ASSESSMENT OF THE BURDEN OF DISEASE DUE TO $PM_{2.5}$ AIR POLLUTION FOR THE BELGRADE DISTRICT

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The health effects attributed to exposure to ambient $PM_{2.5}$ concentrations above 10 μg/m^3 by using the AirQ$^+$ modeling software were assessed. The hourly concentrations of $PM_{2.5}$ were collected from 13 air pollution monitoring stations in the Belgrade district during Jun and July 2021., which were further used as input data for the AirQ$^+$ software. The average concentration of $PM_{2.5}$ for two-month monitoring from all sampling sites in the city was 14.8 μg/m^3, the maximum daily concentration was 55.7 μg/m^3, while the maximum concentration per hour was 365 μg/m^3. The spatial distribution of concentrations was mapped using geostatistical interpolation, revealing hotspots within the city centre and industrial area of the district. The burden of disease, such as stroke, ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD) and lung cancer (LC), due to the ambient $PM_{2.5}$ pollution was evaluated according to the WHO methodology for health risk assessment of air pollution. The model used for this assessment is based on the attributable proportion defined as the section of the health effect related to exposure to air pollution in an at-risk population. The estimated attributable proportion was 19.4% for stroke, 27.2% for IHD, 15.3% for COPD and 9.0% for LC. The estimated number of attributable cases per 100,000 population at risk, due to $PM_{2.5}$ air pollution, for stroke, IHD, COPD, and LC, was 28, 34, 15, and 8, respectively.

Keywords*: Ambient air monitoring, AirQ$^+$, GIS, Population exposure, Health risk assessment, Attributable proportion*

1. Introduction

Air quality has become a burning issue for organizations and governments worldwide in the last few decades due to its harmful effects on the population and environment. Air pollution in the urban environment occurs due to industrial activities, motor vehicle emissions, transport, domestic heating, dust, etc[1]. The World Health Organization (WHO) assessed that more than half of a million people die preterm per year in Europe as a consequence of the health problems ascribed to the inhalation of airborne toxic pollutants [2]. The ambient fine particulate matter $PM_{2.5}$ (particulate matter with an aerodynamic diameter of less than 2.5 μm) caused more than four million deaths per year worldwide [3]. Furthermore, a significant correlation was noted between ambient $PM_{2.5}$ inhalation and the incidence of chronic obstructive pulmonary diseases [4]. Cardiovascular and respiratory diseases are among the most common chronic diseases attributed to $PM_{2.5}$ exposure [5,6].

Many efforts have been made to establish an automated air quality monitoring network to monitor ambient air pollution in the Balkan peninsula in the last decades. For the Balkan region in previous years, air monitoring data accompanied by health impact assessment was done by several studies [7-9]. Based on the characterization of $PM_{2.5}$ sources in Belgrade and applying positive matrix factorization analysis, five main groups of emission sources: biomass burning (14.5%), traffic (3.9%), regional combustion/secondary sulfates (28.8%), local combustion/secondary nitrates (29.7%) and soil (5.4%) was revealed [10]. Still, there are gaps or incomplete data for appropriate medical records (e.g. hospital admissions, deaths due to specific causes) on a daily basis will lead to a better health impact assessment.

The AirQ^{+} modeling software tool, developed by WHO Europe to estimate human health outcomes related to exposure to pollution in a particular area in a specific time interval, was recently employed by several authors [7, 11-14]. The software can assess the effects and estimate the impacts of long-term and short-term exposure to ambient air pollutants, such as $PM_{2.5}$, PM_{10}, NO_2, O_3, and black carbon (BC). In addition, the AirQ^{+} software can estimate natural mortality and mortality due to the burden of diseasesuch as stroke, ischemic heart disease (IHD), chronic obstructive pulmonary disease (COPD), and lung cancer (LC) [15].

In this work, the diurnal distribution of $PM_{2.5}$ was evaluated in the Belgrade district of the Republic of Serbia, including the spatial distribution, which was mapped using geostatistical interpolation. The burden of disease: stroke, IHD, COPD, and LC due to the ambient $PM_{2.5}$ concentration was assessed using the AirQ^{+} modeling software.

2. Materials and Methods

2.1. Study area - Belgrade district

Belgrade (44.8125° N, 20.4612° E), the capital of the Republic of Serbian, is situated in the continental part of the Balkan Peninsula. It is industrially very developed, and in the zone of influence of most of the Serbian energy sector. The largest coal fired power plant ‘Nikola Tesla’ complex, which uses lignite from the Kolubara open coal mine is located southwest of the district [16]. Belgrade district consists of 17 municipalities, covers an area of 3234 km^2 and based on the last residents census, has 1.69 million citizens [17]. In addition, it is estimated that about 2 million inhabitants from neighboring districts are present during the working days in Belgrade. For this work, the target population is all exposed citizens to the measured pollution, here $PM_{2.5}$. Based on the data from the health statistical yearbook of the Republic of Serbia, in Serbia in 2020, the mortality rate per 100 000 population due to different causes of death was as follows: neoplasms 310; diseases of the circulatory system 802; diseases of the respiratory system 97 [18].

2.2. Ground air monitoring $PM_{2.5}$ data

Ambient air $PM_{2.5}$ concentrations were collected, within the national air quality monitoring network, at 13 in-situ automatic air quality monitoring stations during Jun and July 2021. The regulatory-grade systems provide the most accurate and robust in-situ observations, nevertheless, the disadvantage is that those systems are expensive to install and maintain. In a metropolitan Belgrade area, a denser network of in-situ air quality control measuring stations should have been established. Air monitoring stations were classified per type (source of pollution), as background (eight), traffic (three), and industrial (two); and per residential zone, as urban (eight), suburban (four), and rural (one). In Fig. 1, the map of the Belgrade district with the spatial location of the air quality monitoring stations is presented. The diurnal means of $PM_{2.5}$ concentrations were derived for each station by averaging hourly measurements. Furthermore, a city-specific diurnal mean of $PM_{2.5}$ concentrations was derived for the Belgrade district by averaging all diurnal mean data from all air monitoring stations. Further, those values were assumed to represent the average public exposure [19,20].

Fig. 1. The map of the Belgrade district with monitoring stations locations

To visualize the distribution of the $PM_{2.5}$ concentrations for the Belgrade district, the ordinary kriging method of interpolation using the ArcGIS ver. 10.7 software was applied.

2.3. AirQ$^+$ modeling software

For assessment of the burden of disease due to $PM_{2.5}$ air pollution, the AirQ$^+$ 2.0 modeling software package was used. AirQ$^+$ is a user-friendly software estimates the magnitude of the most important and the best-recognized effects of air pollution in a given population. The WHO European Center for Environment and Health recommended the AirQ$^+$ as a reliable tool for burden diseases assessment caused by human exposure to air pollution [21]. According to the concentration-response functions, using the AirQ$^+$ model approach is obtained the relation between baseline incidence rates and population exposure to the specific pollutants. Detailed information about the AirQ$^+$ could be found elsewhere [7, 22]. For the $AirQ^+$ assessment, the following input data were used: average air quality data, the population at risk for a given health endpoint, baseline incidence rates, cut-off value for consideration (for $PM_{2.5}$ was used 10 μg/m^3), and relative risk values. The $AirQ^+$ uses data processed by excel to estimate the relative risk of the accident and the attributable component and displays the result as morbidity or mortality. In this study we used default values for relative risk for assessed health endpoint pairs and these values are obtained from meta-analysis studies. The relative risk is an indication of the degree of the probability of experiencing health effects when pollutants exposure concentration increases (per 10 μg/m^3 increase). The $AirQ^+$ estimates the attributable proportion (%), the number of attributable cases, and the number of attributable cases per 100,000 people related to the at-risk population.

The attributable proportion (*AP*, in %) is the fraction of a health endpoint that can be related to the exposure in a population *P(c)* to the category of exposure *(c)*, where *RR(c)* is the relative risk value of the air pollutant c concentration:

$$AP = \Sigma\{[RR(c) - 1] \times P(c)\} / \Sigma[RR(c) \times P(c)]$$

For a selected health endpoint, the number of attributable cases per 100,000 people related to the at-risk population was calculated as the baseline incidence rates multiplied by the attributable proportion.

3. Result and Discussions

3.1. $PM_{2.5}$ concentrations in the Belgrade district ambient air

The air pollutants in the Belgrade district are emitted mostly from domestic heating, road traffic, and industrial operations [10, 23]. Currently, the annual limit for $PM_{2.5}$ in the EU is 25 μg/m^3 [24], which is five times higher than the novel WHO guideline of 5 μg/m^3 [2]. In this study, the average diurnal $PM_{2.5}$ concentration was 14.8 μg/m^3, while the maximum diurnal concentration was 55.7 μg/m^3. Average hourly diurnal $PM_{2.5}$ concentrations for each monitoring station in the Belgrade district are presented in Fig. 2. During the two-month investigation period, the same hourly diurnal trend was observed at all monitoring stations, with higher PM2.5 concentrations during the night. We assumed that the reason was temperature inversion conditioned by a different cooling rate of ground and air during the night in the summer season.

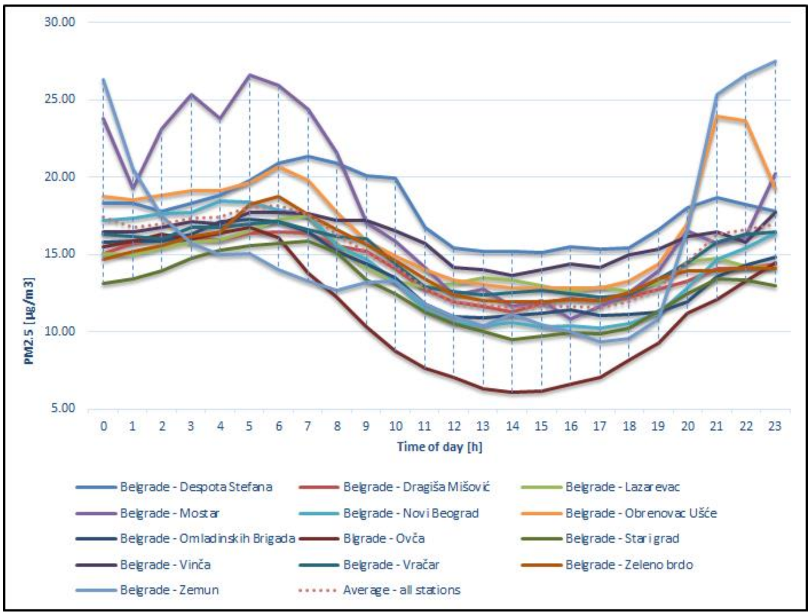

Fig. 2. Average hourly $PM_{2.5}$ concentrations at the air monitoring stations

According to the annual report on air quality in the Republic of Serbia in 2020., the average $PM_{2.5}$ concentration for the Belgrade district was 23.5 µg/m^3 [25]. For the territory of Serbia for 2001-2016, using the high-resolution gridded data set V4.EU.02, the mean annual $PM_{2.5}$ values in the range of 13.9-28.9 µg/m^3 were reported [26]. Sufficient precipitation and active atmospheric circulation led to low pollution on summer days [27, 28]. This work confirmed that finding, based on a comparison between average concentrations in this work and average annual concentration from 2020 for the Belgrade district.

The annual mean concentration of fine particles ($PM_{2.5}$) in urban areas of the EU gradually decreased to 12.6 µg/m^3 in 2019. The annual mean concentration of fine particles ($PM_{2.5}$), among the EU Member States, was highest in urban areas of Bulgaria (19.6 µg/m^3) and Poland (19.3 µg/m^3), followed by Romania (16.4 µg/m^3) and Croatia (16.0 µg/m^3) [29]. Hourly PM2.5 concentrations for 336 Chinese cities in 2015 and 2016 were evaluated, and it was noticed that annual average $PM_{2.5}$ concentrations decreased by 2.27 µg/m^3, from 48.33 µg/m^3 in 2015 to 46.06 µg/m^{3}in 2016 [13]. Annual average concentrations of $PM_{2.5}$ in Delhi, India, was 111.7 µg/m^3 in 2018 [30], while in Isfahan, Iran was 31.2 µg/m^3 in 2018-2019 [12]. In Rome, Italy, in 2014 the mean $PM_{2.5}$ concentration was 15.6 µg/m^3, with an hourly peak $PM_{2.5}$ concentration of 71.0 µg/m^3 [11]. In this work, the maximum concentration per hour was 365 µg/m^3, which was detected in the area near the coal-fired power plant in Obrenovac. The high level of $PM_{2.5}$ exposure in central and southwest Taiwan was primarily due to emissions from coal-fired power plants and heavy industry factories [31]. In 2015 for Marseille, France, an urban-industrial city, the highest hourly $PM_{2.5}$ concentration of 93.1 µg/m3 was reported [32]. For Bosnia and Herzegovina in 2018, the $PM_{2.5}$ annual mean for Tuzla was 39.4 (range 2.69 - 223) µg/m^3, and for Lukavac was 53.0 (range 4.49 - 313) µg/m^3 [33]. All those results indicated the wide range of ambient air $PM_{2.5}$ concentrations, and it is highly needed to maintain a system of continuous in-situ automatic air monitoring worldwide.

3.2. Spatial distribution of $PM_{2.5}$ concentrations

The average two-month $PM_{2.5}$ concentrations recorded at the monitoring stations are presented in Table 1.

Table 1. Monitoring station classification and $PM_{2.5}$ average concentrations

No.	Station name	Classification	Zone	Average $PM_{2.5}$ [μg/m^3]
1	Beograd Mostar	traffic	urban	17.7
2	Beograd Dragiša Mišovic	traffic	urban	14.1
3	Beograd Stari grad	background	urban	12.6
4	Beograd Despota Stefana	traffic	urban	17.8
5	Beograd Vračar	background	urban	14.8
6	Beograd Zemun TB	background	urban	14.8
7	Beograd Oml. brigada	background	urban	13.8
8	Beograd Novi Beograd	background	urban	14.2
9	Beograd Zeleno brdo	background	suburban	14.5
10	Beograd Vinča	industrial	suburban	16.0
11	Beograd Ovča	background	suburban	11.4
12	Beograd Lazarevac	background	suburban	14.5
13	Beograd Obrenovac Ušće	industrial	rural	16.9

The spatial distribution of average and maximum $PM_{2.5}$ concentrations in air for the Belgrade district obtained by GIS software are presented in Fig. 3. From Fig. 3, it can be concluded that the concentrations of $PM_{2.5}$ varied across the Belgrade district. The highest $PM_{2.5}$ concentrations were in the southwest of the district, in the area around the power plant near the city of Obrenovac, and in the central urban area of Belgrade city. It has been observed that the spatial pattern of $PM_{2.5}$ in Serbia follows the population distribution with the highest values for urban areas [26]. Applying GIS techniques for the zoning of the concentrations of $PM_{2.5}$ in urban areas of Isfahan, Iran, as annual and seasonal (warm and cold) revealed that the distribution of $PM_{2.5}$ approximately follows a similar pattern [12].

The spatiotemporal distributions of $PM_{2.5}$ concentrations and the frequency of heavy pollution events for the five target regions over China during 2014–2019, using long-term surface observations and satellite remote sensing data, were systematically characterized. As a result, it was revealed that a key $PM_{2.5}$ receptor, associated with the regional pollutant transport over Central and Eastern China triggered by the climate change of East Asian winter monsoons, is found to alter the distribution patterns of $PM_{2.5}$ pollution over China [34].

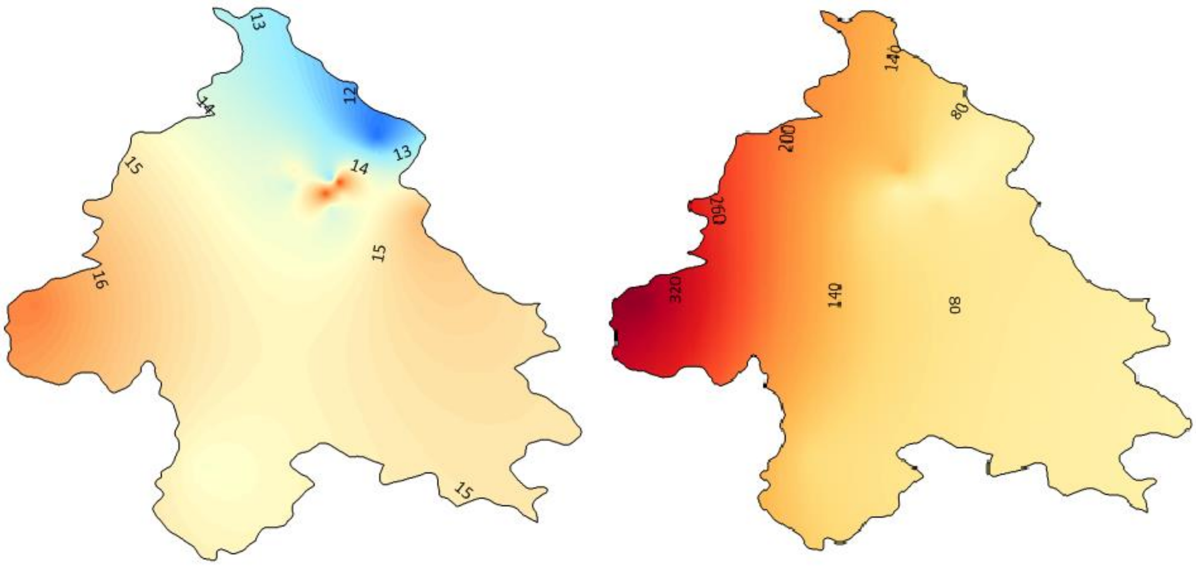

Fig. 3. The spatial distribution of average (left side) and maximum (right side) $PM_{2.5}$ concentrations for the Belgrade district (expressed in μg/m^3)

3.3. Disease burden attributable to $PM_{2.5}$ exposure

This study estimated how many particular health effects, such as stroke, IHD, COPD, and LC, are attributable to $PM_{2.5}$ pollution in the Belgrade district using the AirQ$^+$. Heart disease and stroke are the most common reasons for premature deaths attributable to air pollution, followed by lung diseases and lung cancer [35]. Furthermore, the International Agency for Research on Cancer (IARC) has classified air pollution in general and PM as a major component of air pollution mixtures as carcinogenic [36].

Based on the average measured $PM_{2.5}$ ambient air concentration for the Belgrade district and the relative risk functions, the population attributable proportion (AP) of cause-specific mortality due to $PM_{2.5}$ was calculated. According to results, the AP estimated for the stroke, IHD, COPD, and LC attributable to $PM_{2.5}$ concentrations were 19.4%, 27.1%, 15.3%, and 9.0%, and the excess death cases were estimated to be 416, 516, 223, and 125, respectively. In addition, the assessment of results showed that ischemic heart diseases are the most highly affected by $PM_{2.5}$. The most significant factors that can lead to cardiovascular disease mortality eare the median household income and annual average ambient concentrations of PM2.5. Higher cardiovascular disease mortality rates were associated with lower median household income levels and higher concentrations of PM2.5. It was revealed that leisure-time physical inactivity, health insurance status, and urban rural status do not contribute to aggravated cardiovascular diseases related mortality [37]. Yang et al. reported that the absolute COPD burden attributed to ambient PM2.5 largely increased from 3.52×10^5 to 6.95×10^5 from 1990 to 2019, and that the high COPD burden occurred in the middle sociodemographic indices region. [38]. Gorgna et al. pointed out that chronic PM2.5 exposure is associated with the different processes of lung cancer [39]. Based on comprehensive study reviews [40, 41], short-term exposure to ambient PM2.5 was associated with COPD mortality. Furthermore, it was reported that a 10 μg/m^3 increase in daily PM2.5 was associated with a 2.5% increase in COPD mortality [40].

Results obtained in this assessment for the Belgrade district were in the range of burden of disease assessed worldwide. Due to the short-term exposure to $PM_{2.5}$ in Iran attributable proportion of the natural mortality was in the range of 5-8.23% in Ahvaz [42], while in Hamadan, it was 4.42% [43]. For the capital of Iran, Teheran, in the period March 2017 to March 2018, the estimated attributable proportion was 56.6% for stroke, 55.51% for IHD, 13.79% for COPD, and 14.8% for LC [44], while for Isfahan, Iran, in period 2018 - 2019, estimated attributable proportion was 13.1% for stroke, 15.15% for IHD, 13.41% for COPD and 15.96% for LC [12]. In different parts of Taiwan, the attributable proportion ranged from 14.0% to 25.6% for IHD, from 7.8% to 30.7% for stroke, from 4.7% to 17.4% for LC, and from 3.8% to 13.9% for COPD [31]. The difference in the value of baseline mortalities could be the reason for the contradiction between the assessed numbers of deaths among different case studies [12].

Over the period 2010-2019, the number of premature deaths for non-accidental causes attributed to $PM_{2.5}$ above 10 μg/m^3 ranged from 16.7 per 10^5 inhabitants in 2011 to 4.2 per 10^5 inhabitants in 2019. The number of hospital admissions due to cardiovascular and respiratory diseases per 10^5 people was 19.9 and 16.0 in 2011, and 4.9 and 4.0 in 2019, respectively [32].

Over the years, it has been noted that decreasing $PM_{2.5}$ concentrations worldwide will undoubtedly lead to a decrease in premature deaths due to air pollution. Additionally, in 2021 the WHO has changed counterfactual concentrations from 0 to 5 μg/m^3 [2], which will decrease health outcomes and impact the estimation of premature deaths, especially for countries with high annual $PM_{2.5}$ concentrations.

4. Conclusion

The diurnal and spatial distributions of $PM_{2.5}$ and health burdens in the Belgrade district, Republic of Serbia, were evaluated on hourly $PM_{2.5}$ concentrations. The average ambient air $PM_{2.5}$ concentration for two months of monitoring ranged from 11.6 to 18.1 μg/m^3. The Belgrade district area with the highest $PM_{2.5}$ concentration is oriented southwest, where the energy industry sector is located, and in the city's central urban area. Albeit the $PM_{2.5}$ levels were above the WHO standard, decreases in $PM_{2.5}$ concentrations have been noticed compared to recent years. The $AirQ^+$ software was used to estimate mortality due to stroke, IHD, COPD, and LC attributed to exposure to $PM_{2.5}$, and the assessed number of deaths for the Belgrade district was 416, 516, 223, and 125, respectively. In this case study, we assumed that for the assessment of the burden of disease due to PM2.5 air pollution, all individuals were exposed to the same PM2.5 levels on average from all city air quality monitoring stations in the Belgrade district. In addition, human daily mobility and exposure to indoor air pollutants, where people spend most of the day, were neglected. Further work should be oriented towards assessing $PM_{2.5}$ ambient air concentration during the year, aiming to perceive concentration changes during the winter-summer season and a broader picture of the air pollution problem in the Belgrade district. It is highly needed that the city council in real time inform citizens regarding air pollution to avoid staying outdoors when the air is polluted to maintain health. Cognition in this paper could enhance public awareness regarding the health risks caused by $PM_{2.5}$. Effective measures that curb air pollution need to be improved as soon as possible. Additionally, regional $PM_{2.5}$ concentrations and trends should be fully considered.

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