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Premature deaths due to exposure to PM2.5 in Belgrade before and at the beginning of the COVID-19 pandemic

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Abstract: Prolonged breathing in unhealthy levels of fine particulate matter ($PM_{2.5}$) often leads to respiratory and cardiovascular diseases and increases mortality. A statistical analysis of $PM_{2.5}$ concentrations per hour was performed from April 28 to May 28, from 2018 to 2020, before the onset of the COVID-19 pandemic and the first few months after. Quantification of the health effects of exposure to air pollution was done through calculations of attributed deaths in 2018 and 2019 using the AirK + impact assessment for $PM_{2.5}$ in Old and New Belgrade. It was found that the in 2020 the maximum concentrations of $PM_{2.5}$ concentrations decreased compared to 2019, most likely as a result of quarantine measures due to the COVID-19 pandemic. Estimated number of attributed cases in 2019, compared to 2018, a larger decrease was recorded in the Old Town than in New Belgrade. The increase in the number of attributed cases is a consequence of the faster development of New Belgrade in relation to Old Belgrade, as well as the increasing intensity of traffic in that part of the city. A progressive reduction in PM2.5 concentrations would bring major health benefits from improved air quality in Belgrade.

Keywords: health impact assessment, attributable cases, premature deaths, air pollution, particulate matter $PM_{2.5}$, AirQ+, COVID-19

1. Introduction

With increasing and intensive urbanization and industrialization, air pollution has become one of the main environmental problems of global proportions, which has an extremely detrimental effect on human health (Forouzanfar et al., 2016; Landrigan et al., 2018). Air pollution from both outdoor and indoor sources represents the single largest environmental risk to health globally. The World Health Organization (WHO) estimated that air pollution was responsible for more than 550,000 premature deaths in the WHO European Region in 2016, almost 6,600 of which were attributed to air pollution in Serbia (WHO, 2019). Air pollution is rightly considered a "silent killer" that is likely to affect almost all organs in the body. According to the WHO, in 2012, 16 percent of lung cancer deaths, 11 percent of chronic obstructive pulmonary disease deaths, and more than 20 percent of ischaemic heart disease and stroke are associated with ambient fine particulate matter. The economic cost of the approximate 600,000 premature deaths and of the diseases caused by air pollution in the WHO European Region in 2010 has been estimated in 1.5 trillion Euros[1] (EC, 2016). It is estimated that in the western Pacific region, it causes the death of 2.2 million inhabitants(Larsson & McNaull, 2020).Atmospheric pollution is mainly the result of unsustainable combustion

[1] 1 Euro = 1.18 US$

of fossil fuels in energy conversion devices, as well as increased vehicle traffic, biomass combustion, etc. Measured air pollutants include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon oxides (CO) and particulate matter (PM). Particles represent a major health risk factor (Lim et al., 2012).Depending on the aerodynamic equivalent diameter, PM can be classified into PM_{10} and $PM_{2.5}$, which is the main reason for shortening the lifespan, because various harmful substances can be easily incorporated into the respiratory system (Lelieveld et al., 2015). These air pollutants cause serious challenges in the environment and most often pose a significant threat to clean air. $PM_{2.5}$ pollution is caused mainly by anthropogenic activities (especially coal-fired heating).

In the past period (2001-2016), the municipalities with the highest amount of $PM_{2.5}$ pollution in Belgrade were Stari Grad and Novi Beograd. Apart from industrial activity and population concentration, there is a physical-geographical factor in the presence of pollution. Municipalities with a higher altitude have a lower concentration of $PM_{2.5}$ in winter (Luo et al., 2020; Stanojevic et al., 2019). Global air pollution by $PM_{2.5}$, observed globally, is considered to be 25 percent emissions from transport, 15 percent from industrial activities, 20 percent from household fuel combustion, 22 percent from unspecified sources of human origin and 18 percent from natural dust and salt (Karagulian et al., 2015).

It was found that at higher values of solar radiation temperatures, $PM_{2.5}$ concentrations are lower and that such an inverse correlation applies to relative humidity and atmospheric pressure, i.e., the lower their values are, the higher is the $PM_{2.5}$ concentration. Many studies reveal that PM is a major health risk factor in almost all urban areas around the world (Ganguly et al., 2009; Lim et al., 2012; Satsangi et al., 2011; Yadav et al., 2014). $PM_{2.5}$ particles are one of the air pollutants that cause special concern due to their potential negative effects on human health of vulnerable categories of people, primarily children and the elderly (Silva da Silva et al., 2015; Zeng et al., 2016). More than 80 percent of the population in the WHO European Region lives in cities with PM levels that exceed the WHO Air Quality Guidelines(Ligus, 2018; WHO, 2013) Prolonged exposure to $PM_{2.5}$ particles often leads to respiratory and cardiovascular diseases and increases mortality (Grange et al., 2013; Han & Naeher, 2006). The impact on health of air pollution in Europe causes 1.8-6.4 percent of deaths of European children aged 0-4. Air pollution causes 100,000 deaths and 725,000 years of lost lives (Disability-Adjusted Life Year) in European cities and $PM_{2.5}$ pollution caused 350,000 premature deaths in 2000. Average life expectancy of European citizens' is 9 months shorter due to air pollution (USAID, 2012). Many health problems are caused by increased concentrations of $PM_{2.5}$ above limit value (LV), such as: respiratory illness, asthma, pneumonia, tuberculosis, cancer, cardiovascular diseases, pregnancy complications, sick building syndrome (Ahmed et al., 2019; Po et al., 2011). The $PM_{2.5}$ LVs are presented in Table 1, according to Serbian regulations, the EU directive(EU Directive, 2008) and WHO recommendations including the revision of the Air Quality Directive which puts the EU on track to achieve zero air pollution by 2050 (EEA, 2019, 2022; SEPA, 2019; WHO, 2021).

Table 1. LV according to the Serbian Regulation, EU Directive and WHO recommendation.

Period	RS	EU	WHO
	$PM_{2.5}$	**$PM_{2.5}$**	**$PM_{2.5}$**
1 hr (μg/m^3)	-	-	-
24 hr* (μg/m^3)	-	-	15
1 year (μg/m^3)	25	25**	5

*- 99th percentile (i.e. 3–4 exceedance days per year)

**- 10 μg/m³ reduction by 2030

Exposure of pregnant women to the environment of $PM_{2.5}$ during the third trimester of pregnancy is associated with high blood pressure in children aged 3 to 9 years. An increasing number of studies have investigated the impact of maternal exposure to air pollution, especially $PM_{2.5}$, during pregnancy and the risk of adverse birth outcomes, especially low birth weight (<2,500 g at birth) and preterm birth (<37 completed weeks of gestation) (Sapkota et al., 2012). It is also known that air pollution reduces the productivity of workers both outdoors and indoors (Chang et al., 2016; Mazzanti & Zoboli, 2009).

The aim of the study was to determine the maximum $PM_{2.5}$ concentrations and daily mean values (DMVs) in the period April 28-May 28 for 6 years, 2015-2020, in Belgrade, i.e., its old and new part, to determine the level of pollution. Based on the number of premature deaths caused by $PM_{2.5}$ pollution, the situation in the old and new part of Belgrade was analysed, in order to point out the possible increase in the number of attributable cases, so appropriate measures can be taken to overcome the worrying situation with air pollution and its consequences for human health.

2. Materials and Methods

The statistical analysis is made from the $PM_{2.5}$ concentration data obtained from 3 monitoring stations in Belgrade (Table 2), for the period from 28 April to 28 May during for two years, from 2018 to 2020.

Table 2. Monitoring stations in Belgrade.

Monitoring station	Classification	Latitude	Longitude
Old Belgrade	urban background	44.82112	20.45911
New Belgrade	urban background	44.80318	20.40015
Belgrade, Mostar	urban traffic	44.79875	20.45018

The Health Impact Assessment (HIA) included $PM_{2.5}$ DMVs from 3 monitoring stations. The number of attributable cases was determined on the number of premature deaths for Old Belgrade and New Belgrade for the period 2018-2020.

2.1. Overview of the study region

Belgrade is the capital and largest city of Serbia. It is located at the confluence of the Sava and Danube rivers and the crossroads of the Pannonian Plain and the Balkan Peninsula. The city has an urban area of 360 km^2, while together with its metropolitan area it covers 3,223 km^2. Nearly 1.7 million people live within the administrative limits of the City of Belgrade, a quarter of the total population of Serbia (RSO, 2018). The urban part of the city has a population of 1,364,453 (WHO, 2019).

Old Belgrade encompasses older sections of urban Belgrade, which occupies an area of 319.04 km^2, with an estimated number of 932,813 inhabitant (City of Belgrade, 2021; *Municipality SG*, 2021; WHO, 2021).

New Belgrade is modern part of the City of Belgrade, built since 1948 in a previously uninhabited area on the left bank of the Sava river, opposite of Old Belgrade, which covers an area of 40.96 km^2(*Municipality NB*, 2021), with 431,640 inhabitants (WHO, 2019).

2.2. Data sources

The analysis is based on the DMV of $PM_{2.5}$ concentrations in the period 2018-2020, obtained on the basis of measurement results from all measuring stations in Belgrade. The measurement results were obtained from the database of the Serbian Environmental Protection Agency (SEPA), Ministry of Environmental Protection of the Republic of Serbia.

2.3. Methodology

Validated measurements from both automatic and manual sampling are submitted to the European Commission (EC) every year until the end of September of the year following the year in which the measurements were performed. The EC uses them to verify compliance with the requirements of the ambient air quality directives. In addition to measurements, countries can also use models to assess air quality (EEA, 2019).

2.4. Automatic measurement methods and equipment for air quality monitoring

Unfortunately, monitoring of all parameters for which automatic monitoring is foreseen is not yet possible at all measuring stations, which also applies to $PM_{2.5}$ (SEPA, 2020).

Time series of concentrations of the $PM_{2.5}$ are useful to assess their variability and to monitor possible trends in their evolution.

2.5 Suspended $PM_{2.5}$ particles

Determination of $PM_{2.5}$ concentrations is performed continuously with GRIMM EDM 180 Aerosol Spectrometer devices. The method is equivalence with SRPS EN 14907, Ambient air quality - Standard gravimetric method for the determination of the mass fraction of $PM_{2.5}$ (Regulation, 2013; SEPA, 2012).

2.6 Health impact assessment (HIA) analysis

The method is based on the recent WHO recommendations for concentration–response functions developed in the Health Risks of Air Pollution in Europe project (WHO, 2019). The estimated AP of total mortality attributable to air pollutants was assessed by the AirQ+ program. The AirQ + model is an effective method for quantifying health effects in a given area, due to its convenient combination of data on pollutants and data on the number of cases of premature death.

The HIA analysis in AirQ+ was used to calculate the number of attributable deaths for $PM_{2.5}$ (WHO, 2021). The data required to run the analysis is the total population at risk (adults aged 30+), pollutant caused premature deaths ($PM_{2.5}$) and the average pollutant concentration ($PM_{2.5}$). The program`s default relative risk (RR) for all (natural) cases and the cut-off value of 10μg/m^3 was used. RR due to air pollution is usually modelled with a log-linear funcion

$$RR = exp(\alpha + \beta X)/exp(\alpha + \beta X_0) = exp[\beta(X - X_0)] \qquad (1)$$

where X denotes the pollutant concentration (μg/m^3), and Xo denotes the cut-off value. In the log-linear model, ß denotes the change in the RR for a one-unit change in concentration X.

3. Results

3.1. Results of descriptive analysis

Due to the large number of hourly concentration data for $PM_{2.5}$ from measuring station 3, during the period of 3 years, an analysis for the period of one month was done (28 April to 28 May).

The period from 28 April to 28 May was taken into consideration for two reasons:

– it is not the heating season, thus the impact of traffic on the pollution level is dominant
– it is before the vacation season, so it can be taken as a period of usual or average traffic intensity.

Results of the descriptive analysis for the period from 28 April to 28 May for six years, from 2018 to 2020, based on the DMVs of $PM_{2.5}$ concentrations from 3 monitoring stations, are shown in Table 3.

Table 3. Descriptive analysis results for $PM_{2.5}$ concentration for 2018-2020 period.

Year / Conc. (μg/m^3)	2018	2019	2020
Average	8.17	10.23	9.56
Max	16.47	26.10	20.40
VARP	17.88	21.09	14.89
VARS	18.48	21.80	15.38

From the descriptive analysis results it can be seen that the biggest $PM_{2.5}$ DMV was in 2019, whilst the maximal $PM_{2.5}$ concentration value was recorded in 2019, and in 2020 a decrease of maximal $PM_{2.5}$ concentration -21.83 percent. The maximal $PM_{2.5}$ concentration is higher than LV only in 2019.

Variables indicate a deviation in the $PM_{2.5}$ concentrations from DMV in the observed period and it is the biggest in 2019 when there were the most deviations from DMV, followed by slighty less in 2018. The second lowest value of variable was recorded during 2020.

Figure 1 shows a graphical representation of the distribution of the $PM_{2.5}$ concentrations in the observed period for the 3 years considered.

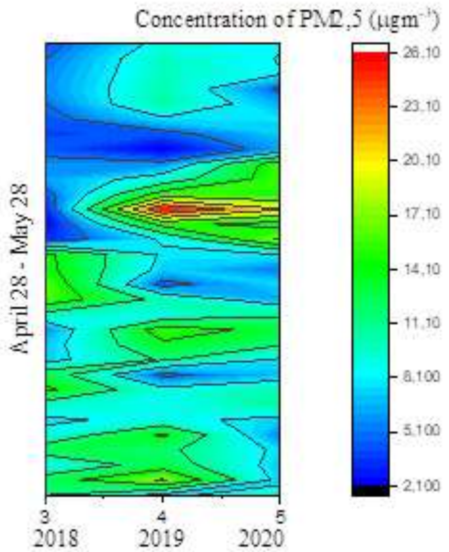

Figure 1. Graphical representation of the distribution of the $PM_{2.5}$ concentrations.

3.2. Results of HIA analysis

Table 4 shows the estimated number of cases that can be attributed in Old and New Belgrade, which was obtained by applying the impact assessment model in AirQ+.

Using Impact Assessment in AirQ+, the number of attributable cases for Old Belgrade PM2.5 in 2018 is estimated to 2,265 (lower 1,518, upper 2,927, which represents a dean increase of; in 2019 is 2,057 (lower 1,373 and upper 2,668), which represents a decrease of -9.18 percent (-9.55 percent and -8.85 percent for lower and upper cases respectively) compared to 2018.

Table 4. Estimated number of Attributable Cases in Belgrade.

Part of Belgrade	**Attributable cases**		
Old Belgrade	Central	Lower	Upper
2018	2265	1518	2927
2019	2057	1373	2668
New Belgrade	Central	Lower	Upper
2018	2159	1445	2794
2019	2298	1539	2973

The number of attributable cases for New Belgrade $PM_{2.5}$ in 2018 is estimated to 2,159 (lower 1,445, upper 2,794); in 2019 is estimated to 2,298 (lower 1,539 and upper 2,973), which represents an increase of 6.44 percent (6.51 percent and 6.41 percent for lower and upper cases respectively) compared to 2018.

4. Discussion

4.1. Discussion of the descriptive analysis results

The maximal $PM_{2.5}$ concentration value was recorded in 2019, and in 2020 a decrease of maximal $PM_{2.5}$ concentration -21.83 percent.

Variables indicate a deviation in the $PM_{2.5}$ concentrations from DMV in the observed period and it is the biggest in 2019 when there were the most deviations from DMV.

On Figure 1 it can be seen that the maximal $PM_{2.5}$ concentration was on 16-18. May during 2019 and slightly lower in the same period during 2020. In 2020 a decrease of maximal $PM_{2.5}$ concentration of 21.83 percent compared to 2019 is noticeable. Trend of $PM_{2.5}$ DMV growth, as well as maximal $PM_{2.5}$ concentration ended in 2020, probably as an aftermath of COVID-19 pandemic lockdown measures. Ambient air pollution plays an important role in the spread and impact of the COVID-19 pandemic, which has been the subject of many scientific studies in recent years (Bao & Zhang, 2020; Berman & Ebisu, 2020; Dantas et al., 2020; Gautam, 2020; He et al., 2020; Marshall, 2020; Rodríguez-Urrego & Rodríguez-Urrego, 2020).Although the total lockdown measures ended right on 28 April, many people kept on working from home, and a lot of people lost their job due to economic crisis caused by the pandemic. Minimal $PM_{2.5}$ concentrations can be noticed on 15-19 2018, 23-26 May 2018, 2019 and slightly less in 2020, as well as 11 May 2019. Most maximal concentrations were in the end of the second decade of May, and most minimal concentrations also in the second as well as the third decade of May. $PM_{2.5}$ concentration, except from anthropogenic sources (Rajšić et al., 2004), primarily traffic, depended on the weather conditions, primarily wind intensity. It is necessary to do additional analysis that will determine that dependence more precisely.

4.2. Discussion of the results of HIA analysis

The estimated number of attributable cases in 2019 compared to 2018 was at a decrease of 9.18 percent for Old Belgrade, and at an increase of 6.44 percent for New Belgrade.

In recent years, it has become the central business district of Belgrade and its fastest developing area, with many businesses moving to the new part of the city, due to more modern infrastructure and larger available space (Stanojevic et al., 2019).That led to further traffic intensification in that part of the city, as well as an increased need for heating large amount of office buildings which were built there in recent years, which inevitably leads to an increase in the concentration of all pollutants generated by those activities, and thus to an increase of $PM_{2.5}$ concentration, which can be explained through the difference in estimated number of attributable cases of deaths for the population at risk.

5. Conclusion

For the descriptive analysis the period of one month out of the heating season (28 April to 28 May) was considered, so the dominant pollutant source is traffic of usual, average intensity. The largest $PM_{2.5}$ concentration value fluctuation is observed during the second decade of May. As the result of a newly emerging systemic crisis of human development the intensity of traffic was lowered. that reflected in a lower maximal value and in a decrease of $PM_{2.5}$ DMV compared to 2019.

The estimated number of attributable cases in 2019 compared to 2018 was at a decrease of 9.18 percent for Old Belgrade, and at an increase of 6.44 percent for New Belgrade. In recent years, it has become the central business district of Belgrade and its fastest developing area, with many businesses moving to the new part of the city, due to more modern infrastructure and larger available space. That led to further traffic intensification in that part of the city, as well as an increased need for heating large amount of office buildings built there in recent years, inevitably leading to an increase in the concentration of all pollutants generated by those activities, and thus to an increase of $PM_{2.5}$ concentration, which can be explained through the difference in estimated number of attributable cases of deaths for the population at risk.

Progressive reductions in current $PM_{2.5}$ concentrations would bring major health benefits from improving air quality in Belgrade, especially in urban municipalities.

The results of this analysis indicate the importance of reliable air quality monitoring and the need for interventions to reduce the burden of air pollution in Belgrade. Progressive reduction of current concentrations of $PM_{2.5}$ would bring great health benefits from the improvement of air quality in Belgrade, especially in New Belgrade, due to its accelerated development and increased traffic intensity as a consequence of the increased degree of urbanization.

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Prerane smrti zbog izloženosti $PM_{2.5}$ u Beogradu pre i na početku pandemije COVID-19

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Abstrakt: Produžena izloženost uticaju vazduha zagađenog finim suspendovanim česticama ($PM_{2.5}$) često dovodi do respiratornih i kardiovaskularnih bolesti i povećava mortalitet. Statistička analiza satnih koncentracija $PM_{2.5}$ urađena je za period od 28. aprila do 28. maja, od 2018. do 2020. godine. Kvantifikacija zdravstvenih efekata izloženosti zagađenju vazduha urađena je kroz proračun pripisanih smrtnih slučajeva usled dejstva $PM_{2.5}$ 2018. i 2019. godine korišćenjem AirK + procena uticaja za $PM_{2.5}$ u Starom i Novom Beogradu. Utvrđeno je da su 2020. godine maksimalne koncentracije $PM_{2.5}$ smanjene u odnosu na 2019. godinu, najverovatnije kao rezultat karantinskih mera zbog pandemije COVID-19. Procenjeni broj pripisanih slučajeva 2019. godine u odnosu na 2018. beleži veći pad u Starom gradu nego na Novom Beogradu. Porast broja pripisanih slučajeva posledica je bržeg razvoja Novog Beograda u odnosu na Stari Beograd, kao i sve većeg intenziteta saobraćaja u tom delu grada. Progresivno smanjenje koncentracije $PM_{2.5}$ donelo bi velike zdravstvene koristi od poboljšanja kvaliteta vazduha u Beogradu.

Ključne reči: procena uticaja na zdravlje, pripisani slučajevi, prerane smrti, zagađenje vazduha, suspendovane čestice $PM_{2.5}$, AirK+, COVID-19
