Comparative Analysis of Indoor and Outdoor TSP Concentrations in Bombay, Toronto, and Zagreb

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1 INTRODUCTION

Air pollution concentrations in urban areas vary in both time and space (Munn, 1981). Time variations are strongly influenced by changes in human activities. Several activities occur repeatedly at regular intervals thus producing cycles in air pollution changes, like daily variations in CO concentration due to the change in traffic density or seasonal variations in air pollution (e.g., from heating systems which in moderate climates operate mainly in cold months).

Spatial patterns of pollution concentrations over a given area depend on the number, type, strength, and distribution of various sources, and on the diffusion potential of the atmosphere. Such patterns will change somewhat according to prevailing weather conditions. However, the basic underlying pattern of air pollution concentrations over a given area generally remains fairly constant with some areas having higher levels most of the time (e.g., busy downtown) than the other areas (e.g., suburbs).

Most urban areas employ networks of stationary air monitoring stations to measure levels of air pollutants. Such networks serve a useful purpose in that they indicate both spatial and temporal variations in concentrations of an air pollutant. The purpose of this monitoring is to protect human health by assuring that concentrations have not exceeded health-based concentrations or standards.

The assumption that a set of ambient air pollution measurements adequately delineate a person's exposure is now being questioned. First, most people move about during their daily activities, from areas of relatively low pollution concentrations to high ones and back again. Secondly, persons spend on the average 80 to 90 percent of their time indoors breathing indoor, not outdoor, air. Lastly, several studies have shown that indoor air pollution can be quite high depending on climatic conditions, building construction, and lifestyle factors (e.g., cooking practices and cigarette smoking).

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To test some of the above statements, a few years ago the World Health Organisation initiated four air pollution exposure studies. These studies were carried out in Toronto (WHO, 1982a), Zagreb (WHO, 1982b), Bombay (WHO, 1984) and Beijing. They form part of the Global Air Monitoring project which is being carried out as part of UNEP's Global Environment Monitoring System (GEMS).

The specific objectives for these studies were to:

(1) Demonstrate personal monitoring techniques that measure exposure to chemicals in air;

(2) Compare findings between outdoor, indoor, and personal exposure measurements; and

(3) Compare human exposures to air pollutants in cities with different pollution profiles, climates, and lifestyles.

The pollutant examined in each study was suspended particulate matter (TSP). The exposure to CO was also measured in Zagreb and Beijing, to NO_2 and SO_2 in Toronto and to sulphate in Bombay. The investigation included measurement of personal exposure, pollutant levels indoors, outdoors in the immediate vicinity of the indoor site, and outdoors at the network monitoring station during summer and winter.

This paper presents the results of three studies of TSP exposure levels in three cities.

2 EQUIPMENT AND METHODS

Measurements of each type were performed by using portable (personal) samplers. In Zagreb and Bombay, cyclone samplers were used to remove the "nonrespirable" fraction of particles. There was a slight difference in cyclone performance; the one used in Zagreb separated particles according to the cut-off curve agreed upon at Johannesburg Conference (Orenstein, 1960) while the one used in Bombay separated particles according to the Los Alamos agreement (Lippman and Harris, 1962). The 50 percent cut off of the first cyclone was at 5 μm aerodynamic diameter and of the second at 3.5 μm; the difference in total mass of respirable fraction collected by the two samplers was not significant. The "Gage" samplers used in Toronto for this study were designed to entrain particles of 25 μm or less.

In Zagreb and Bombay, at the network monitoring sites, samples of total suspended particulates were collected by high volume (HV) samplers. In Zagreb, the respirable fraction was obtained by calculation from four stage HV Andersen Cascade Impactor data; in Bombay by portable samplers described earlier. In Toronto, a Gage sampler was also used for outdoor measurements.

3 SAMPLING PROGRAMME

To assess the extent that data obtained by stationary samplers were representative of personal exposure, a sampling programme was designed to measure simultaneously:

(1) Personal exposure to respirable particles of a limited number of subjects;

(2) Concentration of total (TSP) and respirable (RSP) suspended particles at the nearest outdoor network station;

(3) Indoor concentration (IN) in the homes of subjects; and

(4) Outdoor concentrations (OUT) in the immediate vicinity of homes.

The measurements were performed in summer and winter to reveal seasonal differences. Data obtained in Bombay during the monsoon season were not included in this analysis, since they cannot be related to the data from other cities.

4 RESULTS AND DISCUSSIONS

The data on personal exposure and simultaneously measured TSP and/or RSP concentrations indoors, outdoors, and at the outdoor network station are shown in Table 1 along with the IN/OUT and RSP/TSP ratios. The winter/summer ratios of all the data are shown in Table 2.

In spite of some differences in instrumentation, the analysis of results reveals some characteristic features of the personal exposure to particulate matter and of the IN/OUT relationship in the summer and winter seasons:

(1) In each city, personal exposure was higher than indoor or immediate outdoor concentration; in Toronto, it was also higher than the network station data;

Table 1. Exposure to RSP and TSP on the basis of personal, indoor, outdoor, and network station data

		Arithmetic means $\mu g\ m^{-3}$						
						Network Station		
Season	City	Personal	Indoor	Outdoor	In/Out	RSP	TSP	RSP/TSP
Winter	Zagreb	187	90	152	0.59	193	269	0.72
	Bombay	127	118	117	1.05	112	384	0.29
	Toronto	105	68	60	1.12		79	
Summer	Zagreb	114	71	69	1.03	55	102	0.54
	Bombay	67	65	64	1.05	53	220	0.23
	Toronto	124	81	79	1.02		108	

Table 2. Winter/summer ratio of RPS and TSP data

City	Personal	Indoor	Outdoor	Network Station RSP	Network Station TSP	RSP/TSP
Zagreb	1.64	1.26	2.21	3.50	2.64	1.33
Bombay	1.92	1.82	1.83	2.28	1.74	1.31
Toronto	0.85	0.83	0.76		0.73	

(2) In the summer, the indoor and the outdoor levels were similar in all the three cities; and

(3) Due to open windows, the differences between indoor and outdoor concentrations were negligible (i.e., IN/OUT ratio was close to unity).

In winter, the differences between cities were more pronounced because of specific climatic and topographic conditions. In Toronto, TSP concentrations were generally lower in winter possibly due to snow cover which prevents re-entrainment of particles. In Zagreb and Bombay, concentrations were considerably higher in winter than summer; in Zagreb, this was due to space heating and in Bombay, probably to lack of rain.

Zagreb stands out with a much lower indoor/outdoor concentration ratio in winter. This is, however, in better agreement with earlier studies aimed at establishing the infiltration rate (Yocom, 1976). And indeed, the ratio may have been more influenced by the infiltration rate than by the dust created by residents, since the indoor levels were measured in rooms not frequently occupied. The subjects' exposure "at home," monitored separately, was considerably higher than the indoor levels, and showed a very close correlation with the personal exposure.

The analysis of IN/OUT ratio in relation to the site location for Zagreb and Bombay shows that it also decreased with increasing outdoor concentration (WHO, 1982b, 1984) as can be seen from Table 3.

The Bombay data are characterised by very high outdoor TSP concentrations which are not followed by RSP concentration levels. The data from the network monitoring station show that in Bombay only 29.4 percent of TSP in winter and 22.5 percent in summer are in the respirable fraction, while in Zagreb RSP amounts to 72 percent of TSP in winter and 54 percent in summer. The emission data show that over 30 percent of TSP in Bombay is generated by traffic. There are no quantitative data for Zagreb, but combustion is no doubt a major source.

The analysis of the length of time the subjects spent in various microenvironments in Zagreb and Bombay (Table 4) shows that in both cities they spent more than 60 percent of time at home and more than 80 percent indoors. In Zagreb, the subjects spent more time at home in winter,

Table 3. Indoor/outdoor RSP concentration levels and ratios in relation to site location

			Average RSP concentrations $\mu g\ m^{-3}$ and in/out ratios					
		No. of		Winter			Summer	
City	Area	sites	In	Out	In/Out	In	Out	In/Out
Zagreb	Suburb							
	South	3	74	97	0.77	75	72	1.04
	Center	2	99	165	0.55	72	72	1.00
	North	2	105	162	0.67	62	62	1.00
	West[a]	2	99	245	0.42	75	65	1.15
Bombay	Main artery	1	148	172	0.86	111	92	1.21
	Away from traffic	1	81	68	1.19	50	62	0.81

[a] Cement plant in the vicinity

while in Bombay more time was spent at home in summer. The difference could be attributed to the difference in climate; the increase of time spent at home in Bombay in summer could not be accounted for by less time spent at work.

5 CONCLUSIONS

A comparative analysis of personal, indoor/outdoor and network monitoring station data on suspended particulate matter in Zagreb, Toronto, and Bombay has shown that, in spite of differences in climate, topography, and living habits, there are some common characteristics in the relationship of personal exposure and stationary measurement data. It was shown that personal exposure cannot be assessed from single station data but only by personal monitoring. Approximation of a true exposure is likely to be obtained from many concentrations measured in various microenvironments

Table 4. Time (%) spent by subjects in various microenvironments

City Season		At home	At work	Commuting	Other
Zagreb	Winter	66.1	23.1	4.9	5.9
	Summer	63.5	22.6	6.0	7.5
Bombay	Winter	69.7	21.6	6.6	2.2
	Summer	76.9	16.5	5.1	1.6

and by defining critical chemical constituents and their total intake from all routes of entry.

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