Influence of Forest Fires on Levels of PM_{10} and $PM_{2.5}$ in Northern Region of Portugal: Preliminary Study

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Abstract — Every year European citizens become victims of devastating fires being especially disastrous for citizens of Southern European countries. Apart from the obvious damages, such as lost lives and burnt properties, fires generate hazardous pollutants that are further introduced into environment, representing serious risks for public health. In that regard, particulate matter (PM) is among the most important pollutants. Thus, this work aims to evaluate the influence of forest fires on levels of particulate matter, considering PM_{10} and $PM_{2.5}$ fractions collected in north of Portugal in 2010. The results showed that 21 424 forest fires occurred in Portugal in 2010. Northern region was the most affected by forest fires with 27% occurrences in Oporto Metropolitan Area. The annual PM_{10} and $PM_{2.5}$ concentrations of the studied area were 25.9 ± 15.5 μg m^{-3} and 8.4 ± 6.0 μg m^{-3}. The highest levels of both PM fractions were obtained between July and September (31.9 ± 18.1 μg m^{-3} for PM_{10} and 9.6 ± 6.0 μg m^{-3} for $PM_{2.5}$), when the majority (81%) of forest fires occurred. PM_{10} daily limit was exceeded during 16 days (i.e. 4% of the total year days); 63% of exceedances occurred during forest fire season.

Keywords — Air pollution, forest fires, PM_{10}, $PM_{2.5}$

1 Introduction

Since 1990 the number of forest fires has been continuously increasing with longer fire seasons and more potent fires. Although in previous years these increases were supposedly linked with fire suppression policies and weak forest fire prevention strategies, the recent data also suggest a possible influence of climate change and increased global temperature [1].

In Europe forest fires affect mainly southern European countries, such as Portugal, Spain, France, Italy and Greece. During the current decade, fires in those five countries burnt in total average area of 430 798 ha, Portugal represented 1/3 of that area with 150 101 ha [2]. In order to prevent forest fires, European Union invests every year millions of Euros, but the results are not satisfactory, particularly in Mediterranean high risk areas. In 2008 Portuguese Authorities significantly increased the number of means available for surveillance, detection and fire-fighting operations. Despite these efforts, in 2009 the burnt area has increased up to 86 674 ha being 5 times higher than during the previous year [2]. Regarding the number of forest fires, the increase was 40% in relation to 2008, showing that in 2009 both number of fire occurrence and burnt area has increased [2]. Typically the Northern and Central region of Portugal are the most affected by the forest fires, possibly due to their vegetations.

The consequences of forest fires are devastating. Apart from the obvious damages, such as lost lives, burnt properties and forests, fires generate hazardous pollutants.

Forest fires are major sources of trace gases and aerosol, and these emissions are believed to significantly influence the chemical composition of the atmosphere and the earth's climate system. The wide variety of pollutants released by forest fires includes greenhouse gases, photochemically reactive compounds, and most importantly, particulate matter [3]. These compounds are then further introduced into environment, representing a serious risk for public health as thousands of people are exposed to high levels of hazardous pollutants [3-4], some of them being more toxic than equal doses collected from ambient air [5].

Particulate matter (PM) is a mixture of solid and/or liquid particles suspended in the air [6]. Chemical composition of PM includes both organic and inorganic substances, covering a wide range of particle diameters, from <0.1 μm up to some 100 μm; the individual particles also vary in their shape and origin. It is usual to classify particles by their aerodynamic diameter and in that regard PM is

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typically divided into two major groups [7]: fine particles that are smaller than 2.5 μm in aerodynamic diameter ($PM_{2.5}$), and coarse particles ($PM_{2.5-10}$) with aerodynamic diameter between 2.5 and 10 μm. PM_{10} then represents particles with aerodynamic diameter smaller than 10 μm [8].

The size of particles is especially important. Upon inhalation particles are deposited on the walls of airways and lungs; the smaller the particles the deeper the penetration within the respiratory system [9]. While larger particles deposit mainly in the nose and throat, fine particles (i.e. $PM_{2.5}$) penetrate in the deeper parts of the lungs, being able to reach the alveoli and causing severe health impacts. Particulate matter is considered among the most relevant health-hazardous air pollutants. Up to this date epidemiological studies both in Europe and North America [7], [10-14] have shown associations between the increased ambient PM levels and the increase of morbidity and mortality rates, caused by pulmonary and cardiovascular diseases. Exposure to particulate pollution may also lead to lung cancer, cardiac arrhythmias, and to a number of other adverse health effects, such as increasing respiratory symptoms, cough, sore throat, and others [15].

As European Union has recognized the risk that particles pose to the human health it settled the respective standards [8]. Regarding PM_{10}, the legislation sets the values of PM_{10} daily and annual limits. The value of PM_{10} daily limit is 50 μg m^{-3} not being allowed more than 35 exceedances (i.e. 10%) of total year days. For the annual average the standard is 40 μg m^{-3}. The directive is rather recent as it was issued in May 2008; the Member States should have brought this directive in force before June 2010. For Europe, the directive represents a significant step forward as for the first time $PM_{2.5}$ standards were promulgated. So far, the directive does not consider 24 h limit value (or target) for $PM_{2.5}$. Regarding the annual limit value, the directive considers two different implementation phases, the first one till 2015 and the second one till 2020, with annual $PM_{2.5}$ limits of 25 μg m^{-3} and 20 μg m^{-3}, respectively (depending on the evidence, feasibility and outcomes of the 2013 review) [8].

The objective of this work was to evaluate the influence of forest fires on levels of particulate matter considering PM_{10} and $PM_{2.5}$ fractions. PM concentrations were monitored during 365 days of 2010 in north of Portugal at an urban background site.

2 MATERIALS AND METHODS

2.1 Sample Collection

PM_{10} and $PM_{2.5}$ concentrations were monitored in Oporto Metropolitan Area [16-20] situated in north of Portugal, at Sobreiras site (latitude 041° 08' 51" N, longitude 008° 39' 32" W). The site belongs to the Portuguese monitoring network and is considered as urban background.

PM concentrations were obtained through the beta radiation attenuation method, considered equivalent to the one advised by EU Directive 1999/30/CE [21] and by Decreto-Lei n◦ 111/2002 [22], using the equipment MPSI 100 I et E from Environment S.A. The equipments were submitted to a rigid maintenance program being periodically calibrated. The measurements were made continuously registering hourly averages of concentrations in μg m^{-3}. The hourly, daily, monthly and annual averages of PM_{10} and $PM_{2.5}$ concentrations in the respective site were statistically analysed between January 1 and December 31 of 2010. The Student's t-test was applied to determine the statistical significance ($P<0.05$, two tailed) of the differences between the means determined.

3 RESULTS

3.1 Forest Fires

The 2010 provisional data of Portuguese Forest Fires Registry show that during the respective year total area of 128 842 ha was burnt during 21 424 forest fire incidents [23]. This occurrence includes 17 674 smaller fires (i.e. burnt area of each incident less than 1 ha) and 3 750 fires (area burnt during an incident bigger than 1 ha).

Table 1 shows the 2005-2010 forest fire occurrences in Portugal and the respective burnt areas.

Table 1. 2005-2010 data on forest fires in Portugal: occurrences and burnt area (ha) [23-28]

Year	Occurrence	Burnt area (ha)
2005	35 698	338 262
2006	21 816	74 342
2007	18 722	31 450
2008	13 832	17 244
2009	26 136	86 674
2010	21 424	128 842
$\Sigma_{2005-2010}$	137 628	676 814

After devastating fires in summer of 2005 the Portuguese Authorities settled a reform on the national system for forest fire prevention and suppression, adopting the National Fire Plan with the goal of total annual burnt area lower than 100 000 ha (to be obtained by 2012) [2]. As it can be seen in Table 1, Portugal was able to meet this target of the National Fire Plan between 2006 and 2009. Other policy measures included, for example, the establishment of preventive measures for forest fires prevention [29-30], definition of forest management plan concerning risks namely for forest fires [31], definition of fire district plans [32] or publishing regulation of prescribed fires and other technical fires [33]. Despite these continuous efforts which required vast financial resources, the target of the annually burnt area was not met in 2010. In comparison with 2009, the year of 2010 was characterized by fewer fire incidents but with much larger area burnt (an increase of 49%) [23].

To evaluate the seasonal distribution of forest fires, Table 2 shows fire occurrences and respective burnt area during the four trimesters of 2010. Furthermore, the mean temperatures of the respective periods are also shown.

Table 2. Distribution of forest fires during four trimesters of 2010 in Portugal: occurrences and burnt area (ha) [23]

Trimester	Temperature (°C)	Occurrence	Burnt area (ha)
I	12	530	740
II	18	2 882	2 761
III	23	17 450	123 162
IV	14	562	1 578

The majority of forest fires occurred during the 3rd trimester. This trimester, which includes July, August, and September, was characterized by the highest temperatures (mean of 23 ± 2 °C) and accounted for 81% of the total fires occurrences and 96% of the total burnt area. Specifically, 43% of forest fires occurred in August resulting in 98 234 ha (i.e. 77%) of burnt area; in July and September 25% and 15% of forest fires occurred with 21 177 ha (i.e. 17%) and 3 751 ha (3%) burnt, respectively. Due to the meteorological conditions, summer months are generally more typical for forest fires incidences [1] and as it can be seen in Table 2; 2010 data corroborates these findings. On the contrary, during the 1st trimester, which was the coldest period of year (i.e. January till March, mean temperature of 12 ± 1 °C) the occurrence of forest fires and the respective burnt area were the lowest, showing the association with the meteorological parameters.

To evaluate occurrences of forest fires in relation of geographical location, Table 3 presents data for five Portuguese regions: Northern, Central, Lisbon and Tejo Valley, Alentejo, and Algarve.

Table 3. Number of forest fires in 2010 in five Portuguese regions and the respective burnt area (ha) [23]

District	Occurrence	Burnt area (ha)
Northern	11 983	68 997
Central	6 607	54 660
Lisbon and Tejo Valley	2 313	4 199
Alentejo	199	882
Algarve	322	104

As it can be seen in Table 3, Northern and Central regions were the Portuguese regions that were the most affected by the forest fires in 2010. 56% of forest fires occurred in the Northern region (Fig.1), which corresponded to 54% of the total area burnt. Regarding Oporto Metropolitan Area that belongs to the Northern region, the number of forest fires was 5 879 (27%), being the highest one in Portugal. The respective burnt area was, however, relatively small, i.e. 8 508 ha (approximately 7%). These results were due to the high number of fire incidents (90%) that burnt an area smaller than 1 ha.

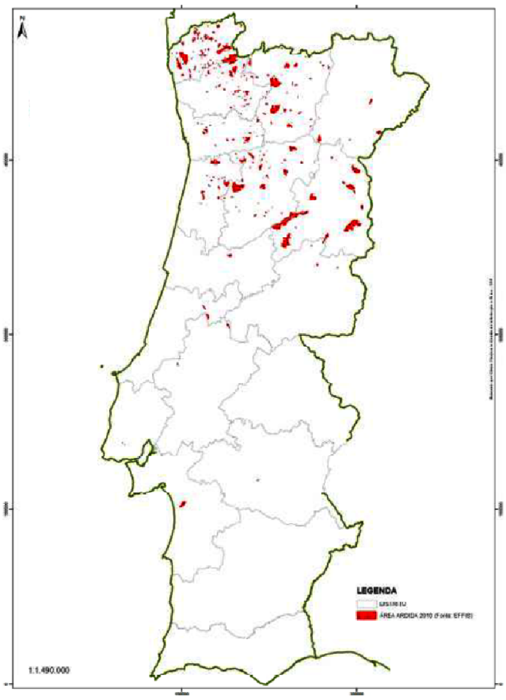

Fig. 1. Burnt areas due to forest fires incidents in Portugal during 2010, adapted from "Portuguese Forest Fires Registry" [23].

3.2 PM_{10} and $PM_{2.5}$ concentrations

The obtained annual average at Sobreiras was 25.9 ± 15.5 µg m^{-3} for PM_{10} and 8.4 ± 6.0 µg m^{-3} for $PM_{2.5}$. Table 4 presents the statics of the obtained data.

Table 4. Statistics for PM_{10} and $PM_{2.5}$ concentrations measured at Sobreiras (μg m^{-3}) during 2010

Parameter	PM_{10}	$PM_{2.5}$
Average	25.9	8.4
Standard deviation	15.5	6.0
Minimum	3.0	1.0
Maximum	95.0	77.0
25th percentile	15.0	5.0
75th percentile	32.5	10.0

In order to analyze the exceedances of PM_{10} and $PM_{2.5}$ concentrations, the values collected at Sobreiras site were compared with the limits settled in the Directive 2008/50/EC [8]. As it can be seen, both obtained PM_{10} and $PM_{2.5}$ annual averages met the European Directive limits of 40 μg m^{-3} and 25 μg m^{-3}, respectively [8]. The daily limits were evaluated only for PM_{10}, once they do not exist for $PM_{2.5}$. The value of 50 μg m^{-3} of PM_{10} daily limit was exceeded at Sobreiras during 16 days (i.e. 4% of the year days), thus fulfilling the European legislation.

To evaluate PM levels during various periods of year, Table 5 present the PM_{10} and $PM_{2.5}$ concentrations at Sobreiras during the four trimesters of 2010.

Table 5. PM_{10} and $PM_{2.5}$ mean concentrations at Sobreiras during four trimesters of 2010

Trimester	PM_{10}	$PM_{2.5}$
I	21	7.4
II	23	7.6
III	32	9.6
IV	20	7.0

The highest levels of both PM fractions were observed during the 3rd trimester when the majority of forest fires occurred (Table 2). Specifically a mean of PM_{10} concentrations with values of 33.5 ± 18.1 μg m^{-3} and 32.9 ± 16.5 μg m^{-3} were obtained in July and August, respectively, whereas in September the PM_{10} mean was 23.5 ± 12.4 μg m^{-3}. Regarding the $PM_{2.5}$, the corresponding means were 9.3 ± 7.0 μg m^{-3} and 10.7 ± 4.1 μg m^{-3} during July and August 2010, respectively; whereas it was 7.6 ± 3.0 μg m^{-3} in September. It is possible to conclude that forest fires increased the respective levels PM_{10} and $PM_{2.5}$ in air. Showing the strong influence of forest fires accidents, the 3rd trimester also represents a period with the highest exceedances of PM_{10} daily limits as demonstrated in Table 6; 63% of the total PM_{10} daily exceedances occurred during summer months (i.e. July-September) when the frequency of forest fires was the highest.

Table 6. Exceedances of PM_{10} daily limit during four trimesters of 2010 at Sobreiras

Trimester	Number of days
I	1
II	2
III	10
IV	3

4 Conclusions

Forest fires represent a serious risk, therefore in order to protect public health and environment it is fundamental to reduce their occurrence.

During the year of 2010, 21 424 forest fires occurred in Portugal, which resulted in burnt area of 128 842 ha. 81% of the incidents occurred during the summer months, i.e. between July and September of 2010. Northern region was the most affected Portuguese region by forest fires (87% of occurrences). Specifically, 27% of the forest fires occurred in Oporto Metropolitan Area, 90% of those fires was smaller incidents with burnt area less than 1 ha.

The annual concentrations obtained at Sobreiras was 25.9 ± 15.5 μg m^{-3} for PM_{10}, and 8.4 ± 6.0 μg m^{-3} for $PM_{2.5}$; both values met the annual limits of the current European Directive.

Forest fires increased the levels PM_{10} and $PM_{2.5}$ in air. The highest levels of both PM fractions were obtained between July and September (31.9 ± 18.1 μg m^{-3} for PM_{10} and 9.6 ± 6.0 μg m^{-3} for $PM_{2.5}$), which corresponded to the period when the majority of forest fires occurred. Finally, the value of PM_{10} daily limit was exceeded during 16 days at Sobreiras (i.e. 4% of the total year days); 63% of those exceedances occurred during the forest fire season.

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