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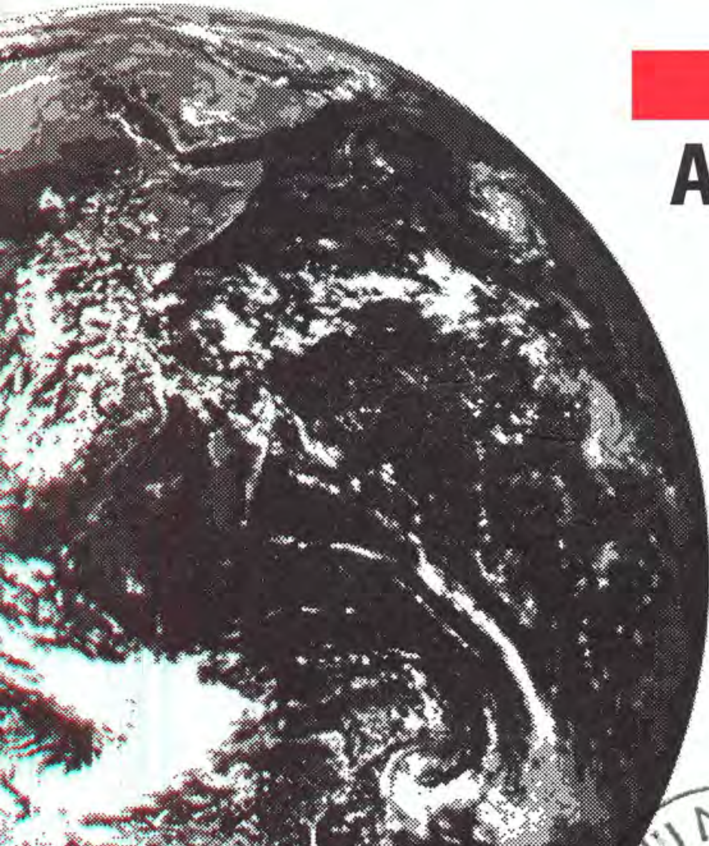

Air Pollution & its Health Effects in China

UNEP

IPCS

International Programme on Chemical Safety

Office of Global and Integrated Environmental Health
World Health Organization

Air Pollution and its Health Effects in China: A Monograph

The understanding gained to date of air pollution in China and its health effects is far from complete. Efforts are therefore being made to bring together relevant data published in China to improve this understanding. This monograph is a contribution to these efforts and a companion volume to the *Proceedings of the WHO/UNEP Air Pollution Workshop, Beijing, China — October 1993* (WHO/EHG/PCS/95.22). It contains two papers. The first is a review paper that seeks to consolidate current knowledge and information concerning outdoor and indoor air pollution in China in urban and rural areas, and the health effects arising from it. The second paper focuses on air pollution and mortality in Shenyang, Liaoning Province, China. A detailed case study, it provides insight into the extent of air pollution in Shenyang and the methodology that can be used to conduct an epidemiology study when only limited resources are available.

Contents

Introduction

Since 1974, the World Health Organization (WHO) and the United Nations Environment Programme (UNEP) have collaborated on an urban air quality monitoring programme that forms part of the Global Environmental Monitoring System (GEMS). Commonly referred to as the GEMS/Air programme it collects air quality data for a large number of cities worldwide. In China, high or very high levels of total suspended particulates and moderate to high levels of sulphur dioxide have been recorded for Shenyang, Xi'an, Beijing, Shanghai and Guangzhou. Rapid economic development means that other cities in China are likely to experience similarly high air pollution levels unless preventive action is taken.

Given that China is a very large country, the GEMS/Air Programme is able to cover only a small number of its cities. The understanding gained so far of air pollution in China and its health effects is therefore far from complete. Efforts are accordingly being made to bring together other relevant data published in China to improve this understanding. This monograph is a contribution on the part of WHO and UNEP to such efforts. It is intended as a companion volume to the *Proceedings of the WHO/UNEP Air Pollution Epidemiology Workshop, Beijing, China, October 1993* (WHO/EHG/PCS/95.22) and contains two papers. The first is a review paper and seeks to consolidate current knowledge and information concerning outdoor and indoor air pollution in China in urban and rural areas, and the health effects arising from exposure to it. Some of these effects are similar to those that have already been well documented in developed countries, including not only elevated morbidity of respiratory diseases, but also elevated mortality among high risk groups. Others appear to be unique to China and due to specific exposure situations. This is the case, for instance, with respect to the association between female lung cancer and indoor combustion of coal for heating and cooking, and the association between airborne endemic fluorosis and indoor combustion of coal with a high fluoride content. WHO and UNEP are very much in favour of this type of national review and hopes that the information provided here will also be useful to other developing countries in their efforts to preserve and/or improve ambient air quality.

The second paper is more specific, focusing on air pollution and mortality in Shenyang, Liaoning Province, China. A detailed case study, it provides insight into the extent of air pollution in Shenyang and the methodology that can be used to conduct an epidemiology study when only limited resources are available. WHO and UNEP have since been pleased to learn that measures are now being taken to study and reduce air pollution in a number of other Chinese cities.

Dr T. Kjellström, Office of Global and Integrated Environmental Health, WHO; Dr H.N.B. Gopalan, Human Health, Welfare and Settlements, UNEP,

and Dr B.H. Chen, International Programme on Chemical Safety (IPCS), were the responsible officers for this project. Dr B.H. Chen was the scientific editor and Ms J. Sawyer, Office of Global and Integrated Environmental Health, WHO, the language editor of this monograph.

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A Review of Air Pollution and its Health Effects in China

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1. Introduction

The study of the health effects of ambient air pollution in China dates back to the 1960s. However, due to insufficient or incomplete data, and lack of analytical quality control in monitoring stations and laboratories, early exposure assessment was for the most part limited to general description of air pollution concentrations and the health complaints of those exposed. It was not until the early 1970s that analytical quality control (AQC) was introduced in some of the major cities. Data quality also improved after China joined the GEMS programme in 1979, AQC gradually becoming accepted as an integral part of laboratory practice.

The first epidemiological studies of air pollution in China were undertaken in occupational settings. But once it became more commonly understood that the chemicals emitted by industrial facilities were a potential health hazard — particularly for local populations — such studies were extended to include residents living in the vicinity of industrial premises. Thereafter, epidemiological air pollution studies were further broadened to include the general population of an urban district, or a city, and a suburban control area. This was the case for a 1976 study on sulfur dioxide (SO_2) air pollution in and around a sulfuric acid plant in Suzhou.

In terms of the literature, the first important collection of air pollution epidemiology papers consisted of the abstracts of papers presented at the first National Conference on Environmental Health convened in Taiyuan, Shanxi, in 1979. The papers were compiled and edited by the Department of Health and Epidemic Prevention, Chinese Ministry of Public Health in Beijing, 1983.(1) This Department was also responsible in 1984 for compiling and editing data collected during a number of air pollution and mortality studies (descriptive) conducted between 1976 and 1981 in 26 cities, namely: Beijing, Shanghai, Tianjin, Haerbin (Harbin), Jilin, Shenyang, Dalian, Urumqi, Lanzhou, Xi'an, Chengdu, Guiyang, Kunming, Taiyuan, Chengzhou, Guilin, Guangzhou (Canton), Wuhan, Changsa, Sanming, Suzhou, Hangzhou, Nanjing, Xiamen (Amoy), Qingdao (Tsintao), and Chongqing.(2)

From then on, relevant papers began to appear in Chinese professional journals. However, most of the studies were descriptive or cross-sectional.

Case–control studies, retrospective cohort studies and time-series studies were not reported on until the late 1980s and early 1990s.

The earlier studies described exposure levels in general terms such as "heavily polluted area", "moderately polluted area", and "suburban control area". This made inter-city comparison difficult, if not impossible. Moreover, the effects of smoking and indoor air pollution were either not referred to at all, or not controlled for. Therefore, with respect to many of the papers published before 1980, it is difficult to distinguish between the health effects of smoking or indoor pollution and those of ambient air pollution. It should also be noted that some of the data analysis methods that are currently in use require computers and software that were not available in China at that time.

Chinese professional journals on environmental health are not readily available worldwide and often of limited circulation, and those written in Chinese are largely inaccessible to readers outside China. This paper therefore seeks to present the relevant data on air pollution in China and its health effects as fully as possible, so that it may serve as both a review paper and a data source. However, shortage of time and difficulty in acquiring unpublished data, mean that this review is not exhaustive.

1.1 Principal air pollutants in China

In China, coal is the predominant fuel. The principal air pollutants are therefore suspended particulates and SO_2. Carbon monoxide (CO) is also a major pollutant in certain circumstances. Nitrogen oxide (NO_x) concentrations used to be relatively low, but have risen considerably in urban areas due to the doubling and tripling in the number of motor vehicles.

2. Assessment of ambient air pollution levels

2.1 Coal-smoke type air pollution in cities

Nearly all the air pollution problems of Chinese cities — other than those caused by the emission of heavy metals or chemicals from industrial complexes — are due to coal combustion. In order to demonstrate the overall situation regarding ambient air pollution levels in a number of Chinese cities, mean concentrations (where available) of total suspended particulates (TSP), SO_2, No_x and benzo(a)pyrene (B(a)P) are presented in Table 1. The cities are listed from north to south, in approximate order of latitude. Names that appear under the name of a city are either urban districts or towns. However, due to differences in data collection methods and the year in which the air quality monitoring was carried out, these figures are not directly comparable.

Neither are they exhaustive. It should be noted that in terms of ambient air pollution levels, there are usually considerable spatial differences between the various districts of a metropolitan city, due to the functional nature of the districts and the direction of the prevailing winds.

The Chinese health-based standard for daily mean concentrations of TSP and SO_2 is 0.15 mg/m^3. Table 1 shows that TSP concentrations in many cities exceeded 0.15 mg/m^3 . In some of the cities and districts — for example, Wanghua District in Fushun, Tiexi District in Shengyang, Beijing, Lanzhou, Jinan and Chengdu — the TSP concentrations exceeded or were close to 1 mg/m^3. This is several times higher than the national health-based standard, although in the case of Beijing the high TSP concentrations might be partly due to desert storms in the north. SO_2 concentrations in Chongqing, town D of Boshan, and Shenyang were markedly high.

2.2 Air pollution from motor vehicles

Air pollution from motor vehicles is not a major problem in most Chinese cities. For example, in Shanghai, which has an urban population of around 7 000 000, there are approximately 400 000 cars only. However, for traffic policemen or people working at customs checkpoints or road tunnels, motor vehicle air pollution has become a major health hazard. Table 2 presents exposure levels to motor vehicle air pollution for some Chinese cities.

2.3 Sulfuric acid mist

Data for sulfuric acid mist concentrations in ambient air in five Chinese cities (Dalian, Taiyuan, Jinan, Wuhan and Chongqing) are presented in Table 3.[27]

Formerly known as the "Foggy Capital", Chongqing is noted for its high levels of fog. On foggy days, concentrations of SO_2, NO_x and TSP increase 2.37, 2.0 and 1.72 times, respectively.[28]

2.4 Air pollution in the vicinity of industrial facilities

A number of epidemiological studies have been conducted among residents living in the vicinity of industrial facilities that emit metal and non-metal pollutants such as lead, cadmium, mercury, vanadium, fluoride, chlorine, phenol, nitrochlorobenzene, vinyl chloride and other petro-chemicals. Table 4 presents exposure data for these pollutants.

Table 1: Ambient air pollution levels in Chinese cities*

City	Year	TSP	SO_2	B(a)P	NO_x	Ref.
Haerbin	1980–1	$x_G = 0.50$	$x_G = 0.02$	$x_G = 1.15$	—	(2)
Changchun	1983	0.68	0.13	—	0.06	(3)
		0.30	0.03	—	0.03	
Urumqi	1980–1	$x_G = 1.03$	$x_G = 0.16$	—	—	(2)
Jilin	1980–1	$x_G = 0.48$	$x_G = 0.07$	$x_G = 2.98$	—	(2)
Liaoyuan	1983	0.63	0.23	5.44	—	(4)
Yanji	1986	>0.15	>0.15	—	—	(5)
Fushun						
Wanghua	1989	0.98	—	3.9	—	(6)
Shenyang	1983	0.69	0.29	—	—	
industrial		0.73	0.41	—	—	
residential		0.56	0.16	—	—	
suburban		0.27	0.05	—	—	(7)
polluted	1980–4	0.52	0.21	2.02	—	
moderate	1980–4	0.47	0.08	2.54	—	
light	1980–4	0.25	0.05	1.26	—	(8)
Tiexi District						
heavy	1986	0.45	0.13	—	—	
moderate	1986	0.43	0.05	—	—	
control	1986	0.19	0.03	—	—	(9)
Tiexi District	1984	0.94	—	—	—	
Beilin	1984	0.31	—	—	—	(10)
Beijing	1980–1	$x_G = 1.15$	$x_G = 0.06$	$x_G = 0.36$	—	(2)
Haidian	1989	0.24	0.02	—	—	(11)
Dalian	1980–1	$x_G = 0.38$	$x_G = 0.03$	$x_G = 1.17$	—	(2)
Tianjin	1980–1	$x_G = 0.52$	$x_G = 0.09$	$x_G = 0.75$	—	
Yinchuan	1992					
residential		0.49	0.11	—	0.03	
industrial		0.66	0.15	—	0.03	
commercial		0.76	0.26	—	0.04	
control area		0.27	0.05	—	0.03	(12)
Taiyuan	1980–1	$x_G = 0.74$	$x_G = 0.18$	$x_G = 1.30$	—	(2)
Boshan	1984					
town B		0.66	0.90	5.24	—	
town S		0.56	0.79	4.45	—	
town D		0.44	1.04	8.79	—	
town F		0.46	0.85	7.26	—	(13)
Jinan						
urban	1983	1.11	0.12	—	—	
suburban		0.41	0.07	—	—	
urban	1984	1.21	0.27	—	—	
suburban		0.48	0.07	—	—	
urban	1985	1.12	0.22	—	—	
suburban		0.37	0.05	—	—	(14)
Qingdao	1980–1	$x_G = 0.36$	$x_G = 0.18$	1.70	—	(2)
Lanzhou	1980–1	$x_G = 1.14$	$x_G = 0.04$	0.77	—	(2)

Table 1 continued

City	Year	TSP	SO_2	B(a)P	NO_x	Ref.
Chengzhou	1980–1	$x_G = 0.61$	$x_G = 0.05$	0.35	—	(2)
	1992	0.82	0.09	0.47	—	
		$x_G = 0.40$	$x_G = 0.03$	$x_G = 0.10$	—	(15)
Xi'an	1980–1	$x_G = 0.39$	$x_G = 0.05$	$x_G = 0.13$	—	(2)
polluted	1981	0.30	0.02	—	0.08	
control		0.15	0.02	—	0.02	(16)
polluted	1985	0.28	0.06	—	0.06	
control		0.21	0.03	—	0.05	(16)
Maanshan						
polluted	1982	0.45	0.03	—	—	
control		0.27	0.01	—	—	(16)
Suzhou	1980–1	$x_G = 0.31$	$x_G = 0.06$	$x_G = 0.18$	—	(2)
Shanghai	1980–1	$x_G = 0.30$	$x_G = 0.09$	$x_G = 0.55$	—	(2)
A	1990	0.16	0.07	—	—	
B		0.29	0.07	—	—	
C		0.46	0.04	—	—	(17)
E	1991	0.11	0.02	—	—	
G		0.15	0.14	—	—	(18)
K	1992	0.06	0.01	—	—	
L		0.11	0.16	—	—	
M		0.24	0.18	—	—	
N		0.31	0.16	—	—	(19)
Wuhan	1980–1	$x_G = 0.34$	$x_G = 0.06$	$x_G = 0.94$	—	(2)
Chengdu	1980–1	$x_G = 0.49$	$x_G = 0.18$	$x_G = 1.98$	—	(2)
urban	1980–4	0.07–1.55	0.02–0.97	0.17–13.6	0.05	
suburban		0.02–0.56	0.01–0.06	0.02–2.74	0.02	(20,21)
Hangzhou	1980–1	$x_G = 0.22$	$x_G = 0.06$	$x_G = 0.01$	—	(2)
Chongqing						
urban	1985–7	0.46	1.29	6.0–16.3	—	
suburban		0.37	0.39	2.1–11.0	—	(22)
Changsa	1980–1	$x_G = 0.32$	$x_G = 0.16$	$x_G = 0.80$	—	(2)
residential 1		0.28	0.24	1.35	0.11	
residential 2		0.28	0.23	1.10	0.11	
residential 3		0.27	0.27	1.05	0.09	
industrial		0.29	0.26	0.40	0.12	
control area		0.20	0.05	0.27	0.03	(23)
Sanming	1980–1	$x_G = 0.29$	$x_G = 0.03$	$x_G = 0.12$	—	(2)
Guiyang	1980–1	$x_G = 0.33$	$x_G = 0.53$	$x_G = 1.19$	—	(2)
Guilin	1980–1	$x_G = 0.16$	$x_G = 0.06$	$x_G = 0.75$	—	(2)
Kunming	1980–1	$x_G = 0.28$	$x_G = 0.07$	$x_G = 0.72$	—	(2)
urban	1981	0.17–0.46	0.02–0.24	0.04–3.23	—	
suburban		0.06–0.51	0.01–0.05	0.05–0.42	—	(24)
urban	1986	0.03–0.71	0.04–0.25	0.21–23.05	—	
suburban		0.12–0.43	0.01–0.20	0.71–4.56	—	(24)
Xiamen	1980–1	$x_G = 0.25$	$x_G = 0.05$	$x_G = 0.04$	—	(2)

Table 1 continued

City	Year	TSP	SO_2	B(a)P	No_x	Ref.
Liuzhou	1988					
heavily polluted		—	0.28	—	—	
moderately polluted		—	0.15	—	—	
control area		—	0.01	—	—	(25)
Guangzhou	1980–1	x_G = 0.29	x_G = 0.09	x_G = 1.09	—	(2)
	1983	—	—	x_G = 0.24	—	
		—	—	m = 0.31	—	
	1984	—	—	x_G = 0.40	—	
		—	—	m = 0.42	—	
	1985	—	—	x_G = 0.16	—	
		—	—	m = 0.18	—	
	1986	—	—	x_G = 0.33	—	
		—	—	m = 0.32		(26)

* B(a)P is given in μg/100m^3; TSP, SO_2 and NOx are given in mg/m^3

Table 2: Air pollution levels from motor vehicles

City + area	CO (mg/m^3)	Pb (μg/m^3)	Nox (mg/m^3)	TSP (mg/m^3)	B(a)P (μg/100m^3)	Ref.
Shenzhen						
customs	6.58	—	—	—	—	
downtown	4.13	—	—	—	—	
suburban	0.20	—	—	—	—	(29)
Yulin						
crossroads	—	0.11	0.02	0.66	1.04	
controls	—	0.07	<0.01	0.12	0.14	(30)
Shanghai						
crossroads	10.61	1.07	—	1.09	—	
urban 1	5.41	0.42	—	0.70	—	
urban 2	2.16	0.14	—	0.42	—	(31)
Shaoguan	—	0.15	—	—	—	(32)
		0.39				

Table 3: Sulfuric acid mist data for five cities (monthly averages, μg/m³)

	Dalian	Taiyuan	Jinan	Wuhan	Chongqing
January	10.2	22.6	19.7	10.6	26.2
April	6.2	—	—	8.1	—
July	12.4	8.3	—	6.1	19.7
October	4.2	—	—	7.1	—
Annual averages, μg/m³:	8.3	15.5	—	8.0	22.9

Table 4: Air pollution levels in the vicinity of industrial facilities*

Type of plant	Chemical	Place	Concentration	Ref.
Sulfur plant	Sulfur	Zhunger Banner, Yikezhao League, Inner Mongolia,		(33)
		vicinity of plant	SO_2: 0.39 TSP: 0.93	
		Control area	SO_2: 0.01 TSP: 0.41	
Smelter	Lead	Shenyang		(34)
		Industrial	Pb: 0.0137	
		Residential	Pb: 0.0010	
Smelter	Lead	Linyi		(35)
		Village A;	Pb: 11.21 μg/m³	
		1 month after the smelter was closed down	Pb: 1.51 μg/m³	
		Village B;	Pb: 3.69 μg/m³	
		1 month after the smelter was closed down	Pb: 0.61 μg/m³	
		Control area	Pb: 0.36 μg/m³	
Battery plant	Lead	Hefei		(36)
		Vicinity of plant	Pb: 0.187	
		Downtown	Pb: 0.0002	
Smelter	Lead	Guichi		(37)
		Polluted area	Pb: 51.8 μg/m³	
		School A	Pb: 30.56 μg/m³	
		School B	Pb: 1.14 μg/m³	
	Cadmium	School A	Cd: 0.08 μg/m³	

Table 4 continued

Type of plant	Chemical	Place	Concentration	Ref.
Smelter	Cadmium	Jinzhou 500 m from the plant 1000 m from the plant 1500 m from the plant	 Cd: 21.53 μg/m³ Cd: 8.0 μg/m³ Cd: 4.7 μg/m³	(38)
Barometer workshop	Mercury	Hunan Province 30 m from workshop	Cd: 25.64 μg/m³	(39)
Steel plant	Vanadium	Panzhihua polluted area control area	 V: 0.82 μg/m³ V: 0.49 μg/m³	(40)
Aluminium plant	Fluorine	Ningxia Province Village A,1000 m from the plant Village B,1500 m from the plant Village C,1000 m downwind from the plant, heavily polluted Control area	 F_2: 0.014 F_2: 0.011 F_2: 0.044 F_2: 0.002	(41)
PVC plant	Chlorine	Yichong 200 m downwind from the plant	Cl_2: 0.15	(42)
Bakelite & epoxy resins workshop	Phenol	Baodin and Hengshui	phenol: 0.018–0.055 phenol (maximum): 0.125–0.155	(43)
Incinerator	Nitrochlorobenzene (NCB)	Changchun incinerator 50 m downwind from plant School	 NCB: 0.01–0.11 NCB: 0.10 NCB: 0.06–0.07	(44)
PVC plant	Vinyl chloride (VC)	Yichong	VC: 0.17	(45)
Petrochemicals plant	NH_3, No_x, SO_2	Zhenghai School 1 School 2 School 3	NH_3 / NO_x / SO_2 0.06 / 0.02 / 0.01 0.05 / 0.02 / 0.01 — / 0.03 / 0.03	(46)

* mg/m³, unless otherwise stated

3. Assessment of health effects

3.1 Mortality

3.1.1 Total mortality and cause-specific mortality (other than cancers)

The reports of the studies of air pollution and mortality undertaken in 26 Chinese cities (see Section 1) were first published in 1984. Since then, a number of papers on this topic have been published in professional journals in China.

A study on fog and meteorological factors is of particular interest.[28] It may be the only study of its kind to have been published in a Chinese medical journal. Chongqing is a city that experiences fog all year round. Let:

X_1 = number of foggy days in that month
X_2 = monthly average of relative humidity
X_3 = monthly average of air pollution level

and:

Y_1 = monthly total number of deaths

then:

$$Y_1 = 238.5599 + 4.9411 X_1 + 3.7888 X_3$$

and:

the correlation coefficient (r) = 0.7597.

If:

Y_2 = monthly total number of deaths from respiratory diseases

then:

$$Y_2 = 547.7289 + 1.8210 X_1 - 4.5226 X_2 - 7.6146 X_3$$

and:

$r = 0.7908$.

If:

Y_3 = monthly total number of deaths from cardio-cerebral diseases

then:

$$Y_3 = 119.9134 + 2.2634\ X_1 - 0.8817\ X_2 + 1.3393\ X_3$$

and:

$$r = 0.3497.$$

The mean pH value of fog in Chongqing ranged from 3.0 to 4.07. On foggy days the concentrations of SO_2, NO_x and TSP increased 2.37, 2.0 and 1.72 times respectively. Therefore, this study may also be considered to be a study of air pollution and mortality, although it appears to focus on meteorological factors and their effect on mortality.

In Shenyang in 1983, cor pulmonale mortality was 90/100 000, or one-fifth of total mortality.(7) Some time later, a time-series study examined the relationship in Shenyang between ambient air quality data and daily mortality for 1992. Very high concentrations of SO_2 and TSP (mean concentration 197 $\mu g/m^3$ and 430 $\mu g/m^3$ respectively) were observed in both the residential and commercial areas. Daily counts of deaths were regressed using multiple linear regression on SO_2 and/or TSP levels, controlling for air temperature and humidity. Current day and previous three-day running averages of SO_2 and TSP were used as air pollution variables. A highly significant association with total mortality was found for both SO_2 and TSP. When mortality was analysed separately by cause, SO_2 was found to be a significant predictor of chronic obstructive pulmonary disease (COPD), and TSP a significant predictor of cardiovascular disease (CVD). Because of the high collinearity of TSP and SO_2 when estimating the effect of each pollutant, both pollutants were included in the model simultaneously. TSP and SO_2 remained significant for CVD and COPD respectively.(47)

The first time-series study published on TSP, SO_2, temperature, humidity and mortality in China was a study undertaken in Haidian District, a semi-suburban district of Beijing.(11, 48) The study analysed mortality data for Haidian District for the period January–September 1989.

A Poisson regression model was used to fit the data:

$$\log (E(Y_i)) = \alpha + \beta_i X_i$$

where:

$E(Y_i)$	=	expected daily number of deaths
Xi	=	independent variables
α	=	coefficient
β_i	=	regression coefficient of independent variables.

This model was later modified as:

$$\log E(Y_t) = \alpha X_t + \beta Z_t + \tau_j Y_{t-j}$$

where:

t	=	1, 2.......365 (day of the year)
j	=	1, 2....... 5 (lag day for mortality)
Y_t	=	number of deaths on day t
X_t	=	the vector of controlling variables on day t for quintiles of temperature, quintiles of humidity, and an indicator for Sunday (the only day of the week that differed significantly);
Z_t	=	the vector of air pollution variables on day t.

The regression coefficients were estimated by using a quasi-likelihood approach.[(49)]

The average number of deaths per day was 11.7. The average numbers of deaths from COPD, cardiovascular disease (CVD) and cancer were 1.49, 4.84 and 2.93 respectively. The collinearity of the TSP and SO_2 concentrations was high. The health effects of TSP and SO_2 were therefore evaluated separately. It was found that SO_2 had a significant effect on total mortality; for every increase of 100 $\mu g/m_3$ in SO_2, there was an increase of 19% ($p < 0.05$) in the relative risk (RR). On the other hand, the effect of TSP on total mortality was marginal ($p = 0.08$). However, for cause-specific mortality, the effect of TSP was significant (for every increase of 100 $\mu g/m^3$ in TSP, there was an increase in RR of 9% for COPD, and 7% for CVD). Age-specific analysis indicated that the effect was more noticeable among the elderly.

Haidian District is a comparatively "clean" area and the ambient TSP and SO_2 concentrations are only half or less than half of those encountered elsewhere in Beijing. The investigators concluded, therefore, that the increase in mortality that occurred when ambient air pollution levels increased, was significant.

3.1.2 Lung cancer mortality

Lung cancer is of particular concern for Chinese city dwellers, since it generally ranks first, second or third among all cancer deaths. In Chengdu, Sichuan Province, in 1987, lung cancer ranked first as cause of death from cancer. Standardized cancer mortality was 19.86/100 000 in the urban area and 14.45/100 000 in the surburbs.[20] Even in remote cities such as Yanji (Yanbian Prefecture, Jilin Province) cancer mortality for the period 1984–1989 was more than twice that for the period 1963–1972. In 1986, lung cancer deaths totalled 19.33/100 000; TSP and SO_2 levels all exceeded the national health-based standard of 0.15 mg/m^3 (daily averages).[5]

Annual average concentrations of TSP in Guangzhou (Canton) were around 195–217 μg/m^3 for the period 1981–1985; malignant tumours ranked second among all causes of death. Among malignant tumours, lung cancer ranked first as cause of death. Standardized lung cancer mortality was calculated at 21.86/100 000.[26] Of course, smoking could be the most important etiological factor leading to lung cancer, as demonstrated by a study in Wanghua District in Fushun. Here, lung cancer mortality was 13/100 000; it was only half this in the suburbs (6.5/100 000). Lung cancer mortality among smokers was 38.5/100 000 (25.5/100 000 in the suburbs), but was only 3.3/100 000 among non-smokers (0.9/100 000 in the suburbs).[6]

In Boshan, Shandong Province, lung cancer mortality ranked first among malignant tumour mortalities; standardized lung cancer mortality was calculated as 27.79/100 000. Boshan is a widely dispersed urban area, consisting of a number of towns. Standardized lung cancer mortality rates in most of these towns exceeded those of their counterparts in the surrounding area (Table 5).

Table 5: Standardized lung cancer mortality in Boshan (1/100 000, 1977–1980) [13]

Town	Lung cancer mortality	Township*	Lung cancer mortality
B	28.15	G	17.60
S	29.87	L	18.21
D	26.28	Z	11.54
F	44.57	Y	16.91
W	16.30		

* In China, a township is an administrative area in the countryside.

There was a marked increase in B(a)P in ambient air in Kunming between 1981 and 1986 (Table 1). Comparison of lung cancer mortality data for the period showed that there was a slight increase in lung cancer mortality among males, but a decrease among females (Table 6).[24] However, the underlying cause for this decrease was not clear.

Table 6: Standardized lung cancer mortality (1/100 000) in Kunming

Year	Area	Males	Females	Total
1981	Suburban	14.32	5.23	9.43
1986	Suburban	17.78	2.76	9.02
1978–1980	Urban	17.01	7.96	11.96
1986	Urban	17.65	6.68	12.23

A cause-specific mortality study (1976–1979) undertaken in Changsa showed that lung cancer ranked first among malignant tumours as cause of death. It also demonstrated that lung cancer mortality was closely correlated with concentrations of B(a)P in ambient air, but not related to SO_2 or NO_x levels. The correlation coefficient for B(a)P was 0.85 ($p < 0.01$).[23] Air pollution levels did not appear to be any lower in the residential areas than in the industrial area (Table 7).

Xuanwu District is an urban district in the south-western part of Beijing with a population of around half a million. Total mortality for the period 1977–1979 was 596.91/100 000. Mortality due to malignant tumour was 111.68/100 000; standardized lung cancer mortality was 14.44/100 000, or 19.6% of all cancer deaths. The correlation coefficient between daily mean concentration of SO_2 and lung cancer mortality was 0.81.[48]

Table 7: Lung cancer mortality and air pollution variables in Changsa (1976–1979)

Area	TSP (mg/m^3)	SO_2 (mg/m^3)	NOx (mg/m^3)	B(a)P ($\mu g/100m^3$)	Lung cancer (1/100 000)
Residential 1	0.28	0.24	0.11	1.35	32.62
Residential 2	0.28	0.23	0.11	1.10	39.14
Residential 3	0.27	0.27	0.09	1.05	23.41
Industrial	0.29	0.26	0.12	0.40	19.83
Control	0.20	0.05	0.03	0.27	3.36

Investigators in Chengzhou, Henan Province, studied the relationship between air pollution levels and lung cancer mortality. They found that TSP and B(a)P concentrations and standardized lung cancer mortality were highly correlated.[15] Thus for B(a)P concentration X_1 and lung cancer mortality Y, the correlation coefficient $r = 0.972$ ($p < 0.01$), the regression coefficient $\beta = 5.57$ ($p < 0.01$), and $Y = 3.94 + 5.57/X_1$. For TSP concentration X_2 and lung cancer mortality Y, the correlation coefficient $r = 0.942$ ($p < 0.05$), the regression coefficient $\beta = 5.62$ ($p < 0.01$), and $Y = 4.28 + 5.62/X_2$. But the correlation coefficient between SO_2 and lung cancer mortality was only -0.10, ($p > 0.05$).

In a study of lung cancer mortality (1980–1991) in Xuzhou, Jiangsu Province, ridge regression analysis was performed on air pollution independent variables that had high collinearity. Standardized lung cancer mortality in Xuzhou was found to have reached 29.12/100 000, or almost double the figure for 1981. Female standardized lung cancer mortality was found to be 20.02/100 000.

Using concentrations of SO_2 (X_1), NO_x (X_2), annual dustfall (X_3), CO (X_4), photochemical oxidants (X_5) and TSP (X_6) as the independent variables, a correlative association was found between standardized lung cancer mortality (Y) and TSP, dustfall, NO_x and oxidants, as follows [50]:

$$Y = 0.0018\,X_2 + 0.0474\,X_3 + 0.00034\,X_5 + 0.36113\,X_6.$$

Chongqing was found to experience the highest concentrations of polynuclear aromatic hydrocarbons (PAH) in ambient air — with the exception of perylene — when compared with Beijing, Taiyuan, Wuhan and Shanghai (Table 8).[22] Lung cancer mortality in urban areas of Chongqing was 42.21/100 000 in 1984 and 42.88/100 000 in 1985 (and 26.41 and 24.01 in the suburbs). The relative risk for lung cancer was 1.6–1.8 (RR = 1.7–2.2 for males and 1.1–1.3 for females).

Table 8: Comparison of concentrations of polynuclear aromatic hydrocarbons in ambient air in Chongqing, Beijing, Taiyuan, Wuhan and Shanghai (µg/m³)

	Chongqing	Beijing	Taiyuan	Wuhan	Shanghai	Urban suburbs
Anthracene	7.1	—	4.17	2.36	0.70	0.15
Fluoranthene	8.3	—	5.44	4.51	1.76	0.21
Pyrene	8.6	—	4.75	3.79	1.06	0.18
B(a)P	16.3	11.0	3.68	4.90	1.83	0.15
Perylene	6.0	2.1	52.90	17.00	1.91	0.48
Benzo(ghi)-perylene	8.6	3.0	2.78	4.19	1.17	0.87

3.2 Prevalence of respiratory symptoms and disease

3.2.1 Rhinitis, pharyngitis and tonsilitis

A number of studies have investigated the increase in the prevalence of rhinitis, pharyngitis and tonsilitis among populations exposed to ambient air pollution. Of the cities where such studies were conducted, data from Chengdu, the provincial capital of Sichuan, showed a very high prevalence of chronic rhinitis and chronic pharyngitis.[21] (Table 9; see Table 1 for exposure levels.)

Table 9: Prevalence of chronic rhinitis and pharyngitis in residents of Chengdu (%)

Area	Chronic rhinitis	Chronic pharyngitis
Urban	38.5–55.1	56.7–82.0
Suburban	31.8 ($p < 0.05$)	37.5 ($p < 0.05$)

The prevalence of rhinitis, pharyngitis and tonsilitis among children in Shenyang, a city with heavy industries, and noted for its air pollution problems, is given in Table 10.

Table 10: Prevalence of rhinitis, pharyngitis & tonsilitis in children in Shenyang (%)[61]

	Heavily polluted area	Moderately polluted area	Control area
Rhinitis	15.4	5.8	5.0
Pharyngitis	5.9	5.9	4.2
Tonsilitis	39.4	19.6	28.2

$p < 0.01$

Studies in Shanghai and Yulin have shown that individuals exposed to traffic exhaust gases and dusts also experience high prevalence rates of rhinitis and pharyngitis (Table 10).[30, 31]

Table 11: Prevalence of rhinitis and pharyngitis among traffic police in Shanghai (%)[31]

	Rhinitis				Pharyngitis			
	Smokers		Non-smokers		Smokers		Non-smokers	
	n	%	n	%	n	%	n	%
Traffic police	94	37.23	56	14.29	94	47.87	56	44.67
Controls	24	16.67	27	3.70	24	41.67	27	7.41

Prevalence of rhinitis and pharyngitis in Yulin was 57.6% and 22.0% respectively for road maintenance workers, but only 18% and 12.7% for people living in the same area but performing other jobs.[30]

Due to fluoride pollution in ambient air, the prevalence of nasopharyngitis among people living in the vicinity of an aluminium plant in Ningxia Hui Autonomous Region was found to be much higher than among the controls. The increased prevalence among children was particularly striking (Table 12).

Similar findings were reported for the area around a cement plant in Loudi, Hunan Province. Owing to high levels of particulate pollution, prevalence of chronic pharyngitis and tonsilitis was 18.90% and 9.58% respectively among the 762 people examined, but only 4.71% and 2.74% in the control area.[52]

Similarly, prevalance of rhinitis, pharyngitis and tonsilitis among a population living in the vicinty of a sulfur plant emitting SO_2 from stacks was found to be high (Table 13).[53]

Table 12: Prevalence of nasopharyngitis among residents (%) in the vicinity of an aluminum plant in Ningxia[41]

Location	Children	Adults
Village A	22.2 ($p < 0.01$)	30.7 ($p < 0.05$)
Village B	24.2 ($p < 0.01$)	23.5 ($p < 0.01$)
Village C	16.5 ($p < 0.01$)	29.6 ($p < 0.05$)
Controls	2.0	14.4

Table 13: Prevalences of upper respiratory tract disorders among a population (%) residing in the vicinity of a sulfur plant

Subjects	n	Chronic rhinitis	Chronic pharyngitis	Tonsilitis
Teenagers living nearby	878	31.2	61.3	17.0
Controls	1298	0.8	11.6	0.6
Adults living nearby	410	55.9	62.7	5.9
Controls	468	4.3	29.1	0.2

An elevated prevalence of atrophic rhinitis, hypertrophic rhinitis and neurasthenia and disturbance of the autonomic nervous system, were observed among a population exposed to hydrochloric acid (daily average concentration 0.24 mg/m^3 in ambient air), xylene (daily average concentration 1.74 mg/m^3 in ambient air), benzene and toluene, in Zibo, Shandong Province.[54]

3.2.2 Chronic respiratory disease

Chronic respiratory disease (CRD) — particularly chronic obstructive pulmonary disease (COPD) — is a major health concern in China. CRD ranks third among the leading causes of death in many large Chinese cities. (The two leading causes of death are cardiovascular/-cerebral diseases and malignant tumour.) As the mortality rate for CRD is generally quite low, the number of people suffering from CRD is high. A study of a sample of 46 000 residents in Wanghua District (population 300 000), in Fushun, Liaoning Province, demonstrated that the prevalence of CRD was 2.7% (1.6% in the suburban control area). Prevalence of CRD among smokers and non-smokers in Wanghua District was 5.7% and 1.4% respectively, while in the suburban area it was 3.7% for smokers and 0.7% for non-smokers.[6]

The prevalence of and relative risks for COPD (including chronic bronchitis, bronchial asthma, emphysema, as well as cor pulmonale) in Shenyang, Liaoning Province, are shown in Table 14. Prevalence of chronic bronchitis is given in Table 15.[51]

Table 14: Prevalence (%) and relative risks of COPD among residents over 40 years of age in Shenyang

	Heavily polluted area		Moderately polluted area		Control area	
	%	RR	%	RR	%	RR
Chronic bronchitis	32.7	6.54	14.3	2.86	5.0	1.00
Bronchial asthma	16.7	5.76	7.7	2.66	2.9	1.00
Emphysema*	4.9	2.13	4.2	1.83	2.3	1.00
Cor pulmonale	3.4	2.83	3.5	2.92	1.2	1.00

* $p < 0.05$; others: $p < 0.01$

Investigators in Shanghai compared the risks in a number of study areas for COPD associated with various concentration levels of TSP and SO_2. In one study the ratio of TSP concentrations was 1:2:3 (0.16, 0.29, and 0.49 mg/m^3 respectively), while SO_2 concentration levels were all relatively low (0.07, 0.07 and 0.04 mg/m^3 respectively). The sample population consisted of 3021 adults who had lived in the study area for at least 5 years, and who used neither coal nor coal briquette (indoors) for domestic cooking. It was found that relative risks for chronic bronchitis and emphysema, as well as for respiratory symptoms such as cough, phlegm and dyspnoea, were significantly higher among residents of the area where TSP concentration levels reached 0.29 and 0.49 mg/m^3, than among residents of the area where the maximum TSP concentration was 0.16 mg/m^3.[55, 56] For each increase of 0.1mg/m^3 in mean TSP concentration, the increases observed in the odds ratios (ORs) were as follows: 1.20 for cough; 1.23 for phlegm; 1.13 for dyspnoea; 1.29 for chronic bronchitis and 1.59 for emphysema.[57]

In another study, the ratio of SO_2 levels was 1:4:7 (0.02, 0.08 and 0.14 mg/m^3 respectively), and the TSP levels were comparable (0.11, 0.14 and 0.15 mg/m^3 respectively). The number of study participants was 4403. It was found that for each increase of 0.06 mg/m^3 in mean SO_2 concentration, the OR increased as follows: 1.31 for cough; 1.71 for dyspnoea and 1.32 for chronic bronchitis.[58]

Table 15: Prevalence of chronic bronchitis (comparison of the effect of ambient air pollution, indoor air pollution and smoking) in Shenyang

Subjects	Control area		Moderately polluted area		Heavily polluted area		
	%	RR	%	RR	%	RR	P
Non-smokers who do not use coal	2.3	1.00	7.0	3.04	24.4	10.61	< 0.01
Non-smokers who use coal	2.7	1.17	12.3	5.35	28.3	12.30	< 0.01
Smokers who do not use coal	10.4	4.52	18.3	7.95	33.7	14.65	< 0.01
Smokers who use coal	6.6	2.87	19.4	8.43	50.0	21.74	< 0.01

Other studies have been made of the elevated prevalence of respiratory symptoms such as cough, phlegm and dyspnoea among populations of cities with various degrees of ambient air pollution. However, the data on exposure levels was categorical, and terms such as "heavily polluted", "moderately polluted" or "slightly polluted" were used, as was the case with a study undertaken in Sanming, Fujian Province.[59] This lack of exposure-level data and the inclusion of possible confounders render such studies unsuitable for inter-city comparisons.

3.3 Congenital malformations

A study undertaken in the vicinity of a power plant in Yanbei, Shanxi Province, revealed a high prevalence of congenital malformations for the period 1981–1984 (Table 16). The prevalence of congenital malformations in Shanxi Province as a whole was 27.52 per 1000 live births, and 12.96 per 1000 live births in the Yanbei region as a whole. Within a radius of approximately 10 km around the power plant, it was considerably higher at 40.82 per 1000 live births (RR = 2.51).

Table 16: Prevalence of congenital malformations in the vicinity of a power plant in Yanbei (1981–1984) [60]

Area	Distance from power plant (km)	No. of live births	No. of congenital malformations	Prevalence (per 1000 live births)
Polluted area	< 3.5	680	35	51.47
	3.3–9.0	694	23	33.14
	> 9.0	145	4	27.59
		1519	62	40.82
Control area		1105	18	16.29

A two-year prospective study on air pollution and birth defects in Shenyang, Zhenzhou and Dalian, undertaken for the period 1987–1989 is of particular interest.[61] Twenty per cent of the total population of Shenyang and Zhenzhou, and 40% of the total population of Dalian was monitored. All pregnant women in the study areas were asked to participate. Though Shenyang was the most polluted of the three cities, and Dalian the least polluted (Table 17), no statistically significant difference in birth defect rates was found (Shenyang: 7.2/1000 live births; Zhenzhou: 7.5/1000; Dalian: 5.4/1000; $p > 0.05$).

Table 17: Comparison of ambient air quality in Shenyang, Zhenzhou and Dalian (1986–1989), daily average concentrations in mg/m^3

City	Year	TSP	SO_2	NO_x
Shenyang	1986	0.51	0.16	0.06
	1987	0.62	0.13	0.06
	1988	0.59	0.10	0.06
	1989	0.46	0.15	0.06
Zhenzhou	1986	0.58	0.07	0.04
	1987	0.59	0.07	0.06
	1988	0.69	0.09	0.12
	1989	0.61	0.06	0.14
Dalian	1986	0.42	0.06	0.06
	1987	0.43	0.06	0.06
	1988	0.44	0.06	0.06
	1989	0.40	0.05	0.06

Nevertheless, the investigators found significant seasonal variations in birth defect rates when the time of conception and early pregnancy (1–12 weeks after conception) was taken into consideration (Table 18).

The relative risk for birth defects was higher for children conceived in winter than for children conceived in summer or spring. However, many of the residents in these cities use coal for domestic cooking and heating, which gives rise to the question how much of the risk was attributable to outdoor air pollution and how much to indoor air pollution.

Table 18: Season of early pregnancy and relative risk for birth defects in Shenyang and Dalian

Season of early pregnancy	No. of live births	No. of birth defects	Birth defect rate (1/1000)	RR	95% CI
Winter	15 175	121	7.9	1.68	1.26–2.24 (W–Sum)
				1.58	1.06–2.35 (W–Sp)
Summer	11 569	66	5.8	1.00	
Spring	5955	30	5.0	0.68	0.56–1.35 (Sum–Sp)

W = winter
Sum = summer
Sp = spring

3.4 Change in pulmonary functions

Pulmonary function tests were used in a number of studies in various cities. Decreases in forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1), and in the ratio of FEV_1:FVC were observed in some of the studies. However, changes in air pollution levels, if small, did not appear to have an effect on FVC or FEV_1, or on the ratio of FEV_1:FVC. One of the difficulties encountered in such studies is deciding whether the spirometric values measured fall within the "normal" range. Published "predicted normal values" from abroad, and Chinese "predicted normal values" for men between 20 and 40 years of age (used when recruiting young workers), are not appropriate for assessing whether the pulmonary functions of children, teenagers, or housewives, have been impaired.

Pulmonary function tests performed on 400 participants (half of them females) in Wanghua District of Fushun, a heavily polluted area in Liaoning Province (annual average concentration of TSP = 0.98 mg/m^3), revealed a marked decrease in both FVC and FEV_1.[6]

A study in Shanghai of the pulmonary function of schoolchildren of 11–13 years of age (263 males and 241 females), resident in areas that experience various levels of particulate pollution, observed an increase in "mean transit time" (MTT) of forced expiratory volume curves and a decrease in $FEF_{25-75\%}$ (forced mid-expiratory flow rate) and $FEF_{75-85\%}$.[17] ($FEF_{25\%}$, $FEF_{50\%}$, $FEF_{75\%}$ and MMEF (maximum median expiratory flow) are used as indirect measures of changes in bronchiole resistance.)

A pulmonary function study undertaken in Shenyang demonstrated a high correlation between TSP and FEF ($r = 0.96$ for $FEF_{50\%}$ and TSP; $r = 0.95$ for $FEF_{25\%}$ and TSP; $p < 0.05$).[8]

Investigators in Liuzhou, Guangxi Zhuang Autonomous Region, studied the association between ambient SO_2 concentrations and changes in pulmonary function. The daily average concentration of SO_2 was 0.28 mg/m^3 in the heavily polluted area, 0.15 mg/m^3 in the polluted area and 0.01 mg/m^3 in the unpolluted control area. Statistically significant differences were found not only in $FEF_{25-75\%}$ and MMEF, but also in FEV_1 and FVC.[25]

A similar study in Sanming, Fujian Province, of 679 non-smokers living in the city proper (404 males and 275 females), using 458 suburban non-smokers as controls (314 males and 144 females), showed that $FEF_{25\%}$, $FEF_{50\%}$, MMEF, FVC and FEV_1 decreased appreciably in polluted areas.[59]

3.5 Changes in immune functions

3.5.1 PHA skin test

Phytohemagglutinin (PHA) is a protein extracted from *Phaseolus vulgaris*. The PHA skin test has been used in a number of cities to monitor the immune function of study participants. (The test consists of subcutaneous injection of a tiny amount of PHA in the forearm and then measuring the diameter of erythema that appears the following day.)

Schoolchildren of 10–11 years of age were examined during the period 1983–1985 in Jinan, Shandong Province. One group of pupils lived in a polluted district, and another group lived in a relatively unpolluted district. The PHA skin test findings are shown in Table 19. It can be seen that the response to the PHA skin test decreased over the years; children living in the polluted area showed the greatest decrease in response. The difference in response between the groups became even more prominent in 1985. No significant difference in response was observed between boys and girls.[14]

The results of a study undertaken in three districts in Shenyang revealed gradual changes in PHA skin test response. Tiexi District is a heavily polluted district with non-ferrous plants, chemical plants and machine factories. Shenhe District is considered to be moderately polluted. Beilin District — a scenic site — served as the control.[9]

The average diameters of erythema found when applying the PHA skin test were as follows:

Tiexi District (n = 58): 2.00 cm	SD 0.49 cm
Shenhe District (n = 41): 2.50 cm	SD 0.49 cm
Beilin District (n = 54): 2.60 cm	SD 0.48 cm.

Studies in Chengdu showed that 40.74–48.02% only of urban participants had a strong positive response (diameter of erythema > 2.0 cm), while in the suburban area the strong positive response rate was 69.14% ($p < 0.01$).[21] The distribution of the diameters of erythema for the four types of district in Chengdu is presented in Table 20.

Table 19: Follow-up survey of PHA skin test in Jinan (diameter of erythema in cm)*

Year	District	n	mean	SD	p
1985	Polluted	55	2.40	0.70	> 0.05
	Unpolluted	57	2.45	0.89	
1986	Polluted	58	2.23	0.36	< 0.05
	Unpolluted	56	2.46	0.40	
1987	Polluted	57	1.56	0.55	< 0.01
	Unpolluted	59	1.98	0.50	

* An erythema with a diameter of > 1.50 cm is considered a positive response in a PHA skin test.

Table 20: PHA skin test results for various districts in Chengdu, according to diameter of erythema (%) [20]

District	n	<10 cm	10 cm–	20 cm–	30–36.7 cm
Residential	177	1.70	50.28	47.46	0.56
Industrial	162	8.64	50.62	39.51	1.23
Commercial	162	3.09	54.32	41.36	1.23
Suburban	175	6.29	24.57	65.71	3.43

3.5.2 Salivary lysozyme

Salivary lysozyme, a measure of local non-specific immune function, is one of the most widely used immunological indices in Chinese epidemiological studies owing to its ease of application. The amount of lysozyme in saliva is generally found to be lower in subjects who live in heavily polluted areas than in those who live in relatively unpolluted areas. Thus the amount of salivary lysozyme was 76.6 + 0.1 μg/ml among urban residents in Wanghua District in Fushun, compared with 171.6 + 0.3 μg/ml among suburban residents.[6] The amount of salivary lysozyme among children living in various districts in Shenyang followed more or less the same pattern, although the differences were not so marked.[9] Salivary lysozyme levels were as follows (for residents of all ages):

Tiexi District: 92.82 μg/ml + 16.79 μg/ml (n = 34)
Shenhe District: 100.42 μg/ml + 6.90 μg/ml (n = 41)
Beilin District: 98.18 μg/ml + 7.47 μg/ml (n = 50).

Evidently, the amount of salivary lysozyme varied according to the age of the child in question; very young children have a lower level of salivary lysozyme, as can be seen in Table 21.

Table 21: Salivary lysozyme levels (μg/ml) in children in Changchun, Jilin Province, according to age and area of residence [9]

Area	n	Mean	Geometric mean	p
Children 3–6 years of age				
Polluted area	164	15.87	10.29	< 0.01
Clean area	140	29.01	22.29	
Children 7–14 years of age				
Polluted area	338	59.15	51.82	< 0.01
Clean area	265	82.21	69.31	

A study of housewives in Shanghai demonstrated similar patterns (Table 22).[58]

Table 22: Comparison of salivary lysozyme levels (μg/ml) among housewives living in Shanghai in areas of differing SO_2 levels

SO_2 level	n	Mean	SD	F	p
0.02 mg/m³	51	128.17	23.37		
0.08 mg/m³	40	130.29	23.39	4.05	< 0.05
0.14 mg/m³	56	117.45	25.88		

The levels of salivary lysozyme of residents living in various areas in Chengdu, Sichuan Province, are shown in Table 23. Similar differences were found among children in Hefei, Maanshan (Table 24) and among residents in Yinchuan, Ningxia Hui Autonomous Region (Table 25).

Table 23: Comparison of lysozyme levels (μg/ml) of residents living in different areas of Chengdu [20]

District	n	Geometric mean	SD_G	p
Residential	135	66.11	1.67	< 0.01
Industrial	138	69.28	1.61	< 0.01
Commercial	164	61.55	1.59	< 0.01
Suburban	132	90.78	1.73	

Table 24: Comparison of salivary lysozyme levels (µg/ml) of children living in different areas of Heifei and Maanshan, Anhui Province [16]

City	Year	Polluted area	Controls	p
Hefei	1981	44.07	53.25	< 0.01
	1985	50.27	56.79	< 0.01
Maanshan	1982	121.20	132.50	< 0.01

Table 25: Comparison of salivary lysozyme levels (µg/ml) of residents of various districts of Yinchuan

District	n	Geometric mean	SD_G	p
Residential	254	109.65	1.55	< 0.01
Industrial	176	89.55	1.90	< 0.01
Commercial	268	109.30	2.08	< 0.01
Suburban	277	211.20	1.80	

A study in Shenzhen where ambient CO pollution levels are high showed that the amount of salivary lysozyme among residents in the downtown area ranged between 4.4 and 5.6 µg/ml, which was much lower than in the suburban area where it was around 14.0 µg/ml.[29]

3.5.3 Salivary secrective immunoglobulin A

Stepwise regression analysis of data relating to Shanghai housewives of 50–59 years of age showed that the level of SO_2 was the most important independent variable in relation to the decrease in the amount of salivary secretory immunoglobulin (SIgA). Since the data was skewed, the square root of SIgA was used as the dependent variable in the regression. The mean value of salivary SIgA among housewives was 14.23 µg/ml in the low SO_2 concentration (0.02 mg/m^3) area, 12.65 µg/ml in the area where the concentration of SO_2 was 0.08 mg/m^3, and 11.72 µg/ml in the area where the concentration of SO_2 was high at 0.14 mg/m^3.[58]

3.5.4 Salivary IgG and IgA

Investigators in Chengdu compared the amount of salivary IgG and IGA in four functional areas (i.e. residential, commercial, industrial and suburban areas) of Chengdu (Table 26).[20] Salivary IgG was observed to be lower for residents of industrial and commercial areas.

Table 26: Comparison of salivary IgG and IgA among residents in Chengdu (geometric mean, µg/ml)

Area	n	IgG mean	SD_G	n	IgA mean	SD_G
Residential	158	11.83	2.62	178	61.91	25.55
Industrial	163	9.23	2.97	167	73.91	23.14
Commercial	128	6.67	3.78	164	58.73	18.85
Suburban	163	12.80	2.76	173	71.87	25.60

3.5.5 Salivary $APT_{1/2e}$

The half-life of antipyrine ($APT_{1/2e}$) serves as an indirect measurement of liver mixed function oxidases such as aromatic hydrocarbon hydroxydase (AHH). $APT_{1/2e}$ has been found to be correlated negatively with the activity of liver AHH. Therefore, a decrease in salivary $APT_{1/2e}$ time generally indicates an increase in AHH activity.

A study carried out in Yinchuan, Ningxia Hui Autonomous Region, of 872 schoolchildren resident in different areas did not reveal a statistically significant difference in their $APT_{1/2e}$ time, although a high correlation was found between TSP and $APT_{1/2e}$ ($r = -0.957$, $p < 0.025$)[12]. A similar study of 682 school children in Chengdu showed that salivary $APT_{1/2e}$ time was 8.68 hours for those living in urban areas and 13.72 hours for those living in the suburbs ($p < 0.05$). The correlation between $APT_{1/2e}$ and B(a)P was extremely high ($r = -0.998$, $p < 0.01$).[20, 21]

3.5.6 Serum IgG, IgA and IgM

In addition to local non-specific immune function indices, specific body fluid immune indices such as serum IgG, IgA and IgM were measured during epidemiological studies undertaken in Shenzhen, a city with a large number of motor vehicles, bordering Hong Kong.

Table 27: Serum IgG, IgA and IgM levels of residents exposed to CO in Shenzhen (μg/ml) [29]

Area	IgG	IgA	IgM
Customs	30.4 ($p < 0.01$)	3.9 ($p < 0.05$)	1.4 ($p < 0.05$)
Downtown	15.7 ($p < 0.01$)	9.5 ($p < 0.01$)	15.6 ($p < 0.01$)
Suburban	2.1	0.1	3.2

3.5.7 Correlation between TSP, B(a)P, SO_2 and salivary lysozyme, E_T-RFC, serum IgG, IgA and IgM

The amount of lysozyme in saliva, serum IgG, IgA, IgM levels and quantity of E-rossett forming cells, were found to be correlated negatively with B(a)P and TSP in Shenyang; but this was not the case for SO_2 (Table 28).

Table 28: Correlation between immune function indice and air pollution parameters in Shenyang [82]

	TSP		B(a)P		SO_2	
	r	p	r	p	r	p
Salivary lysozyme	-0.94	<0.05	-0.96	<0.05	-0.46	>0.05
E_T-RFC	-0.97	<0.05	-0.59	>0.05	-0.90	>0.05
Serum IgG	-0.99	<0.01	-0.85	>0.05	-0.67	>0.05
Serum IgA	0.18	>0.05	-0.46	>0.05	0.79	>0.05
Serum IgM	0.37	>0.05	-0.30	>0.05	0.88	>0.05

3.6 Body burden of metals

3.6.1 Lead

Epidemiological studies have shown that in areas surrounding smelters and battery plants, lead air pollution has negative impacts on human health. This applies to urban and rural areas alike. In a study of lead air pollution in Shenyang, the correlation coefficient between lead in air and blood was $r = 0.961$. For each increase of 1.0 μg/m^3 of lead in air, blood lead increased by 1.4 μg/dl.[63]

Table 29: Lead concentration levels in ambient air (μg/m³), blood lead levels (μg/dl) in children, and children's FEP, in Shenyang

Area	Pb in air	Pb in blood	FEP
Industrial	11.19	25.11	69.9
Commercial	1.11	11.56	32.7
Residential	0.77	10.95	28.9
Residential		14.70 (34)	32.7 (34)
Suburban	0.55	5.17	

A study of traffic policemen in Shanghai revealed that their blood lead level was 18.40 ± 6.71 μg/dl (n = 51; the blood lead level of the controls was 11.4 ± 4.31 μg/dl, $p < 0.01$).[31]

In the suburban areas of Shaoguan of Guangdong Province, the lead concentration of ambient air has been recorded at 0.10 ± 0.03 μg/m³. Shaoguan is a city that has recently undergone considerable economic expansion and consequently has a large number of motor vehicles.[32] Senior high school students in School A (lead concentration in ambient air: geometric mean 0.39 ± 0.09 μg/m³) in Shaoguan were found to have blood lead levels of 15.2 ± 1.53 μg/dl and aminolevulinic acid dehydratase (δ-ALAD) levels of 194 ± 1.9 IU/l. Students attending a school in a less polluted area (School B, lead in ambient air 0.15 ± 0.06 μg/m³) had blood lead levels of 13.5 ± 1.33 μg/dl and δ-ALAD levels of 157 ± 1.2 IU/l.

A study of lead pollution and δ-ALAD activity was conducted in Jinan. Lead concentrations in ambient air were found to be 9 times as high as those in the control village. For city residents, δ-ALAD levels were found to be 207.8 ± 48 IU/l. The sample size was small (n = 18) however. The level of δ-ALAD was found to be 120.57 IU/l for farmers living in the vicinity of a smelter and 155.84 IU/l for farmers in the control village. The δ-ALAD level for the farmers of the control group was found to be much lower than that of their city counterparts. This was thought to be related to differences in haemoglobin levels and warrants further study.[64]

Investigators in Linyi, Shandong Province, monitored the blood and urine lead content of farmers living in the vicinity of a smelter. Five months after the smelter had been closed down, lead concentrations in ambient air had decreased. The farmers' blood lead levels had also decreased, but not significantly. The mean lead level in urine was 0.16 μg/l, and 480.63 μg/l in blood; $r = 0.42$ ($p < 0.05$). The δ-ALAD level of 29 subjects in the polluted village was 120.57 IU/l; and 154.84 I.U/l ($p < 0.01$) in the control village for the same number of subjects. The protoporphyrin concentration of 30 subjects resident in the polluted village was 120.38 μg/dl/whole blood. In the control village it was 32.02 µg/dl, $p < 0.05$. A high correlation was found between the sister chromatoid exchange rate and blood lead levels, $r = 0.98$, $p < 0.01$.[35]

A study undertaken in Guichi, Anhui Province, also compared the levels of lead and cadmium in the blood of students attending a school (A) in the vicinity of a smelter, with those of students of a control school (B). The average blood lead level was 67.91 µg/l in School A and 32.26 µg/l in School B. In School A, the blood cadmium level was 1.83 µg/l and 0.86 µg/l in School B. The δ-ALAD level of students in school A was also inhibited, at 138.23 IU/l. In School B it was 185.65 IU/l. The red blood cell (RBC) counts of students in School A were also decreased in comparison with those of School B.[37]

A study of the lead body burden of battery workers, street sweepers and college students in Hefei revealed significantly high blood lead levels, a marked increase in FEP, and a decrease in δ-ALAD (Table 30).[36]

Table 30: Comparison of lead body burden of residents of Hefei

	n	Blood lead (µg/dl)	δ-ALAD (IU/l)	FEP (µg/dl)
Lead workers	20	31.81 + 1.58	116.33 + 1.67	259.59 + 1.61
Street sweepers	20	12.93 + 1.61	168.86 + 1.45	57.56 + 1.70
College students	20	9.45 + 1.54	209.14 + 1.28	56.69 + 1.74

$p < 0.01$

The investigators calculated the ratio of δ-ALAD activity in heated and unheated specimens and found it to be > 1.5. They concluded that the decrease in δ-ALAD activity was due to lead absorption.

According to a study in Guangzhou, lead content and δ-ALAD in urine could be used as early warning sentinels of lead absorption. The study authors proposed that 0.2 mg/l of lead in urine and 6.0 mg/l of δ-ALAD in urine be used as the criteria in the screening process. It was estimated that 25 000 people in Guangzhou were at risk from lead exposure, of whom 3700 showed various degrees of lead absorption. Since measuring lead in urine is non-invasive, the authors considered that this procedure could be adopted for identifying people at risk.[65]

Investigators in Shanghai studied the relationship between lead air pollution, and blood lead levels and its adverse effect on IQ.[66] The study was conducted among primary school pupils in the vicinity of a battery plant in the suburbs of Shanghai. Mean lead level in ambient air was 1.71 μg/m^3. The blood lead level of pupils of the same age in two schools — one in the polluted area (School A) and the other in an unpolluted area (school B) — were measured. The blood lead level of pupils was in the range of 19.84 ± 6.65 μg/dl in School A and 15.73 ± 6.32 μg/dl in School B. The Wechsler intelligence scale for children (WISC-R) was used to test the pupils' IQ. Blood lead levels and mean IQ were as follows:

<10 μg/dl	mean IQ = 109
10–20 μg/dl	mean IQ = 97
20–30 μg/dl	mean IQ = 78
>30 μg/dl	mean IQ = 72.

3.6.2 Cadmium

In Jinzhou, Liaoning Province, in an area around a zinc smelter that emits cadmium oxide from stacks, high concentrations of cadmium were found in ambient air, nearby soil and local farm produce. The cadmium concentration 500 m downwind from the stacks ranged from 21 to 53 μg/m^3. At 1000 m it was 8 μg/m^3, and at 1500 m it was 4.7 μg/m . Among 45 women living 500–1000 m downwind from the stacks, cadmium content in urine and hair was found to increase in accordance with the amount of time that they had resided in the polluted area (Table 31); 45.6% of the women interviewed complained of pain in their legs or throughout their body.[38]

Table 31: Cadmium content of urine and hair of women living near a smelter in Jinzhou

Length of residence in polluted area	Cadmium in urine (μg/l)	Cadmium in hair (μg/g)
<10 years	5.68	2.71
10–14 years	5.25	2.80
15–20 years	8.08	3.84
21–25 years	8.13	—
26–30 years	—	8.97

3.6.3 Cobalt, nickel and iron

In a preliminary report of a retrospective cohort study on malignant tumours and air pollution relating to an area near a smelter in Chengdu, elevated contents of cobalt and nickel were found among exposed residents (cobalt in hair: 0.10 μg/g among those exposed and 0.04 μg/g among controls; $p < 0.01$; nickel in hair: 0.78 μg/g among those exposed and 0.49 among controls; $p < 0.01$).[67] In Wanghua District, Fushun, an elevated iron content was found among residents (33.0 and 39.1 μg/kg for males and females in the urban area, and 22.7 and 26.9 μg/kg among controls).[6]

3.6.4 Mercury

The body burden of mercury of residents living within a 30 m radius of a small barometer workshop in Changsa, Hunan Province, was evaluated by measuring the mercury content of their blood, urine and hair (Table 32). Although the amount of mercury in blood, urine and hair was higher among residents in the polluted area than among controls, the amount of mercury in blood and hair was was within the range of normal values for Changsa. The amount of mercury in urine, however, exceeded the normal value for that region.[39]

Table 32: Body burden of mercury in blood, urine and hair

Area	Blood mercury (μg/dl)	Urine mercury (ppb)	Hair mercury (ppm)
Polluted	9.52 (n = 96)	7.35 (n = 96)	1.24 (n = 96)
Control	4.26 (n = 87)	2.69 (n = 84)	0.83 (n = 91)
Values considered normal in Changsa:			
	10	4.6	3.72

3.6.5 Vanadium

In polluted areas of Panzhihua, Sichuan Province, — the location of a large steel complex — the vanadium concentration in ambient air was 0.82 $\mu g/m^3$. The amount of vanadium in urine was statistically higher among exposed children (8–13 years of age; n = 270; 1.58 μg/l) than among the controls (0.64 μg/l).[40]

3.7 Other health effects

3.7.1 Carboxyhaemoglobin and haemoglobin

A study of CO air pollution and carboxyhaemoglobin (COHb) in blood in Shenzhen revealed a significant difference in COHb content between non-smokers exposed to CO in the downtown area and non-smokers exposed to CO in the suburbs (1.24% ± 0.82% in the downtown area and 0.72% ± 0.38% in the suburbs).[29]

Another study in Liaoyuan, Jilin Province, showed that children of 9–13 years of age living in the polluted area had lower haemoglobin levels and lower red blood cell counts than children living in non-polluted areas (Table 33). But it is not easy to ascertain whether these decreases were due to deterioration of ambient air quality alone (TSP level: 0.91 mg/m^3 in the polluted area, 0.39 mg/m^3 in the control area; SO_2 level: 0.30 mg/m^3 in the polluted area, 0.08 mg/m^3 in the control area). However, there was no statistically significant difference between the two groups with respect to white blood cell counts.[4]

Table 33: Comparison of haemoglobin and red blood cell (RBC) counts among children in Liaoyuan

	Area	n	Mean haemoglobin (g/dl)	RBC (1000/mm^3)
Boys	Polluted	105	12.5 ± 0.10	4056* ± 25.6
	Control	97	13.2 ± 0.12	4423 ± 35.7
Girls	Polluted	105	12.5 ± 0.09	4036 ± 23.6
	Control	94	13.1 ± 0.10	4420 ± 32.1

* i.e. 4 056 000

3.7.2 Olfactory threshold

Air pollutants can damage the respiratory tract. In Shenyang, the olfactory threshold of schoolchildren living in heavily polluted areas was found to be impaired (Table 34).[7]

Table 34: Percentage of schoolchildren with varying olfactory threshold, Shenyang (%)

Area	n	Good	Moderate	Poor
Heavily polluted	725	36.7	45.0	18.3
Residential	620	38.9	43.7	17.4
Suburban	475	46.1	49.0	4.9

3.7.3 Lung markings

X-ray examinations revealed lung markings among schoolchildren in Shenyang (Table 35).[7]

Table 35: Percentage of schoolchildren in Shenyang with varying degrees of lung marking

		Lung markings		
Area	n	I	II	III
Heavily polluted	473	78.0	17.6	4.4
Residential	518	80.1	7.1	0
Suburban	451	82.7	6.9	0

I, II and III refer to the degree or extent of lung markings

Of 1524 secondary school and primary school pupils in Xuanwu District in Beijing, X-ray examination showed that 16 students had lung markings. In another, cleaner, urban district, none of the 1431 students examined showed any lung markings.[48]

3.7.4 Subjective complaints

A survey conducted in Mouming, Guangdong Province, in the area around a petroleum refinery, showed that of the 444 persons interviewed, 71.2% complained of offensive odours, 44.6% of dizziness, 44.6% of headache, 34.6% of tightness of chest, 28% of nausea, 24% of nasal irritation, 16% of eye irritation and 17.5% of loss of appetite.[68]

3.7.5 Rickets

In Shenyang, ultraviolet radiation levels (17.2 μA) have decreased due to a very high TSP level (0.94 mg/m^3) in ambient air. As a result, the prevalence of rickets among kindergarten children in Tiexi District, Shenyang, reached 77.6% (n = 94). In Beilin District, where UV radiation was 21.2 μA and the TSP level reached only 0.31 mg/m^3, the prevalence of rickets was considerably lower at 44.3% (n = 70).[(10)]

3.8 Health effects and body burden of chemicals relating to individual industries

3.8.1 Fluoride

Children in three villages situated about 1 km from an aluminum plant in Ningxia Hui Autonomous Region were found to have a high concentration of F^- (fluorine ion) in their urine, as follows:

Village A, 1 km from plant, 0.98 ± 0.51 mg/l, n = 259
Village B, 1.5 km from plant, 0.93 ± 0.51 mg/l, n = 93
Village C, 1 km from plant, 1.33 ± 1.19 mg/l, n = 122
(Controls, 9 km from plant, 0.98 ± 0.55 mg/l, n = 183).

No data on stack height or topography were given in the paper. Moreover, the content of F^- in urine was also quite high among children in the control village, 9 km away from the aluminum plant. Assessing how much of the urinary F^- was due to fluoride pollution in ambient air and how much to ingestion of water with a high fluoride content, is therefore difficult.[(41)]

3.8.2 Chlorine

There have been several reports of accidental chlorine (Cl) leakage from the chlorine dehydration towers and pipes of alkaline plants in China. Those affected complained not only of irritation of the eyes and mucous membrane, but also of headaches, dizziness, tightness of chest and cough.[(69)]

In Yichong, Hubei Province, Cl emissions from a PVC plant resulted in an ambient Cl_2 level of 0.15 mg/m^3, 200 m downwind from the plant. The amount of salivary lysozyme among local residents was accordingly much lower (83.71 μg/ml) than among the controls (124.42 μg/ml, $p < 0.001$).[(42)]

3.8.3 Phenol

Phenol air pollution 300 m downwind from two bakelite and epoxy resin factories in Baoding and Hengshui, Hebei Province, was investigated. The amount of phenol in schoolchildren's urine was much higher than would normally be anticipated. The daily average phenol concentration in ambient air was in the range of 18–55 μg/m^3, with short-time maximum concentrations reaching 125–155 μg/m^3. The recommended daily average allowable concentration for phenol in ambient air is 15 μg/m^3. The recommended short-time maximum concentration is 45 μg/m^3. The current Chinese hygienic standard for phenol is 20 μg/m^3.(43) (The aforementioned recommended levels are air pollution levels that are considered acceptable by Chinese public health professionals, but that have not yet been approved by the State and hence not yet adopted as hygienic standards.)

3.8.4 Nitrochlorobenzene

Schoolchildren of 8–14 years of age exposed to nitrochlorobenzene in Changchun suffered from dizziness, nausea and vomiting; some of them developed cyanosis. Decreased RBC counts and temporarily increased white blood cell (WBC) counts were also reported (Table 36).(44)

3.8.5 Petro-chemicals

Daqing, a petrochemical city in the north-eastern part of China, is noted for its rich petroleum deposits. Air pollutants levels in the petrochemical area of Daqing and in a control area are shown in Table 37.

Table 36: Percentage of children with temporarily increased WBC counts in Changchun

		WBC counts (counts/mm^3)					
Time	n	8100–	10000–	12000–	14000–	16000–	18000–
September	499	16.03	24.65	14.03	5.61	3.41	2.00
October	306	22.22	12.09	11.76	5.56	2.29	0.97
November	104	10.00	5.00	3.57	0	0	0

Table 37: Comparison of air pollutant levels (mg/m^3) in Daqing, 1984–1986

Area	SO_2	No_x	TSP	CO	Total HCs	Non-methane hydrocarbons
Polluted	0.03	0.03	0.23	2.35	5.60	2.65
Control	< 0.01	< 0.01	0.12	1.68	3.29	1.83

The amount of salivary lysozyme among residents in the polluted area was 58.82 µg/ml (54.44 µg/ml among controls, $p < 0.01$), and positive incubation of streptococci β from the nasopharyngeal tract was 1.03%. (The latter was not detected among controls.) [68]

Decreased WBC counts and immune function were reported among schoolchildren (second and fifth grades) living in the vicinity of a petrochemical complex in Zhenhai, Zhejiang Province (Table 38).[46]

Table 38: Comparison of WBC counts (counts/mm^3) among schoolchildren, Zhenghai (concentrations of pollutants in mg/m^3)

School	Distance from petrochemical complex	SO_2	NO_x	NH_3	n	mean
1	1 km	0.01	0.02	0.06	151	5619 + 1600
2	2 km	0.01	0.02	0.05	181	6016 + 1587
3	5 km	0.03	0.02	—	184	6462 + 1700

$p < 0.05$

3.8.6 Vinyl chloride

A study carried out in Yichong showed that when vinyl chloride concentration in ambient air reached 0.17 mg/m^3, the amount of salivary lysozyme among children 10–14 years of age was elevated rather than inhibited (12.34 ± 2.54 µg/ml among those exposed, and 6.38 ± 1.78 µg/ml among the controls). Additionally, a decreased T-cell transformation rate (72.9%) was observed among adult participants.[45]

3.8.7 Vitreous (yellow) phosphorous

In Sichuan Province, 200 m downwind from a vitreous phosphorous plant, the P_2O_5 concentration (maximum daily average) was 0.17 mg/m^3. Elevated serum phosphorous (8.6% among those exposed, 2.6% among controls) and decreased serum calcium (28.5% among those exposed, 14.3% among controls) were reported. Table 39 shows the prevalences of relevant health effects.(70)

Table 39: Prevalences of health effects near a vitreous phosphorous plant

Disease	Prevalence Among residents	Among non-smokers	Controls
Mucous irritation	31.6%		
Chronic pharyngitis	41.4%	16.2%	6.9%
Chronic bronchitis	19.2%	12.3%	5.3%
Neurasthenia	53.1%		

3.8.8 Harbin railway station

Since relatively high concentrations of air pollutants are emitted from locomotives — both steam-powered and diesel-powered — the health of people working in and around railway stations merits attention.

Total mortality in the Harbin railway station area was 569.29/100 000 in 1987. Mortality due to malignant tumour was 127.18/100 000 which ranked first (23.34%) among all causes of death for the area. Lung cancer and liver cancer were the two most important causes of death from cancer. TSP concentrations reached 0.46 mg/m^3 in 1981, 0.89 mg/m^3 in 1982, and 0.86 mg/m^3 in 1983. Comparison of mortality due to malignant tumour among people working in the area under various conditions showed that malignant tumour mortality was highest among those working outdoors; those working indoors had a much lower mortality rate (Table 40).(71)

From the data presented above, it can be seen that ambient air pollution in China is characterized by high concentrations of TSP, and to a lesser degree, SO_2. This is to be expected given the type of fuel (i.e. coal) generally used in China.

Table 40: Comparison of mortality (%) due to malignant tumour among people working in the Harbin railway station area

Cancer site	Outdoor workers	Indoor workers	Indoor clerks	Support workers	Total
Lung	17.46	3.17	7.95	—	28.57
Liver	17.46	6.35	3.17	1.59	28.57
Oesophageal	3.17	—	—	—	3.17
Stomach	4.76	4.76	—	—	9.13
Intestine	1.59	1.59	1.59	—	4.76
Colon	—	1.59	3.17	—	4.76
Mammalian glands	—	1.59	—	—	1.59
Lymphoma	6.35	—	—	—	6.35
Other cancers	4.76	1.59	3.17	3.17	12.70
	55.56	20.63	19.05	4.76	100.00

Studies undertaken throughout the country have shown that this ambient air pollution has resulted in elevated mortality and prevalence of respiratory diseases, depressed immune functions, impaired pulmonary functions, and elevated body burdens of metals. It has also contributed to elevated lung cancer mortality.

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Study of Severe Air Pollution and Mortality in Shenyang, China

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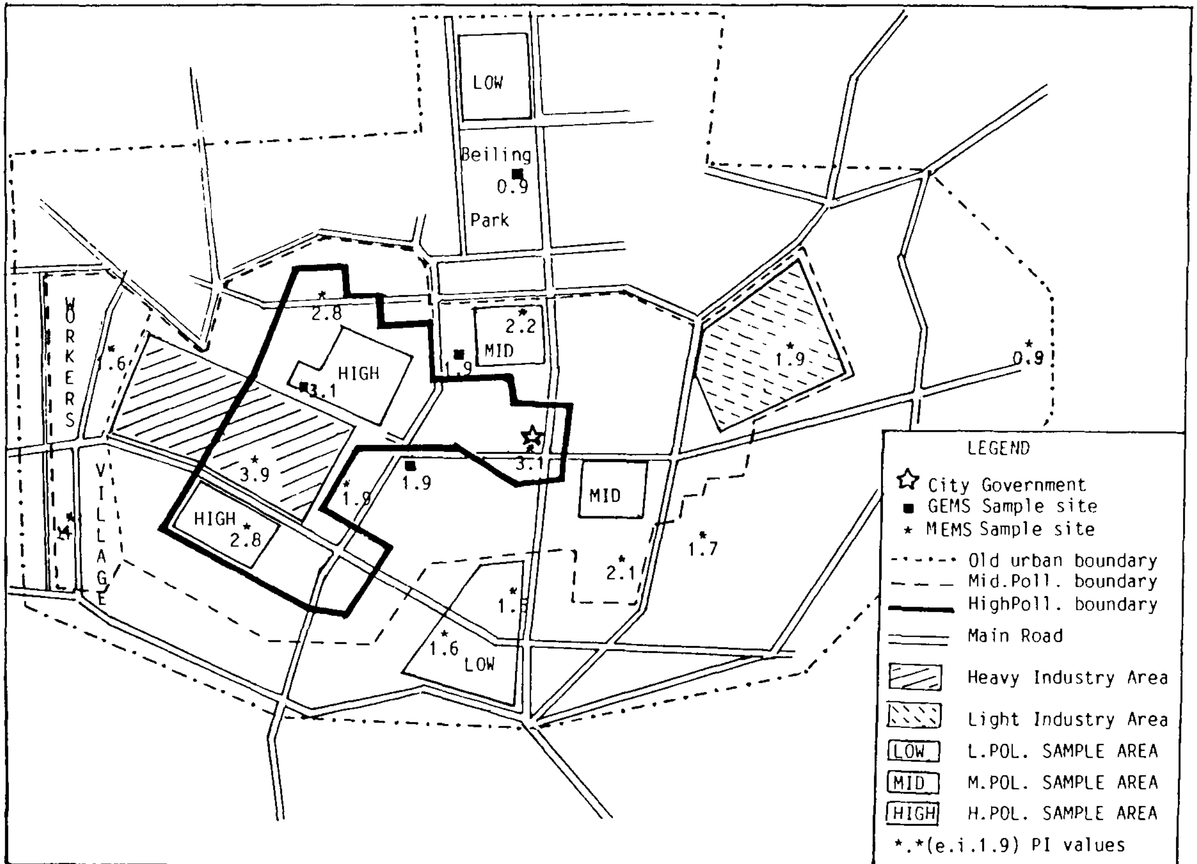
1. Introduction

Shenyang, the capital of Liaoning Province, is the largest heavy-industry city in China. Located in the north-east of the country, it has a population of 4.5 million and an urban area of 500 km^2.

The major source of air pollution in Shenyang is industrial and domestic coal combustion. Ferrous and non-ferrous metallurgical plants, manufacturers of machinery, various chemical industries, as well as coke, gas, and thermal power plants, are located in the western part of the city, creating a "thermal island". Additionally, thousands of light-industry plants and street enterprises are scattered throughout the city, and to such an extent that there are no distinct residential, commercial or industrial divisions in the urban area. However, since the heavy industries are located in the western part of the city and the prevailing wind blows south-southwest, it is the north-western part of the city that is the most severely polluted (Figure 1).

Coal consumption in Shenyang amounts to 8 million metric tons per year, 20% of which is used for domestic heating and cooking. Heating is generally operated for 150 days per annum. Domestic chimneys are usually less than 20 m in height. Emissions due to combustion for domestic heating and cooking account for around 50% of the ambient air pollution in Shenyang.

Figure 1: Map of Shenyang and boundary of pollution areas



The number of motor vehicles in Shenyang is still relatively small, but has increased rapidly in recent years (from 40 000 in 1981 to 150 000 in 1992). Emissions from motor vehicles that use leaded fuel are therefore becoming another major source of air pollution in Shenyang.

Air pollution levels in Shenyang are high. In a recent Global Environmental Monitoring System (GEMS)/AIR report, Shenyang's air pollution level was recorded as the second highest among the 41 cities listed worldwide.[1] According to a GEMS summary report for China, for the period 1981–1992, the daily average level of total suspended particulate (TSP) exceeded the second grade of the Chinese national standard for air quality (300 $\mu g/m^3$) for 60% of the year, and the national standard for residential areas (210 $\mu g/m^3$) for 80% of the year.[2] In the last decade, the annual mean TSP level ranged from 352 to 446 $\mu g/m^3$ (WHO guideline value = 90 $\mu g/m^3$), and the annual mean SO_2 level from 67 to 178 $\mu g/m^3$ (WHO guideline value = 60). However, although there has been rapid economic development in recent years, and rapid expansion of street enterprises throughout the city, the concentrations of air pollutants have remained constant and even decreased in some cases (Figure 2).

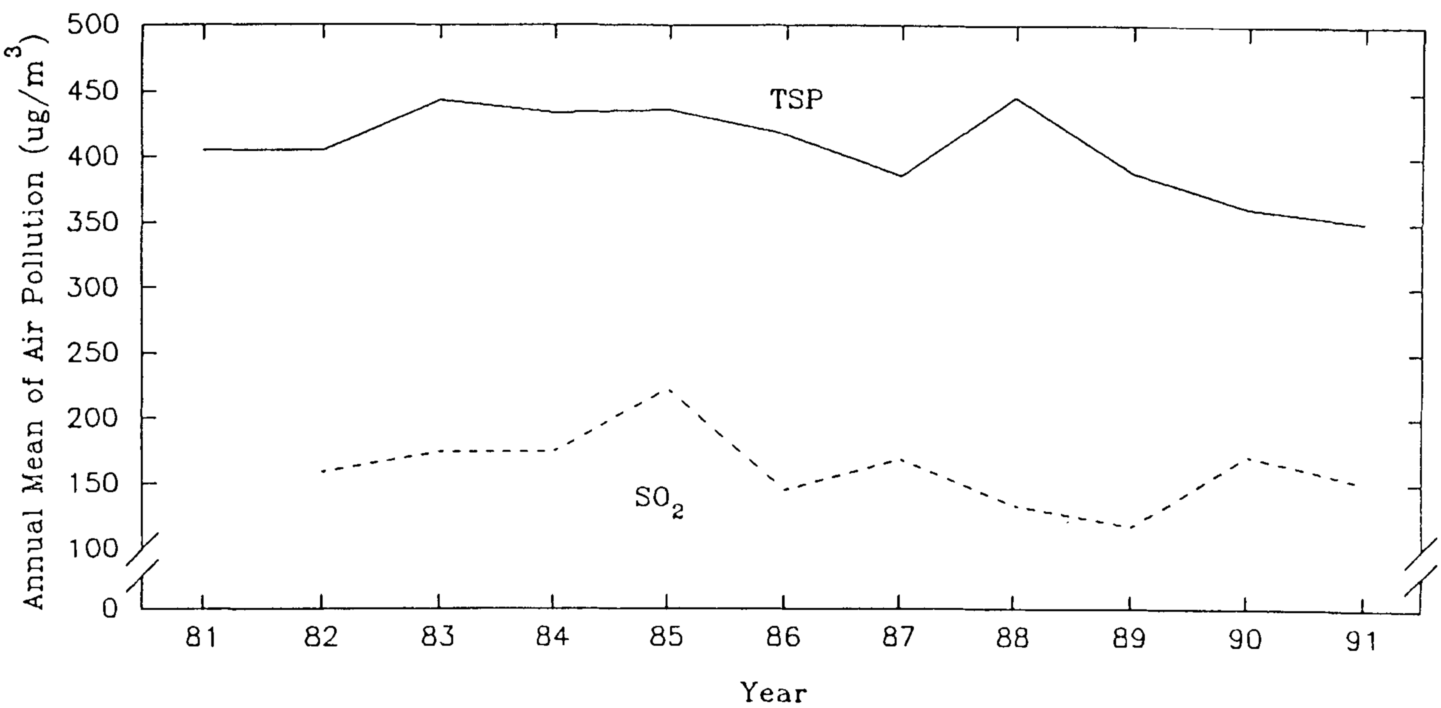
According to a study carried out by the Liaoning Provincial Environmental Monitoring Centre, 70% of TSP in winter is due to coal combustion; 70% of the particles are less than 10 μm in diameter. In summer, 65% of TSP originates from natural dusts resulting in particles with larger diameters. (A significant proportion of TSP consists of polynuclear aromatic hydrocarbons (PAH) and benzo(a)pyrene (B(a)P).) The ambient PAH concentration is 1354 $\mu g/m^3$ (the range is 616–2472 $\mu g/m^3$); the average level of B(a)P content is 50 ng/m^3. The B(a)P concentration in Shenyang is 50 times higher than that of cities in developed countries and is the highest among the five Chinese cities monitored by GEMS.[2, 3, 4] TSP in Shenyang contains appreciable quantities of heavy metals such as lead, arsenic and cadmium emitted from non-ferrous and ferrous smelters; indeed, TSP collected in Shenyang was found to be more toxic than that collected in the four other Chinese cities monitored by GEMS.[5]

Shenyang's air pollution is of great concern to the local government. With the support of the Chinese Ministry of Public Health, the World Health Organization (WHO) and the United Nations Environment Programme (UNEP), a study was designed to answer the following questions, and thereby to contribute to assessing the health consequences of air pollution in China:

- Which diseases are associated with air pollution in Shenyang?

- What is the quantitative- or semi-quantitative relationship between air pollution (mainly TSP and SO_2) and mortality and respiratory disease?

Figure 2: Time trend of air pollution in Shenyang



- What is the estimated attributable risk of air pollution for diseases in Shenyang after controlling for the potential effects of meteorological factors (such as temperature and humidity)?

2. Method

A number of studies have been carried out — using a cohort study design in several locations, or a longitudinal mortality study design in a single location — of the relationship between air pollution levels and health outcomes. But these types of study design are difficult to apply in a rapidly developing city such as Shenyang where both the beneficial and adverse effects of development have been observed simultaneously. Beneficial effects include improved living conditions, better housing, improved medical services, and availability of mains-supplied gas for cooking. Adverse effects include an increase in the number of unregulated enterprises and restaurants, increased traffic, and an increase in cigarette smoking. It would therefore be unwise to attribute changes in mortality over time to environmental pollution alone. Thus an ecological study design (geographic correlation), and a time-series study design (correlation between daily counts of deaths and daily pollution levels) undertaken in a restricted area and year (1992), were chosen for this particular investigation so as to minimize confounding associated with recent and rapid urban development.

For the ecological study, three city areas were selected and each classified as a high, medium or low pollution area, according to monitoring data collected at 19 fixed sampling sites (Table 1). However, misclassification was unavoidable, especially with respect to residents of streets that crossed boundaries. Therefore, in order, to obtain a better measure of pollution levels, three sample areas (including 12 residential street-blocks) were selected in three city areas that had monitoring sites. To control for potential confounding related to lifestyle factors, randomly selected families in these sample areas were interviewed, using a structured questionnaire, to obtain prevalence rates for respiratory diseases and information on individual exposures to indoor and occupational air pollution, history of cigarette smoking and length of residence in the particular area.

For the time-series study, the variation in daily counts of total mortality (excluding accidents) was unlikely to be affected by social confounders, but was likely to be affected by meteorological factors. Daily temperature and humidity were therefore controlled for by being included as confounders in the regression analysis that was carried out to identify the potential acute or aggravating effect of air pollution on chronic diseases leading to death.

Table 1: Average air pollution levels ($\mu g/m^3$) in different city areas

	GEMS [4 years]			MEMS [4 years]			
TSP	**no. of sites**	**range**	**annual average**	**no. of sites**	**range**	**annual average**	**value used in the study/ μg/m3**
High pollution area	1	472–539	503	5	490–750	618	560
Middle pollution area	2	371–531	443.5	4	480–630	550	497
Low pollution area	1	255–295	266	6	230–530	440	353
City average	4		414	15		520	467
SO_2							
High pollution area	1	212–233	219	5	160–280	204	212
Middle pollution area	2	81–150	115	4	90–140	117	116
Low pollution area	1	40–54	47	6	60–140	103	75
City average	4		124	15		141	133

3. Data collection and data analysis

3.1 Air monitoring data

Two air monitoring systems are operated in Shenyang: the Global Environmental Monitoring System (GEMS) (under the responsibility of the Shenyang Municipal Public Health Station) and the Municipal Environmental Monitoring Station (MEMS). Both systems were established in 1981 and are operated independently of each other.

The GEMS programme is run according to WHO/UNEP guidelines. There are four monitoring sites: the industrial area site located to the north of the city's non-ferrous smelter, half a kilometre away from the main stack; the commercial area site located in the centre of the city; the residential area site located in the northern part of the city, four kilometres downwind from the non-ferrous smelter; and the relatively "clean" site located in the northern part of the city, in the centre of Beiling Park, which has an area of 3 km^2, and no noticeable pollution sources nearby. Air samples are collected continuously for 24 hours from 0:00 to 0:00 every other day, for at least 12 days a month.

MEMS collects air samples for five consecutive days in mid-January, April, July and October, representing the four seasons. It has 15 sampling sites, and thus obtains detailed information on the distribution of air pollution throughout the city. The locations of the GEMS and MEMS sampling sites are shown in Figure 1.

Air monitoring data were collected from both GEMS and MEMS for this study. The stations' records were checked and outlying values revised when possible.

3.2 Air pollution categories of city areas

The current city area of Shenyang has an area of 500 km^2 and a population of 4.5 million. The original urban area was only about 230 km^2, with a population of 3.1 million. The growth in urban area during the past 10 years has taken place in what was a suburban agricultural area where air pollution levels were much lower than those in the original urban area. Only the residents of the original urban area (referred to hereafter as the urban area) were included in this study.

Air pollution categories were assigned to the different parts of the urban area on the basis of estimates of air pollution levels. A pollution index (PI) was used to describe the TSP and SO_2 levels for each GEMS and MEMS site, using the following formula:

$$PI = \sqrt{\max\left(\frac{Ci}{Si}\right) \times \frac{1}{2}\sum_{i=2}^{2}\left(\frac{Ci}{Si}\right)}$$

here:

PI = a dimensionless composite index, incorporating both the mean and the maximum concentrations of TSP and SO_2

Ci = the annual mean concentration of TSP and SO_2 ($\mu g/m^3$)

Si = the second grade Chinese national air quality standard for TSP and SO_2; TSP = 300 $\mu g/m^3$, SO_2 = 60 $\mu g/m^3$.

After taking into consideration the local conditions in Shenyang, the PI values obtained from the 19 monitoring sites were divided into tertiles. The PIs for high, medium, and low pollution areas were set at > 2.7, 1.9–2.7, and < 1.9 respectively.

The boundary lines for the high, medium and low pollution areas were drawn according to their PI values. Interpolation was used to estimate the PI values between two neighbouring sites (by percentile of distance between them). In drawing the boundary lines, the following sources were also used: the isopleth map of sulfate levels for 65 sampling sites in Shenyang prepared by the Provincial Environmental Monitoring Centre for September to November, 1989 (Figure 3); and the map of the amount of heat generated from coal combustion for each square kilometer of Shenyang (Figure 4) prepared by the Provincial Environmental Monitoring Centre in 1992. Minor adjustments were made in drawing the boundary lines for various pollution areas to correspond with the layout of the streets.

Figure 1 shows the location of the three main types of pollution area in Shenyang. The low pollution area is located on the outskirts of Shenyang, where many new residential buildings have been constructed in recent decades. Five street-blocks in the western part of the city (next to the "Workers Village") have been developed since 1957, and are also located in the low pollution area. While most of the residents moved from the high pollution area and now live in the low pollution area, they continue to work in the heavy-industry factories. Therefore, it was considered appropriate to classify these residents as living in the medium (or mid-) pollution area.

Strictly speaking, the level of air pollution estimated at the address of the deceased does not accurately represent that person's level of exposure to air pollution during his or her lifetime. This applies in particular if the individual moved frequently, or if the air pollution levels near the workplace differed from those near the home. However, most people lived in apartments provided by the factories or institutions where they worked, so that their living quarters were usually close to their workplace. This was particularly true prior to 1992. So the address of the deceased could generally be regarded as representative of his or her exposure category in Shenyang.

To avoid confounding due to the effects of recent large-scale city reforms, that have resulted in the frequent moves of residents, data from sample areas (described below) of the residential areas were used to supplement the calculations of relative risks (RRs) for diseases. (These residential areas had existed for more than 20 years and had not undergone any significant changes following the city reforms.)

3.3 Selection of sample areas

Mortality was compared for sample groups and the city as a whole.

Three sample areas were selected, based on the following criteria:

- complete street-blocks — the location of which could be assigned a single air pollution designation (i.e. low, medium or high pollution) — fall within its boundaries
- the buildings it contains are mainly residential and were constructed at least 20 years ago
- it contains a monitoring site — or alternatively, a monitoring site is located nearby — which provides valid estimates of ambient pollution levels
- it has a population of approximately 150 000 residents (amounting to 1/9, 1/10 and 1/5 of the total population of the high, medium and low pollution city areas, respectively).

The location of the sample areas is shown in Figure 1.

The mean values of pollution levels of neighbouring sites, as recorded by GEMS and MEMS, were taken as representative of the pollution levels of the sample areas (Table 2).

In addition, 1200 families — randomly selected from the sample areas — were interviewed to obtain their prevalence of chronic respiratory diseases and information on individual exposures to indoor and occupational air pollution, history of cigarette smoking, and length of residence. The resultant data were used to compare the RRs for the prevalence of chronic diseases, after controlling for individual exposures with the Rrs had been carried out. (It was not possible to control for confounding for the whole group.)

3.4 Collection of population and age-distribution data

Population census data for 1990, including a breakdown by 5-year age groups for each street-block, were collected from the Bureau of Census Statistics. Data on the geographic or administrative boundaries of residential committees and the population were also collected. In total, population and age-distribution data were collected from 1404 residential committees, 91 street-blocks for the whole urban area, and 3 sample areas.[1]

3.5 Collection of death certificates

Death certificates were collected from the Death Certificate Department of the Shenyang Municipal Public Health Station. The causes of death had been coded according to the ICD-9 (International Classification of Diseases).

For the study, the address of each deceased was coded according to the street-block (from 01 to 91) in which he or she had resided, and the type of pollution area (low, medium or high) in which the street-block was located. In 1992, there were 17 846 deaths in Shenyang, 130 of which could not be coded due to uncertainty regarding address. The results of this study are based on the remaining 17 716 deaths.

The Annual Death Report of the Chinese Ministry of Health requires that deaths be assigned to one of 87 detailed disease groups and to one of 22 disease categories (Chinese Classification of Diseases). In this study, coronary heart disease and myocardial infarction were grouped together to create a single category (CHD), as were the chronic obstructive pulmonary diseases (COPD).

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1 Note: A "street-block" is an administrative sub-unit of an urban district. In China, the administrative system in cities is arranged in the following order: municipal government, district government, street-block committee, and residential committee.

Figure 3: Sulfate isopleth map for September–November 1986

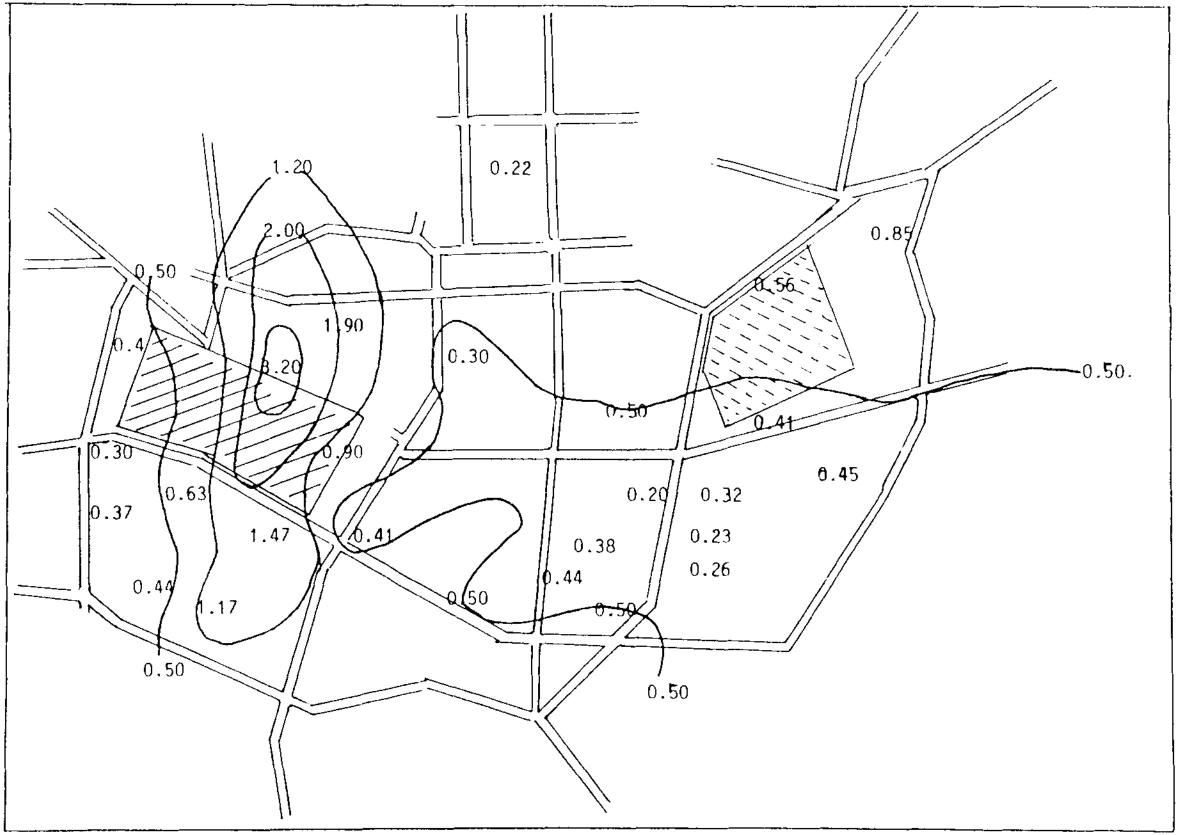


Figure 4: Heat produced by coal-burning in winter, 1992 (kcar/km^2)

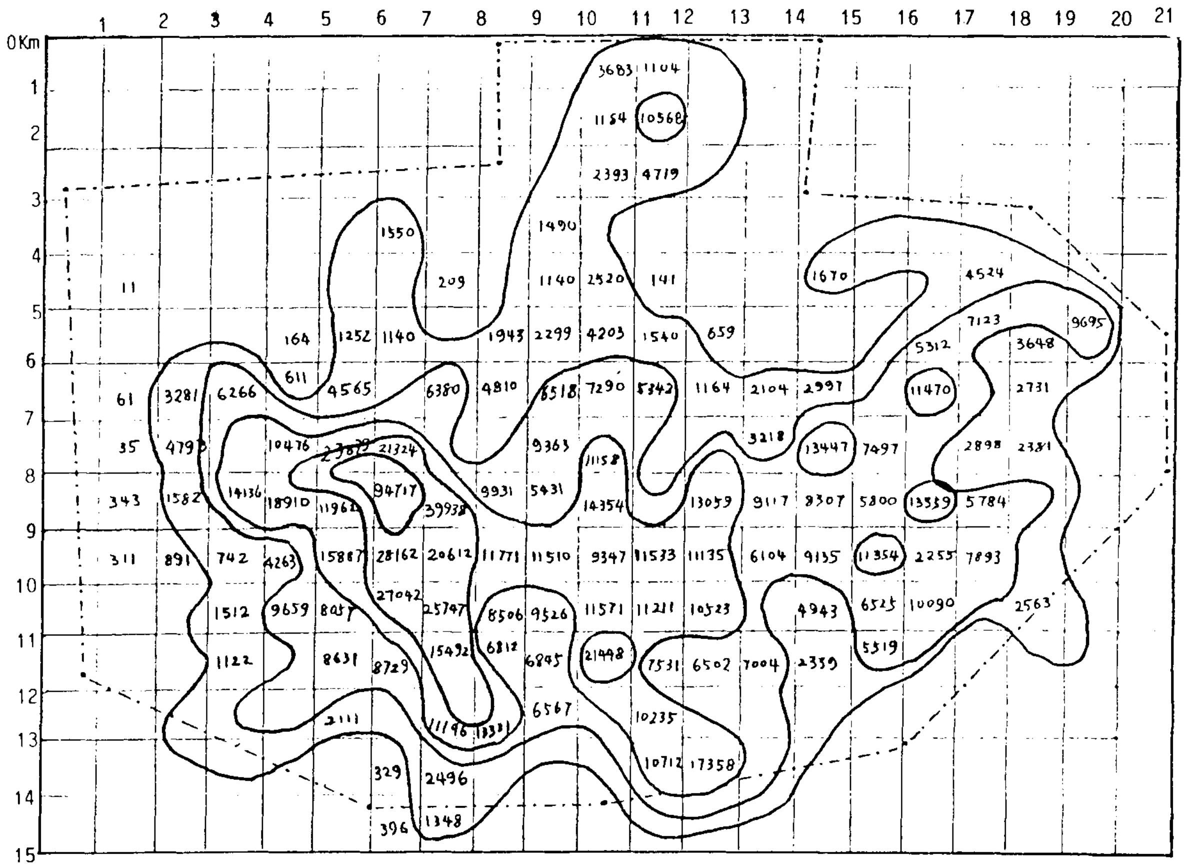


Table 2: Average air pollution levels in different sample areas

	No. of sites		Annual averages [4 years] µg/m³	
	GEMS	MEMS	TSP	SO_2
High pollution area	1	2	518	235
Middle pollution area	2	2	477	128
Low pollution area	1	2	361	64

Table 3: Air pollution levels and mortality rates in three polluted areas

	Population			Air pollution level (mg/m³)			Mortality (1/100,000)		
	total	men	women	TSP	SO_2	no./deaths	crude	adjusted*	RR (95% CI)
Low (C)	918185	465612	452573	353	75	4342	472.89	578.63	1.0
Middle (C)	1523442	766748	756694	497	116	9021	592.15	625.13	1.1 (1.04–1.12)
High (C)	655726	332520	323206	560	256	4350	663.39	691.98	1.2 (1.15–1.24)
Low (S)	156500	80612	75888	361	64	510	325.88	409.05	1.0
Middle (S)	130800	65714	65086	477	128	778	594.80	584.78	1.4 (1.29–1.54)
High (S)	151300	76724	74576	518	235	1006	664.90	697.05	1.7 (1.54–1.88)

C = city area
S = sample area
* = age-adjusted using the world standard population

3.6 Collection of meteorological data

Daily averages for air temperature and relative humidity were supplied by the Shenyang Municipal Bureau of Meteorology.

3.7 Quality control

Death certificate cards were checked before data entry and analysis. If some items, such as address, were incomplete, or the cause of death uncertain, the deceased's next of kin were re-interviewed by the staff of the District Public Health and Anti-epidemic Stations. The coding followed ICD-9 and was made by local death certificate department physicians, and further checked and revised if necessary by experienced physicians at the Liaoning Provincial Public Health Station. In the case of multiple causes of death, the primary cause of death was used in the analysis. All data were checked for errors and revised manually.

3.8 Analysis methods

The mortality data were analysed by means of an ecological study and a time-series study. The former was used to detect the long-term and chronic adverse health effects of ambient air pollution, while the latter was used to identify the acute or aggravating effects of air pollution on chronic diseases leading to death.

Foxbase software was used for data entry. Epi-Info and the SAS statistical package were used: to calculate age-adjusted (age-standardized), age-specific, disease-specific mortality; to establish linear trend correlations for different pollution areas; and to perform time-series multivariate regression analysis for daily pollutant levels, air temperature, humidity, and daily counts of deaths. Several models using a one- to four- day running average of pollutant levels (as the measurement of exposure level) were tested to find possible time-lags for different diseases. The Markov approach was used to deal with auto-correlation.

4. Results

4.1 Assessment of exposure level

Exposure levels for the different city areas and sample areas are presented in Tables 1 and 2.

The annual average TSP level recorded by MEMS was higher than that recorded by GEMS (520 μg/m^3 vs 414 μg/m^3). It is not clear whether this was due to differences in monitoring methods (which appear to be similar), or to the location of the monitoring sites. However, it should be noted that a quarter of the GEMS data were collected in the "clean area", while only one-fifteenth of the MEMS data were collected in the "clean area". Nevertheless, the SO_2 averages recorded by the two systems were comparable (141 μg/m^3 vs. 124 μg/m^3) (Table 1).

4.2 Group-based mortality analysis for the three different pollution areas

Table 3 shows the mortality rates for the city areas and the sample areas. Significant rank correlations for age-adjusted total mortality for the three city areas and the three sample areas were found (Table 3 and Figures 5 and 6). The RRs were 1.0, 1.1 (95% confidence interval 1.04–1.12) and 1.2 (1.15–1.24) for the low, medium and high pollution city areas, and 1.0, 1.4 (1.29–1.59), and 1.7 (1.54–1.88) for the low, medium and high pollution sample areas, respectively. According to analysis of the city area data, a 10% increase in total mortality could be anticipated for each 100 μg/m^3 increase in TSP. According to analysis of the data pertaining to the sample areas, a 35% increase in total mortality could be anticipated for each 100 μg/m^3 increase in TSP. For the population of Shenyang as a whole, it was estimated that 3000 (2700–3300) excess deaths would occur in the medium and high pollution areas when compared with the low pollution area.

4.2.1 Susceptible age groups

Table 4 shows the significant differences in age-specific mortality among the city areas and the sample areas. Two age groups were found to be particularly susceptible to air pollution: the under-14 age group and the over-35 age group.

4.2.2 Association between air pollution and diseases

Table 5 and Figures 7 and 8 show that there was an association between age-adjusted disease-specific mortality and air pollution. Some diseases were found to be positively associated with air pollution levels, including cerebral vascular disease (CVD), chronic obstructive pulmonary diseases (COPD), coronary heart disease (CHD), and cancer (mainly lung, oesophageal and intestinal). For both the city and the sample areas, mortality due to pneumonia in children under 10 years of age was found to increase significantly as air pollution increased. The mortality rates were 4.2, 0.9 and 0.0/100 000 respectively for the three city areas with high, medium and low air pollution levels, and 9.1, 0.0 and 0.0/100 000 respectively for the sample areas with high, medium, and low levels of air pollution (Table 5 and Figure 6). No significant differences in mortality for pneumonia or for other diseases were found for other age groups.

Table 6 and Figure 9 show cancer-specific mortality rates for the three areas. There was no evidence of an association between air pollution and the following cancers: nasal, pharyngeal, stomach, liver, breast, cervix, bladder, lung, oesophageal and intestinal. Nevertheless, a statistically significant increase was found for intestinal cancer. Lung cancer mortality accounted for one-third of all mortality from cancer. A gradual increment was observed from the low- to high-pollution sample areas, but the number of cases was too small to be of statistical significance.

4.2.3 Seasonal variations

Table 7 shows the seasonal variations in age-specific mortality. There was an apparent plateau in winter with a peak in January–February for young children and elderly persons. This pattern coincided with high air pollution levels and low air temperature. There may also be an association between relative humidity and age-specific mortality (Figure 10). It is probable that coal combustion for heating increases with declines in air temperature, leading to higher air pollution levels. Alternatively, the temperature itself may have an impact on disease occurrence.

Multivariable regression analyses of daily mortality and TSP levels, and SO_2 levels, air temperature and humidity, revealed a significant association between daily mortality and air pollution. (This is discussed in more detail in Section 4.3.)

Figure 5

A = Total age-adjusted mortality in different pollution areas
B = Mortality from pneumonia in children under 10 years of age

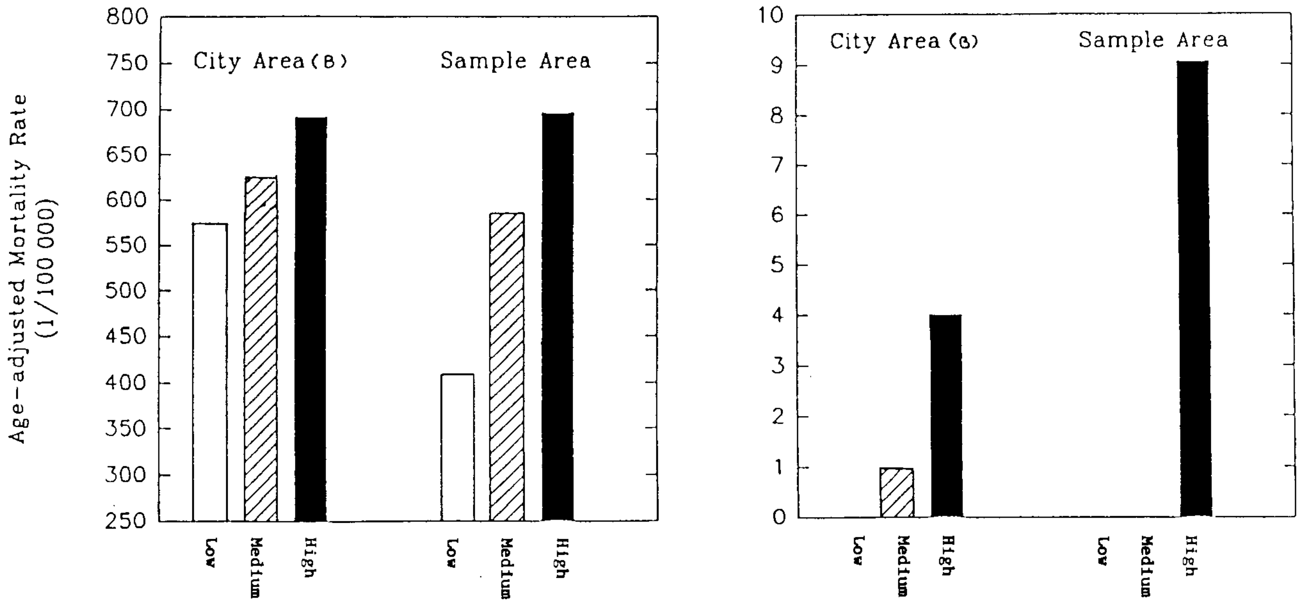
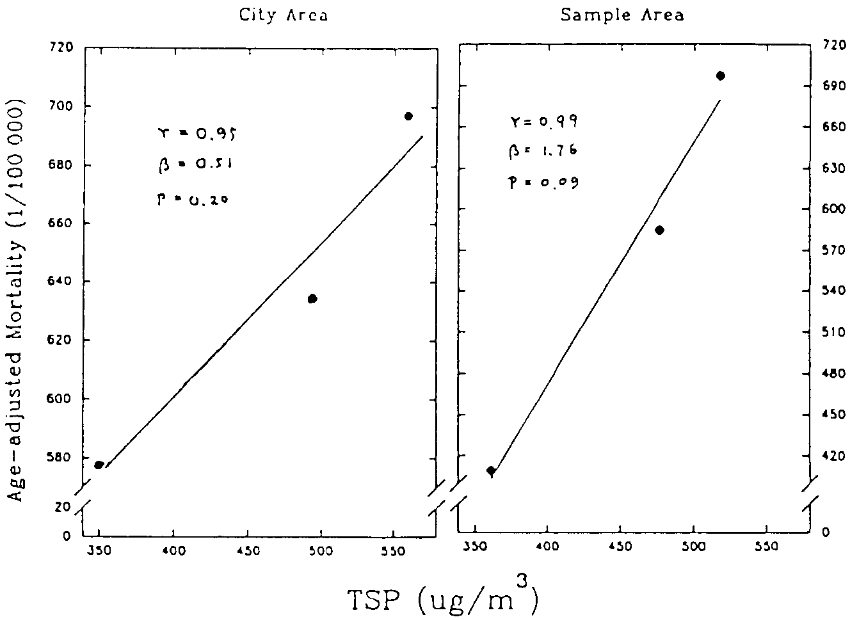


Figure 6: Regression lines for TSP, SO_2 and mortality for city areas and sample areas



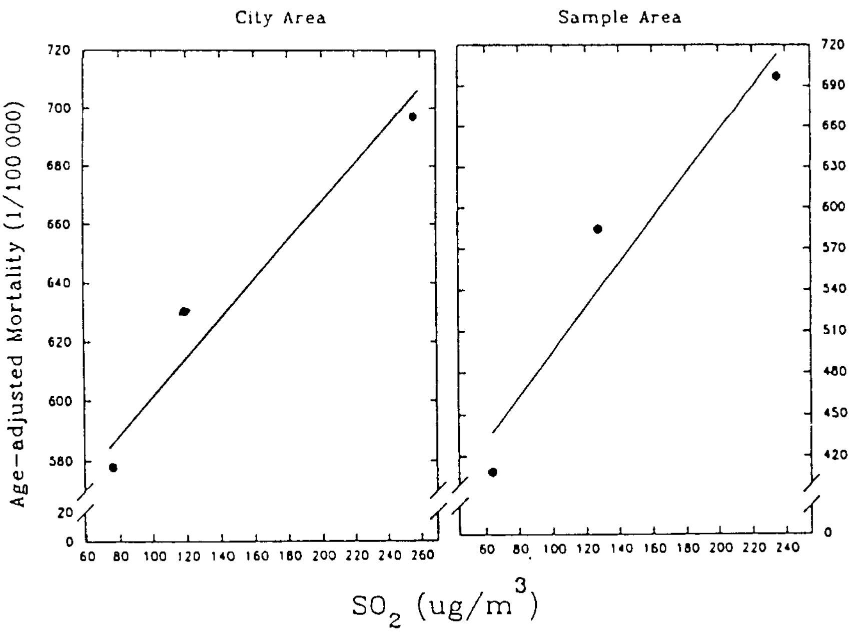
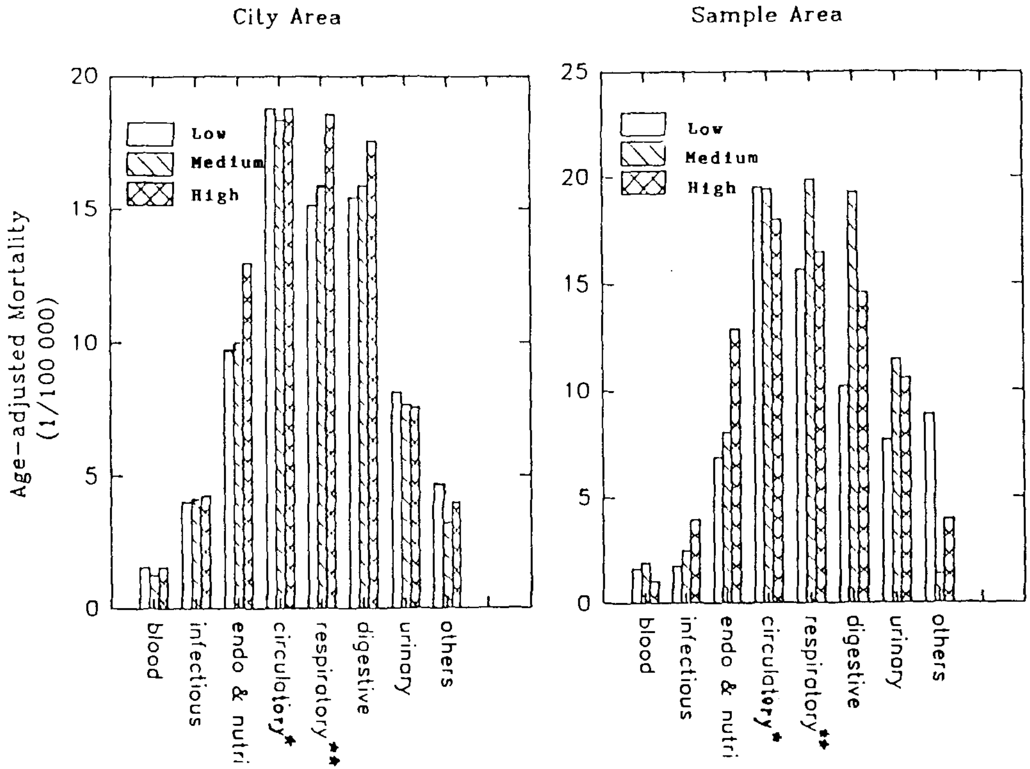


Figure 7: Diseases for which no significant variations in mortality were observed in terms of type of pollution area



* excluding CHD
** excluding COPD

Figure 8: Mortality from various diseases for low, medium and high pollution areas

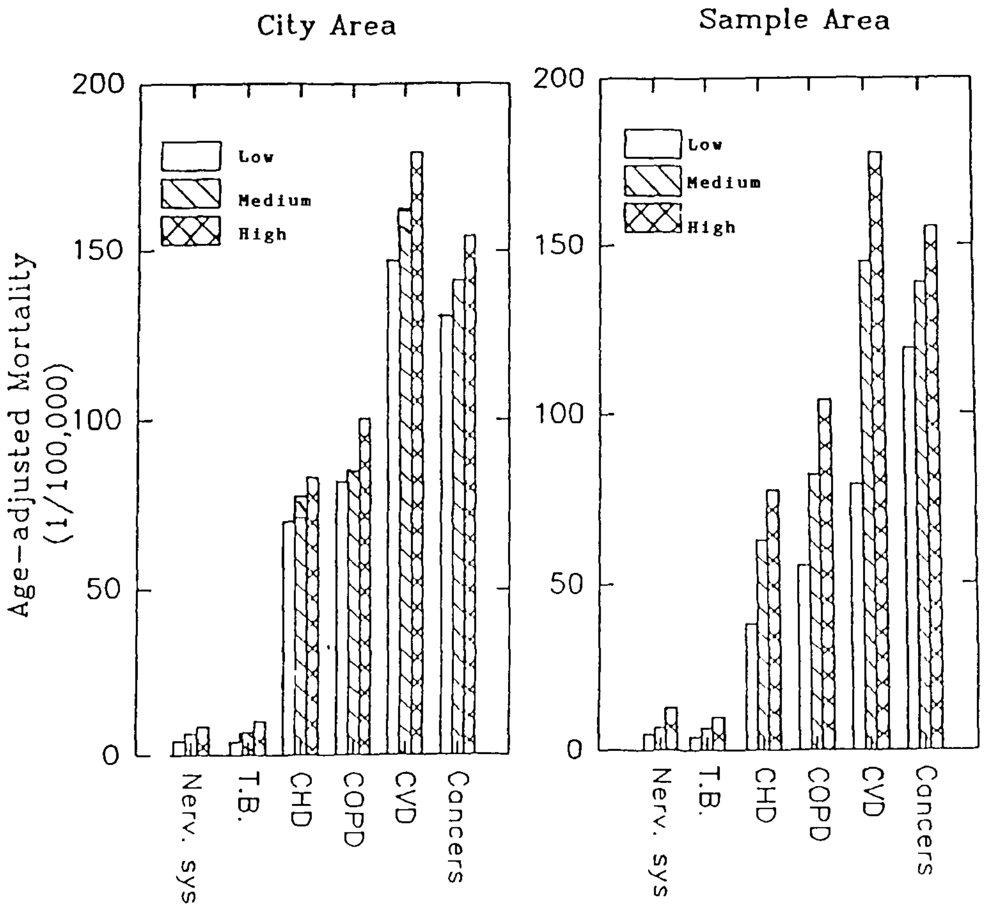


Figure 9: Mortality from cancer in low, medium and high pollution areas

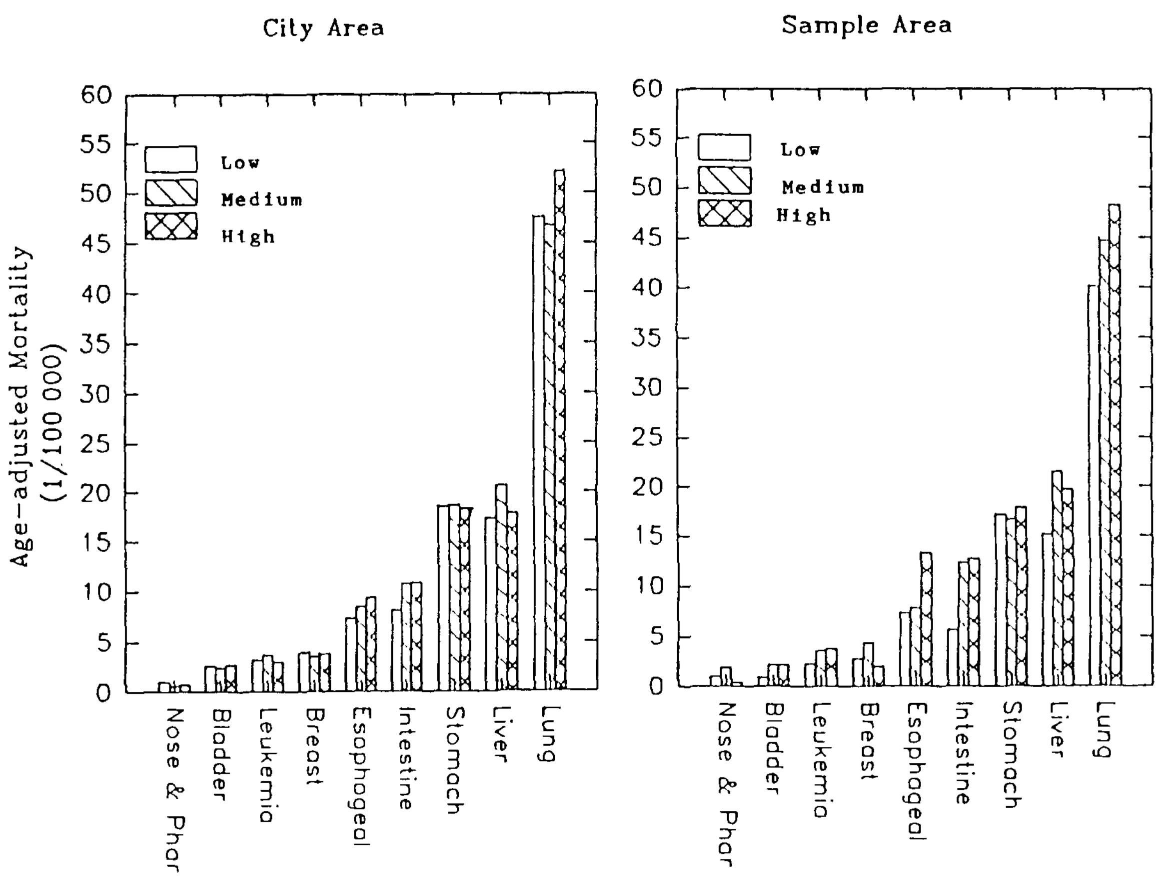


Figure 10: Seasonal changes in TSP levels, humidity and temperature in Shenyang, during 1992

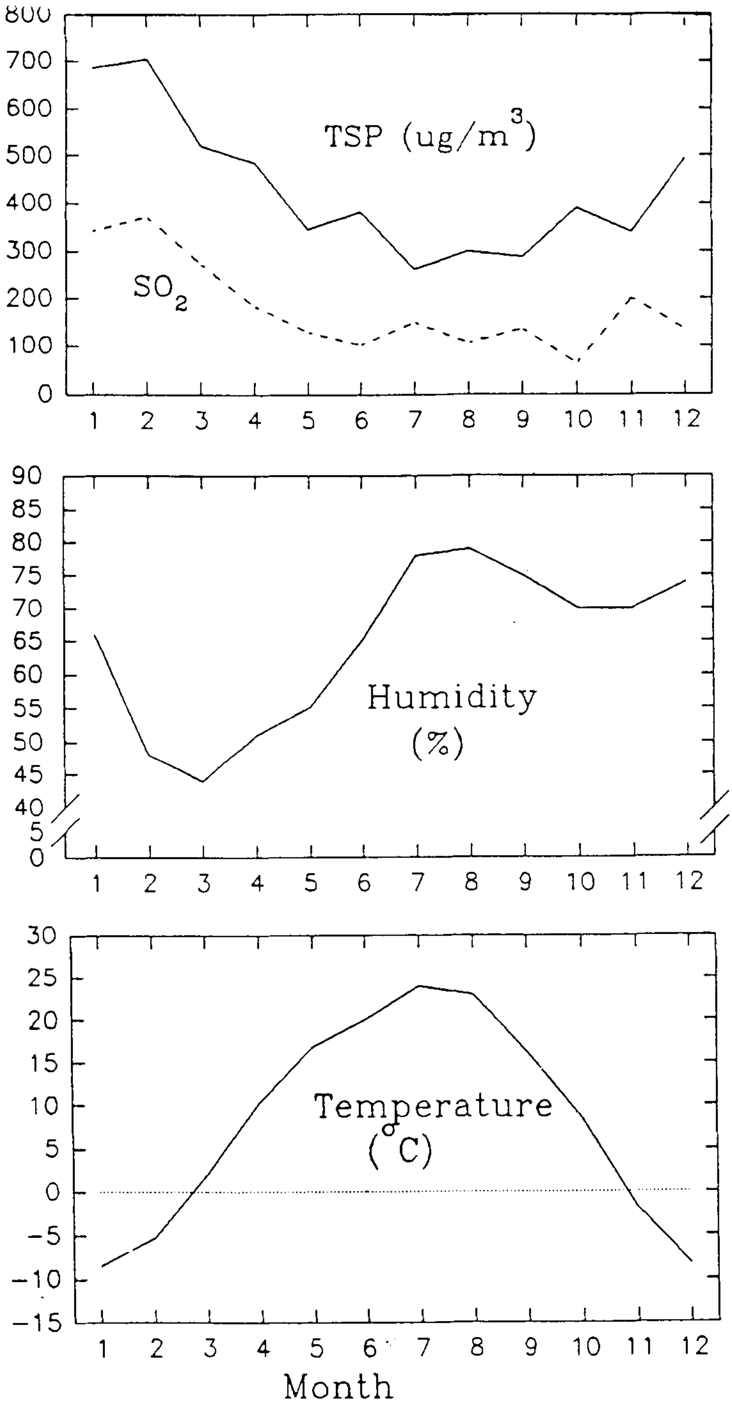


Table 4: Mortality by age group and type of pollution area (1/100 000)

	CITY AREA (B)			SAMPLE AREA		
	Low	Middle	High	Low	Middle	High
0–4	14.56	32.79	33.52	10.03	00.00	38.73
5–9	14.93	24.20	25.43	11.25	29.88	33.91
10–14	23.24	29.54	38.93	25.06	29.60	51.91
15–19	15.79	36.20	29.46	9.34	12.48	51.07
20–24	40.57	56.66	53.24	32.81	62.36	44.37
25–29	54.38	58.57	49.70	39.76	57.59	47.29
30–34	66.76	69.28	92.99	68.86	89.23	110.35
35–39	97.89	135.96	156.94	45.00	156.48	133.37
40–44	161.32	215.95	277.94	114.65	163.69	310.44
45–49	223.27	332.18	367.34	144.59	350.17	467.21
50–54	395.44	450.19	498.46	339.79	406.38	571.35
55–59	903.35	929.44	922.51	636.30	899.55	1024.34
60–64	1720.54	1721.60	1929.54	1126.96	1926.30	3037.01
65–69	3021.16	3097.32	3118.47	2571.43	4028.17	3037.01
70–74	5237.70	5289.27	5675.51	3261.62	4843.30	6252.31
75+	9723.30	10581.06	12613.88	7083.71	9280.00	11364.56

Table 5: Age-adjusted mortality by disease group and type of pollution area (1/100 000)

	CITY AREAS			SAMPLE AREAS		
	Low	Middle	High	Low	Middle	High
Infectious disease	3.88	3.94	4.23	1.75	2.47	3.91
T.B.	5.32	7.42	10.16*	4.09	6.80	10.07
Cancers	133.28	147.86	153.78*	119.06	138.74	155.16*
Endo. & nutr. disease	9.98	10.10	12.89	6.88	8.01	12.88
Blood system disease	1.53	1.32	1.58	1.60	1.92	1.04
Mental system disease	2.51	3.25	4.89	1.26	1.11	3.77
Nervous system disease	4.43	6.67	8.50*	5.14	7.06	13.00
Circul. system disease▲	18.74	18.07	18.76	19.52	19.43	17.98
Coronary heart disease	74.17	78.17	82.62*	38.02	62.85	77.75*
Cerebral vascular disease	146.48	162.27	177.58**	79.26	145.07	177.17**
Respiratory system▲▲	15.16	15.87	18.36	15.65	19.88	16.45
Pneumonia in children < 10 yrs old	0.00	0.90	4.2	0.00	0.00	9.10
COPD	81.50	83.57	99.10*	55.26	82.27	103.89*
Digestive system disease	15.18	16.19	18.47	10.22	19.28	14.58
Urinary system disease	7.99	7.94	7.58	7.70	11.49	10.56
Pregnancy disease	0.00	0.28	0.00	0.00	0.51	0.00
Muscle & bone	1.39	1.00	1.03	0.78	0.00	0.00

	CITY AREAS			SAMPLE AREAS		
	Low	Middle	High	Low	Middle	High
Malformation	4.95	3.46	5.45	1.20	3.17	3.04
Neonate disease	7.62	6.37	8.98	2.41	1.36	3.49
Injury	15.46	15.09	18.15	6.83	9.67	22.75
Others	4.73	3.17	4.20	8.90	1.38	3.98

* $p < 0.05$
▲ exclude coronary heart disease and infarction
** $P < 0.01$
▲▲ exclude COPD

Table 6: Age-adjusted mortality for different cancers, by type of pollution area

	CITY AREAS (B)			SAMPLE AREAS		
	Low	Middle	High	Low	Middle	High
Nose & pharynx	0.92	0.70	0.72	1.07	1.90	0.44
Oesophageal	7.53	8.83	9.31	7.39	7.79	13.33
Stomach	18.64	19.20	18.60	17.18	16.69	17.90
Intestine	7.69	10.96	10.82*	5.71	12.37	12.77
Liver	15.36	21.36	17.80	15.26	21.56	19.76
Lung	47.89	47.04	52.27	40.18	44.71	48.21
Breast	3.90	3.69	3.78	2.84	4.34	1.99
Cervix	0.62	0.65	1.06	0.00	0.69	0.71
Bladder	2.69	2.58	2.64	0.96	2.21	2.24
Leukaemia	2.77	3.96	2.96	2.35	3.57	3.76

Table 8 and Figure 11 show the three main groups of diseases for which a correlation with season was observed. Differences were observed between the three city areas with respect to total mortality and respiratory diseases, including COPD in winter. Since weather conditions were the same in each area, such an increase in total mortality in the high pollution area might be an indication of the adverse effects of ambient air pollution. Mortality from CVD and CHD fluctuated irregularly with respect to the different seasons, and the fluctuations varied in relation to area.

4.3 Time-series analysis of air pollution and mortality

Tables 10 and 11 and Figures 12 and 13 present the results of Poisson linear regression analysis of daily counts of death, and TSP and SO_2 levels, using the previous three-day running average of pollutant levels as the measurement of exposure, and controlling for air temperature, humidity and season.

The average daily total number of deaths (not including deaths from accidents) was 45.5 in Shenyang, and attributable as follows: CVD and CHD — 19.4; COPD — 6.2; cancer — 11.8; others — 8.1 (Table 9).

A significant association was found between total mortality and SO_2, while the association between total mortality and TSP was only marginally significant. Total mortality was estimated to increase by 2% for each 100 $\mu g/m^3$ increase in SO_2, and by 1% for each 100 $\mu g/m^3$ increase in TSP. Analysis of cause-specific mortality indicated that for each 100 $\mu g/m^3$ increase in SO_2, mortality increased significantly for COPD (6%), CVD and CHD (3%), and other diseases (4%), but not for cancer (0%). TSP was significantly associated with cardio-cerebral-vascular disease mortality (2%) only. Since TSP and SO_2 were highly correlated in the data set, both TSP and SO_2 were simultaneously included in the model to estimate the independent effect of each pollutant; TSP and SO_2 each remained significant predictors for cardio-cerebral-vascular disease and COPD mortality.

SO_2 as a characteristic indicator of coal burning was an even better predictor when stratified by season — most noticeably for winter. In summer, the SO_2 level is generally below 150 $\mu g/m^3$, and the adverse effects of TSP originating from sources other than domestic coal combustion (factory, traffic and natural dusts) more pronounced (Table 11).

Table 7: Number of deaths by age group and month

	0–	1–4	5–14	15–24	25–34	35–44	45–54	55–64	65–74	75+
January	24	7	10	19	29	59	103	364	510	517
February	21	6	7	12	39	61	88	398	530	533
March	20	4	10	15	42	65	103	392	465	560
April	21	5	1	17	48	54	91	333	414	441
May	16	6	9	13	43	61	100	370	392	428
June	9	3	14	16	41	52	85	332	392	368
July	22	2	11	18	41	70	98	295	365	323
August	19	7	4	10	45	66	68	330	396	348
Septem.	21	8	7	19	36	62	100	303	378	351
October	10	6	7	11	53	73	98	330	425	455
November	11	3	5	20	43	59	99	338	475	460
December	10	1	9	14	44	57	95	413	491	496

Table 8: Mortality rate by type of disease and month, for low, medium and high pollution areas

	All			Respiratory disease			Circulatory disease			Cerebro-vascular disease		
	L	M	H	L	M	H	L	M	H	L	M	H
Jan.	45.21	55.74	61.15	9.04	8.91	10.83	7.81	9.14	7.63	10.80	13.82	17.69
Feb.	45.65	57.73	64.51	11.06	13.43	15.40	6.67	8.60	10.07	8.95	14.97	14.03
March	46.71	57.35	60.54	8.69	11.21	14.03	8.25	8.68	8.08	11.50	14.05	12.20
April	39.68	46.22	56.58	5.00	5.68	8.54	5.44	6.68	7.47	10.36	12.44	16.93
May	40.38	49.44	51.09	4.92	7.29	6.25	8.08	7.75	7.16	9.57	12.51	12.96
June	37.93	44.68	45.45	3.69	4.45	4.88	5.88	4.99	7.63	10.45	11.13	11.13
July	32.57	43.45	46.97	3.16	4.45	4.27	4.92	5.68	6.25	8.52	9.98	13.12
August	34.33	43.76	50.63	4.13	5.22	6.86	5.18	6.06	7.16	7.81	11.44	13.27
Septem.	36.26	43.38	46.82	2.98	4.38	5.03	4.74	5.91	6.56	10.62	10.59	10.07
October	42.05	47.14	57.19	4.30	5.60	7.47	6.58	7.91	9.15	10.45	12.88	16.62
Novem.	41.18	51.90	56.12	5.18	8.91	8.85	6.85	8.14	8.08	11.94	14.66	17.69
Decem.	51.80	53.59	66.34	9.83	11.21	12.66	7.55	9.60	12.20	11.85	12.90	14.64

* rate per 100 000 persons per year.
L = low pollution area
M = middle pollution area
H = high pollution area

Table 9: Weather, air pollution and mortality in Shenyang in 1992

VARIABLES	DAYS	MEAN	SD	MINIMUM	MAXIMUM
Weather					
Temperature (F)	366	47	22	3	81
Humidity (%)	366	65	16	21	96
Air pollutants					
TSP ($\mu g/m^3$)	157	430	210	103	1140
SO_2 ($\mu g/m^3$)	165	197	159	6	659
Mortality					
Total	366	45.5	8.9	22	76
COPD	366	6.2	3.7	0	21
CVD	366	19.4	4.9	8	34
Cancer	366	11.8	3.0	3	20
Others	366	8.1	3.0	1	18

Table 10: Estimated relative risks of SO_2 and TSP for total and cause-specific mortality using Poisson regression, adjusting for temperature, humidity, and season

	SO_2 (per 100 µg/m³)		TSP (per 100 µg/m³)	
	RR	(95% CI)	RR	(95% CI)
	POLLUTANTS ANALYSED SEPARATELY			
Total	1.02**	(1.01–1.04)	1.01*	(1.00–1.02)
COPD	1.06**	(1.01–1.11)	0.99	(0.96–1.02)
CVD	1.03**	(1.00–1.05)	1.02**	(1.00–1.4)
Cancer	1.00	(0.96–1.03)	1.01	(0.99–1.03)
Others	1.04**	(1.00–1.08)	1.02	(0.99–1.04)
	POLLUTANTS ANALYSED SIMULTANEOUSLY			
Total	1.02**	(1.00–1.04)	1.01*	(1.00–1.02)
COPD	1.06**	(1.01–1.11)	0.99	(0.95–1.02)
CVD	1.02*	(1.00–1.05)	1.02*	(1.00–1.03)
Cancer	1.00	(0.96–1.03)	1.01	(0.99–1.03)
Others	1.03	(0.99–1.07)	1.01	(0.99–1.04)

the variance was calculated using the robust method

* $p < 0.10$

** $p < 0.05$

Table 11: Estimated relative risks of SO_2 and TSP for total and cause-specific mortality using Poisson regression, adjusting for temperature and humidity, separated by summer (May–October) and winter (November–April) seasons; pollutants were analysed simultaneously

	SO_2 (per 100 µg/m³)		TSP (per 100 µg/m³)	
	RR	(95% CI)	RR	(95% CI)
SUMMER SEASON				
Total	1.00	(0.95–1.05)	1.02**	(1.00–1.04)
COPD	0.99	(0.86–1.13)	1.01	(0.94–1.09)
CVD	1.00	(0.92–1.09)	1.04**	(1.01–1.08)
Cancer	1.01	(0.92–1.10)	1.04**	(1.00–1.07)
Others	0.98	(0.88–1.09)	0.98	(0.93–1.03)
WINTER SEASON				
Total	1.03**	(1.01–1.05)	1.01*	(1.00–1.02)
COPD	1.07**	(1.01–1.12)	0.99	(0.95–1.02)
CVD	1.03**	(1.00–1.05)	1.00	(0.98–1.02)
Cancer	0.99	(0.96–1.03)	1.02	(0.99–1.05)
Others	1.04*	(0.99–1.08)	1.04**	(1.01–1.07)

: the variance was calculated using the robust method
* : $p < 0.10$
** : $p < 0.05$

Figure 11: Seasonal changes in mortality for different diseases

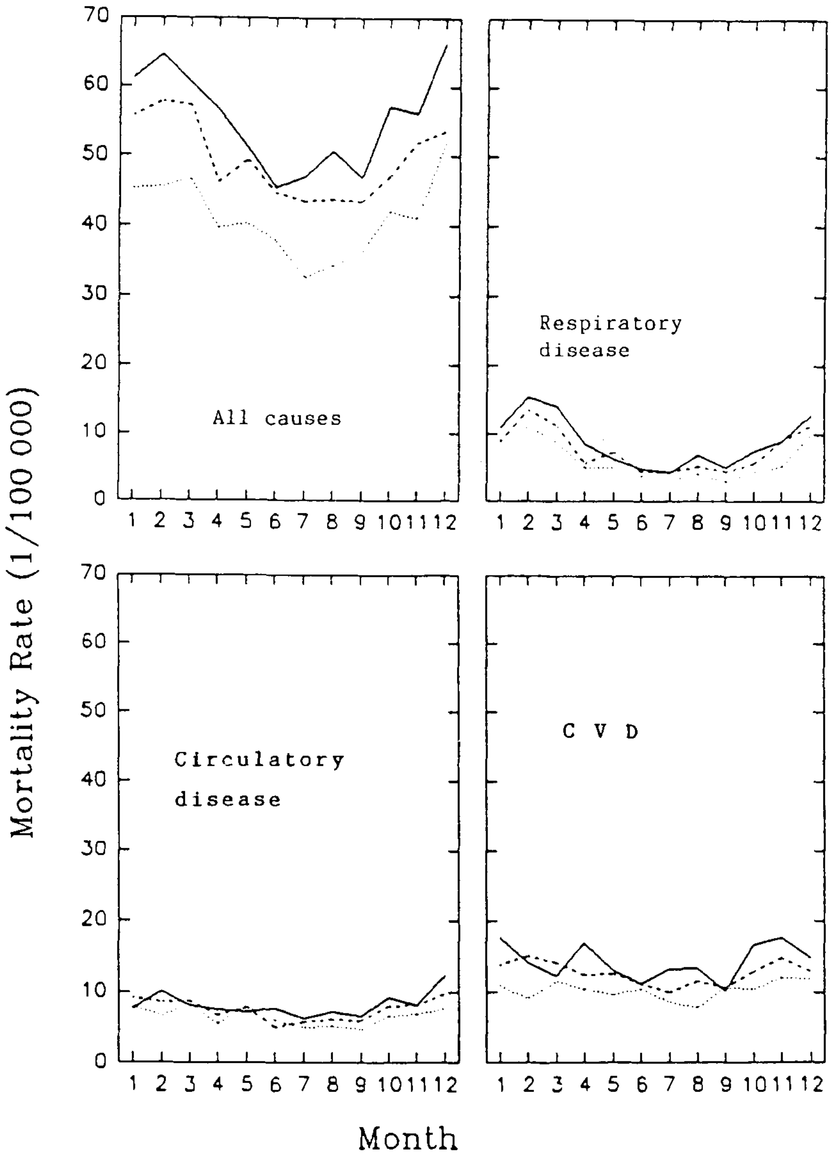


Figure 12: Association between SO_2, TSP and daily mortality

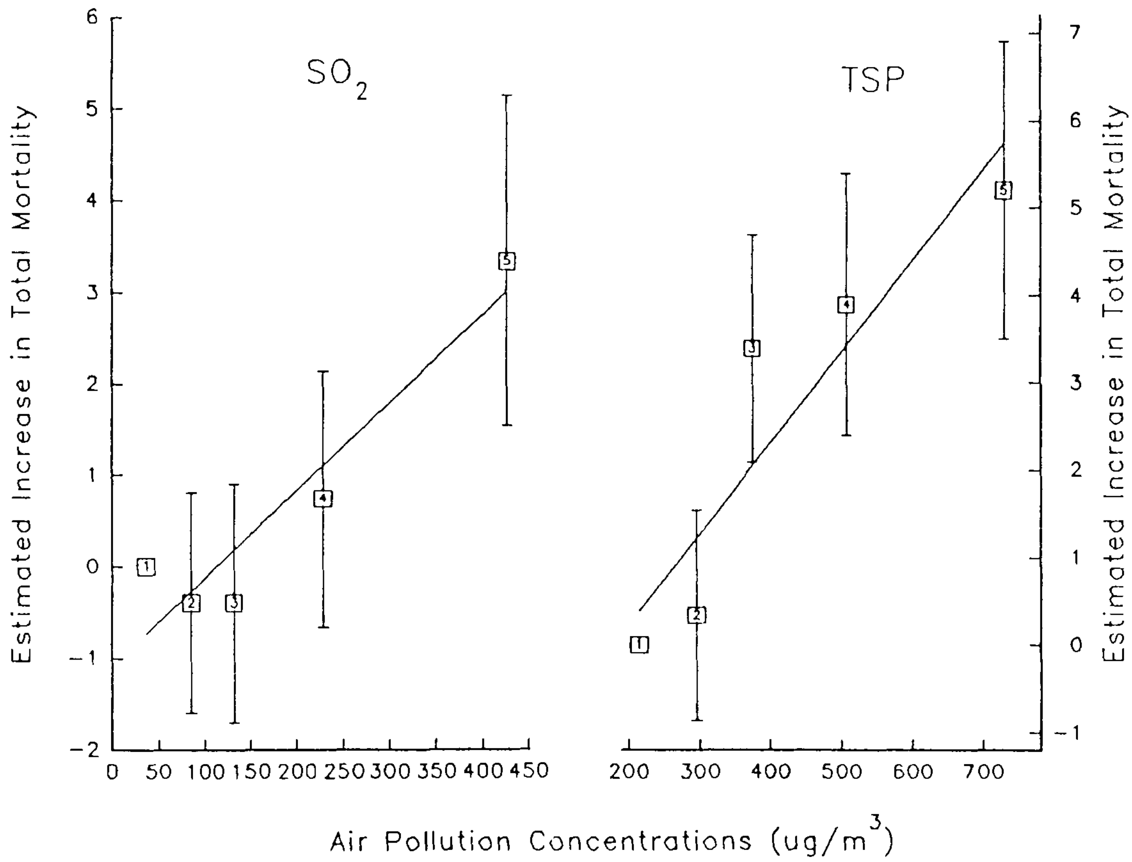
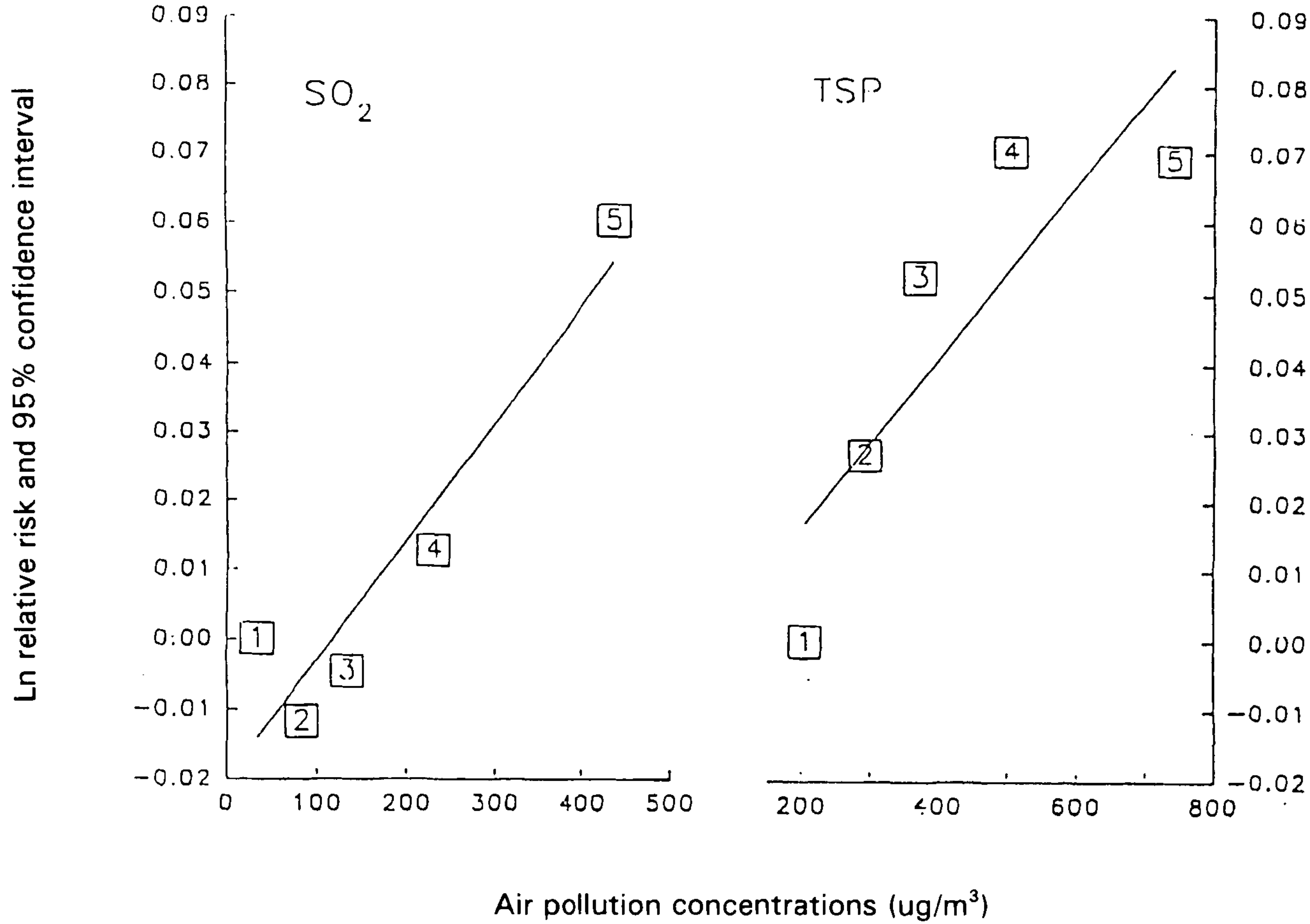


Figure 13: The relative risk of mortality for different levels of TSP and SO_2



4.4 Prevalance of COPD in three sample areas

To provide support for the association between group-based mortality and ambient air pollution, prevalence of COPD was investigated in 1200 families who had resided in the three sample areas for more than 10 years, with an average length of residence of 20 years (Table 12). The prevalence rates of chronic respiratory diseases and pulmonary heart diseases were significantly higher in elevated pollution areas (Table 13). After controlling for age, cigarette smoking and indoor coal combustion, the RRs of chronic bronchitis were calculated as 1.36 and 1.85 respectively for the medium and high pollution areas, and as 1.36 and 1.85 respectively for the medium and high pollution areas for pulmonary heart disease. These risks are comparable to the RRs calculated for mortality from these same conditions in the same geographic areas.

5. Discussion

One-year mortality data (1992) for urban areas with various degrees of air pollution was used in this ecological study. Age-adjusted mortality rates were compared cross-sectionally to eliminate some of the confounding that may have arisen due to the rapid development of the city. Daily counts of death in Shenyang were used in a time-series study, and regressed on daily levels of pollutants to evaluate acute damage or aggravating effects of high concentrations of TSP and SO_2 on susceptible persons. The estimated increase in mortality differed according to which method was used. Nevertheless, for each method, the results obtained showed that air pollution does increase mortality from all causes and mortality from specific diseases.

A cohort study of the prevalence rates of chronic respiratory diseases in families who had lived an average of 20 years in the three sample areas also found an association between increases in disease occurrence and increases in outdoor ambient air pollution.

Table 12: Prevalence rates of chronic respiratory disease and the relative risks of air pollution analysed using multivariate logistic regression model (all age-adjusted prevalence rates 1/100)

	LOW POLLUTION AREA		MEDIUM POLLUTION AREA		HIGH POLLUTION AREA	
	Rate	**(RR)**	**Rate**	**(RR)**	**Rate**	**(RR)**
Chronic bronchitis	4.96	(1.00)	5.0/	(1.36)**	9.01	(1.85)**
Pulmonary heart disease	0.24	(1.00)	0.86	(1.90)*	1.19	(3.61)*
Emphysema	0.57	(1.00)	0.61	(0.98)	0./6	(0.96)
Asthma	0.81	(1.00)	2.01	(1.17)	1.66	(1.37)
Tuberculosis	0.33	(1.00)	0.51	(1.09)*	0.97	(4.94)*
Pneumonia	0.25	(1.00)	1.01	(0.37)	0.09	(0.13)

( ) RRs after adjusted for age, cigarette smoking, indoor air pollution index
* $p < 0.05$
** $p < 0.01$

Table 13: Characteristics of 1200 families living in six streets randomly selected from the three sample areas

	Street name					
	NANHU	SHANDAIZI	LONGJIAN	ZHONGJIE	GUIHE	SHOUQUAN
Ambient air pollution level	low	low	middle	middle	high	high
Average years or residence	14	17	15	31	14	29
Currently using coal in home %	0	0	17.1	96.0	4.1	83.6
Average years of education of head of household	8.9	7.6	8.4	7.2	7.2	6.3
Cigarette smoking rate of persons > 20 years old	37.2	35.8	32.7	34.6	42.4	42.5
% of industrial workers in adults*	31.2	61.4	40.1	50.7	55.4	66.1

* This value was taken from the 1990 census published by the Municipal Bureau of Census Statistics

The results suggest that two age groups — those under 14 years of age and those above 35 years of age — are more susceptible to air pollution than are other age groups. Pneumonia in young children was found to be a predominant index disease, indicating that negative health effects due to air pollution had been experienced previously. It is to be anticipated that acute respiratory infections (ARI) in children under 10 years of age would be a sensitive index disease when assessing the adverse health effects of air pollution. Of course, the excess cases of pneumonia cannot be attributed solely to ambient air pollution, since data on the childrens' exposure to indoor air pollution and passive smoking is lacking. Nevertheless, this apparent excess should be investigated further.

The other sensitive group consists of individuals above 35 years of age. COPD, CVD and CHD are the main causes of death in Shenyang among this particular group, accounting for 50% of the total number of deaths and contributing significantly to the differences in mortality seen among the study areas. Other studies have found an association between COPD mortality and severe air pollution. The results of the time-series analysis supported their findings.

However, although mortality due to CVD or CHD differed significantly among the study areas, the differences were not as significant in the time-series study as in the ecological study (odds ratio = 1.03 for CVD compared with 1.06 for COPD, for an increase of 100 $\mu g/m^3$ in SO_2 levels). This might suggest that air pollution contributes to the aggravation of heart disease. Seasonal variation also appeared to be less significant in the time-series study. The relationship observed in this study between CVD and air pollution and CHD and air pollution suggests that air pollution might aggravate heart disease. Zhang reported that coal-smoke increased the incidence rate of stroke by 250% in Shanghai, with a RR of 2.55 (1.3 to 5.0).(6) Barskurt studied haematological and haemorheological effects of severe air pollution (in this case, an SO_2 level of 292 $\mu g/m^3$) among newly-recruited soldiers in Ankara. He found that exposure to high levels of SO_2 resulted in denatured haemoglobin, hardened the blood cell membrane, and reduced the ability of erythrocytes to change shape. This resulted in decreased blood supply to tissue, which might be one of the underlying causes of increased CHD and CVD in connection with exposure to to coal-smoke type air pollution.(7)

This study indicated that there was a gradient of lung cancer mortality among city and sample areas, with a substantial increase in highly polluted areas. However, no statistical significance was found because the number of cases available in the one-year time period was limited.

A case–control study with 1250 lung cancer subjects and an equal number of controls was conducted in Shenyang in 1989 by the authors to evaluate the association between life-long exposure to indoor and outdoor air pollution, cigarette smoking, and occupational and other factors. Exposure to high levels of indoor coal-smoke is an etiological factor for lung cancer, second only to cigarette smoking; this study found that it increased lung cancer mortality by 60–70%, resulting in an attributable risk of 13–17%.(8) Exposure to radon was not found to affect the risk of lung cancer in Shenyang.(9) Outdoor air pollution was still found to be an independent variable after adjusting for indoor air pollution and cigarette smoking, but it was difficult to evaluate the attributable risk of outdoor air pollution and separate its role from that of indoor air pollution.(8) In Shenyang, outdoor air pollution and indoor air pollution basically consist of the same kind of pollutants (TSP and SO_2). Moreover, levels of outdoor air pollution are similar to those of winter indoor air pollution. Therefore, it is biologically plausible that high levels of outdoor air pollution play a role in the etiology of lung cancer in Shenyang.

The study showed that ambient air pollution accelerates mortality in patients with COPD, CVD, or CHD. Total mortality was estimated to increase by 2% with each 100 $\mu g/m^3$ increase in SO_2, and by 1% with each 100 $\mu g/m^3$ increase in TSP. When mortality was analysed separately by cause of death, SO_2 was found to be a significant predictor of COPD (6%), CVD and CHD (3%), and other causes (4%), but not cancer. The results from this preliminary analysis suggest that the increased daily mortality in Shenyang was associated with high ambient air pollution levels. The time-lag between the peak of daily mortality and ambient air pollution levels was estimated to be 3 days; this is comparable to the results of Xu et al.'s study on air pollution and daily mortality in Beijing.(10) Results differ from those of studies undertaken in a number of US cities and London that showed that TSP, especially PM_{10}, was a better predictor than SO_2 and that the effects of SO_2 were greatly reduced when TSP or PM_{10} particulates were introduced into the models for each location.(11) However, in Shenyang, TSP may contain 30–35% of natural soil dust. So it would appear that SO_2 is a better surrogate of smoky-coal fumes in Shenyang, especially in winter. Additionally, SO_2 levels are 10 times higher in Shenyang that in US cities. In summer, when SO_2 levels are less than 90 $\mu g/m^3$ on most days, the effects of TSP are more apparent.

From this study it was estimated that about 3000 (2700–3300) excess deaths attributable to ambient air pollution occurred each year in the high and medium pollution areas (a total population of 2.18 million was affected). It should be noted that even in the low pollution area, air pollution levels exceeded the Chinese national standard for residential areas by 70% and the WHO guideline values by 300%. Evidently, there is an urgent need to control air pollution in Shenyang and reduce ambient air pollution.

Although evidence was obtained of an association between mortality and air pollution from various sources, this study had inherent limitations due to its study design. Firstly, in the group-based mortality analysis, it was not possible to control for the potentially confounding effects of individual exposures such as cigarette smoking, migration, indoor air pollution, occupation and education. Secondly, even though the divisions were based on sufficient data from air monitoring sites, misclassification relating to the division of the city into the three types of pollution area was a problem. Thirdly, in selecting representative pollution sample areas, bias may have been introduced (Table 13). There is a great difference between different areas in the percentage of subjects using coal in their home. Furthermore, the two street-blocks representing the low pollution area might not contain a representative population. The Nanhu street-block contains several universities with about 10 000 students. Over 60% of the population of Sandaizi consists of factory workers, the majority of whom are employed by an aircraft manufacturer. This could have resulted in confounding due to the "healthy worker" effect and/or occupational exposures. To remedy some of the defects of this study, the 1986–1988 mortality and air monitoring data have been collected and will be analysed with respect to stability of residence (i.e. long-term residence in one place). The advantage of using this data as opposed to data from cities undergoing rapid change and development is that:

- migration of residents was minimal during this period, since city and social reforms had not yet been introduced on a large scale; the address of the deceased is therefore generally the place where the deceased resided for a long period of time

- sample areas can be reselected to avoid selection bias

- the longer study period (three years) will provide larger numbers of cases and a better opportunity to test the statistical significance of RRs for diseases for the different areas.

6. Conclusions

This report analysed the correlation between air pollution and mortality in an ecological study of group-based mortality for three different air pollution areas (city areas supplemented by sample areas), and the results of a time-series study which regressed daily counts of death and daily concentrations of TSP and SO_2. The study results show that:

- With ambient air pollution levels ranging from 350 to 560 $\mu g/m^3$ for TSP and from 75 to 210 $\mu g/m^3$ for SO_2, there was a significant correlation between air pollution levels and total mortality. Each 100 $\mu g/m^3$ increase in the TSP level resulted in a 35% increase in total mortality in the sample areas and a 10% increase in total mortality in the city areas. Based upon the population of the original urban areas, it was estimated that 3000 excess deaths, or 17% of the total number of deaths in the medium and high pollution areas, were attributable to ambient air pollution.

- Air pollution can increase pneumonia mortality in children under 10 years of age.

- The chronic adverse health effects of air pollution include increased mortality in elderly persons due to COPD, CV, CHD and lung cancer.

- Air pollution can accelerate mortality in elderly susceptible persons (mainly patients with chronic diseases). SO_2 was found to be a better predictor than TSP in Shenyang. It was estimated that with each 100 $\mu g/m^3$ increase in SO_2, total mortality increased by 2%, COPD mortality by 6%, and CHD and CVD mortality by 3%. For TSP, the same increase in exposure level would bring about a 1% increase in total mortality and a 2% increase in CVD and CHD mortality.

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The Global Environmental Epidemiology Network

The Network was established by the World Health Organization in 1987 as a means of strengthening education, training and applied research in health effects assessment and environmental epidemiology.

The Network's focus is the collaborative activities among members. These are supported by the Office of Global and Integrated Environmental Health at WHO headquarters, the environmental health staff in the six WHO Regional Offices, and associated technical centres.

To support member activities, the Network produces various documents concerning the development and promotion of environmental epidemiology research and training. These, together with lists of Network members, are distributed regularly and will be made available electronically via Internet. GEENET also organizes training and research workshops in collaboration with national and international agencies.

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