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CLIMATE EFFECTS OF AEROSOLS AND RADON ON COVID-19 PANDEMIC IN BUCHAREST METROPOLITAN AREA

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Abstract. *This paper investigated the influences of urban aerosols and radon (^{222}Rn) together climate parameters variability at both local and regional scales in relationship with COVID-19 pandemic incidence and mortality in Bucharest metropolitan area of Romania, considered one of the European's most polluted hotspots cities. A spatio-temporal analysis of the daily particulate matter in two size fractions PM10 and PM2.5 in relation with daily radon concentrations and meteorological parameters was done through synergy of in-situ monitoring data and MODIS Terra/Aqua time-series satellite data for March 2020-April 2022 time period. This study investigated the COVID-19 waves patterns under different air quality and meteorological conditions, highlighting the role of synoptic anticyclonic stagnant conditions during each COVID-19 wave for SARS-CoV-2 virus spreading. These results contribute to a better understanding of urban decision makers and epidemiologists through considering the specific characteristics of different urban sectors for air quality improvement.*

Keywords: *outdoor Radon, COVID-19, Particulate Matter PM2.5 and PM10, climate parameters, Bucharest, Romania*

1. Introduction

In the frame of the predicted climate change due to the increasing trend of extreme events frequency, the ozone layer depletion and global warming in South-Eastern part of Europe, urban air pollution is an important issue of modern times in scientific research [1]. Air pollution represents one of the most important drivers affecting the Earth's energy balance and hydrological cycle, climate and human health. Several outdoor air pollution exceedance events are driven both by controllable factors (emission sources and strengths), and climate variability acting at local to regional scales associated with the different mixing rates of the planetary boundary layer heights (PBL) [2]. Diurnal, seasonal and synoptic timescale changes of meteorological conditions, depending of the topographic setting, are the main factors influencing atmospheric mixing rates, which affects spatiotemporal variability of air quality [3].

In synergy with outdoor air pollution, natural radioactivity progeny of ^{222}Rn (radon), a decay product of ^{238}U (uranium) decay chain is affecting human the respiratory system and health. Exposure to radon usually occurs both in indoor environments as effect of the radon exhaled from building materials, but also in outdoor environments due to its exhalation from soil or water. Is well recognized that radon and its progeny increases the probability of developing lung cancer, ^{222}Rn being the second cause of lung cancer, behind smoking [4]. It was established that for most cases, the outdoor radon risk is low, its atmospheric concentration being in the range of a few tens to a few hundred Bq/m^3, but under extremely specific meteorological and topographical conditions it could become comparable of few kBq/m^3 order [5-6].

Is well known that most of ^{222}Rn long-lived α- and β progeny attach to aerosol particles (0.1-2.5 μm), which can be inhaled and deposited in the lung, continuing to decay and produce high radiation exposure to the respiratory system, and associated lung inflammation or neuro-inflammation [7-8]. In synergy with SARS-COV-2 pathogens attached to aerosols without or with attached radon progeny as source of exposure to ionizing radiation, these may contribute to additional adverse effects to the human respiratory system, and may contribute to increased COVID-19 severity and lethality [9]. The synergy of climate parameters daily and seasonal variability with air pollution and natural radioactivity can be detrimental for human health during epidemic viral events, acting on the immunity and cardiorespiratory systems, raising the risk of lethality, especially in vulnerable people with comorbidities [10].

This study is focused on the spatiotemporal analysis of the daily inhalable particulate matter (PM) in two size fractions inhalable PM with diameter ≤ 2.5 μm (PM2.5) or ≤ 10 μm (PM10) in relation with daily radon concentrations and meteorological parameters. This analysis used synergy of in-situ monitoring and MODIS Terra/Aqua time-series satellite data for March 2020-April 2022 time period in Bucharest metropolitan area. In order to prevent COVID-19 pandemic spreading it is very important to assess the environmental drivers related to the epidemiological behavior of the viral outbreaks. The rapid spread of the COVID-19 viral infections in large urban areas, characterized by high urbanization and dynamic land-change systems, people's mobility and economic development suggests

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air pollution and climate variability among the determinants of SARS-CoV-2 pathogens transmission at the local and regional level and associated risk factors. This study investigates the COVID-19 waves patterns under different air quality and meteorological conditions, highlighting the role of synoptic anticyclonic stagnant conditions during each COVID-19 wave for SARS-CoV-2 virus spreading. These results will contribute to a better understanding of urban decision makers and epidemiologists through considering the specific characteristics of different urban sectors for air quality improvement.

2. Data and Methods

2.1. Study area

Bucharest, the largest metropolis in Romania, and the tenth-largest city in Europe, is bounded by Latitudes range (44.33°N and 44.66°N) and Longitudes (25.90°E and 26.20°E), being located in a plain landscape along the Dambovița River surrounded by forests, which makes Bucharest a city with large green areas. in a flat region, with a total surface of 625 km² (Figure 1).

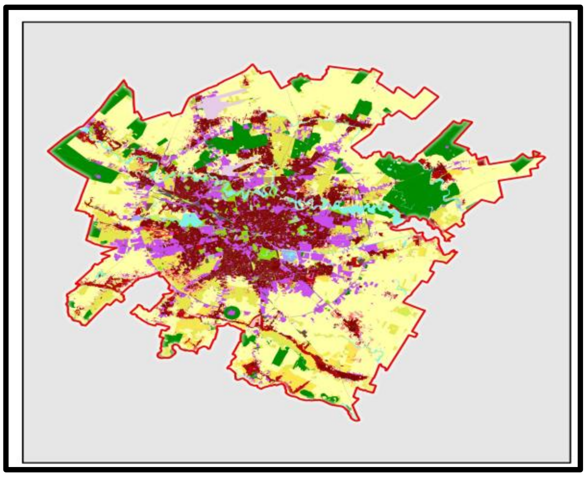

Figure 1. Study area, Bucharest metropolitan city on Copernicus Urban Atlas 2018.

The climate in Bucharest is temperate continental, under the influences of the Western European Climate circulation, the Mediterranean Cyclones, and the East-European Anticyclone, with hot, humid summers and cold, sometimes snowy, or haze and smog formation during winters and extreme climate events. In 2021, its population was 1.794 million residents, a decreased value after 1990. Due to the rapid urbanization of the last decades, associated with industrial and traffic-related air pollution sources, Bucharest is considered one of the largest urban carbon emitters among all Romanian cities, and one of the most air polluted cities in Europe.

2.2. Data sets

This study used the COVID-19 disease Daily New Cases-DNC and Daily New Deaths-DND provided by https://www.worldometers.info/ and www.mai.gov.ro websites. Daily average time series data of air pollutants concentrations PM2.5, PM10, were provided by https://aqicn.org/city/romania/municipiul-bucuresti/ and National Administration of Meteorology anm.ro. Daily time series of meteorological data were collected from http://www.soda-pro.com/web-services/meteo-data/merra and National Administration of Meteorology www.anm.ro.

2.3. Statistical analysis used

In order to evaluate the similarity between two-time series data of the daily mean PM in two size fractions (PM2.5 and PM10) and the daily mean climate observables (air temperature and relative humidity, wind speed, surface solar irradiance Planetary Boundary Layer heights), and COVID-19 incidence and mortality in Bucharest was used cross-correlation analysis and selected Spearman rank correlation. To test coefficients as well as linear regression analysis rank-correlation non-parametric test was used. For normality of the daily mean time-series data sets was selected Kolmogorov-Smirnov Test. ORIGIN 10.0 software version 2021 for Microsoft windows was used for data processing.

3. Results and Discussion

3.1. Particulate matter PM2.5, PM10, ^{222}Rn, and COVID-19 viral disease

Airborne PM in different size fractions between 1 nm to 100 μm of biogenic or chemical constituents, can be considered potential carriers of viral pathogens including SARS-CoV-2, being diffused and transported over long distances, and adversely affecting the COVID-19 disease incidence and severity [11-12].

The Spearman rank correlation analysis of the daily at the ground air pollutants PM2.5, PM10, and ^{222}Rn concentrations shows positive correlations with daily new COVID-19 confirmed (DNC) cases and deaths (DND) (Table 1). Correlations with ^{222}Rn were less significant than PM2.5 and PM10 Spearman correlation coefficients with COVID-19 DNC and DND cases.

Table 1. Spearman rank correlation coefficients and p values between COVID-19-incidence cases, and average daily PM concentrations and ^{222}Rn for Bucharest for the analyzed pandemic period, March 2020-April 2022.

Bucharest	Average daily air pollutant concentration		
COVID-19 incidence	PM2.5 (μg/m³)	PM10 (μg/m³)	^{222}Rn (Bq/m³)
Daily New cases (DNC)	0.40*	0.38*	0.19*
Daily New Deaths (DND)	0.45*	0.43*	0.18*

Note: * p< 0.01

In comparison with the average daily mean PM2.5 concentration recorded for pre-pandemic period 2015-2019 of (32.61 ± 13.21) μg/m³, for the entire analyzed pandemic period in Bucharest, our study found the decreased values of (24.63 ± 12.05) μg/m³. Similar decreased values of the average daily mean PM10 concentrations of (61.92 ± 24.50) μg/m³ were recorded during the entire pandemic period in comparison with (76.32 ± 26.18) μg/m³ for pre-pandemic period 2015-2019. These reduced values of PM2.5 and PM10 concentrations may be attributed to total or partial lockdown restrictions adopted to limit the SARS-CoV-2 spreading in Bucharest metropolitan city. In case of outdoor ^{222}Rn concentration analyzed for COVID-19 pandemic period, this study values of (38.67±22.64) Bq/m^3, comparable with the daily mean ^{222}Rn concentration measured during the pre-pandemic COVID-19 period (2015- 2019).

Like PM2.5, and PM10, lower atmospheric radon concentrations exhibit typical diurnal, seasonal and inter-annual temporal variability patterns. ^{222}Rn provides information about the current state of urban pollution levels near the ground as well as of atmospheric condition changes, being used as a tracer of the lower tropospheric vertical mixing effects better than commonly used meteorology-based stability patterns. On a diurnal scale, the peak of outdoor radon concentration is recorded in the early morning hours [13] and on seasonal, in winter with elevated values under persistent synoptic inversion events, when due to accumulation near the ground, outdoor radon concentrations may be higher for several days. If besides outdoor radon contribution, the cumulative impact of the daily mean indoor radon concentrations with a mean value of 109.4 Bq/m^3 in different buildings in Bucharest city, the daily impact of inhaled radon on human health is considered to be significant [14].

Also, for the entirely investigated period, this study found significant direct correlations between ^{222}Rn and PM2.5 (r= 0.46), and PM10 (r= 0.37).

Temporal patterns of the daily mean ground levels of PM2.5, PM10, and ^{222}Rn concentrations and daily new COVID-19 cases (DNC) and deaths (DND) for the analysed COVID-19 pandemic period in Bucharest city are presented in Figure 2. Because particulate matter in both size fractions (PM2.5 and PM10) are considered to be implicated in the pathogenesis of COVID-19 and its new variants, its positive significant correlation with ^{222}Rn can have a strong impact on the increased transmissibility and immune escape, being naturally selected to promulgate de pandemic.

However, function of exposure time, indoor radon in insufficient ventilated buildings, in synergy with outdoor radon may be considered as a potential additive factor for COVID-19 incidence and lethality in Bucharest city. Indoor ventilation technologies may affect the distribution and colony of indoor microbial pathogens and ^{222}Rn in air concentrations, and sometimes SARS-CoV-2 pathogens transmission [15-16]. The findings of this study support the wide epidemiological evidence that COVID-19 viral disease incidence and severity is associated with high concentration levels of the ambient particulate matter PM, that worse COVID-19 outcomes [17-20].

Due to seasonal variability of air pollutant concentrations, this analysis associates the critical role of increased concentrations of daily mean particulate matter PM2.5 and PM10 during the second, the fourth and the fifth COVID-19 waves in Bucharest and registered high numbers of total daily new COVID-19 cases.

As markers for urban air quality in Bucharest, especially during cloudy and lower planetary boundary layer heights- PBL, PM2.5, PM10 particles and ^{222}Rn at the surface level, together with other pollutants can increase human vulnerability to viruses through reduction of the immune system, and associated risk of pulmonary infections by impairing the function of alveolar macrophages and epithelial cells in the lung [21-22].

Such findings have been reported by the previous studies worldwide, and may support the hypothesis that PM, especially PM2.5 in large cities can be considered as an anthropogenic environmental mutagen of SARS-CoV-2 pathogens with decreasing pulmonary function, and emergence of new COVID-19 variants [23-25].

3.2. Climate parameters variability impact on COVID-19 viral disease

Is recognized that in large metropolitan areas the differences in the local micro and regional macro-climate scale conditions, can significantly influence the viral pathogens circulation. Seasonal variability of meteorological parameters like as air temperature, relative humidity, pressure, wind speed intensity and direction, planetary boundary layer heights, surface solar irradiance variability and synoptic meteorological patterns may have a great impact on air quality and COVID-19 viral infection course. Spatiotemporal patterns of air pollutants concentrations emitted by multi sources are mostly modulated by the evolution of the atmospheric mixing layer PBL height. This study found significant inversely correlations between COVID-19 incidence (DNC) and lethality (DND) between PBL heights over Bucharest metropolitan area during the entire pandemic period (March 2020 - April 2022) as follow: (rDNC= -0.70; p < 0.01) and respectively (rDND= -0.72; p < 0.01). Recorded high levels of daily PBL heights of (1607 ±526) m during the first COVID-19 wave in Bucharest may explain the low intensity of the first COVID-19 wave in comparison with the rest of some European metropolitan cities [26-28].

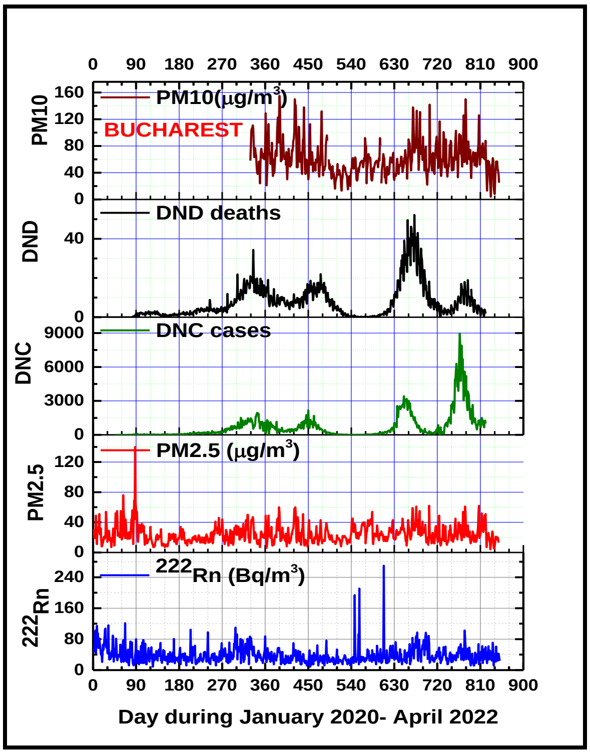

Figure 2. Temporal patterns of the daily mean ground levels of PM2.5, PM10, and ^{222}Rn concentrations and daily new COVID-19 cases (DNC) and deaths (DND) for the analysed COVID-19 pandemic period in Bucharest city.

During the second, the fourth and the fifth COVID-19 waves the daily mean PBL heights recorded unusually low values per each wave, being respectively of (539±292) m, (921±605) m, and (848±462) m, values which due to accumulation of air pollutants and bioaerosols (bacteria, fungi, and viruses) and natural radioactivity near the ground can explain the high rates of viral infectivity and lethality in Bucharest. The daily mean air temperatures and surface solar irradiance were inversely correlated with COVID-19 (DNC and DND) cases as follows: ($r = -0.50$, $p < 0.01$; and $r = -0.60$; $p < 0.01$), and respectively ($r= -0.67$, $p < 0.01$; $r = -0.64$, $p < 0.01$). The results are in good agreement with other published studies [29-30]. Also, the seasonal patterns of daily average climate variables (air temperature, surface solar irradiance), are closely related to lower daily incidence and mortality of COVID-19 patterns during late spring, summer, and early autumn periods with higher sunshine levels.

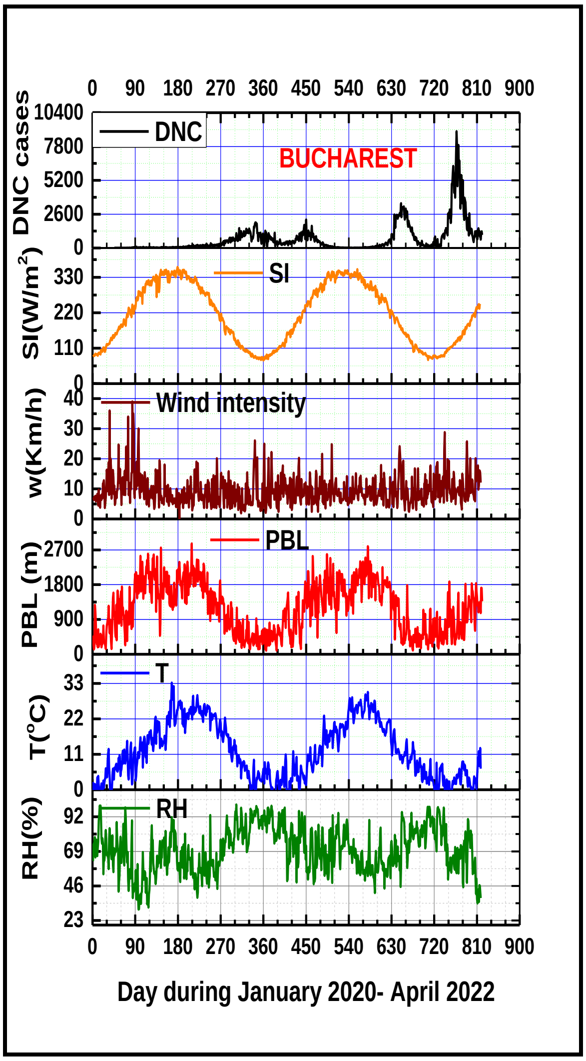

Figure 3. Temporal patterns of the daily mean climate variables (air relative humidity, air temperature, Planetary Boundary Layer height, wind speed intensity, surface solar irradiance) and daily new COVID-19 cases (DNC) and deaths (DND) for the analysed COVID-19 pandemic period in Bucharest city.

Like previous worldwide studies, this study found positive linear Spearman rank correlations between daily mean air relative humidity and air pressure with daily COVID-19 DNC and DND cases as follow: ($r= 0.44$, $p < 0.01$; and $r= 0.48$; $p < 0.01$) and respectively ($r= 0.28$, $p < 0.01$; and $r= 0.36$; $p < 0.01$) [31]. Low inversely correlations have been recorded between daily mean wind speed intensity and daily COVID-19 DNC and DND cases as follow: ($r= -0.33$, $p < 0.01$; and $r= -0.39$; $p < 0.01$). Similar findings have been reported by other several studies [32]. Temporal patterns of the daily mean climate variables (air relative humidity, air temperature, Planetary Boundary Layer height, wind speed intensity, surface solar irradiance) and daily new COVID-19 cases (DNC) and deaths (DND) for the analysed COVID-19 pandemic period in Bucharest city are shown in Figure 3.

3.3. Synoptic atmospheric circulation impact on COVID-19 waves

In the recent years, under strict air pollution control measures, the particulate matter emissions have been significantly reduced across Europe. However, the capital city of Bucharest in Romania located in large a depression-like structure, Romanian Plain surrounded by the Carpathians Mountain barriers, still experiences severe persistent air pollution events, especially associated with large atmospheric circulation anomalies and air temperature inversions in the winters. The high rates of COVID-19 incidence and mortality recorded in Bucharest during the second, third, fourth and fifth pandemic waves have been explained through the coexistence of anomalous anticyclonic synoptic conditions in the mid-troposphere, characterized by stationary conditions. Associated stationary conditions allow accumulation of high concentrations of particulate matter with attached SARS-CoV-2 pathogens near the ground, which potentially affect the urban air quality and favor COVID-19 disease transmission. The downward airflows described by positive omega values of Omega composite average surface maps at 850 mb (~ 1458 m elevation level [33-35] explain the significant stability conditions.

The results of this study suggest that under stagnant cyclonic atmospheric conditions recorded during the second, third, fourth, and fifth COVID-19 waves, the aerosolized virus SARS-CoV-2 could remain infectious for extended periods of time in the Bucharest metropolis, explaining the recorded high rates of COVID-19 DNC positive cases, and higher mortality rates compared with the first wave, when was dominant cyclonic atmospheric circulation in the mid-troposphere.

Climate change together with globalization may favor pathogen transmission and the development of pandemics, particularly for emerging infectious diseases of zoonotic origins [36].

Also, extreme climate events coinciding with COVID-19 have affected viral disease exposure, increased susceptibility of people to COVID-19, emergency responses, and reduced health system resilience to multiple stressors [37].

COVID-19 pandemic caused awareness regarding the climate change perception and climate change solutions for air pollution and waste reduction, the purchase of efficient appliances, and the usage of pro-environmental traffic related issues [38].

4. Conclusion

As major air pollutants, radon and anthropogenic particulate matter have worsened air quality and affected the health of the public and individuals, being associated with cardiopulmonary diseases, bronchial asthma, and respiratory diseases as well as increased mortality rates from viral diseases in recent decades.

This study investigated the impact of the air particulate matter and radon, under climate variability on COVID-19 multi-waves incidence and severity in Bucharest metropolitan area, in Romania. Through a systematic analysis of the daily time-series data of the PM2.5, PM10 and ^{222}Rn, meteorological and synoptic atmospheric conditions, and COVID-19 incidence and mortality, this paper found the existing cross-correlations between environmental variables and the transmission of SARS-CoV-2 pathogens during the entire pandemic period in such datasets. Nevertheless, additional environmental and epidemiological investigations are required to test the causality of air pollution and climate seasonality impacts on viral infections seasonality and the severity.

Also, the findings of this study underline the urgent need to decrease urban air pollution in Bucharest metropolitan area toward global atmospheric emissions reduction and warming especially during pandemic events. This study highlights the imperious need for better implementation of air pollution monitoring technologies, and understanding of the chemical processes of secondary pollutants to emission change under complex climate conditions, along with climate extreme events and socio-economic drivers that can affect future air quality in metropolitan areas. Adoption of the revisions of air quality regulations and new regional and global policies for air quality improvement based on geospatial information must meet the World Health Organization guidelines for European metropolitan cities.

Evaluating the impacts of air pollutants and radon on people's health under pandemic conditions is an essential step of mitigation measures for urban pollution and urban climate, being crucial for more sustainable urban planning and development.

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