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Exposures and health outcomes from outdoor air pollutants in China

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Abstract

China's economy has developed rapidly in the recent two decades. Economic development is usually linked with increase in energy consumption and consumption emissions, which in turn leads to worsening of air quality. Due to the adoption of various control measures, the ambient air quality in a number of large cities in China has actually improved. The ambient air TSP and SO_2 levels in China have been decreasing in the last decade. However, ambient air NO_x level has been increasing due to the increased number of motor vehicles. Coal has been and is still the major source of energy in China. Ambient air pollution in large cities has changed from the conventional coal combustion type to the mixed coal combustion/motor vehicle emission type. A series of epidemiological studies on air pollution and health effects ranging from mortality, morbidity to functional changes have been conducted in China. The results showed that ambient air pollution had acute and chronic effects on mortality, morbidity, hospital admissions, clinical symptoms, lung function changes, etc. The exposure–response relationship between air pollutants and daily mortality, morbidity, hospital admissions, and lung function has been established accordingly.

Keywords: Air pollution; Health outcomes; Time-series study; Mortality; Particulate matter; Sulfur dioxide (SO_2)

1. Introduction

China is a country under rapid development, particularly in the recent two decades. With the advance of development, as can be expected, energy consumption increases, so is the degree of urbanization. As cities grow, more and more people flock to cities. Chinese national census data in 1980 showed that about 19.4% of the population lived in cities and towns, now the figure is around 32%. City construction booms, and construction sites are just about everywhere. More and more young people are drawn into cities looking for new jobs and new opportunities. On the other hand, people living in the central districts of large cities the original city dwellers, are aging resulting in large numbers of elderly people (>65 years of age) in these areas.

With the increase in energy consumption and urbanization, increase in ambient air pollution seemed inevitable. However, through relocation of polluting industries, switching to less polluting fuels, enforcement of zoning regulations, stricter emission standards for mobile and stationary sources, better city planning, and increased investment in city infrastructure

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construction, ambient air quality in a number of large cities has actually improved.

Coal is the major source of energy in China, constituting about 75% of all energy sources. Consequently, air pollution in China predominantly consists of coal smoke, with suspended particulates and sulfur dioxide as the principal air pollutants. With the rapid increase in the number of motor vehicles in recent years, air pollution in large cities has gradually changed from the conventional coal combustion type to the mixed coal combustion/motor vehicle emission type.

2. Exposure

2.1. Trend in air pollution exposure levels

Ambient air pollution in China was severe in the last century. Chinese public health and environmental science professionals began studying air pollution related problems in the early 1950s. Studies conducted in Shenyang in north eastern China in the fifties showed TSP levels sometimes reaching several hundreds to almost 1000 $\mu g/m^3$. Limited by technical know-how and availability of sophisticated monitoring equipment at that time, these measurements were irregular, non-continuous, and without laboratory quality control.

After China joined the Global Environmental Monitoring System (GEMS) program in the late eighties of the last century, regular systematic monitoring of air pollutants has become routine practice and analytical quality control procedure observed. From a GEMS report published by UNEP/WHO, ambient SO_2 level in Beijing in the 1980s was around 100–130 $\mu g/m^3$, TSP level 250–450 $\mu g/m^3$ (UNEP, WHO, 1996). In the past, Beijing and Lanzhou ranked high in TSP level, and Chongqing high in sulfur dioxide level. In the case of Beijing this might be partly due to sandstorms coming from the north. Generally speaking, many Chinese cities were high in suspended particulate level. On the other hand, sulfur dioxide level was mild except in Chongqing, a city surrounded by mountains and is foggy in winter. It is relieving to note that SO_2 levels have improved drastically even in Chongqing since people switched to cleaner fuels there.

Since the late nineties, annual average levels of TSP and SO_2 in large cities had been declining slowly in spite of rapid economic growth in China (China State Environmental Protection Agency, 1990–1998). For example, from 1990 to 2000 annual GDP in Shanghai increased from CNY 75,600 million to CNY 455,100 million, while TSP levels decreased from 360 to 156 $\mu g/m^3$, a 67% reduction; and SO_2 levels decreased from 95 to 45 $\mu g/m^3$, a 53% reduction (Shanghai Municipal Statistics Bureau, 1991–1999). People in Shanghai began seeing clear blue skies again. On the other hand, the number of motor vehicles increased from 210,000 to 1,040,000, and NO_x level in ambient air increased from 65 to 90 $\mu g/m^3$.

In general, suspended particulate concentration levels in cities in northern China are higher than those in southern China, while SO_2 concentration levels do not differ much. Air pollution in winter is generally more serious than that in summer.

In areas where gas or hydroelectric power is not available, many people still use coal and/or coal briquettes for domestic cooking and/or heating, particularly in small cities and the countryside where coal and coal products are generally burned in simple stoves with/without chimneys, resulting in high suspended particulate and sulfur dioxide concentrations indoors. Under such circumstances, indoor air pollution levels may actually be worse than outdoors.

2.2. Factors contributing to change in exposure levels

2.2.1. Urbanization

Urbanization involves the process of migration, social aggregation, industrialization, modernization, and urban living. Along with economic growth has come rapid urbanization, especially in coastal areas: The urban population has grown from 19.4% in 1980 to 30.4% in 1998 (China State Statistics Bureau, 1990–1998). Some 380 million people now live in cities, and this number is expected to grow steadily until mid-21st century.

A phenomenon perhaps peculiar to China is the holiday bi-directional migration of millions of people returning to their native or original place for the lunar New Year, the May 1st vacation and the October 1st vacation, and during sowing and reaping time in the countryside. In a way, a substantial number of the new city dwellers are still farm-bound.

2.2.2. Increase in energy consumption

Coal has been and is still the major source of energy in China and will remain so in the coming years, although recently the demand for other energy sources has increased. Therefore, the impact of coal consumption remains a dominant figure in the assessment of ambient air pollution in China (China State Statistics Bureau, 1990–1998). Other fossil fuels are also important, particularly for mobile energy consumers. Hydroelectric and nuclear power are becoming more popular (China State Statistics Bureau, 1990–1998).

As the world's most populous country, China's GNP has been growing at the average annual rate of 9.6% in the past two decades, although there were ups and downs. Since 1991, the average annual growth rate has been kept at around 10.5%. Along with rapid development, China's energy consumption has been rising steadily, although the extent is smaller in comparison with economic growth. Since 1996, energy consumption in China has been stable and has even decreased slightly (Fig. 1) (China State Statistics Bureau, 1990–1998). This is probably due to progress in technology and change in energy structure.

2.2.3. Increase in number of motor vehicles

The number of motor vehicles has increased almost 10-fold since 1978, climbing from less than 1.4 million in 1978 to 13.2 millions in 1998 (China State Statistics Bureau, 1990–1998). By 2020, the urban vehicle population is estimated to be 13–22 times greater than it is today. This trend is most apparent in China's large cities. For example, from 1986 to 1996, the number of motor vehicles in Beijing increased from 260,000 to 1.1 million.

2.2.4. Improvement in city planning and construction

Earlier thinking in city planning seemed to focus on efficiency in getting people to their workplace and back, leading to minimum distance between manufacturing areas and residential areas, or to minimum distance required by fire, explosion or other hazard considerations. People began to realize the importance of sustainable development and of the balances needed between development and preservation of our environment around late 1980. In the past several years, a large-scale city reconstruction has been going on all over the country, especially in large cities, bringing about improved ambient air quality. For example, in Shanghai, more than 750 industrial enterprises were either moved away from central urban areas and relocated elsewhere, or transformed into other non-industrial or non-polluting entities, resulting in remarkable improvement in ambient air pollution levels and reduction of energy consumption in urban areas.

3. Health outcomes from air pollution

The major air pollutants monitored in China are suspended particulates, SO_2 and NO_x. Health end-points studied in China in association with air pollution include changes in mortality of all causes, of respiratory disease, cardiovascular disease, and cerebrovascular disease, and morbidity, as well as number of out-patients and emergency-room visits. Increase in respiratory and other clinical symptoms and decrease in lung functions and immune functions are also studied. However, in comparison with air monitoring

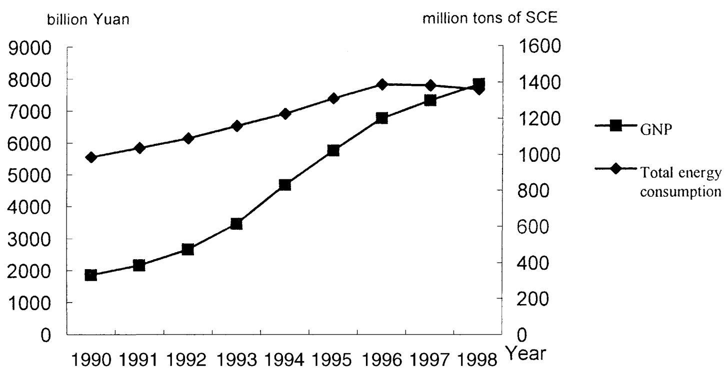

Fig. 1. China's GNP and energy consumption from 1990 to 1998 (SCE: standard coal consumption).

data, data on the effects of human health are limited. In terms of suspended particulates, scarcity of data on PM_{10} or PM_{25} in most cities further hinders the value of such studies. This review covers the health data published mostly in Chinese medical literature in the recent decade.

3.1. Mortality

In China, aside from mortality from infectious diseases which are required by law to be reported to relevant authorities, complete mortality data are available only in selected urban and rural areas (WHO, 1996).

The first 10 causes of death are: respiratory diseases, malignant tumors, cerebrovascular disease, injury and poisoning, diseases of the digestive system, infectious diseases (excluding pulmonary tuberculosis), heart disease, pulmonary tuberculosis, neonatal diseases, and urological and reproductive system diseases. An analysis was conducted to study the change in the leading causes of deaths in the last two decades. It showed that the 10 leading causes of death remained the same from 1970s to 1990s, though the sequence of causes of deaths in 1970s and 1990s differed. Mortality of respiratory diseases showed a decreasing trend, while mortalities of cerebrovascular disease, malignant tumors (especially lung cancer) and heart disease showed an increasing trend (Li et al., 1997; Ling et al., 2001).

An analysis on the respiratory disease mortality in Shanghai from 1991 to 1999 showed that the COPD mortality (Table 1) has been decreasing slightly (Shanghai Municipal Bureau of Public Health, 1992–2000).

Table 1
COPD mortality (per 100,000) in Shanghai (1991–1999)

Year	Shanghai as a whole	Urban districts	Rural counties
1991	117.76	96.35	151.14
1992	NA	NA	NA
1993	131.98	115.87	175.73
1994	121.80	102.57	174.35
1995	126.87	104.87	187.46
1996	120.78	100.34	177.53
1997	109.66	88.60	168.66
1998	111.99	100.66	162.99
1999	98.32	87.96	145.93

Note: COPD includes chronic bronchitis, emphysema and asthma. Number of urban districts in Shanghai varied from 12 in 1991 to 16 in 1998. Urban districts in 1999 refers to the 10 central urban districts of Shanghai.

3.1.1. Acute effects of ambient air pollution on mortality

Several time-series studies aimed at assessing the acute effects of air pollution on mortality were conducted in Beijing, Shenyang, and Shanghai.

The relationship between air pollution and daily mortality was examined in two residential areas of Beijing with a population of 1,419,123 in 1989. The average number of deaths in these two districts in 1989 was 21.6 persons per day. There were no major industries in these areas and motor vehicle traffic was very light. Coal stoves, used for heating in 90% and for cooking in 50% of households, were the major source of air pollution. The concentrations of SO_2 (mean 102 $\mu g/m^3$, maximum 630 $\mu g/m^3$) and TSP (mean 375 $\mu g/m^3$, maximum 1003 $\mu g/m^3$) observed in these areas were extremely high.

A highly significant association was found between ln(SO_2) and daily mortality after controlling for effects of temperature, humidity, and day of the week. The association with a doubling in SO_2 level was significant for total mortality (11%), mortalities of COPD (29%), pulmonary heart disease (19%), and cardiovascular disease (11%). A similar association was found for a doubling in TSP (4, 38, and 8% or total, COPD, and pulmonary heart disease mortality, respectively). In the cause-specific analysis, the strongest effects of SO_2 and TSP on mortality were consistently seen for respiratory disease in both seasons. This study also revealed increased mortality associated with SO_2 pollution levels below the current WHO Air Quality Guideline (Gao et al., 1993; Xu et al., 1994).

A second time-series study was conducted in the same districts of Beijing in 1990–1991. Association was found between air pollutants (TSP and SO_2) and increased daily mortality, mostly among people aged 65 and above. In the cause-specific analysis, the strongest effects of TSP and SO_2 on mortality were seen in cardiovascular disease and respiratory disease. This study also showed an association between increased mortality and SO_2 level even as low as 17 $\mu g/m^3$ (Dong et al., 1995).

Shenyang is the center of heavy industry in north-eastern China. The air pollution levels in the 10 years before 1992 were: annual daily average of TSP 352–446 μg/m^3, SO_2 67–178 μg/m^3, average concentration of B(a)P in winter of 50 ng/m^3. The population under study was 3,097,353. The average number of deaths was 45.5 persons per day in 1992, not including the number of abnormal deaths from accidents. Time-series analysis showed a significant association between daily mortality and daily ambient TSP and SO_2 pollution levels (lagged moving averages of 3 days) after adjusted for daily temperature and humidity. The result showed that with each increase of 100 μg/m^3 of TSP, total mortality, COPD mortality, and cerebrovascular disease (CVD) mortality were estimated to increase by 2, 3, and 2%, respectively; with each increase of 100 μg/m^3 of SO_2, total mortality, COPD mortality, and CVD mortality were estimated to increase by 2 7, and 2%, respectively (Xu et al., 1996a).

The relationship between outdoor air pollution and daily mortality from June 2000 to December 2001 in Shanghai was assessed using a semi-parametric generalized additive model. In the single-pollutant models, an increase of 10 μg/m^3 of PM_{10}, SO_2, and NO_2 corresponded to 1.003 (95% CI, 1.001–1.005), 1.014 (95% CI, 0.008–1.020), and 1.015 (95% CI, 1.008–1.022) relative risk of total non-accident mortality, respectively. Cardiovascular and COPD mortality risks showed a stronger association than total mortality for every pollutant considered. In the multi-pollutants models, the association between SO_2 and daily mortality was not affected by the inclusion of other pollutants; however, for PM_{10} and NO_2, the inclusion of other pollutants may weaken their effects on mortality (Kan and Chen, in press).

Meta-analysis of data pooled from various Chinese studies indicates that with each 10 μg/m^3 increase in PM_{10} level, there is a 0.38% increase in mortality (Kan and Chen, 2002a), while in developed countries with each 10 μg/m^3 increase in PM_{10} level, there is a 0.64% increase in mortality (Stieb et al., 2002). However, the underlying mechanism of the difference needs to be further explored.

3.1.2. Chronic effects of ambient air pollution on mortality

The chronic effects of air pollution on mortality in Shenyang were examined using ecological analysis (Xu et al., 1996a). Annual daily averages for TSP in the high-, medium-, and relatively low-pollution areas were 518, 477, and 361 μg/m^3, respectively, and for SO_2 were 235, 128, and 64 μg/m^3, respectively, The result showed that there were significant differences in total mortality, mortality of COPD, cerebrovascular disease, cardiovascular disease, cancer of all sites, as well as tuberculosis among these areas.

As one of the major iron and steel industry bases in China, and surrounded by mountains, Benxi is one of the most polluted cities in China. Total number of population under study was 667,553. Annual daily average concentrations of TSP and SO_2 varied from 290 to 620 μg/m^3 and 160–240 μg/m^3, respectively. The results showed that with each increase of 100 μg/m^3 of TSP, total mortality, COPD, cardiovascular disease, and cerebrovascular disease mortalities were estimated to increase by 8% (95% CI of OR = 1.02–1.14), 24% (95% CI of OR = 1.04–1.44), 24% (95% Cl of OR = 1.08–1.41), and 8% (95% CI of OR = 1.00–1.15), respectively (Jin et al., 1999).

3.1.3. Lung cancer

In China, lung cancer mortality has increased significantly both in cities and rural areas during the last two decades. Lung cancer mortality in Chinese urban areas were 12.61 per 100,000 for both sexes (16.48/100,000 for males and 8.46/100,000 for females) in the early 1970s. It increased to 27.50/100,000 (38.08/100,000 for males and 16.16/100,000 females) in the early 1990s (Li et al., 1997). However, data on association between lung cancer and air pollution are rather limited. Findings are diverse and inconclusive. At present, with inadequate data, it is felt immature to draw definitive and appropriate conclusions on this topic. More studies need to be done to explore the attributable risk of air pollution to lung cancer and the underlying mechanism.

A distinctive geographic gradient of lung cancer mortality was noted particularly among women residents: the higher the latitude of the city of residence, the higher the lung cancer mortality ($r = 0.69$, $P < 0.01$) (Xu et al., 1986). In an earlier national survey of 500,000 people in China, only 7% of women smoked tobacco, in contrast to the alarming smoking rate of 61% among men over 15 years of age.

The correlation coefficients between lung cancer mortality and SO_2, No_x, and TSP concentration levels were 0.8299 ($P < 0.01$), 0.4049 ($P > 0.05$), and

−0.0820 ($P > 0.05$), respectively, based on a retrospective survey of one-tenth of the population (8.1 million people) in Shandong Province in 1990 (Li et al., 1994).

Based on a case-control study and a nested-case-control study conducted in Shenyang and Anshan, associations between lung cancer and life style and environmental pollution were explored. Smoking was found to be the most important risk factor with a population attributable risk (PAR) of 55% for males and 37% for females. PARs of indoor air pollution for males and females were 13 and 17%, respectively. After controlling for smoking and indoor air pollution, ambient air pollution was still found to be a risk factor. The prevalence rate of lung cancer in the polluted area was 1.3 times higher than that in less polluted area, though PAR of ambient air pollution could not be estimated (Xu et al., 1996b).

3.1.4. Estimation of number of avoidable deaths associated with ambient air pollution

Percentage increase of mortality per unit increase of specific air pollutants was documented in a number of studies in China. Comparing the air quality monitoring data against the WHO Air Quality Guidelines (WHO/AQG), and using mortality data published by the Shanghai Municipal Bureau of Health, as well as data on increase in mortality per unit increase of air pollution levels, number of avoidable deaths from air pollution exposure in Shanghai were estimated (Chen et al., 2001a,b).

In 1990, annual daily average concentrations of TSP and SO_2 in Shanghai urban districts were 360 and 95 $\mu g/m^3$, respectively. Number of population exposed was about 7.4 million. The number of avoidable deaths in urban districts of Shanghai in 1990 from exposure to TSP was estimated at 2300–9000, and from exposure to SO_2 at 400–2400. In 1999, annual daily average concentration of TSP decreased to 168 $\mu g/m^3$, the number of avoidable deaths due to TSP exposure was estimated at 400–2000 (Chen et al., 2001a).

The total number of avoidable deaths due to ambient and indoor air pollution in three million population in Shenyang was estimated at about 2000 per year (Xu, 1991).

However, it is not feasible to make a nationwide estimation of the number of avoidable deaths from air pollution exposure at this stage.

3.2. Morbidity

In China, in-patient records are kept by hospitals, but out-patient case histories are generally kept by the patients themselves. Therefore, better precision could be expected when inpatients' records rather than outpatients' records are used in evaluating the association between air pollution and respiratory diseases.

3.2.1. Respiratory diseases and symptoms

Based upon an earlier survey on a sample of 78,920,000 people in China and other studies, the prevalence of chronic bronchitis is estimated at 4%, COPD at 6%, and respiratory diseases at 10% (Fang, 1995). Asthma prevalence is estimated at about 2% (Beijing Medical University and Peking Union Medical College, 1997).

The impact of air pollution on human upper respiratory diseases and symptoms was investigated in Chongqing. In this study, 1555 persons (1284 children and 271 adults) from four primary schools located in different areas with various levels of air pollution were observed. SO_2 levels in the high-, medium-, and relatively low-polluted areas were 830–880, 160 and 60 $\mu g/m^3$ respectively, and IP levels 320–430, 220 and 100 $\mu g/m^3$, respectively. The prevalence of upper respiratory symptoms and diseases were found to be 22.0, 12.9, and 9.1% in the high-, medium-, and relatively low-polluted areas. It was estimated that PAR of air pollution for upper respiratory diseases and symptoms in Chongqing was higher than 20% (Zhou et al., 1996).

A study on 3021 residents in Shanghai was conducted in 1990 to assess the health risk of various concentration levels of suspended particulates (160, 290, and 490 $\mu g/m^3$) where the SO_2 levels were 40–70 $\mu g/m^3$. Logistic regression analysis showed that age, smoking and TSP level were the three major risk factors contributing to prevalence of COPD and occurrence of respiratory symptoms. With each increase of 100 $\mu g/m^3$ TSR the odds ratio (OR) for cough, productive cough, shortness of breath, chronic bronchitis and emphysema were 1.20, 1.23, 1.13, 1.29, and 1.59, respectively (Ma and Hong, 1992).

A study on 4403 residents conducted in Shanghai in 1991 was designed to assess the health risk of different levels of sulfur dioxide (20, 80, 140 $\mu g/m^3$) where the TSP levels were similar (110–150 $\mu g/m^3$). The results showed that with annual average concentration of ambient SO_2 increasing by 60 μg/m^3, odds ratios of cough and short of breath were 1.31 and 1.71, respectively (Chen et al., 1993a).

A study conducted in Shenyang found that when the air IP concentrations were within the range of 260–510 μg/m^3, with every 100 μg/m^3 increase of IP, the chronic bronchitis morbidity increased 8.4% for males and 6.0% for females (Xiao and Xu, 1990).

Morbidity of 3706 persons randomly selected in three areas with different air pollution levels was studied in Shenyang. Annual daily averages in 1992 for TSP in the high-, medium-, and relatively low-pollution areas were 518, 477, and 361 μg/m^3, respectively, while SO_2 levels were 235, 128, and 64 μg/m^3, respectively. Using multivariate analysis, cigarette smoking was found to be the predominant cause and indoor pollution the second major cause for chronic respiratory diseases. After controlling for smoking, indoor pollution, age and education, the OR value of COPD, cardiovascular and cerebrovascular diseases in the low-, medium- and high-pollution areas were 1.0, 0.9, 1.7 and 1.0, 1.4, 1.7, respectively (Xu et al., 1996c).

A four-city study on children and adults respiratory health in relation to long-term exposure to ambient and indoor air pollution in urban and suburban districts were conducted in Lanzhou, Chongqing, Wuhan, and Guangzhou. These cities were chosen because they exhibited wide between-city and within-city gradients of ambient pollutant levels, thus offering a valuable epidemiologic opportunity for exposure–response assessment. Respiratory health effects of long-term exposure to ambient air pollution in 7977 schoolchildren residing in the eight districts (one urban district and one suburban district in each city) of the four cities were examined using two-stage regression approach. The results indicated a markedly positive association between morbidity prevalence and outdoor levels of PM of all size fractions. It was also shown that ambient levels of NO_x and SO_2 were positively associated with children's respiratory symptoms, but the evidence for these two gaseous pollutants appeared to be weaker than that for the PM (Wei et al., 2000; Hu et al., 2001).

In another study (Hu et al., 2001), cluster analysis was conducted to determine the relationship between air pollution and children's and their parents' respiratory health status. The results showed that the prevalence of diseases in the most polluted group is 1.71–3.95 times higher than that in less polluted group, with ORs varying between 3.313 and 6.942. For the children's parents, however, air pollution had mild or moderate impact on the disease prevalence of the respiratory system.

3.2.2. Hospital admissions

A study on 71,853 eases of hospital admissions in Chongqing was conducted in 1991–1992, and the association between number of hospital admissions, air pollution, and meteorological factors were analyzed. The percentage of hospital admissions for COPD patients increased with increase of SO_2 and TSP concentration levels, decrease in air temperature, and increase in number of foggy days, especially among patients aged 50 and over. The correlation coefficient between SO_2 and COPD hospital admissions was the highest. When SO_2 concentration increased from 200 to 300 μg/m^3 the percentage of hospital admission for COPD patients increased to 0.83%. The authors concluded that number of hospital admissions of COPD patients is a good indicator of health impact due to air pollution exposure, particularly SO_2.

3.2.3. Outpatient visits and emergency-room visits

The association between air pollution and unscheduled out-patient visits was analyzed in a community-based hospital in Beijing, in 1991. The effects of TSP and SO_2 on the number of out-patient visits were assessed by linear regression adjusted for temperature, humidity, season, and days of the week as co-variables with Markov correction for auto-correlation in the time-series analysis. There was a significant association between TSP level and non-surgery outpatient visits, but not for surgery visits. No significant association was found between SO_2 exposure and out-patient visits when SO_2 level was higher than 150 μg/m^3. However, there were significant associations between SO_2 exposure and number of out-patient visits in the departments of internal medicine and pediatrics (Dong et al., 1996).

A similar study on the association of air pollution with daily outpatient visits was conducted in another community-based hospital in Beijing: the mean TSP level was 388 μg/m^3 (106–1255 μg/m^3), and the mean SO_2 level 119 μg/m^3 (6–478 μg/m^3).

The average number of daily hospital outpatient visits was 1386, approximately 7.9% of these visits were to the pediatric department, and 20.6% to the internal medicine department. After adjusting for temperature, humidity, season, and day of the week, a large increase in non-surgery outpatient visits was observed in association with increases both in SO_2 and TSP levels in the linear regression models. When the most polluted days were compared with the least polluted days, the estimated effects on non-surgery outpatient visits were an increase of 20 and 17%, respectively, in association with increases in SO_2 and TSP levels. In department-specific analysis, the association was found to be 1.5- to 2-fold stronger for pediatric and internal medicine department visits than for other types of visits (Xu et al., 1995).

It is apparent that ambient air pollution is a predominant risk factor for upper respiratory disease and COPD. Ambient air pollution is also a risk factor for lung cancer, but the importance or weight is less prominent than smoking. Indoor air pollution is also an important risk factor for respiratory disease. However, in large cities, domestic use of coal/coal briquettes has been gradually replaced by gas, natural gas, or electricity, the impact of indoor air pollution needs to be re-estimated accordingly.

3.2.4. Estimation of avoidable disease cases due to air pollution

The number of avoidable disease cases in Shanghai due to air pollution was estimated based on air pollutants monitoring data, increase of morbidity per unit increase of air pollutant, and health data from Shanghai Municipal Bureau of Health (Chen et al., 2001a). In urban districts, the annual daily average concentration of TSP decreased from 360 $\mu g/m^3$ in 1990 to 168 $\mu g/m^3$ in 1999, and the annual daily average concentration of SO_2 decreased from 95 $\mu g/m^3$ in 1990 to 44 $\mu g/m^3$ in 1999. It was estimated that in urban districts in 1990 the number of avoidable COPD due to TSP exposure was about 173,000. One lakh and fifteen thousand avoidable cases were of chronic bronchitis, among which 57,000 avoidable cases were among people who were of 45–60 years of age. The number of avoidable COPD cases due to SO_2 exposure in 1990 was estimated at 41,000–59,000 (among whom 13,000–19,000 were people who were of age 45–60 years). The number of avoidable emergency-room visits from SO_2 exposure in 1990 was estimated at 102,000–335,000. There was also an increase of 516,000 out-patient visits in internal medicine departments and an increase of 158,000 out-patient visits in pediatrics departments. The number of avoidable chronic bronchitis in urban districts of Shanghai from TSP exposure in 1999 was estimated at 31,000, among which 15,000 occurred in people 45–60 years of age.

Due to rapid increase in the number of motor vehicles and related increase in NO_x level in recent years, the number of avoidable respiratory disease cases was estimated to have increased from 54,000 in 1990 to 95,000 in 1999, a 75% increase as compared against the 1990 estimate (Chen et al., 2001a).

Data on morbidity in relation to air pollution are fewer and less reliable in quality (except hospitalization data) than those on mortality. Certain indice such as COPD morbidity and percentage of COPD in-patients among all in-patients could be used in assessing health effects of air pollution as well as indicators reflecting the cost or benefit of air pollution abatement programs.

3.3. Lung function and other changes

3.3.1. Lung function

Lung functions of 1440 non-smokers, 40–69 years of age in residential, suburban and industrial areas in Beijing were studied. The annual mean concentrations of SO_2(TSP) in three representative areas were 128(389), 18(261) and 57(449) $\mu g/m^3$, respectively. The measured lung function indices included FVC and FEV_{10}. After adjustment for height, sex and age, regression analysis results towed that a per unit increase in ln SO_2(TSP) concentration ($\mu g/m^3$) could result in a 35.6(131.4) ml reduction in $FEV_{1.0}$ and a 142.2(478.7) ml reduction in FVC (Xu et al., 1991).

By measuring peak expiratory flow (PEF) of 60 healthy children in Beijing consecutively for a month, the association between ambient air pollution and dynamic changes in human PEF was studied. The daily average concentrations of NO_2 and SO_2 were 90 (maximum 800) $\mu g/m^3$ and 210 (maximum 370) $\mu g/m^3$, respectively. PEF values were within the range of 205–406 ml/min, which were accordant with the normal lung function of healthy children. After controlling for sex, age, height, body weight, and indoor air pollution, multivariate analysis showed that the concentration of NO_2 in the ambient air and individual SO_2 exposure level were closely associated with changes in children's PEF. The author recommended that PEF could be used as an index in assessing the effect of ambient air pollution on lung function (Wang et al., 1994).

Lung functions of 105 women (aged 50–59) and 98 children (aged 10–12) were measured in Shanghai in two areas with different SO_2 levels while TSP concentration levels were similar (Chen et al., 1993b). Stepwise regression analysis showed that an increase of 100 $\mu g/m^3$ SO_2 concentration could result in a 99.48 ml reduction in FVC, 70.15 ml reduction in $FEV_{1.0}$ in children, and 56.53 ml reduction in FVC in women.

Pulmonary function tests on 604 children in three regions of different TSP concentrations where SO_2 pollution levels were similar were performed in Shanghai. After controlling for age, height, passive smoking and indoor air pollution, the reduction in $FEF_{25–75\%}$ and $FEF_{75–85\%}$ were closely associated with TSP pollution levels. The result indicated that long-term exposure to particulate pollution might lead to adverse effects on children's lung function (Ma and Hong, 1991).

The relation between outdoor air pollution and children's lung function were studied in Lanzhou, Chongqing, Wuhan, and Guangzhou. The results showed significant statistical association between particulate matter ($PM_{2.5}$, PM_{10}, TSP) and lung function indexes, e.g. FEV_1, adjusted mean of FEV_1/FVC, and abnormality rate of PLV_1/FVC ($\leq$80%). However, SO_2 and NO_x was not found be positively associated with children's lung function indexes (Wei et al., s2001).

3.3.2. Immune function and others

Immune function has been another sensitive indicator in detecting the adverse effect of ambient air pollution. The immune indices of pupils living in various ambient and indoor air pollution levels were measured by Wang et al. (1989). The measured indices included PHA skin tests, amounts of lysozyme in saliva, contents of serum IgA, IgM, IgG, and T-lymphocyte transformation activity. The weighted average exposure concentration of suspended particulates in these three groups were 1108, 462, and 220 $\mu g/m^3$, respectively. The immune function of pupils living in mildly polluted areas and their family using coal for cooking were more significantly inhibited than the immune function of those living in heavily polluted areas and using gas for cooking, while the immune function of pupils living in mildly polluted areas and using gas for cooking were the best. The result suggested that ambient air pollution could affect the immune function of children, although indoor air pollution might play a more important role in the process.

It was found that a reduction of birth weight was 7.3 and 6.9 g for each 100 $\mu g/m^3$ increase in SO_2 and TSP, respectively (Wang et al., 1997).

Ambient air lead pollution levels have been declining since leaded gasoline was banned in 1997 in large cities. Unleaded gasoline became available nationwide in 2000. Just 1 year after the introduction of unleaded gasoline in Shanghai blood lead in children gradually decreased from 83 to 80 μg/l, and further down to 76 μg/l after 2 years (Yan et al., 2002).

In recent years, more in-depth studies were conducted on the impact of air pollution on human health and sustainable development, including inventory of air pollution sources, time-spatial distribution of pollutants, exposure–response relationship between air pollution level and mortality/morbidity (both acute and chronic effects). These studies enabled us to make quantitative assessment of the impact of air pollution and health, from which economic analysis could be made. For instance, a study in Shanghai indicated that the health impact from exposure to air pollution constituted a 1.6% loss in GDP in 2000. In this study, environment and health impacts under various energy scenarios were also analyzed, thus providing various options for decision makers. It also provides a practical new approach or an alternative way of thinking in making similar health-based risk assessment in other Chinese cities (Kan and Chen, 2002b).

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