Sluser](#) ^{*}

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Article

Urban Air Quality: Aerosol Pollution Exploration and Impact Assessment

Ioana Tanasa ¹, Marius Cazacu ^{1,*}, Dumitru Botan ¹, John D. Atkinson ², Viktor Sebestyen ³ and Brindusa Sluser ^{1,*}

¹ "Gheorghe Asachi" Technical University of Iasi, 73 Prof. D. Mangeron Blvd., 700050, Iasi, Romania

² State University of New York at Buffalo, 12 Capen Hall, Buffalo, New York 14260-1660, USA

³ Pannonia University, 10 Egyetem, 8200 Veszprem, Hungary

* Correspondence: marius-mihai.cazacu@academic.tuiasi.ro (M.C.);

brindusa-mihaela.sluser@academic.tuiasi.ro (B.S.)

Abstract

Although the implementation of the European Union's policies has contributed substantially to reducing air pollution in recent years, PM_{2.5} remains a pollutant that poses significant risks to the environment and public health. The present study examines the application of a novel method for assessing the environmental impact and risk associated with this pollutant. The new integrated approach for air quality evaluation and prediction of the effects and risk of certain pollutants is based on AOD analysis, considering the AERONET database. For its validation, the new approach was applied based on monitoring air quality data for two cities in Romania, considering 13 years (from 2011 to 2023) in one case and 12 years (from 2012 to 2023) in the other. The results demonstrated that an AOD risk index can be developed and utilised for air quality evaluation and prediction, enabling the estimation of impacts and risks. In this case, the aerosols measured by AERONET over Cluj-Napoca for 13 years (2011 – 2023) were dominated by the occurrence of a 46% elemental carbon (EC) and organic carbon (OC) mixture, while the measurements over Iasi city for 12 years (2012 – 2023) were dominated by the occurrence of 55% EC and OC mixture. The impacts and risks, as calculated by the AOD index for EC, show few significant ones, with an AOD range of 0.88 to 1.05 for Iasi city and 0.73 to 0.88 for Cluj-Napoca.

Keywords: air quality; integrated impact assessment; risk assessment; AERONET; aerosols

1. Introduction

Air quality plays a vital role in both human and ecosystem health, with poor air quality causing numerous health problems and approximately 3.3 million deaths annually since 2000 [1–5]. This underscores the necessity for clear strategies and policies to address air pollution. Globally, countries have adopted legislative measures to reduce pollution and establish limits for key pollutants [6–8]. As an EU member state, Romania is also making efforts to improve air quality, including promoting sustainable clean energy technologies and implementing strategies such as the Green Deal, which aims to reduce greenhouse gas emissions to zero by 2050 [9].

Approximately 65% of urban areas worldwide have experienced an increase in PM_{2.5} concentrations since 2000 [1–4]. This pollutant, generated by specific sources, has a varied composition and different toxicological, physical, and chemical properties. Elemental carbon (EC) and organic carbon (OC) are key components of particulate matter with distinct sources and behaviours. Biomass burning is a major contributor to both, generally producing a higher proportion of organic carbon (OC), resulting in a low elemental carbon to organic carbon (EC/OC) ratio. Desert dust, primarily composed of minerals, can interact with anthropogenic emissions, incorporating EC and OC into complex aerosol mixtures. In such cases, the EC/OC ratio serves as a valuable indicator

of source contribution and mixing processes, with implications for both air quality assessment and source apportionment [10–12]. These aerosol types (biomass burning, desert dust, and mixtures) are associated with a wide range of health effects due to their varying chemical composition, particle sizes, and toxicological properties, as summarized in Table 1. Biomass burning aerosols and mixtures are the most hazardous to health, as they contain toxic chemicals, polycyclic aromatic hydrocarbons and black carbon. These fine particles enter the bloodstream and deposit in organs, causing serious health effects. Although desert dust can affect health, especially in vulnerable people (children, the elderly, the chronically ill), it is considered less hazardous than aerosols from biomass burning, which are strongly linked to chronic diseases and mortality [13–25]. The sources of elemental carbon in Romania include both local (vehicular traffic) and long-range transport (Eastern European High and regional influences, as well as agricultural activities) [26–29].

Table 1. Health Effects of Aerosol Exposure.

Aerosol Type	Main health effects
Biomass burning	Pulmonary toxicity, respiratory and cardiovascular diseases, chronic obstructive pulmonary disease, infections, cancer, and premature death.
Mixtures (Fine&Coarse Particles)	Influenza, tuberculosis, skin reactions, inflammation, oxidative stress, and cardiorespiratory risks.
Desert Dust	Asthma, coughing, wheezing, bronchitis, pneumonia, allergic rhinitis, high blood pressure, and heart issues.

Given these risks, accurately assessing the presence and distribution of PM2.5 is essential. A critical parameter for evaluating atmospheric aerosol loadings is Aerosol Optical Depth (AOD), which measures the attenuation of solar radiation due to scattering and absorption by particles suspended in the atmosphere. Although AOD does not directly represent surface-level PM2.5 concentrations, it serves as a valuable proxy when integrated with other datasets. The relationship between AOD and PM2.5 is complex and context-dependent, affected by local meteorology, aerosol type, and geographical factors. Nonetheless, several studies have demonstrated the utility of AOD for tracking pollution patterns and identifying aerosol sources, particularly when supported by the Ångström exponent (AE), precipitable water (PW), and atmospheric models like HYSPLIT [30–35].

The primary objective of this paper is to propose a new integrated approach for evaluating air quality and predicting the impact and risk of specific pollutants based on AOD analysis. The new approach was applied based on monitoring air quality data for two cities in Romania for 13 and 12 years, respectively (for the period 2011-2023 and 2012-2023). By integrating AOD into environmental impact and risk assessment, this research provides a novel toolset for monitoring pollution dynamics, identifying high-risk periods, and supporting policy making. The framework enhances traditional monitoring by enabling broader spatial analysis and improved forecasting capabilities. Furthermore, it emphasises the importance of aerosol classification and source apportionment in understanding local air quality trends, ultimately contributing to more informed and effective mitigation strategies.

2. Materials and Methods

2.1. Site Description

According to European regulations, Romania monitors air quality through 148 stations: 30 traffic-type (assessing the impact of traffic), 58 industrial-type (monitoring industrial activity), 37 urban and 13 suburban background (assessing the influence of settlement and human activity), 7 regional reference stations, and 3 EMEP stations (for monitoring cross-border pollution). To enhance

aerosol property analysis, Romania also hosts 8 AERONET stations in Timisoara, Cluj-Napoca, Iasi, and Bucharest, which monitor local and long-range transported aerosol events. This study considers Iasi and Cluj-Napoca for integrated air quality assessment. Iasi (northeast Romania) faces major air pollution issues, with PM_{2.5} levels 2.3 times above the legal limit. In Cluj-Napoca (northwest), PM_{2.5} is also the main pollutant. In both cities, the primary sources of PM_{2.5} pollution include industrial activity, traffic, and residential heating. Iasi, with about 271,692 residents and 60,000 students, is a major cultural and academic centre. It has six air quality stations and one AERONET station (Iasi_LOASL) (**Figure 1**). Cluj-Napoca, known as "the heart of Transylvania", has about 286,598 inhabitants, five air quality stations, and one AERONET station at a university lab (Cluj_UBB) [36–40].



Figure 1. Iasi city and Cluj-Napoca city air quality monitoring network.

2.2. Experimental Data

The values used in this study come from the AERONET (Aerosol Robotic Network) database - a global aerosol monitoring system operated by NASA and partners (agencies, universities, institutions, researchers, etc.). Unlike models limited to ground-level or full-column data via remote sensing, this study focuses on optical aerosol parameters that indicate aerosol type, such as fine-mode particles (EC/OC mixtures) signalling biomass burning or soot; coated large particles that absorb solar radiation (black carbon, polluted dust); and mixtures like OC/dust, dust/EC, or dust-dominated aerosols [26,41–44].

Adapting the Integrated Impact and Risk Assessment method to aerosol-type characterisation via photometric data enables impact analysis on atmospheric components. AERONET data are categorized into three levels: unscreened (Level 1.0), cloud-screened (Level 1.5), and quality-assured cloud-screened (Level 2.0). Aerosol Optical Depth (AOD) - a key parameter - serves diverse applications in climate and weather modelling, visibility, aviation safety, and air quality due to its indication of total aerosol load [45–48]. Higher AOD values indicate a greater presence of aerosols, which negatively affects visibility and air quality [49,50]. AOD helps fill gaps where ground monitoring stations are lacking and correlates with PM_{2.5}, a major health-impacting pollutant. Studies have shown that PM_{2.5} estimates improve when AOD is integrated into machine learning models [51–53].

For this study, AERONET photometric data from Iasi (LOASL: 47.19°N, 27.55°E) and Cluj-Napoca (UBB: 46.77°N, 23.55°E) stations were used. Both stations have improved understanding of local air quality by contributing aerosol optical property data and validating satellite-based observations [54–56].

We used inversion products from Level 1.5 data (version 3), selected using Level 2.0 criteria: solar zenith angle $>50^\circ$ and retrieval error $<5\%$ [57]. AOD at 400 nm was used to cover both polluted and unpolluted events. Level 1.5 was preferred due to its near-real-time availability – within one hour of measurement [58–62] – important for timely risk and impact assessment [63–66]. Note that Level 2.0 data require annual instrument calibration and verification.

Following established clustering methods, absorption Ångström exponent (AAE) and scattering Ångström exponent (SAE) were calculated at 440 nm and 675 nm, respectively, to classify aerosol types [42,54,62,67].

2.3. Integrated Assessment Methodology

Integrated Impact and Risk Assessment is an approach for quantifying environmental impact. The first step consists of establishing the environmental components, which are given a degree of importance (values from 0 to 1), depending on the specifics of the assessed activity and the opinions of the environmental specialist. Based on matrix calculations, normalised scores and importance units (IU) are obtained, which are subsequently used in calculations. The next step is represented by environmental quality quantification (Q), as shown in Equation (1). Finally, considering the units of importance (IU) and environmental quality (Q), environmental impact quantification (EI) and risk quantification (ER) are completed using Equations (2) and (3) [63–66]. In this case, the method was adjusted, and the importance of the environmental component under assessment (AOD) was considered at its maximum value (1). Thus, the IU were 1000, while the probability of pollution occurrence (p) was also considered at its maximum value (1). It results that ER is similar to EI, having the same values.

$$Q = \frac{MAC_i}{MC_i} \quad (1)$$

Equation 1. Environmental quality quantification (Q)

Where:

Q is the environmental quality;

MAC is the maximum allowed concentration (in the absence of clear maximum allowed concentrations established by legislation for aerosols, it was necessary to adapt the integrated assessment method; in this case, we considered for the MAC the highest AOD value measured in our data set);

MC is the measured concentration.

$$EI_i = \frac{IU}{Q} \quad (2)$$

Equation 2. Impact on environmental quality quantification (EI)

Where:

EI_i is the environmental impact considering the quality indicator i ;

IU is the importance unit assigned to each environmental component;

Q is the quality of the environmental component considering the quality indicator i .

$$ER_i = EI_i \times p \quad (3)$$

Equation 3. Environmental risk quantification (ER)

Where:

ER_i is the environmental risk;

EI_i is the environmental impact considering the quality indicator i ;

P is the probability of impact/pollution occurrence.

After quantifying the environmental impact and risk, their classification follows, depending on the scenario in which the obtained EI values fall, according to Table 2.

Table 2. Classification of environmental impact and risk [63–66].

Impact scale	Description	Risk scale	Description
<100	Natural environment, not affected by industrial/human activities	<100	Negligible/insignificant risks
100-350	Environment modified by industrial activities within admissible limits	100-200	Minor risks, and monitoring actions are required
350-500	Environment modified by industrial activities causing discomfort conditions	200-350	Moderate risks at an acceptable level, monitoring and prevention actions are required
500-700	Environment modified by industrial activities causing distress to life forms	350-700	Moderate risks at an unacceptable level, control and prevention measures are needed
700-1000	Environment modified by industrial activities, dangerous for life forms	700-1000	Major risks, remediation, control and prevention measures are needed
>1000	Degraded environment, not proper for life forms	>1000	Catastrophic risks, all activities should be stopped

2.4. Rescaling Method

The scores resulting from the initial impact and risk assessment method exceeded the threshold of 700, which, according to the interpretation in Table 2, indicates a severely affected environment, unsuitable for life. However, the measured AOD values don’t reflect a critical or catastrophic risk. For this reason, it was deemed necessary to develop a rescaling method that would more accurately reflect the actual implications of different types of aerosols. The applied calculation formula is shown in Equation (4).

$$y = \frac{(x - x_{min}) \cdot (y_{max} - y_{min})}{(x_{max} - x_{min})} + y_{min} \tag{4}$$

Equation 4. Rescaling formula

Where:

- x is the value to be rescaled;
- x_{max}, x_{min} are the limits of the original interval (EI calculated);
- y_{max}, y_{min} are the limits of the new interval (we stopped at 700 because no measurements were made under catastrophic conditions);
- y is the rescaled value.

Since the scientific literature demonstrates the distinct health and environmental effects of different aerosol categories, we performed a classification, selecting EC (elemental carbon) and DD (desert dust) for analysis and applying differentiated rescaling for these categories. While biomass burning – the main source of EC – is associated with severe diseases and increased mortality rates [13–25], DD aerosols tend to have less severe effects (**Table 1**). The environmental impacts of these two aerosol types also differ significantly. Although DD pollution poses certain risks, especially in arid regions, scientific studies consistently show that its environmental impact is substantially lower compared to that of EC from biomass burning. The latter releases complex toxic compounds and contributes more significantly to global warming, whereas DD increases suspended particle concentrations with more localized and less severe impacts [68–73]. Furthermore, considering that the intensity of health and environmental effects depends on the distance from the emission source, the negative impact of DD diminishes significantly as it travels farther from its origin and approaches the study areas considered here (Table 3) [13–25,68–73]. Since aerosol mixtures originate from both natural and anthropogenic sources, including this category in the risk score assessment complicates the linkage between emission sources and policy development. Based on these differences and the risk categories presented in Table 2, the EI (environmental impact) values for EC were rescaled between 0 and 700, while those for DD were rescaled between 0 and 350, thus reflecting the different magnitude of the impact on the environment and health. Rescaling was applied starting from 0, as

scenarios without significant pollution were also included, allowing for rescaling from the minimum value.

Table 3. Variation in the intensity of desert dust environmental and health effects depending on the distance from the source.

Distance from the source	Health/environmental impact	Example evidence
Close to the source	High PM, severe health effects, frequent exposure	Most epidemiological studies, systematic reviews
Far from source	Lower PM, milder or less frequent health effects, still detectable dust	WHO fact sheet, atmospheric transport studies

Moreover, to validate the rescaling method, the standard assessment method was applied again, this time assigning differentiated scores to aerosol categories. EC was considered of utmost importance (assigning a score of 1 in impact assessment), while for the DD category, scores ranging from 0.1 to 1 were assigned progressively.

Furthermore, to validate both the proposed rescaling method and the risk-level-based scoring system, two standard statistical indicators were calculated: Root Mean Square Error (RMSE) and Mean Absolute Error (MAE), which are presented in the following section.

2.5. Validation With Statistical Indicators – Error Calculation: Root Mean Square Error (RMSE) and Mean Absolute Error (MAE)

The performance of the proposed rescaling method and the risk-level-based scoring system was evaluated using two widely recognized statistical indicators: Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). These parameters allow quantifying the difference between the rescaled values and the values obtained from applying the integrated method for EC and DD, thereby providing an objective basis for evaluating the method’s performance. RMSE is sensitive to large deviations and penalizes them more heavily, making it useful for identifying score combinations that generate significant discrepancies – an essential aspect in establishing the most suitable pair of scores for EC and DD. At the same time, MAE indicates the average absolute deviation, offering a clear picture of the average error across the entire dataset. The use of both indicators allows for solid validation and a comprehensive understanding of the method: RMSE helps detect situations with large errors, while MAE provides a general benchmark of the method’s overall accuracy. Although there is no international standard for classifying RMSE and MAE values, applied literature in the fields of climate, energy, and air quality model evaluation frequently uses percentage thresholds to interpret performance. Based on this, we have structured a guideline table (Table 4) that classifies RMSE and MAE values according to their degree of agreement with the reference. In principle, the smaller the error, the more accurate the model [74–80].

Table 4. Guideline table for classification of RMSE and MAE.

Percentage Range (%)	Interpretation of RMSE % / MAE %	Comments/Observations
0-5	Very low error, excellent performance	The model predicts with very high accuracy, errors almost negligible
5-10	Low error, good performance	The model provides good predictions, acceptable errors for many applications
10-15	Moderate error	Performance is decent, but errors can be significant in sensitive applications
15-20	Relatively high error	Errors are noticeable; model accuracy is limited for critical applications
>20	High error, poor performance	The model struggles to make accurate predictions, requiring major improvements

3. Results and Discussion

3.1. Overview of Aerosol Type Distribution (Iasi and Cluj-Napoca)

3.1.1. Iasi AERONET Monitoring Site

For the city of Iasi, 1209 measurements were selected from the period 2012-2023, of which 975 correspond to the elemental carbon category, and 234 to the desert dust category. The aerosols measured by AERONET over Iasi for 12 years (2012 – 2023), in general, were dominated by the occurrence of an elemental carbon (EC) and organic carbon (OC) mixture at 55% (see “EC/OC mixture” in Figure 2). The fine mode particles, grouped as “EC dominated” in Figure 2, indicate that 18% of the aerosol came from combustion/biomass burning or soot particle types. The aerosol types: “Dust/EC mix” (1%), “Mix” (2%), “OC dominated” (3%), “OC/Dust Mix” (6%) and “Coated large particles” (11%) were not discussed here, since they were present in relatively small percentages compared to “EC/OC mixture” and “EC dominated”.

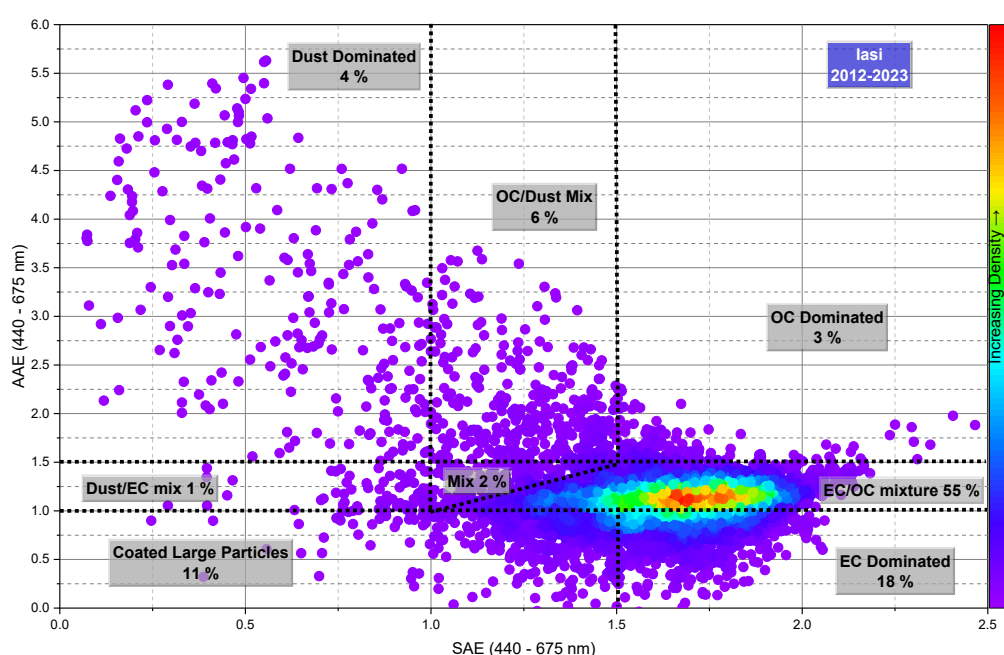


Figure 2. Absorption Ångström Exponent [AAE at 440-675 nm] vs. Scattering Ångström Exponent [SAE at 440-675 nm] in the number density plot from Iasi monitoring site (2012 - 2023).

3.1.2. Cluj-Napoca AERONET Monitoring Site

For the city of Cluj-Napoca, 1380 measurements were selected from the period 2011-2023, of which 1222 correspond to the elemental carbon category, and 158 to the desert dust category. Also, the aerosols measured by AERONET over Cluj-Napoca for 13 years (2011 – 2023), in general, were dominated by the occurrence of an elemental carbon (EC) and organic carbon (OC) mixture at 46% (see “EC/OC mixture” in Figure 3). The “EC dominated” in Figure 3 indicates that 22% of the aerosol came from combustion/biomass burning or soot particle types. Similarly, the aerosol types: “Mix” (2%), “Dust/EC mix” (3%), “OC/Dust Mix” (8%), “Coated large particles” (8%) and “OC dominated” (10%), were not discussed here.

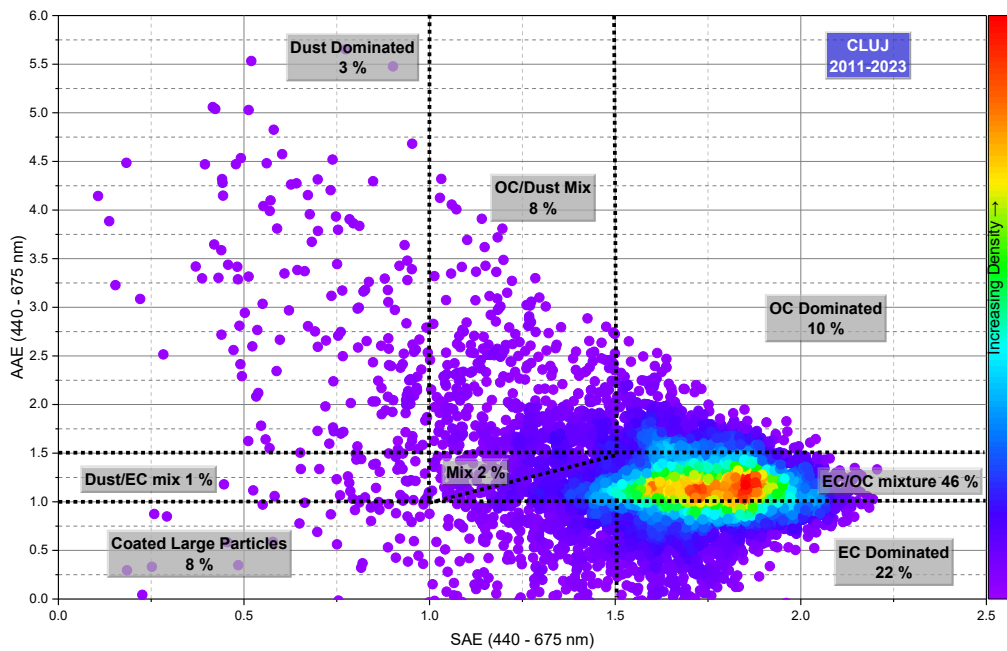
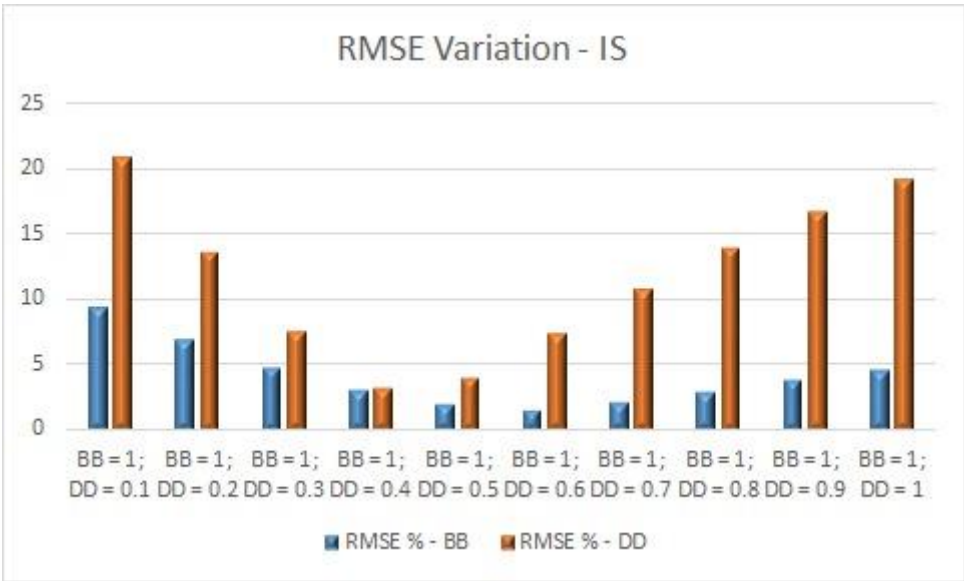


Figure 3. Absorption Ångström Exponent [AAE at 440-675 nm] vs. Scattering Ångström Exponent [SAE at 440-675 nm] in the number density plot from Cluj-Napoca monitoring site (2011 - 2023).

3.2. Performance Evaluation Using RMSE and MAE

To validate the rescaling method and identify the most appropriate pair of scores for EC and DD, we based our analysis on the error classification presented in Table 4.

The results showed that, for both cities, the lowest values of both error metrics (RMSE and MAE), located in the percentage range 0-5% (which means a very small error and an excellent performance, according to Table 4) were achieved with importance scores of 0.4 and 0.5 for DD and 1 for EC (Figure 4). Therefore, the error analysis confirms the validity of the selected rescaling thresholds and importance scores, demonstrating their effectiveness in accurately capturing the real differences between aerosol categories.



(a)

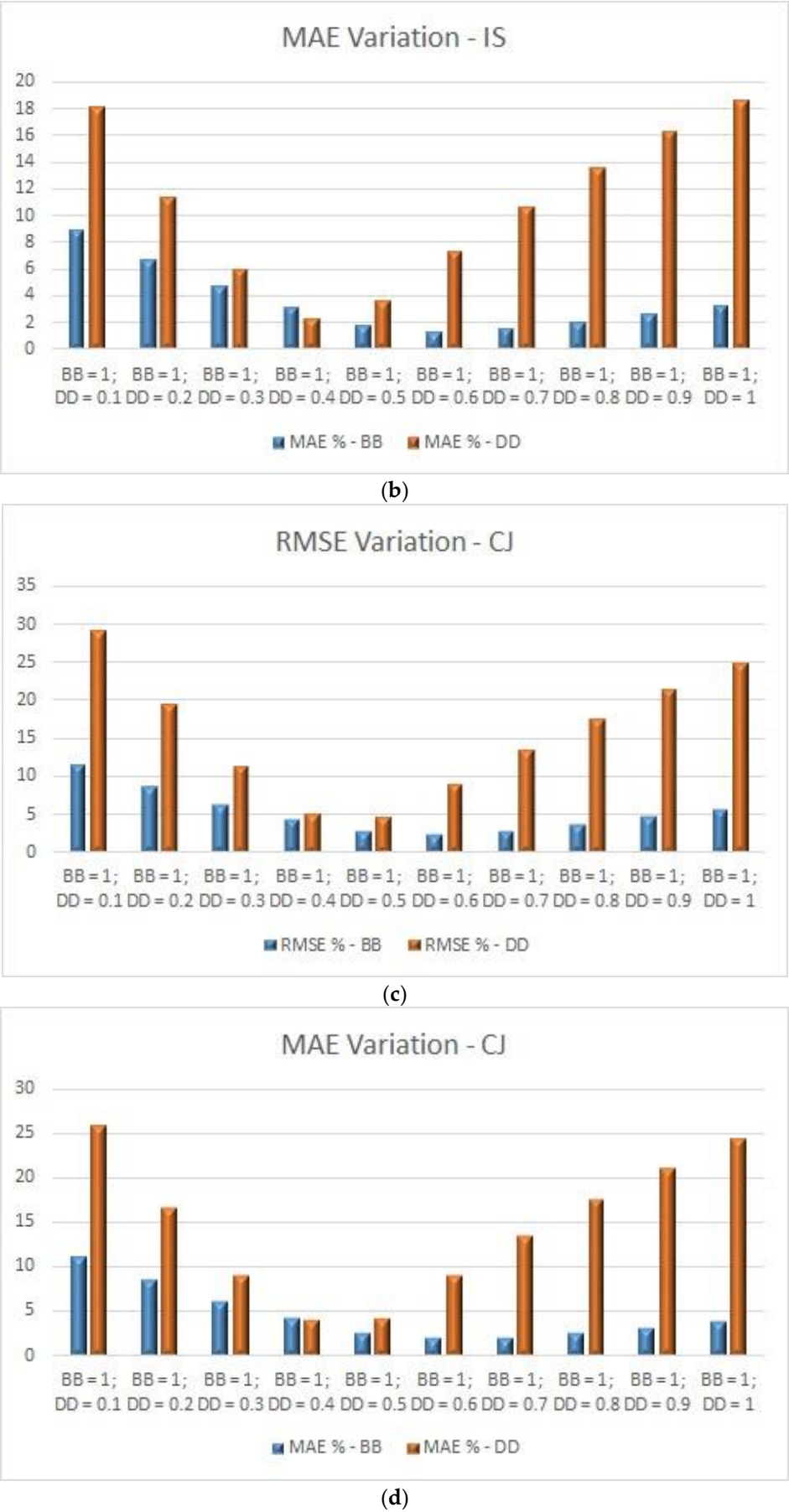


Figure 4. (a) RMSE variation for Iasi; (b) MAE variation for Iasi; (c) RMSE variation for Cluj-Napoca; (d) MAE variation for Cluj-Napoca.

3.3. Environmental Impact Quantification Calculated Using AERONET Data

Figures 5–8 show the rescaled EI, calculated using AOD values from the Iasi and Cluj-Napoca monitoring stations, considering only the “dust-dominated” and “EC-dominated” categories. The “EC-dominated” category falls within the subset of fine particulate matter associated with pollution from anthropogenic sources, such as fossil fuel combustion, industrial emissions, and road traffic. The methodology employed to quantify the impact is described in *Section 2 – Materials and Methods*.

The categories “EC/OC mixture” and “OC dominated” are also specific to fine particles; however, in terms of health effects, elemental carbon (carbon black) is considered more toxic than organic carbon [29]. The “EC/OC mixture” combines natural and anthropogenic sources, making it complex to consider this category when calculating a risk score and correlating pollution sources with policymaking.

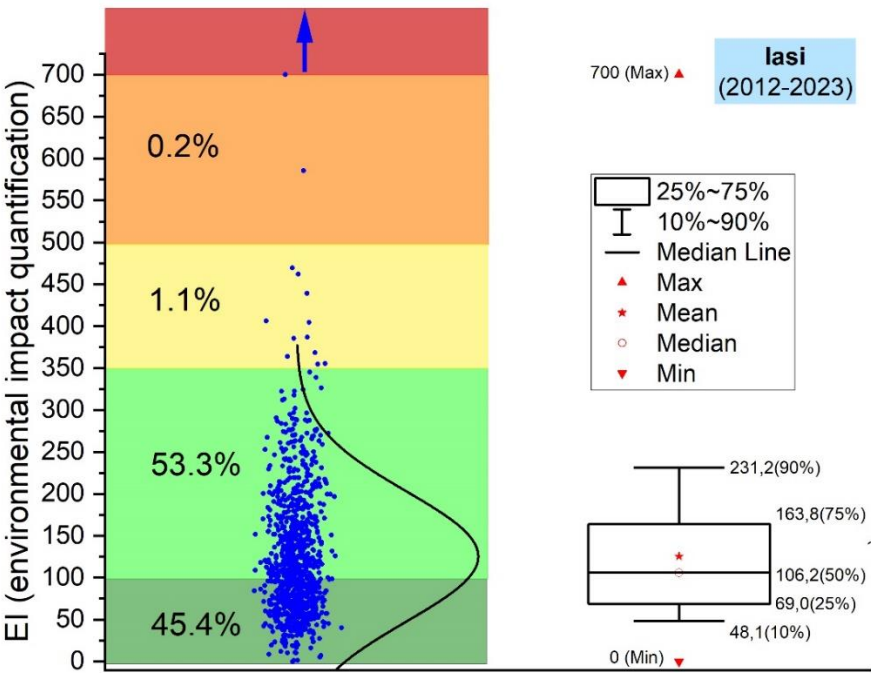


Figure 5. Environmental impact quantification statistics for elemental carbon category (EC), by using AERONET data from the Iasi monitoring site for 12 years (2012 – 2023).

The distribution of the rescaled environmental impact values for the elemental carbon category (EC) in Iasi (Figure 5) shows a predominance in the minor to moderate risk range. More than half of the recorded values (53.3%) fall between 100 and 350, suggesting an acceptable level of impact that still requires monitoring. Only 0.2% of the values exceed the threshold of 500, indicating isolated episodes of severe pollution, likely attributed to meteorological conditions or intense anthropogenic sources. The AOD associated with these episodes ranges from 0.88 to 1.05, reflecting a significant aerosol load on the atmospheric column. Therefore, EC remains a major pollutant of concern for local public health and environmental strategies.

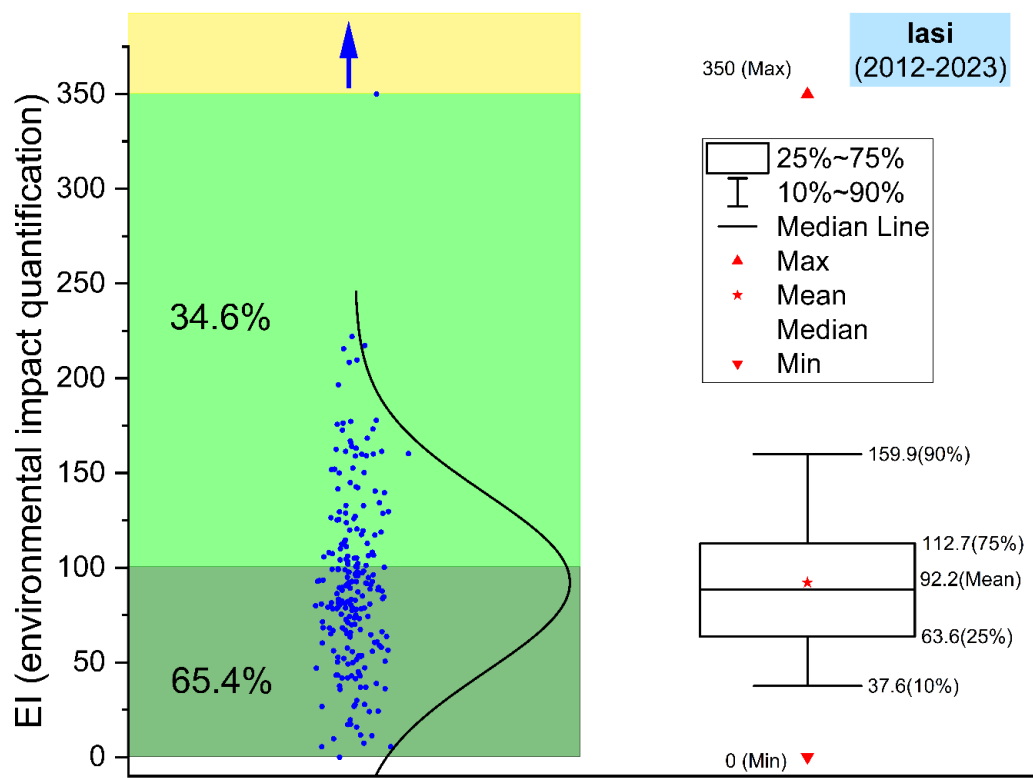


Figure 6. Environmental impact quantification statistics for desert dust category (DD), by using AERONET data from the Iasi monitoring site for 12 years (2012-2023).

For the desert dust category (DD) in Iasi, the impact distribution is significantly more attenuated (Figure 6). The majority of rescaled values (65.4%) fall below the threshold of 100, reflecting minor or even negligible risks. This trend is consistent with the hypothesis that DD effects diminish significantly with increasing distance from the emissions source. Even during episodes with higher AOD, the rescaled impact rarely exceeds 300, supporting the validity of the differentiated impact assessment method. Thus, DD’s contribution to air quality degradation in Iasi appears to be marginal compared to that of EC.

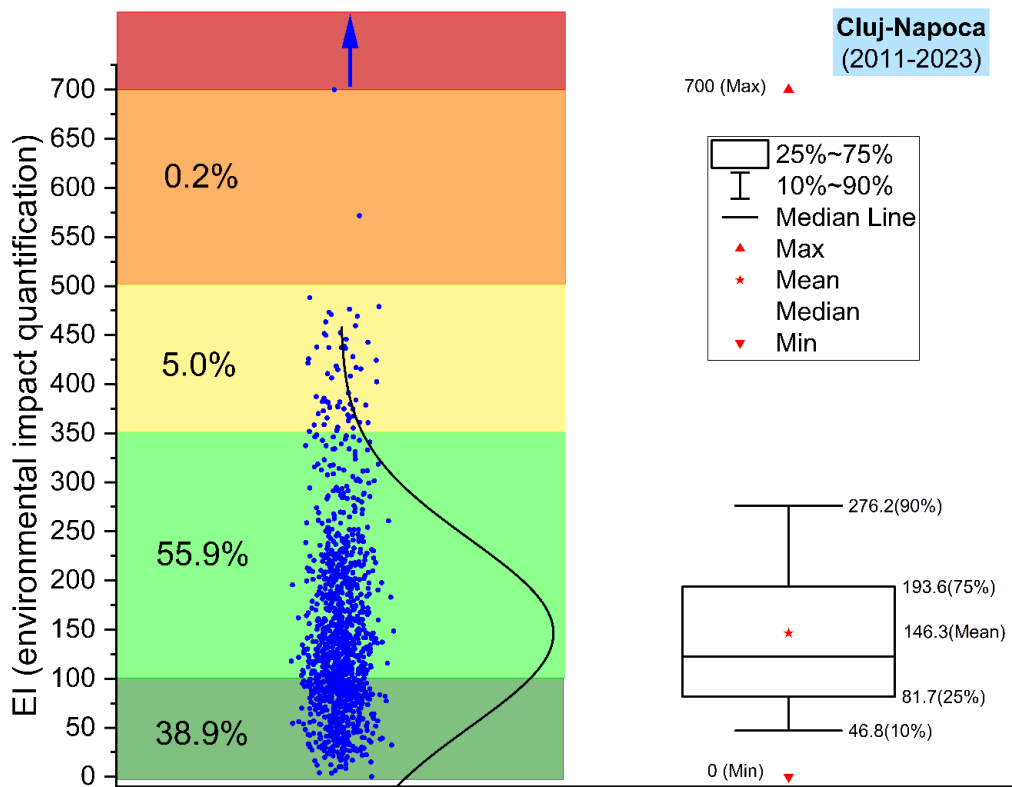


Figure 7. Environmental impact quantification statistics for elemental carbon category (EC), by using AERONET data from the Cluj-Napoca monitoring site for 13 years (2011 – 2023).

For Cluj-Napoca, the impact distribution for the EC category (Figure 7) is similar to that observed in Iasi, with 55.9% of values falling between 100 and 350, indicating moderate but acceptable risks. As in Iasi, only 0.2% of the values exceed the threshold of 500, suggesting a low incidence of critical pollution events. The maximum recorded AOD value (0.88) is slightly lower than in Iasi, which may reflect either lower combustion source intensity or more efficient pollutant dispersion. These results confirm that EC remains a dominant factor in atmospheric impact within the urban environment.

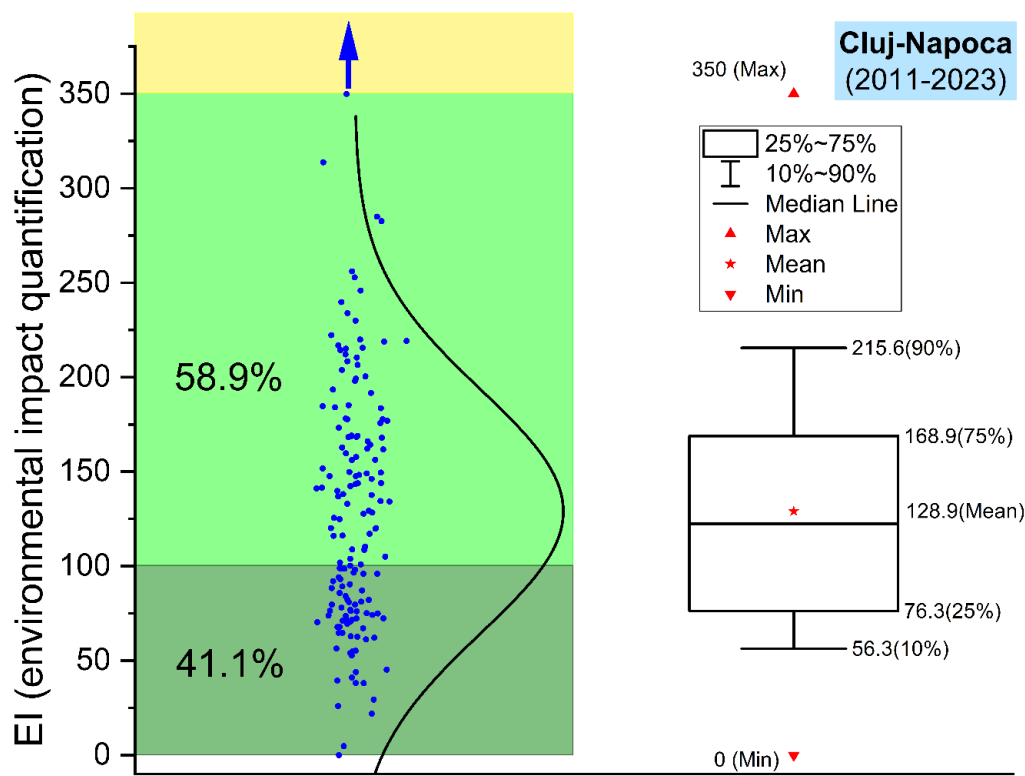


Figure 8. Environmental impact quantification statistics for the desert dust category (DD), by using AERONET data from the Cluj-Napoca monitoring site for 13 years (2011-2023).

For DD in Cluj-Napoca (Figure 8), the impact distribution follows the same pattern as in Iasi, with generally low values; however, the majority (58.9%) falls within the 100-350 range, characteristic of minor risks where monitoring actions are required. The AOD associated with this interval ranges from 0.24 to 0.67. This behaviour confirms the secondary role of DD in the pollution profile of Cluj-Napoca.

Because the traditional approach to air quality assessment does not correlate with ground data, this study's results underscore the urgent need to utilise an AOD risk index to effectively highlight the impact of pollution on the entire atmospheric column. Thus, in addition to the climate change already highlighted by scientists, the radiative budget (influenced by aerosol intrusion) can also negatively impact life quality and may be of interest.

4. Conclusions

This research demonstrated the applicability and relevance of an innovative integrated approach for air quality evaluation and the assessment of impact and risk related to atmospheric pollutants, using AOD (Aerosol Optical Depth) as a key indicator. The study was conducted for two representative Romanian cities – Iasi and Cluj-Napoca – using AERONET data collected over extended periods (12 and 13 years, respectively), ensuring the robustness of the findings.

The results revealed a predominance of elemental carbon (EC) and organic carbon (OC) mixtures in both cities, primarily sourced from traffic emissions, biomass burning, and industrial activities. Specifically, Cluj-Napoca exhibited an EC/OC mixture of 46%, while Iasi had 55%. The impacts and risks calculated as the AOD index for EC show a few major ones, with an AOD index range from 0.88 to 1.05 for Iasi city and 0.73-0.88 for Cluj-Napoca.

By adapting the Integrated Impact and Risk Assessment method to the specific context of aerosol characterization, the study offered a differentiated classification of aerosol types, emphasizing the


higher risks associated with EC compared to desert dust. The proposed method was statistically validated using RMSE and MAE indicators, achieving excellent performance (<5%).

Therefore, this study offers an effective and replicable tool to support environmental authorities in monitoring, forecasting, and decision-making processes regarding air quality – especially in urban areas where PM2.5 pollution is persistent and often insufficiently quantified by ground-based monitoring networks.

Given the high performance of the proposed method, a future research direction involves its application at a more detailed temporal scale – enabling the analysis of aerosol pollution risks based on seasonality, specific days, or annual variations – as well as extending the study to other urban or rural regions to allow for comparative assessments and the development of regional pollution control strategies.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript.” Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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Data Availability Statement: The dataset regarding AOD for Iasi_LOASL and CLUJ_UBB AERONET stations is available at https://aeronet.gsfc.nasa.gov/new_web/webtool_inv_v3.html

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Abbreviations

The following abbreviations are used in this manuscript:

AOD	Aerosol Optical Depth
EC	Elemental carbon
OC	Organic carbon
DD	Desert dust
RMSE	Root mean square error
MAE	Mean absolute error
AERONET	Aerosol Robotic Network

References

1. Sicard, P.; Agathokleous, E.; Anenberg, S. C.; Marco, A. D.; Paoletti, E.; Calatayud, V. Trends in urban air pollution over the last two decades: A global perspective. *Science of The Total Environment* **2023**, 858 part 2. <https://doi.org/10.1016/j.scitotenv.2022.160064>.
2. Raaschou-Nielsen, O.; Antonsen, S.; Agerbo, E.; Hvidtfeldt, U. A.; Geels, C.; Frohn, L. M.; Christensen, J. H.; Sigsgaard, T.; Brandt, J.; Pedersen, C. B. PM2.5 air pollution components and mortality in Denmark. *Environment International* **2023**, 171. <https://doi.org/10.1016/j.envint.2022.107685>.

3. Wang, J.; Wan, Y.; Cheng, L.; Xia, W.; Li, Y.; Xu, S. Arsenic in outdoor air particulate matter in China: Tiered study and implications for human exposure potential. *Atmospheric Pollution Research* **2020**, *11*(4). <https://doi.org/10.1016/j.apr.2020.01.006>.
4. Chifflet, S.; Guyomarc'h, L.; Dominutti, P.; Heimbürger-Boavida, L. E.; Angeletti, B.; Louvat, P.; Jaffrezo, J. L.; Vu, C. T.; Uzu, G.; Mari, X. Seasonal variations of metals and metalloids in atmospheric particulate matter (PM_{2.5}) in the urban megacity Hanoi. *Atmospheric Pollution Research* **2024**, *15*(1). <https://doi.org/10.1016/j.apr.2023.101961>.
5. Bartholy, J.; Pongrácz, R. A brief review of health-related issues occurring in urban areas related to global warming of 1.5°C. *Current Opinion in Environmental Sustainability* **2018**, *30*, 123-132. <https://doi.org/10.1016/j.cosust.2018.05.014>.
6. Wang, P. China's air pollution policies: Progress and challenges. *Current Opinion in Environmental Science&Health* **2021** *19*. <https://doi.org/10.1016/j.coesh.2020.100227>.
7. He, C.; Jiang, K.; Chen, S.; Jiang, W.; Liu, J. Zero CO₂ emissions for an ultra-large city by 2050: case study for Beijing. *Current Opinion in Environmental Sustainability* **2019**, *36*, 141-155. <https://doi.org/10.1016/j.cosust.2018.10.006>.
8. Naser, H. A. Technology for environmental management in Small Island Developing States: the case of Bahrain. *Current Opinion in Environmental Sustainability* **2022**, *59*. <https://doi.org/10.1016/j.cosust.2022.101219>.
9. Simionescu, M.; Neagu, O.; Gavurova, B. The role of quality of Governance in reducing pollution in Romania: an ARDL and nonparametric bayesian approach. *Frontiers in Environmental Science* **2022**, *10*. <https://doi.org/10.3389/fenvs.2022.892243>.
10. Sopčić, S.; Godec, R.; Jakovljević, I.; Bešlić, I. The influence of biomass burning on the organic content of urban aerosols. *Biomass* **2025**. <https://doi.org/10.3390/biomass5010001>.
11. Wang, W.; Zhou, H.; Lyu, R.; Shao, L.; Li, W.; Xing, J.; Zhao, Z.; Li, X.; Zhou, X.; Zhang, D. Organic carbon and elemental carbon in two dust plumes at a coastal city in North China. *Aerosol and air quality research* **2024**. <https://doi.org/10.4209/aaqr.240002>.
12. Hou, D.; Zhang, X.; Zhao, J.; Qiang, J.; Wang, J.; Wang, P.; An, Q.; Wang, Y.; Wang, L.; Yuan, S.; Zhang, F. Source apportionment of elemental carbon in different seasons in Hebei, China. *Frontiers in environmental science* **2022**. <https://doi.org/10.3389/fenvs.2022.949504>.
13. Filonchyk, M.; Peterson, M. P.; Zhang, L.; Yan, H. An analysis of air pollution associated with the 2023 sand and dust storms over China: Aerosol properties and PM₁₀ variability. *Geoscience Frontiers* **2024**. <https://doi.org/10.1016/j.gsf.2023.101762>.
14. Georgakopoulou, V. E.; Taskou, C.; Diamanti, A.; Beka, D.; Papalexis, P.; Trakas, N.; Spandidos, D. A. Saharan dust and respiratory health: Understanding the link between airborne particulate matter and chronic lung diseases (Review). *Experimental and Therapeutic Medicine* **2024**. <https://doi.org/10.3892/etm.2024.12750>.
15. Sadeghimoghaddam, A.; Khankeh, H.; Norozi, M.; Fateh, S.; Farrokhi, M. Investigating the effects of dust storms on morbidity and mortality due to cardiovascular and respiratory diseases: A systematic review. *Journal of Education and Health Promotion* **2021**. 10.4103/jehp-jehp_1272_20.
16. Pardo, M.; Li, C.; He, Q.; Levin-Zaidman, S.; Tsoory, M.; Yu, Q.; Wang, X.; Rudich, Y. Mechanisms of lung toxicity induced by biomass burning aerosols. *Particle and Fibre Toxicology* **2020**. <https://doi.org/10.1186/s12989-020-0337-x>.
17. Sigsgaard, T.; Forsberg, B.; Annesi-Maesano, I.; Blomberg, A.; Bølling, A.; Boman, C.; Bønløkke, J.; Brauer, M.; Bruce, N.; Héroux, M. E.; Hirvonen, M. R.; Kelly, F.; Künzli, N.; Lundbäck, B.; Moshhammer, H.; Noonan, C.; Pagels, J.; Sallsten, G.; Sculier, J. P.; Brunekreef, B. Health impacts of anthropogenic biomass burning in the developed world. *European Respiratory Journal* **2015**. <https://doi.org/10.1183/13993003.01865-2014>.
18. Assad, N. A.; Kapoor, V.; Sood, A. Biomass smoke exposure and chronic lung disease. *Current Opinion in Pulmonary Medicine* **2016**. 10.1097/MCP.0000000000000246.
19. Amnuaylojaroen, T.; Parasin, N. Perspective on Particulate Matter: from biomass burning to the health crisis in Mainland Southeast Asia. *Toxics* **2023**. <https://doi.org/10.3390/toxics11070553>.

20. Sangkham, S.; Phairuang, W.; Sherchan, S. P.; Pansakun, N.; Munkong, N.; Sarndhong, K.; Islam, M. A.; Sakunkoo, P. An update on adverse health effects from exposure to PM_{2.5}. *Environmental Advances* **2024**. <https://doi.org/10.1016/j.envadv.2024.100603>.
21. FERN. Available online: <https://www.fern.org/fileadmin/uploads/fern/Documents/briefingnote%20burning%20biomass.pdf> (2025)
22. Yin, S. Effect of biomass burning on premature mortality associated with long-term exposure to PM_{2.5} in Equatorial Asia. *Journal of Environmental Management* **2023**. <https://doi.org/10.1016/j.jenvman.2022.117154>.
23. Water and Air Quality Bureau, Health Canada. Available online: <https://www.canada.ca/en/health-canada/services/publications/healthy-living/human-health-effects-wildfire-smoke.html> (2025).
24. Karanasiou, A.; Alastuey, A.; Amato, F.; Renzi, M.; Stafoggia, M.; Tobias, A.; Reche, C.; Forastiere, F.; Gumy, S.; Mudu, P.; Querol, X. Short-term health effects from outdoor exposure to biomass burning emissions: A review. *Science of The Total Environment* **2021**. <https://doi.org/10.1016/j.scitotenv.2021.146739>.
25. Habybabady, R. H.; Sis, H. N.; Paridokht, F.; Ramrudinasab, F.; Behmadi, A.; Khosravi, B.; Mohammadi, M. Effects of dust exposure on the respiratory health symptoms and pulmonary functions of street sweepers. *The Malaysian Journal of Medical Science* **2018**. <https://doi.org/10.21315/mjms2018.25.6.8>.
26. Bostan, D. C.; Miclaus, I. M.; Apetroaie, C.; Voiculescu, M.; Timofte, A.; Cazacu, M. M. Long-Range Transport Analysis Based on Eastern Atmospheric Circulation and Its Impact on the Dust Event over Moldavia, Romania in August 2022. *Atmosphere* **2023**. <https://doi.org/10.3390/atmos14091366>.
27. Marmureanu, L.; Vasilescu, J.; Slowik, J.; Prévôt, A. S. H.; Marin, C. A.; Antonescu, B.; Vlachou, A.; Nemuc, A.; Dandocsi, A.; Szidat, S. Online Chemical Characterization and Source Identification of Summer and Winter Aerosols in Magurele, Romania. *Atmosphere* **2020**, *11*. <https://doi.org/10.3390/atmos11040385>.
28. Liu, F.; Peng, L.; Dai, S.; Bi, X.; Shi, M. Size-Segregated Characteristics of Organic Carbon (OC) and Elemental Carbon (EC) in Marine Aerosol in the Northeastern South China Sea. *Atmosphere* **2023**, *14*. <https://doi.org/10.3390/atmos14040661>.
29. Hussein, T.; Li, X.; Bakri, Z.; Alastuey, A.; Arar, S.; Al-Hunaiti, A.; Viana, M.; Petäjä, T. Organic and Elemental Carbon in the Urban Background in an Eastern Mediterranean City. *Atmosphere* **2022**, *13*. <https://doi.org/10.3390/atmos13020197>.
30. Xu, D.; Lin, W.; Gao, J.; Jiang, Y.; Li, L.; Gao, F. PM_{2.5} Exposure and Health Risk Assessment Using Remote Sensing Data and GIS. *International Journal of Environmental Research and Public Health* **2022**, *19*. <https://doi.org/10.3390/ijerph19106154>.
31. Matandirotya, N. R.; Anoruo, C. M. An assessment of aerosol optical depth over three AERONET sites in South Africa during the year 2020. *Scientific African* **2023**, *19*. <https://doi.org/10.1016/j.sciaf.2022.e01446>.
32. Tariq, S.; Qayyum, F.; Ul-Haq, Z.; Mehmood, U. Remote sensing of nighttime air quality over the megacity of Lahore, Pakistan. *Urban Climate* **2023**, *49*. <https://doi.org/10.1016/j.uclim.2023.101498>.
33. Said, S.; Salah, Z.; Abdel Wahab, M. M.; Alfaro, S. C. Retrieving PM₁₀ Surface Concentration from AERONET Aerosol Optical Depth: The Cairo and Delhi Megacities Case Studies. *Journal of the Indian Society of Remote Sensing* **2023**, *51*, 1797-1807. <https://doi.org/10.1007/s12524-023-01736-7>.
34. Nguyen, T. T. N.; Pham, H. V.; Lasko, K.; Bui, M. T.; Laffly, D.; Jourdan, A.; Bui, H. Q. Spatiotemporal analysis of ground and satellite-based aerosol for air quality assessment in the Southeast Asia region. *Environmental Pollution* **2019**, part 1. <https://doi.org/10.1016/j.envpol.2019.113106>.
35. Verma, J.; Singh, P. Air pollution induced biochemical changes in the selected roadside ornamental tree in Ludhiana city, India. *Environmental Engineering and Management Journal* **2025**. <http://doi.org/10.30638/eemj.2025.018>
36. Tanasa, I.; Cazacu, M.; Sluser, B. Air Quality Integrated Assessment: Environmental Impacts, Risks and Human Health Hazards. *Applied Sciences* **2023**, *13*(2). <https://doi.org/10.3390/app13021222>.
37. AERONET. Available online: <https://aeronet.gsfc.nasa.gov/> (2025).
38. Stefanie, H. I.; Radovici, A.; Mereuta, A.; Arghius, V.; Camarasan, H.; Costin, D.; Botezan, C.; Ginsca, C.; Ajtai, N. Variation of Aerosol Optical Properties over Cluj-Napoca, Romania, Based on 10 Years of AERONET Data and MODIS MAIAC AOD Product. *Remote Sensing* **2023**, *15*(12). <https://doi.org/10.3390/rs15123072>.
39. IQAir. Available online: <https://www.iqair.com> (2024).

40. Civitas. Available online: <https://civitas.eu/cities/iasi> (2024).
41. Ajtai, N.; Stefanie, H.; Ozunu, A. Description of aerosol properties over Cluj-Napoca derived from AERONET sun photometric data. *Environmental Engineering and Management Journal* **2013**, *12*, 227-232. <https://doi.org/10.30638/eemj.2013.025>.
42. Sfica, L.; Iordache, L.; Ichim, P.; Leahu, A.; Cazacu, M. M.; Gurlui, S.; Trif, C. T. The influence of weather conditions and local climate on particulate matter (PM10) concentration in metropolitan area of Iasi, Romania. *Present Environment and Sustainable Development* **2018**, *11*, 109-117. <https://doi.org/10.2478/pesd-2018-0029>.
43. Tîmpu, S.; Sfica, L.; Dobri, R. V.; Cazacu, M. M.; Nita, A. I.; Birsan, M. V. Tropospheric Dust and Associated Atmospheric Circulations over the Mediterranean Region with Focus on Romania's Territory. *Atmosphere* **2020**, *11*, 349. <https://doi.org/10.3390/atmos11040349>.
44. Nemuc, A.; Belegante, L.; Radulescu, R. One year of sunphotometer measurements in Romania. *Romanian Journal of Physics* **2011**, *56*, 550-562.
45. Laszlo, I.; Liu, H. EPS Aerosol Optical Depth (AOD) Algorithm Theoretical Basis Document, NOAA NESDIS Center for Satellite Applications and Research, 2020.
46. Daxini, R.; Wu, Y. Review of methods to account for the solar spectral influence on photovoltaic device performance. *Energy* **2024**. <https://doi.org/10.1016/j.energy.2023.129461>.
47. Jin, J.; Henzing, B.; Segers, A. How aerosol size matters in aerosol optical depth (AOD) assimilation and the optimization using the Ångström exponent. *Atmospheric Chemistry and Physics* **2023**. <https://doi.org/10.5194/acp-23-1641-2023>.
48. Xun, L.; Lu, H.; Qian, C.; Zhang, Y.; Lyu, S.; Li, X. Analysis of Aerosol Optical Depth from Sun Photometer at Shouxian, China. *Atmosphere* **2021**. <https://doi.org/10.3390/atmos12091226>.
49. Earth Observatory, Aerosol Optical Depth. Available online: https://earthobservatory.nasa.gov/global-maps/MODAL2_M_AER_OD (2024).
50. Huang, F.; Ma, W.; Wang, S.; Feng, C.; Kong, X.; Liu, H. Analysis and Validation of the Aerosol Optical Depth of MODIS Products in Gansu Province, Northwest China. *Remote Sensing* **2023**. <https://doi.org/10.3390/rs15122972>.
51. Tian, Z.; Wei, J.; Li, Z. How Important Is Satellite-Retrieved Aerosol Optical Depth in Deriving Surface PM_{2.5} Using Machine Learning?. *Remote Sensing* **2023**. <https://doi.org/10.3390/rs15153780>.
52. Singh, D.; Nanda, C. Aerosol Optical Depth (AOD) Variation Over Haryana Due to Lockdown Amid Covid-19 as an Indicator of Air Quality. *IEEE India Geoscience and Remote Sensing Symposium (InGARSS)* **2020**, 170-172, Ahmedabad, India. <https://doi.org/10.1109/InGARSS48198.2020.9358971>.
53. Talib, N.; Sa'aidi, N. A. M.; Narashid, R. H.; Zaki, N. A. M.; Saad, N. M.; Abdullah, S.; Mohd, F. A. Relationship between Particulate Matter (PM_{2.5}) Concentration and Aerosol Optical Depth (AOD) throughout Peninsular Malaysia. *IOP Conference Series: Earth and Environmental Science* **2022**. <https://doi.org/10.1088/1755-1315/1019/1/012017>.
54. Cazacu, M.; Timofte, A.; Unga, F.; Albina, B.; Gurlui, S. AERONET data investigation of the aerosol mixtures over Iasi area, One-year time scale overview. *Journal of Quantitative Spectroscopy and Radiative Transfer* **2015**. <https://doi.org/10.1016/j.jqsrt.2014.09.004>.
55. Ajtai, N.; Mereuta, A.; Stefanie, H.; Radovici, A.; Botezan, C.; Zawadzka-Manko, O.; Stachlewska, I. S.; Stebel, K.; Zehner, C. SEVIRI Aerosol Optical Depth Validation Using AERONET and Intercomparison with MODIS in Central and Eastern Europe. *Remote Sensing* **2021**. <https://doi.org/10.3390/rs13050844>.
56. Callewaert, S.; Vandenbussche, S.; Kumps, N.; Kylling, A.; Shang, X.; Komppula, M.; Goloub, P.; Maziere, M. D. The Mineral Aerosol Profiling from Infrared Radiances (MAPIR) algorithm: version 4.1 description and evaluation. *Atmospheric Measurement Techniques* **2019**. <https://doi.org/10.5194/amt-12-3673-2019>.
57. Holben, B. N.; Eck, T. F.; Slutsker, I.; Smirnov, A.; Sinyuk, A.; Schafer, J.; Giles, D.; Dubovik, O. AERONET's Version 2.0 quality assurance criteria. Available online: http://aeronet.gsfc.nasa.gov/new_web/Documents/AERONETcriteria_final1.pdf.
58. Zheng, C. Chapter 9 -Assessment Methods for Air Pollution Exposure, Spatiotemporal Analysis of Air Pollution and Its Application in Public Health, 2020, 197-206. <https://doi.org/10.1016/B978-0-12-815822-7.00009-1>.

59. Cazorla, A.; Bahadur, R.; Suski, K. J.; Cahill, J. F.; Chand, D.; Schmid, B.; Ramanathan, V.; Prather, K. A. Relating aerosol absorption due to soot, organic carbon, and dust to emission sources determined from in-situ chemical measurements. *Atmospheric Chemistry and Physics* **2013**, *13*, 9337-9350. <https://doi.org/10.5194/acp-13-9337-2013>.
60. Dubovik, O.; Holben, B.; Eck, T. F.; Smirnov, A.; Kaufman, Y. J.; King, M. D.; Tanré, D.; Slutsker, I. Variability of Absorption and Optical Properties of Key Aerosol Types Observed in Worldwide Locations. *Journal of the Atmospheric Sciences* **2002**, *59*, 590-608. [https://doi.org/10.1175/1520-0469\(2002\)059<0590:VOAAOP>2.0.CO;2](https://doi.org/10.1175/1520-0469(2002)059<0590:VOAAOP>2.0.CO;2).
61. Giles, D. M.; Sinyuk, A.; Sorokin, M. G.; Schafer, J. S.; Smirnov, A.; Slutsker, I.; Eck, T. F.; Holben, B. N.; Lewis, J. R.; Campbell, J. R. et al. Advancements in the Aerosol Robotic Network (AERONET) Version 3 database—Automated near-real-time quality control algorithm with improved cloud screening for Sun photometer aerosol optical depth (AOD) measurements. *Atmospheric Measurement Techniques* **2019**, *12*, 169-209. <https://doi.org/10.5194/amt-12-169-2019>.
62. Russell, P. B.; Bergstrom, R. W.; Shinozuka, Y.; Clarke, A. D.; DeCarlo, P. F.; Jimenez, J. L.; Livingston, J. M.; Redemann, J.; Holben, B.; Dubovik, O. et al. Absorption Angstrom Exponent in AERONET and related data as an indicator of aerosol composition. *Atmospheric Chemistry and Physics* **2010**, *10*, 1155-1169. <https://doi.org/10.5194/acp-10-1155-2010>.
63. Sluser, B.; Plavan, O.; Teodosiu, C. Environmental Impact and Risk Assessment. In *Assessing Progress Towards Sustainability*, Elsevier Ed., 2022.
64. Neamtu, R.; Sluser, B.; Plavan, O.; Teodosiu, C. Environmental monitoring and impact assessment of Prut River cross-border pollution. *Environmental Monitoring and Assessment*, **2021**, 193.
65. Zait, R.; Fighir, D.; Sluser, B.; Plavan, O.; Teodosiu, C. Priority Pollutants Effects on Aquatic Ecosystems Evaluated through Ecotoxicity, Impact, and Risk Assessments. *Water* **2022**, *14*(20):3237. <https://doi.org/10.3390/w14203237>.
66. Zait, R.; Sluser, B.; Fighir, D.; Plavan, O.; Teodosiu, C. Priority Pollutants Monitoring and Water Quality Assessment in the Siret River Basin, Romania. *Water*, **2022**, *14*(1):129. <https://doi.org/10.3390/w14010129>.
67. Niculae, A.L.; Racovitza, A.; Chiriac, R. Study of the influence of nanoparticle addition in diesel-ethanol blend on fuel jet characteristics. *Environmental Engineering and Management Journal* **2024**, *23*(7): 1383-1389.
68. Ealo, M.; Alastuey, A.; Ripoll, A.; Pérez, N.; Minguillón, M. C.; Querol, X.; Pandolfi, M. Detection of Saharan dust and biomass burning events using near-real-time intensive aerosol optical properties in the north-western Mediterranean. *Atmospheric Chemistry and Physics* **2016**. <https://doi.org/10.5194/acp-16-12567-2016>.
69. Bauer, S. E.; Im, U.; Mezuman, K.; Gao, C. Y. Desert dust, industrialization, and agricultural fires: health impacts of outdoor air pollution in Africa. *Journal of Geophysical Research: Atmospheres* **2019**. <https://doi.org/10.1029/2018JD029336>.
70. Zhou, D.; Ding, K.; Huang, X.; Liu, L.; Liu, Q.; Xu, Z.; Jiang, F.; Fu, C.; Ding, A. Transport, mixing and feedback of dust, biomass burning and anthropogenic pollutants in eastern Asia: a case study. *Atmospheric Chemistry and Physics* **2018**. <https://doi.org/10.5194/acp-18-16345-2018>.
71. Dong, X.; Fu, J. S.; Huang, K.; Zhu, Q.; Tipton, M. Regional climate effects of biomass burning and dust in East Asia: Evidence from modeling and observation. *Geophysical Research Letters* **2019**. <https://doi.org/10.1029/2019GL083894>.
72. Gama, C.; Pio, C.; Monteiro, A.; Russo, M.; Fernandes, A. P.; Borrego, C.; Baldasano, J. M.; Tchepel, O. Comparison of methodologies for assessing desert dust contribution to regional PM10 and PM2.5 levels: a one-year study over Portugal. *Atmosphere* **2020**. <https://doi.org/10.3390/atmos11020134>.
73. Chen, J.; Li, C.; Ristovski, Z.; Milic, A.; Gu, Y.; Islam, M. S.; Wang, S.; Hao, J.; Zhang, H.; He, C.; Guo, H.; Fu, H.; Miljevic, B.; Morawska, L.; Thai, P.; LAM, Y. F.; Pereira, G.; Ding, A.; Huang, X.; Dumka, U. C. A review of biomass burning: Emissions and impacts on air quality, health and climate in China. *Science of The Total Environment* **2017**. <https://doi.org/10.1016/j.scitotenv.2016.11.025>.
74. Chai, T.; Draxler, R. R. Root mean square error (RMSE) or mean absolute error (MAE)? - Arguments against avoiding RMSE in the literature. *Geoscientific Model Development* **2014**. <https://doi.org/10.5194/gmd-7-1247-2014>.

75. Hodson, T. O. Root-mean-square error (RMSE) or mean absolute error (MAE): when to use them or not. *Geoscientific Model Development* **2022**. <https://doi.org/10.5194/gmd-15-5481-2022>.
76. ASHRAE. ASHRAE Guideline 14-2002: Measurement of Energy and Demand Savings. American Society of Heating, Refrigerating and Air-Conditioning Engineers. Available online: <https://www.ashrae.org/technical-resources/bookstore/guideline-14-2002> (2025).
77. Efficiency Valuation Organization (EVO), 2017. International Performance Measurement and Verification Protocol: Concepts and options for determining energy and water savings – Volume I (IPMVP). Available online: <https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp>.
78. Coakley, D.; Raftery, P.; Keane, M. A review of methods to match building energy simulation models to measured data. *Renewable and Sustainable Energy Reviews* **2014**. <https://doi.org/10.1016/j.rser.2014.05.007>.
79. Willmott, C. J.; Matsuura, K. Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Research* **2005**. <https://doi.org/10.3354/cr030079>.
80. Hyndman, R. J.; Koehler, A. B. Another look at measures of forecast accuracy. *International Journal of Forecasting* **2006**. <https://doi.org/10.1016/j.ijforecast.2006.03.001>.

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