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Assessment of particulate pollution in a medium sized Greek city - the effect of biomass burning and COVID-19 lockdown

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Abstract

Airborne particulate matter (PM) with an aerodynamic diameter of 10μm or less has severe negative effects on human health. In many European urban environments, small residential heating appliances contribute significantly to the degradation of air quality by generating a substantial quantity of PM. In the present work, trends of PM_1, $PM_{2.5}$ and PM_{10} have been evaluated in a medium – sized European city, Ioannina, NW Greece. We analyze the most recent available surface concentration observations for the period 2014–March 2021. The analysis showed that even if there is a strict legislation at EU and national level, PM emissions from residential combustion processes contribute significantly to air pollution during wintertime in Ioannina. Local topography, local-scale meteorological conditions and local sources impose a local plan of action to monitor air pollution. The analysis highlights the need for coordinated actions in local and national scale.

Keywords: $PM_{2.5}/PM_{10}$, $PM_1/PM_{2.5}$, urban air quality, biomass burning

1. Introduction

What we know today is that citizens in most cities all over the world are exposed to high concentrations of particulate matter which is related to severe negative effects on their health. Scientific research has shown remarkable concern to warn and enhance awareness about impacts of short-term and long-term exposure to PM. The available evidence suggests a causal association between long- and short-term PM exposure and cardiovascular and respiratory morbidity and mortality (Anderson et al., 2011). The International Agency for Research on Cancer classified outdoor air pollution and particulate matter as carcinogenic to humans, on the basis of sufficient evidence for cancer of the lung in humans (IARC, 2016). Long-term ambient $PM_{2.5}$ exposure is associated with lung cancer incidence even at concentrations below current EU limit values and possibly WHO Air Quality Guidelines (Hvidtfeldt et al, 2021).

It is known that combustion processes such as biomass burning are an important source of airborne particulate matter. But in the mean time, biomass burning is a renewable source of energy and serves the goals of a low carbon society. There have been many incentives to citizens all over Europe to use biomass burning instead of fossil fuels for residential heating (Bahja et al, 2017). Controlling the resulting emissions especially in densely populated areas can be accomplished by setting strict limits on new appliances and on the quality of biomass used as a fuel. European standards have been set for domestic heating systems aiming to improve their environmental performance and minimize the emissions (2009/125/EC; 2015/1189/EC) but the legislation does not seem to have a direct market impact. Incentives given to citizens to renew the existing appliances with technologically advanced systems are not always adequate.

Emissions from residential biomass combustion have been shown to be mainly in the PM_1 range (Price-Allison, 2019; Jaworek et al, 2021). Saffari et al (2013) demonstrated association between increased $PM_{2.5}$ and wood burning tracers' concentrations, because of the expanding use of wood in domestic heating in the city of Thessaloniki, Greece. The high values of $PM_{2.5}/PM_{10}$ and $PM_1/PM_{2.5}$ ratios indicate influence by combustion processes and secondary particle sources. The lower $PM_{2.5}/PM_{10}$ and $PM_1/PM_{2.5}$ ratios indicate influence by natural sources and mechanical processes generating larger particles (Khan et al, 2021; Munir, 2017).

There are limited studies investigating the contribution of residential heating in air quality in Ioannina, northwestern Greece. Sintosi et al (2019, 2021) investigated the regime of air pollution in the city for the period 2010 - 2017 and found that according to European Air Quality Index, the quality of air is characterized as "poor" and "very poor" as far as PM_{10} and $PM_{2.5}$ were concerned because of wood burning for residential heating. In the present work we assess PM_{10},

$PM_{2.5}$ and PM_1 trends in Ioannina for the period 2014 – March 2021 and the effect of COVID-19 lockdown, highlighting the effect of residential heating.

2. Materials and Methods

2.1. Study area and main PM_x emission sources

Ioannina is a city with a population of almost 120.000 citizens. It is the capital of Region of Epirus, Northwestern Greece, located in a plateau (length 37Km and width 13Km) which is surrounded by mountains. It is located 480m above sea level. The city lies along the western shoreline of Lake Pamvotis which has average surface 19.9 Km^2 and mean depth 5m. This certain topography (Fig.1) affects atmospheric circulation, the climate (Koletsis et al, 2009) and as a result air quality. Stable atmospheric conditions are developed which leads to the accumulation of atmospheric pollutants (Pilidis et al, 2005).
The industrial activity of the city is minimal, but the third sector of services is well developed and includes retail trend, tourism, banks, public and private educational institutes and health services. The University of Ioannina, the two hospitals and the airport play a key role in the city's function. The main sources of anthropogenic air pollution are central heating during the cold period of the year and vehicle circulation. Since 2010 the economic recession in Greece forced the majority of citizens to install wood burning appliances for residential heating. Citizens had a financial incentive to switch from fossil fuel to biomass burning. According to the latest inventory in Greece (National Statistical Service of Greece, 2011), there are almost 30.000 buildings in the city. As far as vehicles are concerned, for the year 2020, almost 73.000 passenger cars are in circulation (0.6 per inhabitant) (Hellenic Statistical Authority, www.statistics.gr).

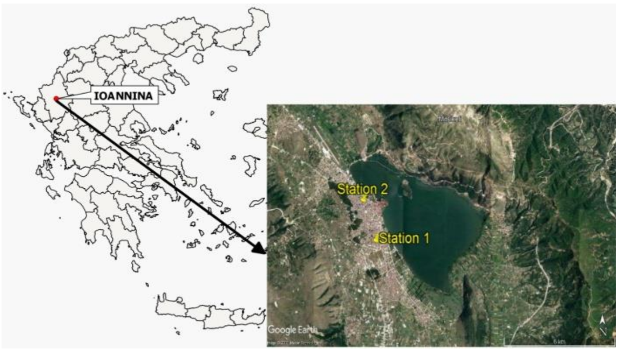

Figure 1. Topography of the study area.

2.2 Climatic characteristics

The climate is continental Mediterranean and is characterized by low temperatures in winter and high temperatures in summer. The warmest months are July and August (mean value 24 - 25^{0}C) and the coldest month is January (mean value 4.6 ^{0}C). Froze is frequent from November to April. The mean wind velocity is 1.5m/s. The highest wind velocity is in March (mean value 1.9m/s). The prevailing wind direction is from north – northwestern direction.
NW Greece is the wettest area of the country with a mean annual precipitation of 1200mm per year (Houssos and Bartzokas, 2006). Precipitation plays a significant role for air quality, as it is high during wintertime and leads to the deposition of PM. According to the data obtained from the meteorological station which is located at the island in the middle of the lake (20°52΄26΄΄, 39°40΄31΄΄, 472m a.s.l.), November is the month with the highest levels of precipitation. Relative humidity is also high in winter with mean value 77% (Fig.2).

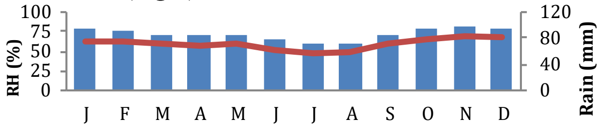

Figure 2: Mean monthly values of Rain (red line) and Relative Humidity (blue bars) in Ioannina for the period 2008-2016.

2.3 Data and instrumentation

In the current work we analyze data about PM_{10}, $PM_{2.5}$ and PM_1 concentrations recorded at the two regional monitoring stations in the city. Both stations are characterized as urban background as they are not directly influenced by emission sources and are representative of the general urban population exposure. The monitoring station at the southern residential area of the city (39^{0}39'11''N, 20^{0}51'15''E, 485m a.s.l.), was set in operation in 2008. The monitoring station located in the city center (39^{0}40'16'' N, 20^{0}50'47''E, 481m a.s.l.), was set in operation in 2019.
In order to assess the contribution of residential heating to the particulate pollution, the cold period is defined from December to February while the warm period of the year is defined from May to October.

3. Results and discussion

During the period of study there are a lot of missing data (Table 1) which is a major limitation for having good understanding of the local pollution problem.

Table 1. Percentage of available PM datasets for the period of study (2014 - March 2021).

Year	PM_1 (%)	$PM_{2.5}$ (%)	PM_{10} (%)	Year	PM_1 (%)	$PM_{2.5}$ (%)	PM_{10} (%)
2014	-	-	100	**2018**	-	-	67
2015	-	-	98	**2019**	93	89	93
2016	-	-	64	**2020**	100	100	94
2017	-	-	73	**2021**	25	25	25

As recorded at the monitoring stations in Ioannina, for the period 2014 – 2020 the annual EU limit value of 40μg/m^3 that is proposed by the EU Directive 2008/50/EC was not exceeded. The mean annual value showed an almost steady variance 30 - 38 μg/m^3 (Fig.3). It must be noted that PM concentrations are highly variable from one year to another dependent not only on meteorology and emissions from anthropogenic sources, but, also, on emissions from natural sources and long-distance dust transport (Saharan dust) (Matthaios et al, 2017).

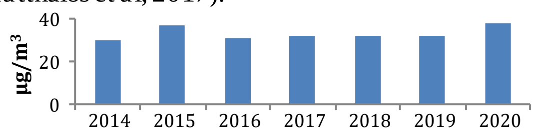

Figure 3. Temporal variation of mean annual values of PM_{10}.

The daily EU limit value 50 μg/m^3 was exceeded more than 35 times a year in 2014 with 37 days in 365 cases, in 2015 with 67 days in 357 cases, in 2018 with 36 days in 246 cases, in 2019 with 40 days in 341 cases and in 2020 with 65 days in 342 cases (Fig.4). The days of exceedances are mainly referred to the cold period of the year.

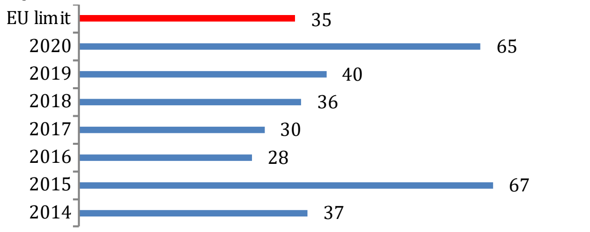

Figure 4. Number of days with daily mean value of PM_{10} more than 50μg/m^3. EU limit: 50 μg/m^3 daily value of PM_{10} not to be exceeded more than 35 days in a year.

Ioannina presents high PM_{10} concentrations during winter, even higher than PM_{10} recorded in larger cities in Greece such as Larisa and Volos, Region of Thessaly, Central - East Greece. Larisa, the fifth most populous city in Greece (almost 162.591 citizens), is an agricultural centre at 67m above sea level. Volos, the sixth most populous city in Greece (almost 144.500 citizens), is a coastal city at 0 - 5m above sea level. The analysis showed that in cold period, population exposure to PM_{10} was higher in Ioannina (Fig.5). Because of their topography, their climatic characteristics are milder than the city of Ioannina which is located in a mountainous area. The lower ambient temperatures in Ioannina during the cold period lead to the need for more residential heating and further to more emissions from stoves, fireplaces, biomass burning combustion appliances.

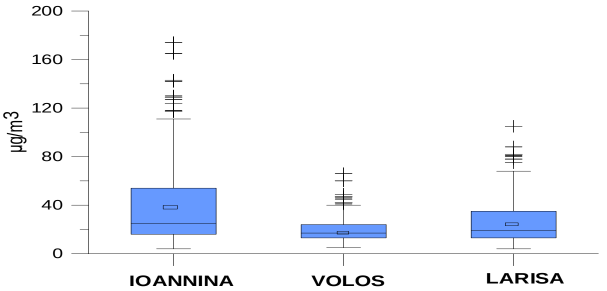

Figure 5: Box – Whisker plots of the daily averages of PM_{10} concentrations at three cities for the period December 2015 to February 2016. Definition of box plots: Line inside box: median. Box limits: quartiles: 25th percentile (lower), 75th percentile (upper). Whiskers: range. - : maximum and minimum value, + : outliers, ◻ : mean value.

The mean value of PM_{10} during the cold months 2015 – 2016 when residential heating is more intense was 40μg/m^3 at Ioannina, 19μg/m^3 at Volos and 26μg/m^3 at Larisa. The maximum daily mean value was at Ioannina 174μg/m^3, at Volos 66μg/m^3 and at Larisa 105μg/m^3. The trend of PM_{10} concentrations in Ioannina during the period 2014-2021 is described by the box plots (Fig. 6 and 7). Significantly high PM_{10} concentrations occur during the cold period (December – January – February) and lower concentrations during the warm period (May to October). During the cold months the mean value ranged from 34 to 60μg/m^3 but during the warm period the mean value ranged from 18 to 33μg/m^3.

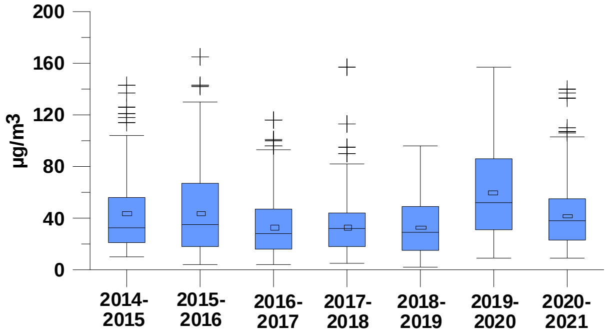

Figure 6: Box – Whisker plots of PM_{10} concentrations in cold period (December – January - February) in Ioannina.

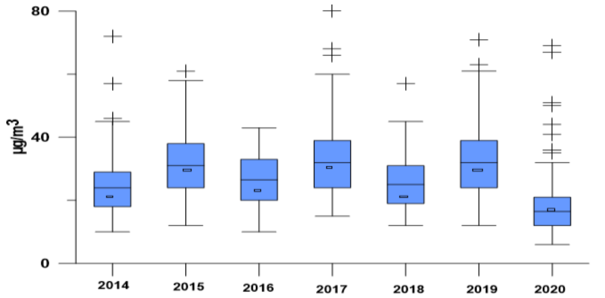

Figure 7: Box – Whisker plots of PM_{10} concentrations in warm period (May to October) in Ioannina.

As far as $PM_{2.5}$ concentrations are concerned, in 2019 the mean annual value was 20μg/m^3 and the average hourly trend presented high values between 19:00-24:00 when there is need for intense house – heating (Fig.8).

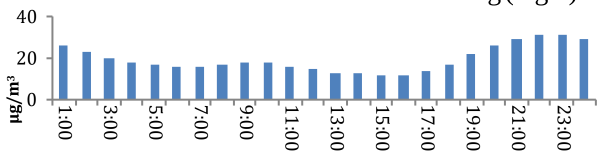

Figure 8: Average hourly $PM_{2.5}$ values in 2019.

In 2020 the available datasets showed that the $PM_{2.5}$ annual mean value was 26μg/m^3 exceeding the annual EU limit value 25μg/m^3. The annual mean value for PM_1 was 23μg/m^3. $PM_{2.5}$ and PM_1 concentrations were higher during the cold heating period (Fig. 9).

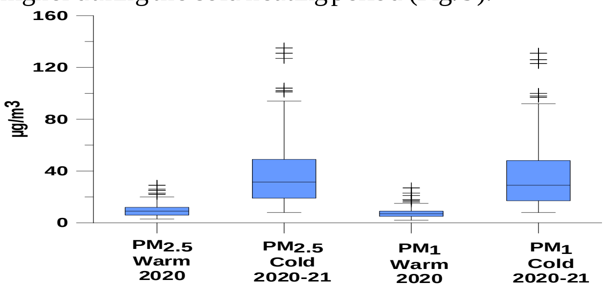

Figure 9: Box - Whisker plots of the daily averages of $PM_{2.5}$ and PM_1 concentrations.

The $PM_{2.5}/PM_{10}$ and $PM_1/PM_{2.5}$ ratios were 0.58 and 0.78 respectively for the warm period of 2020 and for the cold months of the year they showed higher values 0.89 and 0.94 respectively (Table 2).

Table 2: PM ratios of mean daily concentrations 2020.

2020	$\frac{PM_{2.5}}{PM_{10}}$	$\frac{PM_1}{PM_{2.5}}$
Warm period (May – October)	0.58	0.78
Cold months (Jan – Feb – Dec)	0.89	0.94

According to the literature (Khan et al, 2021; Munir, 2017), the higher PM ratios during the cold period of the year could be explained by influence of combustion processes.

During December 2020 – February 2021, the lockdown measures introduced to reduce transmission of COVID-19, caused a decline in the mean values of primary PM_x but did not have any significant influence on PM ratios (Table 3). Even if citizens had to stay indoors and the outdoor activity (vehicular circulation, resuspension of dust) was significantly reduced, substantial quantities of PM were still emitted in air due to residential heating. The $PM_{2.5}/PM_{10}$ and $PM_1/PM_{2.5}$ ratios before and during the lockdown measures did not change. The high values indicate that the emitted PM mass is in the fine mode (Table 3). Because of the low contribution of vehicle emissions, the ratios are mainly affected by residential combustion processes.

Table 3: PM_x mean values and ratios of mean daily concentrations before and during COVID lockdown.

Dec – Jan - Feb	PM_{10}	$PM_{2.5}$	PM_1	$\frac{PM_{2.5}}{PM_{10}}$	$\frac{PM_1}{PM_{2.5}}$
	Mean value (μg/m^3)				
2019 – 2020 (before lockdown)	60	54	51	0.88	0.94
2020 - 2021 (during lockdown)	45	40	38	0.87	0.93

3. Conclusions

PM_{10}, $PM_{2.5}$ and PM_1 concentrations recorded at the urban background stations in Ioannina, a medium – sized city in North – Western Greece, were analyzed to highlight the significant contribution of emissions from residential heating to total particle mass. During the period 2014 – March 2021 the available data time-series showed that the highest concentrations of PM_{10}, $PM_{2.5}$ and PM_1 were recorded during the cold period of the year indicating strong relevance with residential heating. $PM_{2.5}/PM_{10}$ and $PM_1/PM_{2.5}$ ratios were higher in winter and lower in the warm period of the year. The COVID-19 lockdown measures caused a decline in PM_x mean values but did not affect PM ratios.

Distant transport from emission sources needs to be adequately investigated and a source apportionment method should be implemented for safe deductions so as to help local authorities to tackle the air pollution problem. This work stresses the merits of tailoring solutions to the localized pollution problem.

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