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Atmospheric Particulate Matter and Ozone under Heat-Wave Conditions: Do They Cause an Increase of Mortality in Croatia?

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Abstract In August 2003 Croatia experienced a heat-wave period during which elevated concentrations of particulate matter (PM10) and ozone in ambient air were measured. By applying the model of Stedman and Rooney et al., it was shown that a significant part of excess mortality during this period can be attributed to PM10 and ozone in ambient air.

Keywords Particulate matter · Ozone · Heat-wave · Excess mortality · Croatia

Some one hundred years elapsed after the discovery of ozone before atmospheric chemists became aware that human activities (mainly production of nitrogen oxides) had increased the concentration of ozone in the planetary boundary layer (Kley and Volz 1988; Lisac and Grubišić 1991; Scheel et al. 1997); and that, throughout this period, there had been a steady increase of the ozone concentration in the lower atmosphere. Life on Earth had never been exposed to such elevated ozone concentrations, and this happenstance could well be a cause for some concern (Cvitaš et al. 2005). Conclusive evidence of an impact on the life expectancy (or mortality) of a population caused by an air pollutant, especially when the pollutant, ozone, is a natural constituent of the atmosphere, could well be very elusive. Nonetheless, there is a broad consensus that such a link exists. Thus, global epidemiological studies (Nel 2005; WHO 2003; Keiser 2005) do show an increase of heart- and respiratory-disease-related deaths linked to exposure to atmospheric particulate matter (PM). PM is a key ingredient of polluted air and, supposedly, is the cause of death >500,000 people annually. Hundreds of studies have suggested that the fine particles emitted by vehicles, factories, and power plants can trigger heart attacks and worsen respiratory disease in vulnerable populations, supposedly causing approx. 60,000 premature deaths per annum in the United States alone (Keiser 2005). Recent papers (Stedman 2004; Fischer et al. 2004) describe a correlation between mortality and air pollution in Great Britain and the Netherlands during the 2003 heat wave implied a causal connection between the increased mortality and the PM/ozone concentrations. These results suggest that high levels of oxidants may have a deleterious effect on life. We attempt here to provide evidence of a similar observation in Croatia.

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Materials and Methods

Ozone was measured spectrophotometrically during the heat wave in August 2003 at the Ruđer Bošković Institute in Zagreb with a Dasibi model 1008 AH instrument; volume fractions were collected every 3 min in a data logger prior to transfer for data processing. An API Ozone Monitor Model 400 was used for the same purpose in Rijeka (at the Teaching Institute of Public Health); it recorded volume fractions every minute and the data were processed on EnviMan software (Opsis).

Particulate samples were measured starting in 1999 at the Institute for Medical Research; the PM were collected on glass-fibre filters at rate of air flow of 2.3 $m^3 h^{-1}$ (101,325 Pa, 20°C) by a low volume sampler (LVS3, Ingenieurbüro Sven Lechel) in compliance with the EU standard EN 12341. Daily, 24-h samples were taken every noon. The filters were weighed on a microbalance (Mettler Toledo MX-5). A TEOM Model 1400a analyzer (Rupprecht&Pataschnik) was used for determination of the PM_{10} fraction in Rijeka, measuring volume fractions every 5 min. This monitoring station was also located in the very same street as the Institute for Public Health, on ground level and adjacent to a busy street.

Results and Discussion

We tried to find a possible correlation of mortality, as recorded in the Statistical Annals (2004) for the cities of Zagreb and Rijeka for the period 1999–2002, with ozone and particulate matter concentrations on the basis of measured daily average ozone concentrations and monthly average concentrations of particulate matter less than 10 μm in diameter (PM_{10}). The effects of ozone and PM concentrations were assumed to be mutually independent and additive, in accord with previous studies (WHO 2003; Stedman 2004), even though it is known that elevated particle concentrations do destroy ozone (Alebic-Juretic et al. 1997; Alebic-Juretic et al. 2000). The monitoring site in Rijeka was adjacent to traffic and, as expected, the PM_{10} count is above normal whereas the ozone count is below average indicating destruction of ozone by exhaust gases. An excess mortality during heat waves is a well known fact, often attributed solely to temperature (Kunst et al. 1993; Donoghue et al. 1995; Michelozzi et al. 2004; Whitman et al. 1997). A few studies have attempted to estimate the independent effects of pollution and heat (Rooney et al. 1998; McMichael 1996). These authors studied the degree to which the heat wave of July 30 to August 3, 1995 produced an excees mortality in England and Wales, and made an attempt to relate it to air pollution. They repeated the analysis for the city of London and made an attempt to separate the effects of heat and pollution. They found that concurrent air pollution could account for 38% and 62% of the excess mortality in Greater London and England/Wales, respectively.

Record high temperatures and ozone concentrations were measured during the second week of August 2003 in Zagreb. Based on the British and Dutch studies, it was estimated that an extra Croatian death toll of 100 (Butković et al. 2004) could be attributed to elevated PM and ozone levels during this heat wave. We now analyze this estimate for Zagreb (population 800,000) and Rijeka (population 150,000) using statistical data for mortality, for daily PM_{10} concentrations expressed as a monthly average, and for daily ozone and PM_{10} concentrations during the photosmog episode of 8–14 August, 2003. We used the Stedman dose-response functions for PM_{10} and ozone (Stedman 2004; COMEAP 1998). In order to assess excess mortality during the heat-wave, we used the data for average annual mortality from the Municipal Bureau on Statistics: an average of 9,710 for the period 1999–2002 in Zagreb and 1559 for the period 2002–2004 in Rijeka, respectively. We also used the British dose-response functions: these attribute a 0.6% mortality rise for every increase of 10 μg m^{-3} (5 ppb) in ozone concentration and a rise of 0.75% for an increase of every 10 μg m^{-3} in PM_{10} concentration, respectively (COMEAP 1998). The average daily values in the two cities for PM_{10} and ozone for the period 8–14 August 2003 are shown in Table 1.

Table 1 Average daily values for ozone and PM_{10}, August 8–14, 2003

DAY	ZAGREB		RIJEKA	
	O_3 (μg/m^3)	PM_{10} (μg/m^3)	O_3 (μg/m^3)	PM_{10} (μg/m^3)
8.8	170.3	20.5	85.6	61.9
9.8	171.5	23.0	84.1	86.8
10. 8.	207.8	16.9	88.8	54.6
11.8	184.4	24.3	80.1	77.2
12.8	197.7	35.4	72.5	48.0
13.8	239.1	20.6	85.4	105.6
14.8	245.4	18.3	90.2	84.1

It is generally acknowledged that all levels of PM do affect health (i.e., that the current detection limit lies above that PM concentration that produces adverse health effects). Ozone is a natural constituent of the atmosphere and there is little hope of ever showing that it affects life below its natural levels. Life on Earth is probably adapted to such conditions. Consequently, we calculated the effect of ozone in two ways: one in the absence of a threshold concentration and the other, previously suggested (COMEAP 1998), on the assumption of a threshold of 100 μg m^{-3}. The average PM_{10} and ozone concentrations for the period 12 noon 8–14 August, 2003 were found to be 22.7 ± 6.1 and 202.3 ± 30.4 μg m^{-3} in Zagreb and 74.0 ± 20.3 and 83.8 ± 5.9 μg m^{-3} in Rijeka, respectively,. For these seven days the average mortality for Zagreb corresponds (very roughly) to $9{,}710 \times 7/365 = 186.2$ and Rijeka to $1{,}559 \times 7/365 = 29.9$. With the assumption of independence (i.e. an additivity of the health effects of these two pollutants), the calculated excess deaths for Zagreb and Rijeka based on the dose-response functions are shown in Table 2.

According to Table 2 and assuming identical conditions for all of Croatia during the same period, we estimate 70 excess deaths due to the combined effects of PM_{10} and

Table 2 Calculated excess deaths for Zagreb and Rijeka during the heat wave 8–14 August 2003 associated with the combined effect of PM_{10} and ozone

	Zagreb			Rijeka		
	PM_{10}	ozone	PM_{10} + ozone	PM_{10}	ozone	PM_{10} + ozone
With limiting value	3	11	14	1.6	0	1.6
Without limiting value	3	22	25	1.6	1.5	3.1

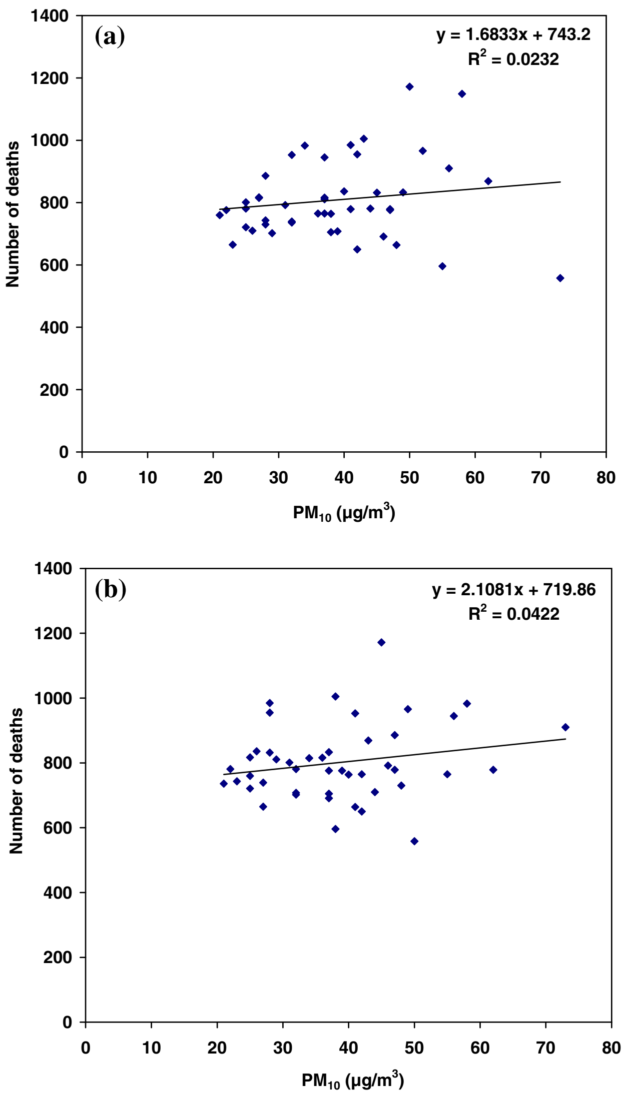

Fig. 1 Correlation of monthly mortality in Zagreb with monthly values for PM_{10}, as measured from 1999 to 2002, with **a** and without **b** a time-shift of 1 month

ozone assuming the suggested threshold value of 100 µg m^{-3} for ozone, or of 125 excess deaths without any such threshold. Of these only 50% can be attributed to air pollution by ozone and particulates because heat exposure takes an additional toll (Rooney et al. 1998). This implies that a residual of 30–60 of the estimated excess deaths remain. It must be said that such an estimate for Zagreb is probably too conservative because its population, in comparison to that in England, is well adapted to high daily temperatures. Although this estimate is not based on actual death cases, it is indicative that, in the statistical records, the number of deaths in Zagreb for the months July–August–September in 2002, 2003 and 2004 were 2258, 2350 and 2259, respectively. Thus in 2003 the year of the photosmog episode, we see an excess of ~100 deaths. A similar pattern appears in the district of Rijeka, where the number of deaths in the same periods in 2002, 2003 and 2004 were 785, 815 and 691, respectively.

We have also tried to compare the British function for PM_{10} with the monthly average values for PM_{10} and mortality in the city of Zagreb (Fig. 1a, b). In spite of low significance ($r^2 = 0.02$) the correlation of these data points shows that an increase of 10 µg m^{-3} in the average PM_{10} concentration results in a higher monthly mortality of 17 persons (Fig. 1a). That is the average mortality in the city of Zagreb (809 deaths/month) increases by 2% for every 10 µg m^{-3}.

Figure 1b indicates that the correlation of PM_{10} concentration and mortality is not as direct: the correlation improves by postponing the mortality response by one month, indicating that the effect is not necessarily short-time. Neither correlation however satisfies the 0.90 significance level ($n = 46$; ?t? = 1.04 and 1.37 for Fig. 1a, b, respectively). We are fully aware that our estimates of excess mortality in Croatia during the heat-wave period in August, 200 can be heavily criticized. Nonetheless, this analysis, which was performed in analogy to much better evaluations, shows that an increased mortality did exist, If we intend to prevent excess deaths in the future, a much better assessment of the relevant factors (e.g., air pollution, epidemiological and mortality statistics on a daily basis) is needed in Croatia. It seems sad that the data we have used are the only ones in existence for the heat-wave.

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References

Alebic-Juretic A, Cvitas T, Klasinc L (1997) Ozone destruction on solid particles. Environ Monit Assess 44:241–247

Alebic-Juretic A, Cvitas T, Klasinc L (2000) Kinetics of heterogeneous ozone reactions. Chemosphere 41:667–670

Butković V, Cvitaš T, Kezele N, Klasinc L, Šorgo G, Žegarac R (2004) Zagreb photosmog episode in August 2003. Croat Meteor J 39:139–140

COMEAP (1998) Quantification of the effects of air pollution on health in Great Britain. Department of Health Comitee on the Medical Effects of Air Pollutants. The Stationary Office. ISBN 0-11-322102-9

Cvitaš T, Kezele N, Klasinc L, McGlynn SP, Pryor WA (2005) New directions: how dangerous is ozone? Atmos Environ 39:4607–4608

Donoghue ER, Kalelkar MB, Boehmer MA, Wilhelm J, Whitman S, Good G, Lyne S, Lumpkin J, Landrum L, Francis BJ (1995) Heat-related mortality-Chicago, JAMA-J Am Med Assoc (1995) 274(8):602–602 (reprinted from MMWR 1995) 44:577–579

Fischer PH, Brunekreef B, Lebret E (2004) Air pollution related deaths during 2003 heat wave in the Netherlands. Atmos Environ 38:1083–1085

Kaiser J (2005) Mounting evidence indicts fine-particle pollution. Science 307:1858–1859

Kunst AE, Looman CWN, Mackenbach JP (1993) Outdoor air temperature and mortality in the Netherlands: time series analysis. Am J Epidemiolog 137:331–341

Kley D, Volz A, Mulheims F (1988) Ozone measurements in historic perspective. In: Isaksen ISA (ed) Tropospheric ozone. D.Reidel Publishing Company, p 63–73

Lisac I, Grubišić V (1991) An analysis of surface ozone data measured at the end of the 19th-century in Zagreb, Yugoslavia. Atmos Environ A 25:481–486

McMichael AJ, Haines A, Stoff R (1996) Climate change and human health, WHO, Geneva

Michelozzi P, Donato F, Accetta G, Forastiere F, Ovidio M, Perucci C, Kalkstein L (2004) Impact of heat waves on mortality–Rome, Italy, June–August 2003. MMWR 53:369–371

Nel A (2005) Air pollution-related illness: effects of particles. Science 308:804–805

Rooney C, McMichael AJ, Kovats RS, Coleman MP (1998) Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. J Epidemiol Commun Health 52:482–486

Scheel HE, Areskoug H, Gei H, Gomiscek B, Granby K, Haszpra L, Klasinc L, Kley D, Laurila T, Lindskog A, Roemer M, Schmitt R, Simmonds P, Solberg S, Toupance G (1997) On the spatial distribution and seasonal variation of lower troposphere ozone over Europe. J Atmos Chem 28:11–28

Statistical annals for the city of Zagreb (2004) In: Šabić M (ed) Statistički ljetopis grada Zagreba. Gradski zavod za planiranje razvoja Grada i zaštitu okoliša. Odjel za statistiku. ISSN 1334-6644. Zagreb p 42

Stedman JR (2004) The predicted number of air pollution related deaths in the UK during the August 2003 heat wave. Atmos Environ 38:1087–1090

Whitman S, Good G, Donoghue ER, Benbow N, Shou WY, Mou SX (1997) Mortality in Chicago attributed to the July 1995 heat wave. Am J Public Health 87:1515-1518

World Health Organization (2003) Health aspects of air pollution with particulate matter, ozone, and nitrogen dioxide. Report on a WHO working group. Available at <http://www.euro.who.int/document/e79097.pdf>. See also UN Environmental Program and WHO Report, Environment (1994) 36:1–33