Time Series Satellite and Observational Data for Assessment of Urban Air Pollution and Climate Dynamics Impacts on COVID-19 transmission in Bucharest

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Abstract: - This study conducts a complex analysis to evaluate urban air pollution and climate dynamics impacts on COVID-19 viral infection incidence and mortality in Bucharest metropolitan city in Romania. It is motivated by the COVID-19 pandemic occurrence and environmental/health challenges caused by increasing urbanization in Bucharest. This paper presents the temporal patterns characteristics of the main air pollutants PM2.5 and PM10 (inhalable particulate matter with aerodynamic size less than or equal to 2.5 μm and 10 μm, respectively) as well as nitrogen dioxide-NO_2, ozone-O_3, sulfur dioxide-SO_2, and carbon monoxide-CO during the period March 2020–March 2022 through the integration of time-series surface observation and satellite data. Through the employing of descriptive statistics and regression models for multiple datasets of air pollutants and climate-related parameters such as air temperature at 2m height (T), relative humidity (RH), wind speed intensity (w), and direction, Planetary Boundary Layer height-PBL, and surface solar irradiance-SI, this study found that seasonal variation of aerosol loading parameters (PM2.5 and PM10) over the investigated metropolitan city have a direct impact on COVID-19 spreading. Nevertheless, additional environmental and epidemiological investigations are required to test the causality of air pollution and climate seasonality impacts on COVID-19 seasonality and its severity.

Key-Words: - Time series satellite and in-situ data, COVID-19, Air pollution, Climate variables, Bucharest, Romania.

Received: March 12, 2022. Revised: August 25, 2023. Accepted: September 27, 2023. Available online: October 26, 2023.

1 Introduction

From 26 February 2020 to 4 May 2023, the Pandemic Coronavirus Disease 2019 (COVID-19), caused more than 68,089 death people and infected more than 3,393,902 people in Romania. Bucharest city, reported 16.98% of all confirmed COVID-19 cases and 8.85% of all deaths, [1]. Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV2), a pathogen with a high risk of transmission and infectious potential promotes COVID-19, the worldwide pandemic Coronavirus disease. Although there are some similarities between the associated invasive pneumococcal disease and previous outbreaks of coronaviruses (SARS-CoV in 2003 and the MERS-CoV in 2012} in terms of nosocomial and super-spreading events, there are also some differences in its genomic and phenotypic structure that could have a high impact on their pathogenesis), [2], [3]. Knowing the COVID-19 pandemic risk in relation to air pollution in the huge, densely populated area of Bucharest is crucial for the potential of future various viral infections developing, with unforeseeable multiwaves. The persistent levels of air pollution in the Bucharest metropolitan region continue to pose a serious threat to the environment, and with an average PM2.5 concentration of 16.4 μg/m^3, Bucharest is included in the category of European cities with poor air quality, [4], [5]. Sulfur dioxide (SO_2) seems to be primarily produced by industrial sources, particularly wood and coal consumption and vehicle exhaust emissions representing the biggest drivers of air pollution from anthropogenic sources. Both sources produce coarse particulate matter with a diameter of 10 μm (PM10) and fine particulate matter with a diameter of 2.5 μm (PM2.5). For large cities, experimental studies suggested that the collected PM2.5 has been generated by industrial and automobile exhaust, along with some biogenic

hygroscopic particles and multi-shape aggregates. The aggregates revealed seasonal patterns, with dust and biogenic particles prevailing in the spring and carbonaceous particles predominant in the autumn and winter, [6], [7]. Particulate matter PM2.5 and PM10, which act as active viral vectors of the pandemic COVID -19 disease disseminating could decrease the respiratory system immunity when they are possible carriers of SARS-CoV-2 virions, [8], [9]. As a major environmental risk factor for morbidity and lethality from cardiorespiratory diseases, both long-term and short-term exposure to outdoor air pollution may affect the incidence and severity of COVID-19, [10], [11]. The variability of climate parameters (air temperature, relative humidity, wind speed and direction, Planetary Boundary Layer height, and surface solar irradiance) at both local and regional scales, as well as synoptic meteorological circulation, affects the levels of outdoor local or regional air pollutants or transboundary levels, [12], [13]. Through synergy use of time series satellite and observational data and statistical analysis, this study investigates the association between daily exposure to air pollutants PM2.5, PM10, O_3, NO_2, SO_2, and CO and COVID-19 incidence and mortality, under climate parameters seasonality during March 2020 and March 2022 in Bucharest metropolitan area. The observed differences in the severity of COVID-19 multiwaves are explained using air pollution, climate, and anomalous synoptic meteorological patterns.

2 Materials and Methods

2.1 Study Site

The urban metropolitan region of Bucharest (Figure 1) capital of Romania is located in the South – Eastern part of the country, and South-Eastern part of Europe, being bounded by latitudes 44.33 ^{O}N and 44.66 ^{O}N and 25.90 ^{O}E and 26.20 ^{O}E longitudes. It has about 1.8 million inhabitants and a surface area of 240 km^2. The study test area covers the city of Bucharest and its surrounding periurban areas, which constitute one of the most air-polluted cities in Europe and have highly complex built, green, and blue environments. Air pollution is mainly produced by industrial activity, traffic-related use of old cars, or heating of fossil fuels, being characterized by high PM2.5, PM10, NO_2, O_3, CO, and SO_2 levels, sometimes exceeding standard admitted limits for Romania, [14]. Its climate is temperate continental, with Western European Climate influences, Mediterranean Cyclones, and the East-European Anticyclone. Five COVID-19 waves were recorded in Bucharest during the entire investigation period (March 2020 to March 2022): the first COVID-19 wave (1 March 2020-15 June 2020), which coincided with a total lockdown (15 March 2020-15 May 2020; the pre-second COVID-19 wave (15 July 2020-30 September 2020), which was triggered by social and tourist activities; the second COVID-19 wave (1 October 2020-31 January 2021); the third COVID-19 wave (1 February 2021-1 June 2021); the fourth COVID-19 wave (1 September 2021-21 December 2021); the fifth COVID-19 wave (22 December 2021- 31 March 2022). If many semi-lockdown measures were set during the second, third, and fourth COVID-19 waves to limit the spread of SARS-CoV-2 infectious agents, the minimum limitations have been implemented during the fifth COVID-19 wave.

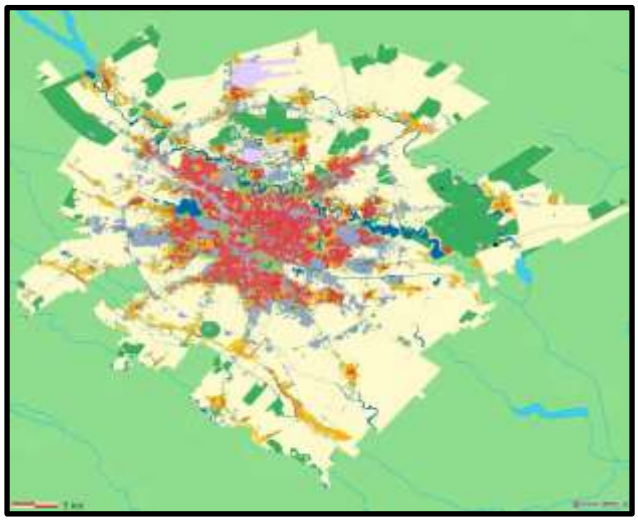

Fig. 1: Bucharest test site, capital of Romania

2.2 Data Used

Official websites, [1], [15], have supplied time series data for the examined period of March 2020–March 2022 for COVID-19 Daily New Cases (DNC) and COVID-19 Daily New Deaths (DND). Also, websites, [16], [17] provided daily average time series data on the measured levels of PM2.5 and PM10 air pollutants for the Bucharest metropolitan region. Time series of average daily meteorological data were collected from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) at, [18], and Climate Change Service of Copernicus (C3S) data, [19]. These data included air temperature at 2 meters height (T), air relative humidity (RH), air pressure (p), wind speed intensity (w), and direction.

2.3 Statistical Analysis

Spearman cross-correlation coefficient was selected as a proper measure of the strength of the linear relationship between pairs of two variables. To compare each air pollutant data with data of climate signals, all the data have been standardized. For better correlation analysis, also a simple regression analysis (quadratic model) was used. This study used also non-parametric test coefficients, and linear regression analysis to determine the similarity between two-time series data of the averaged daily air pollutants, climate observables (air temperature and relative humidity, wind speed, surface solar irradiance Planetary Boundary Layer heights), and COVID-19 incidence and mortality in Bucharest. Kolmogorov-Smirnov Tests of Normality have been carried out to determine whether or not the averaged daily time-series data sets were normal. Spearman rank correlation was chosen to determine the linear correlation between the significant variables: (1) air pollutants PM2.5, PM10 concentrations, climate variables, and (2) COVID-19 incidence and mortality rates because the daily new COVID-19 cases (DNC) and daily new COVID-19 deaths (DND) have a non-normal distribution. Microsoft Windows version 2021 of the ORIGIN 10.0 software was employed.

3 Results and Discussion

To determine the impacts of air pollution, weather conditions, and climate change on COVID-19 incidence and mortality in the Bucharest metropolitan region from March 2020 to March 2022, when five COVID-19 waves were recorded, we carried out an extensive study.

3.1 Role of Air Pollutants on COVID-19

The daily average temporal pattern of air pollutants PM2.5, PM10, O3, NO2, SO2, and CO for Bucharest metropolitan city are illustrated in Figure 2 together with their temporal distribution for the five waves of the COVID-19 pandemic that had been investigated from March 2020 to March 2022. Substantial differences exist in the temporal patterns among several pollutants. However, all pollutants had relatively higher concentrations in the metropolitan areas of Bucharest. The successful implementation of total or partial lockdown restrictions to stop the spread of SARS-CoV-2 in the Bucharest region may be responsible for the significantly decreased values of PM2.5 and PM10 concentrations, especially during the first and third COVID-19 waves. However, the improved urban air quality, which is supported by numerous other studies for the lockdown and pandemic intervals, could be beneficial for both the urban air quality and human health, [20], [21], [22], [23].

The increased concentrations of daily average PM2.5 and PM10 during the second (PM2.5 of 24.77± 11.15 μg/m^3; and PM10 of 72.58±27.40 μg/m^3), the fourth (PM2.5 of 28.21±10.53 μg/m^3; PM10 of 60.59±24.16 μg/m^3), and the fifth (PM2.5 of 25.13±11.65μg/m^3; PM10 of 67.72±22.82 μg/m^3) COVID-19 waves in Bucharest may explain high numbers of the recorded daily new COVID-19 (DNC) cases and deaths (DND), [13]. Daily COVID-19 DNC and DND cases were weekly positively correlated with daily average ground levels of PM2.5 (rDNC= 0.35, p0.01; rDND= 0.37, p0.01) and, respectively, with PM10 concentrations (rDNC= 0.34, p0.01; rDND= 0.39, p0.01), based to a Spearman rank correlation analysis of the pandemic period investigated between March 2020 and March 2022.

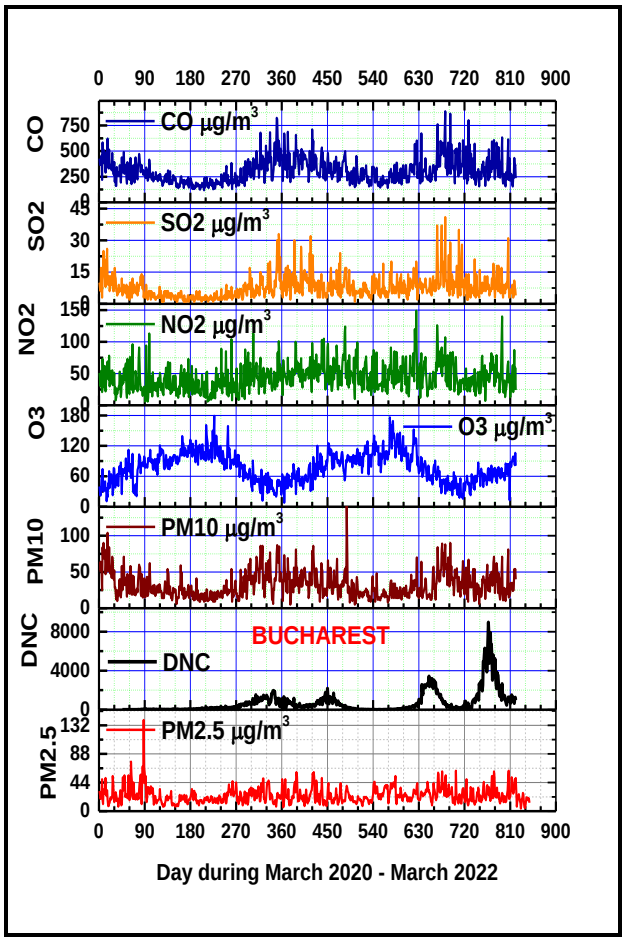

Fig. 2: Temporal patterns of the daily average air pollutants and DNC COVID-19 cases in Bucharest

Our results are consistent with numerous studies that identified that urban air pollution (PM2.5,

PM10, O_2, NO_2, SO_2, CO, etc.) coming from traffic-related products or other anthropogenic sources can trigger oxidative stress, resulting in the production of free radicals, which are capable of damaging the immune and the cardio-respiratory system by altering the host's resistance to bacterial and viral infections, [24], [25], [26]. Additionally, this study found a positive relationship between ambient air pollution levels in Bucharest and COVID-19 incidence and mortality in the general population. However, the entire lockdown measures used during the first COVID-19 wave have led to an increase in O_3 levels and a decrease in PM2.5, PM10, NO_2, SO_2, and CO pollutants levels. The high amounts of particulate matter and gaseous pollutants dispersed in the lower atmosphere can have a dominant impact on the fog-haze formation process during atmospheric inversion periods. Therefore, adverse diffusion conditions might result in an increase in the microbial activity levels in atmospheric aerosols including coronaviruses.

3.2 Climate Variability Effects on COVID-19

Globalization and climate change may promote the spread of viral pathogens and the emergence of pandemics, especially for newly developing infectious illnesses like the SARS-CoV-2 (COVID-19) virus, which caused a serious worldwide health catastrophe. This article focused on the relationship between climate seasonality and COVID-19 incidence and mortality to better understand the impact of weather variables on the COVID-19 spread in Bucharest. The significant negative relationships between COVID-19 incidence and mortality and the selected climatic variables (Planetary Boundary Layer height, air temperature T at 2m height, and solar surface irradiance SI) are presented in Table 1. For air pressure and relative humidity-RH, positive relationships between COVID-19 DNC and DND have been reported (r=0.25 and r=0.31, respectively). Additionally, this study revealed strong associations between air low temperatures and solar surface irradiance associated with elevated COVID-19 daily new incident cases and mortality, consistent with other most recent studies' findings for European cities, [27], [28]. Additionally, relative humidity plays a significant role in the spread of the SARS-CoV-2 virus, while wind speed, intensity, and direction have a weak negative correlation with the spread of the COVID-19 virus. However, there is a strong seasonal correlation between the incidence and mortality of COVID-19 and the seasonal patterns of climate variables. The first COVID-19 wave's relatively low intensity in comparison to other European cities may be justified by the high levels of daily PBL heights of (1607.19 ± 526.06) m, that had been observed in the Bucharest metropolitan area, [29], [30], [31]. High rates of infectivity in Bucharest may be attributed to unusual daily low average PBL heights observed during the second, fourth, and fifth waves, which were (538.74 ± 293.26) m, (920.23 ± 603.25) m, and (846.74 ± 463.01) m, respectively. The PBL height meteorological parameter, which is related to the vertical mixing dynamics and dilution or accumulation of pollutants and bioaerosols (bacteria, fungi, and viruses) near the ground level, is involved in COVID-19 transmission, especially in large urban centers, [32], [33].

Table 1. Spearman rank correlation coefficients and p values between daily COVID-19-incidence cases, and daily climate parameters during the entire analyzed period March 2020- March 2022. * $p<0.01$

COVID-19	PBL (m)	T (ºC)	RH (%)	w (km/h)	SI (W/m^2)
DNC	-0.70*	-0.52*	0.40*	-0.16*	-0.73*
DND	-0.72*	-0.63*	0.46*	-0.14*	-0.74*

All of the study's findings show a strong relationship with meteorological factors. This paper concludes that despite climate plays a significant role in COVID-19 transmission, especially in temperate regions like Bucharest, it cannot completely stop the outbreak as has recently been seen on the second, fourth, and fifth waves when implemented restrictions have been reduced.

3.3 Synoptically Atmospheric Circulation Impacts on COVID-19 Waves

The viral COVID-19 disease is associated with both mesoscale and synoptic scale meteorology. However, previous studies for some European metropolitan areas have found limited association between synoptic variables and the reported number of COVID-19 incidences and mortality. Hence there is an urgent need to establish a clearer association with SARS-CoV-2 transmission in relation to air pollution and the most relevant synoptic meteorological variables to adopt proper strategies during pandemic events. The National Center for Atmospheric Research (NCAR)/NCEP provided daily time series for vertical wind velocity (Omega (Pascal/s) at 850 hPa data and maps, at around 1.4 km above the ground level over Bucharest metropolitan city as compared to the climatology

average (1981–2010) period, during the entire analyzed pandemic period (March 2020–March 2022). At the mesoscale level, it has been found that before and during each COVID-19 wave, downward airflows identified by positive omega values in composite average surface maps at 850 mb were associated with anomalous anticyclonic stationary conditions. These conditions may have a detrimental effect on urban air quality and promote the spread of COVID-19 disease when they are prevalent in Bucharest metropolitan city, [34]. Figure 3 shows the Omega surface chart composite mean (Pa/s) at 850 mb over Romania during the second COVID-19 wave in Bucharest when high numbers of daily COVID-19 incidence and fatality DNC and DND cases had been reported before the vaccination campaign. Due to its position in a large depression-like structure known as the Romanian Plain, surrounded by barriers of the Carpathians Mountains, the Bucharest metropolitan area is affected by strong tropospheric anticyclonic systems. Because Bucharest city usually displays high concentrations of PM under several atmospheric situations, the recorded anticyclonic systems affect it during the late fall and winter seasons, which favor the accumulation of high levels of aerosols including virus-laden aerosols near the ground, which explains the high rates of viral disease transmission.

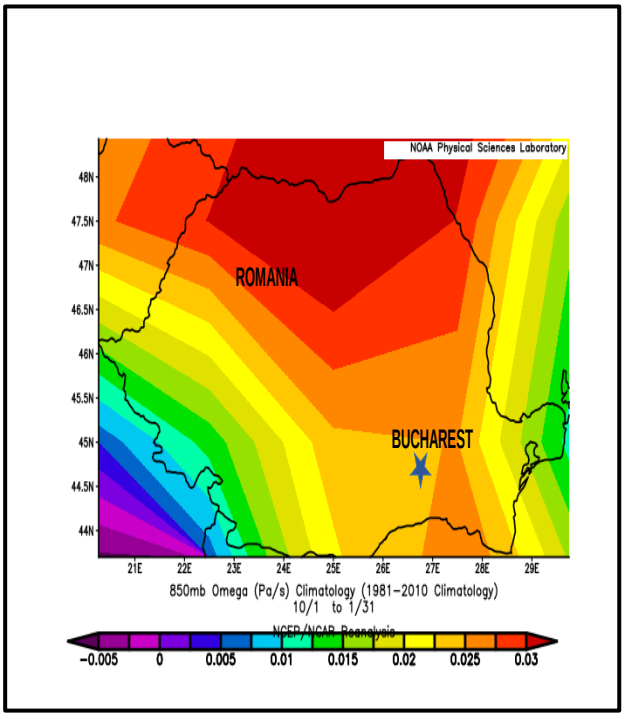

Fig. 3: Omega surface chart composite mean (Pa/s) at 850 mb over Romania during the second COVID-19 wave in Bucharest

4 Conclusion

This study offers convincing evidence of the impact of COVID-19 outcomes during Bucharest's five pandemic waves on exposure to air pollution and climate variability. The initiatives and resources needed to improve the city of Bucharest's air quality, particularly in relation to pandemic occurrences, might be prioritized using the decreasing trends in air pollution that were detected during the COVID-19 total lockdown. Additionally, it highlighted the climatic factors that influence air pollution trends, COVID-19 incidence, and COVID-19 mortality. The findings of this study demonstrate that the daily new COVID-19 cases and deaths in the Bucharest region were influenced by climate and air quality variables, and they can help public decision-makers by offering insightful information about the COVID-19 pandemic and other viral infections. This study provides important information on the detrimental effects of urban air pollution associated with climate variables on people's immune system reduction and viral infections, which is in line with the United Nations Sustainable Development Goals (SDG) agenda, namely Goals 3 (Good health and well-being), 11 (Sustainable cities and communities), and 13 (Climate action), [35].

Acknowledgments:
This work was supported by the Romanian Ministry of Research, Innovation and Digitalization: through Program 1- Contract no. 18PFE/30.12.2021; National Research Development and Innovation Plan 2022-2027, project no. PN 23 05; Grant CNCS-UEFISCDI, project number PN-III-P4-PCE-2021-0585; Romanian Ministry of European Investment and Projects & Romanian Ministry of Research, Innovation and Digitalization, Contract no.8/1.2.1 PTI ap.2/17.02.2023.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Maria Zoran: Conceptualization; Methodology, Supervision, Writing - review & editing.
- Roxana Savastru: Methodology, Validation, Review.
- Dan Savastru: Methodology, Validation, Review. -Marina Tautan: Methodology, Validation.
- Daniel Tenciu: Software.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

This work was supported by the Romanian Ministry of Research, Innovation and Digitalization: through Program 1- Contract no. 18PFE/30.12.2021; National Research Development and Innovation Plan 2022-2027, project no. PN 23 05; Grant CNCS-UEFISCDI, project number PN-III-P4-PCE-2021-0585; Romanian Ministry of European Investment and Projects & Romanian Ministry of Research, Innovation and Digitalization, Contract no.8/1.2.1 PTI ap.2/17.02.2023.

Conflict of Interest

The authors have no conflict of interest to declare.