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ORIGINAL PAPER

Levels, seasonal variations, and health risks assessment of ambient air pollutants in the residential areas

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Abstract People living in the urban area and the surrounding suburban area have disparities in exposure and health risks due to different levels of ambient air pollutants. The main objective of this study is to investigate the concentrations, seasonal variations, and related health risks of ambient air pollutants (PM_{10}, NO_2, and SO_2) in urban and suburban areas of Ningbo, China. The results showed that the average PM_{10}, NO_2, and SO_2 concentrations in the urban area were 85.2, 49.3, and 37.4 μg/m^3, which were 1.13, 1.25, and 1.41 times the values of the suburban area during the period of March 2009 to February 2010. For the potential health risk analysis, the residents have been divided into four age categories namely, infants, children (1 year), children (8–10 years), and adults. The analysis took into account age-specific breathing rates, body weights for different age categories. The results showed that the potential health risks to respiratory disease for all age categories living in urban area were higher than those in suburban area.

Keywords Ambient air pollutants · Exposure · Health risks · Dose–response

Introduction

As the largest developing country in the world, China has achieved rapid economic development. However, this success comes at the cost of deterioration of the environment. Air pollution has become one of the top environmental concerns in China. Numerous studies worldwide have confirmed that both long- and short-term exposures to air pollutants are associated with increases in mortality and morbidity (Dockery 2009; Kan et al. 2008; Venners et al. 2003). According to a World Health Organization (WHO) assessment of the burden of disease due to air pollution, more than two million premature deaths each year can be attributed to the effects of urban outdoor air pollution and indoor air pollution (WHO 2005), and outdoor air pollution was associated with approximately 300,000 premature deaths per year in China (Cohen et al. 2005).

Ningbo (28.51°–30.33°N, 120.55°–122.16°E), which is located in the middle of the coastal line of the Chinese Mainland and in the South of the Yangtze River Delta Region (YRDR), covers an area of 9,817 km^2 with a population of 5.71 million. Ningbo is one of the largest cities in the YRDR and is also one of the most massively industrialized and urbanized cities in South China. Ningbo experiences a typical sub-tropic climate with mean annual precipitation of 1,480 mm. The annual mean temperature is 16.4 °C with July as the hottest month (28.0 °C) and January as the coldest (4.7 °C). Prevailing wind direction is mainly southerly in summer and northerly in winter. During the past decade, Ningbo has undergone the most rapid development and urbanization in its history, and particulate matters (PMs), sulfur dioxide (SO_2), and nitrogen oxides (NOx) have become the major air pollutants.

Exposure to PMs, SO_2, and NOx was associated with deficits in lung function growth between 10 and 18 years of age (Gauderman et al. 2004). More importantly, the concentrations of PMs, SO_2, and NOx vary significantly in different areas of one city. The spatial variations have significant influence on the exposure. Therefore, it is

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necessary to use the PMs, SO_2, and NOx concentrations measured at different areas of one city to assess the population exposure and the related health risks. To our best knowledge, few studies have studied the urban and suburban disparities of exposure to PMs, SO_2, and NOx and the related health risks. Thus, the objectives of this study are to investigate the disparities of exposure and health risks of pollutants (PM_{10}, NO_2, and SO_2) in the ambient air of the urban and suburban areas of Ningbo, and to provide new information about the relationship between air pollution and health risks in Ningbo, which may have implications for local environmental and social policies.

Materials and methods

PM_{10}, NO_2, and SO_2 were continuously measured at three monitoring stations in the urban area, 16 monitoring stations in the suburban area of Ningbo (Fig. 1). The Monitoring stations 1–3 were located in the urban area, and Monitoring stations 4–19 were located in the suburban area. This study was initiated on March 1, 2009 and continued until February 28 2010. We made use of 20,805 daily records (6,395 records for each pollutant) of PM_{10}, NO_2, and SO_2. The arithmetic mean values of the daily records of the three monitoring stations in the urban area were considered as the pollutant concentrations of the urban area. Similarly, the arithmetic mean values of the daily records of the other 16 monitoring stations were considered as the pollutant concentrations of the suburban area. The daily records were obtained from Ningbo Environmental Protection Bureau.

The assessment of health risks of the population associated with inhalation exposure of PM_{10}, NO_2 and SO_2 was based on the estimated dose rates and the lowest observed adverse effect levels (LOAELs). The Health risk assessment is age-specific. The population is divided into four age-specific categories namely, new born, children (1 year), children (8–10 years) and adults (Cerna et al. 1998). The dose rate for each pollutant has been estimated through the following expression (Kalaiarasan et al. 2009; Pandey et al. 2005).

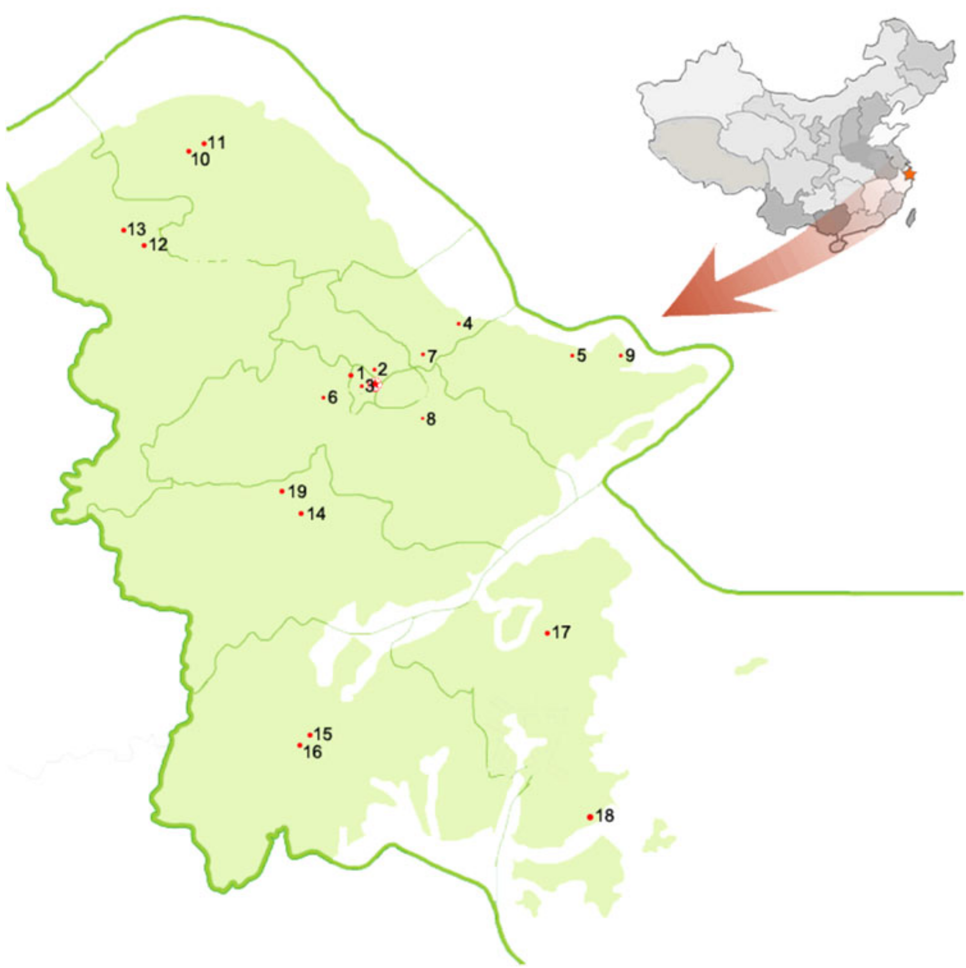


Fig. 1 Location of Ningbo in China and locations of the monitoring stations

$$\text{Dose rate } (D) = [\mathrm{BR/BW}] \int_0^{24} C(t)\mathrm{OF}(t)\mathrm{d}t, \quad (1)$$

where D is the age-specific dose rate (μg/kg), BR is age-specific breathing rate (L/min), BW is age-specific body weight (kg), C (t) is the concentration of each pollutant (μg/m^3); OF (t) is occupancy factor (percentage of population likely to be in the building at a given interval of time). For each pollutant, we assume that the indoor and outdoor concentrations to be equal. Thus, OF (t) equals to 1. The uncertainties due to this assumption will be discussed hereinafter.

LOAELs are defined as the lowest tested doses of pollutants that have been reported to cause harmful (adverse) health effects on people or animal. LOAELs for PM_{10} and SO_2 were taken from Cerna et al. (1998) as average of morbidity values. While for estimating the LOAEL value for NO_2, the following dose–response model was constructed on the basis of data available in Neuberger et al. (2002):

$$Y = 103.6X^{-0.1003}, \quad (2)$$

where Y is the response (in terms of % end expiratory flow rates), X is dose rates (μg/kg) for children estimated from the corresponding values given for NO_2 in Neuberger et al. (2002). The dose value at which end expiratory flow rate becomes lower than 100 % was taken as the LOAEL value for NO_2 (Pandey et al. 2005).

Thus, the health risks have been defined using the following equation (Kalaiarasan et al. 2009; Castro et al. 2011):

$$\text{Health risk} = [(\text{age-specific dose rate})/(\text{age-specific LOAEL})] \quad (3)$$

If the dose rate exceeds LOAEL, there may be concern for potential health risk of residents associated with inhalation exposure of PM_{10}, NO_2 and SO_2. Health risk (HR) is dimensionless and useful for making relative comparisons.

Results and discussion

During the study period, the annual average concentrations and standard deviations of PM_{10}, NO_2 and SO_2 in the suburban area were 75.2 ± 40.4, 39.6 ± 19.6, and 26.5 ± 16.6 μg/m^3, respectively, whereas the average concentrations and standard deviations in the urban area were 85.2 ± 48.0, 49.3 ± 23.9, and 37.4 ± 19.1 μg/m^3, respectively (Fig. 2). The concentrations in the urban and suburban areas were considerably higher than the concentration limits of the national ambient air quality standard Grade I (40, 40, and 20 μg/m^3 for PM_{10}, NO_2 and SO_2, respectively MEP 2000) except the NO_2 concentration in the suburban area, but lower than the national ambient air quality standard Grade II (100, 80, and 60 μg/m^3 for PM_{10}, NO_2 and SO_2, respectively, MEP 2000).

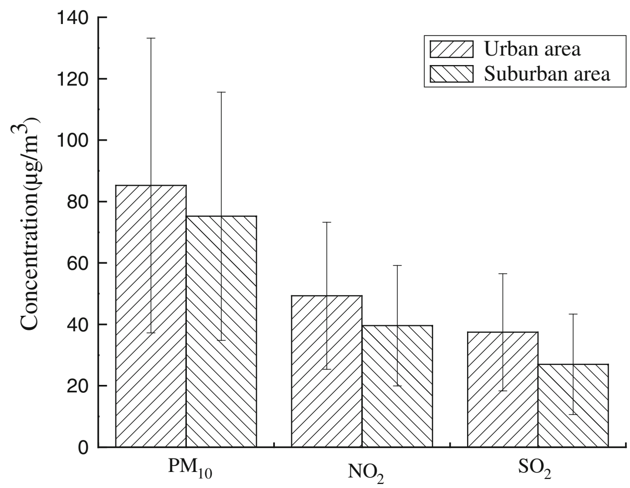


Fig. 2 Annual average concentrations of PM_{10}, NO_2 and SO_2 in urban and suburban area of Ningbo, China

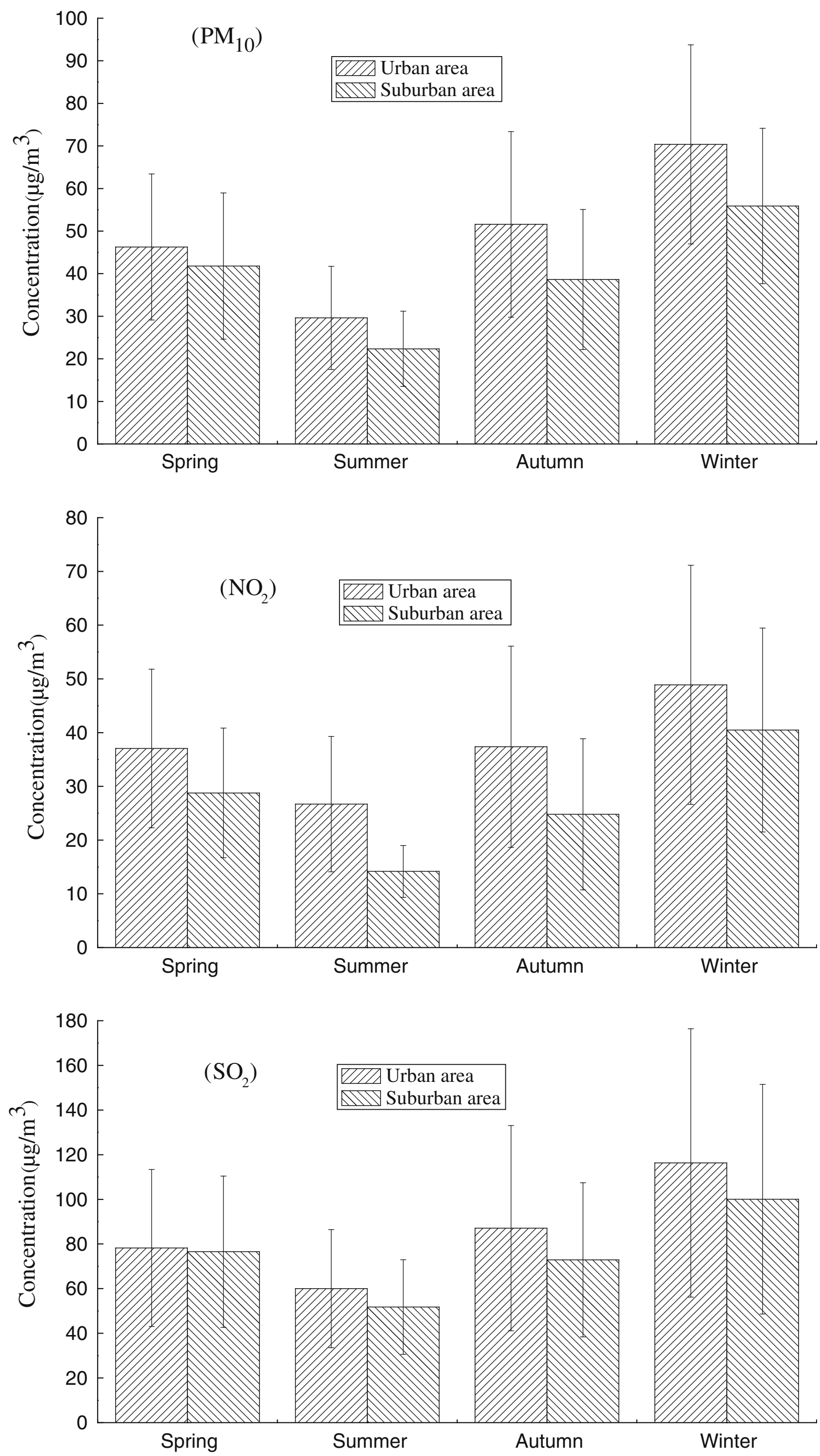
The PM_{10} concentrations were similar to those reported for other densely populated regions of China, such as Beijing (142 μg/m^3, Chan and Yao 2008) and Guangzhou (73 μg/m^3, Wan et al. 2011), but were substantially higher than those reported for big cities in Europe and East Asia, such as Dublin, Ireland (18 μg/m^3, Environmental Protection Agency Ireland 2007) and Tokyo, Japan (29 μg/m^3, Tokyo Metropolitan Government Bureau of General Affairs 2007). NO_2 concentrations were also higher than those reported for big cities in Europe, such as Antwerp, Belgium (25.2 μg/m^3, Stranger et al. 2009). A recent report showed that the average outdoor level for NO_2 in Stockholm, Sweden was only 12.4 μg/m^3 (Wichmann et al. 2010). The average SO_2 concentrations in Ningbo were also very high, compared to the big cities in Europe and North America, such as Antwerp, Belgium (4.8 μg/m^3, Stranger et al. 2009) and Boston, USA (32.3 μg/m^3 in winter, 10.3 μg/m^3 in summer, Brown et al. 2009).

The annual average concentrations of PM_{10}, NO_2 and SO_2 in the urban area were 1.13, 1.25, and 1.41 times the values of the suburban area. Similar results were obtained in recent studies in India (Kulshrestha et al. 2009) and Italy (Dongarrà et al. 2010). The relatively high PM_{10}, NO_2 and SO_2 levels in Ningbo could be attributed to both natural and anthropogenic sources. The increases in motor vehicles, urban construction, residential heating and industrial combustion contribute to the increase of PM_{10}, NO_2 and SO_2 levels (Cao et al. 2009a).

For the investigation of the seasonal variations, the study period was divided into four seasons: spring (March

2009 to May 2009), summer (June 2009 to August 2009), autumn (September 2009 to November 2009), and winter (December 2009 to February 2010). The significant seasonal variations of PM_{10}, NO_2 and SO_2 were obtained during the study period (Fig. 3). For the suburban area, PM_{10}, NO_2 and SO_2 were highest in winter (100.1 ± 51.4, 55.9 ± 18.2, and 40.5 ± 19.0 μg/m^3), followed by spring (76.6 ± 33.9, 41.8 ± 17.2, and 28.8 ± 12.1 μg/m^3), with lower concentrations in autumn (72.9 ± 34.5, 38.6 ± 16.5, and 24.8 ± 14.1 μg/m^3) and summer (51.8 ± 21.2, 22.3 ± 8.8, and 14.2 ± 4.8 μg/m^3). Nevertheless, for the urban area, PM_{10}, NO_2 and SO_2 were highest in winter

Fig. 3 Seasonal variations of PM_{10}, NO_2 and SO_2 in urban and suburban areas of Ningbo, China



(116.3 ± 60.1, 70.4 ± 23.4, and 48.9 ± 22.3 μg/m^3), followed by autumn (87.1 ± 45.9, 51.6 ± 21.8, and 37.4 ± 18.7 μg/m^3), with lower concentrations in spring (78.2 ± 35.2, 46.3 ± 17.2, and 37.0 ± 14.8 μg/m^3) and summer (60.0 ± 26.4, 29.6 ± 12.1, and 26.7 ± 12.6 μg/m^3). The different seasonal variations were likely due to a combination of meteorological conditions coupled with the different emission types of heating sources between the

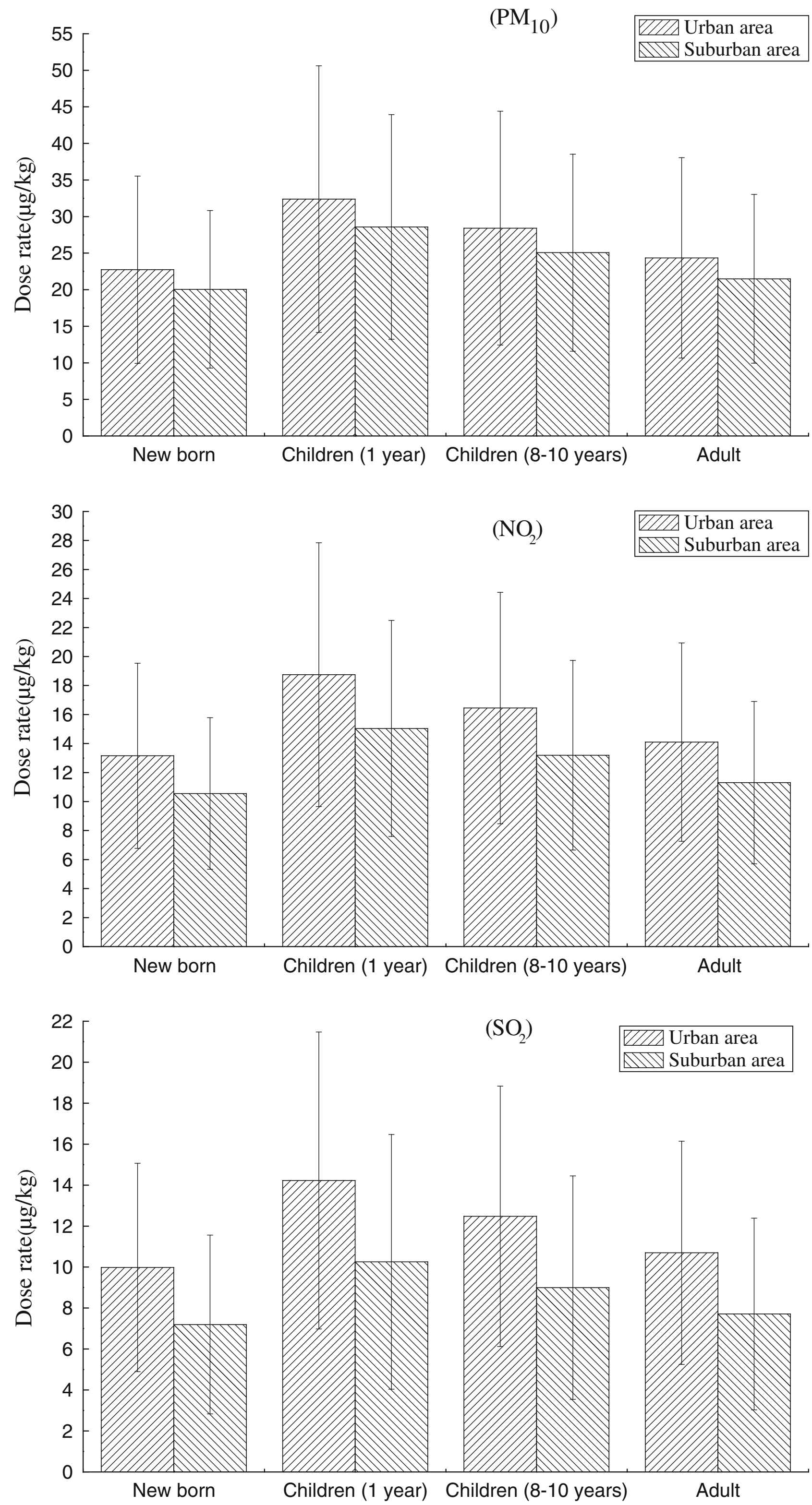


Fig. 4 Dose rates for different age categories due to PM_{10}, NO_2, and SO_2

suburban and urban areas. The air parcels arriving in Ningbo in the summer and autumn were mainly from the East China Sea and carried clean air. On the other hand, air parcels arriving in Ningbo in winter and spring were from the northeast (Yellow Sea) to northwest (inland) directions and carried polluted air from Jiangsu province and Shanghai city (Feng et al. 2006; Li et al. 2011; Zhao et al. 2011), which made pollution in winter and spring more severe than summer and autumn. However, for the urban area, the atmospheric structure was comparatively stable, and temperature inversion often occurs in late autumn and winter, which made the dilution and diffusion of pollutants in the air more difficult, and thus pollution in autumn was more severe than spring (Cao et al. 2009b).

The dose rates, obtained for four age groups living in urban and suburban areas, are shown in Fig. 4. It is observed that dose rates for all age groups living in urban area were higher than those in suburban area, which indicated that the health risks for all age groups in urban area are higher than those in suburban area. At the same time, dose rates for children (1 year) were always higher than those for the other age groups, which indicated that the young children could have higher health risks. The absolute values of the dose rates depended on the concentrations of the pollutants and exposure profiles for different age categories. Children have a greater level of physical activity than adults; hence the intake of air into the lungs is much greater than adults per day (Salvi 2007). So children had higher dose rates than other age categories (Fig. 4). Similar results were obtained in other studies (Castro et al. 2011). However, health risk was estimated as a function which was proportional to the dose rates and inversely to the LOAEL values. The lower the value of pollutant-specific LOAEL, the higher is the health risk. Similarly, the higher is the dose rate, higher is the health risk. Comparison of HR values, which is shown in Table 1, indicated that health risks for all age groups in urban area were higher than those in suburban area. The HR values for all age groups in different seasons were also calculated, and the results showed that in each season, HR values for residents living in urban areas were always higher than those living in suburban areas.

Compared with adults, children are more vulnerable to particulates and gaseous pollutants in the air because of their immature immune systems. Moreover, children have differential abilities to metabolize and detoxify environmental agents and have an airway epithelium that is more permeable to inhaled air pollutants (Schwartz 2004). Due to the increasing emission from the motor vehicles and other sources, concentrations of PM_{10}, NO_2 and SO_2 are greater near major roads. Children living in the urban area inhale more air pollutants than their fellows living in the suburban area, and increased adverse health effects among those living near busy roads in the urban area have been found (Zhu et al. 2002).

There is increasing evidence that exposure to higher levels of air pollution is associated with adverse health outcomes. A recent scientific statement from the American Heart Association concluded that short-term or long-term exposure to air pollution is associated with increased risk of cardiovascular disease and death (Brook et al. 2010). Moreover, high PM_{10}, SO_2 and NO_2 levels could have combination of adverse health effects. Coal combustion was the major source of both particulate and gaseous pollutants in China, thus limiting our ability to separate the independent effect for individual pollutant. In summary, long-term exposure to outdoor air pollution was associated with increased health risks.

Exposure of PM_{10}, SO_2 and NO_2 and related health risks for the residents living in the urban and suburban areas of Ningbo have been studied quantitatively. Our analysis had strengths and limitations. The estimation of exposure and health risks in this study was based on the outdoor air pollution. However, people spend approximately 90 % of their time indoors (Monn 2001). Indoor exposure can be affected by many factors that influence indoor air pollution levels: activities of building occupants, building materials, furnishings and equipment, outdoor contamination levels, season, temperature, humidity, and ventilation rates. Thus, the estimation of indoor PM_{10}, SO_2, and NO_2 levels is with great difficulty. In the past decade, a number of studies have investigated the indoor-outdoor (I/O) ratio of PM_{10}, SO_2, and NO_2 levels (McCormack et al. 2008; Pekey et al. 2010; Mi et al. 2006; Kumar et al. 2007; Wichmann et al.

Table 1 Health risk values for different age categories due to PM_{10}, NO_2 and SO_2

Area	Pollutant	New born	Children (1 year)	Children (8–10 years)	Adult
Urban area	PM_{10}	1.55 ± 0.87	1.55 ± 0.87	1.03 ± 0.58	1.55 ± 0.87
	NO_2	11.76 ± 5.70	11.78 ± 5.71	7.85 ± 3.81	11.79 ± 5.72
	SO_2	1.88 ± 0.96	1.90 ± 0.97	1.26 ± 0.64	1.88 ± 0.96
Suburban area	PM_{10}	1.36 ± 0.73	1.37 ± 0.73	0.91 ± 0.49	1.37 ± 0.74
	NO_2	9.43 ± 4.67	9.45 ± 4.68	6.30 ± 3.12	9.46 ± 4.68
	SO_2	1.33 ± 0.84	1.34 ± 0.84	0.89 ± 0.56	1.33 ± 0.83

2010; Klinmalee et al. 2009). The differences between these outdoor values and the true exposures are an inherent and unavoidable type of measurement error. However, indoor levels do have strong associations with outdoor levels. Thus, the indoor and outdoor concentrations of PM_{10}, NO_2 and SO_2 are assumed to be equal in our study and OF (*t*) equals to 1 (Chao and Wong 2002; Morawska et al. 2001; Stranger et al.. 2009; Wang et al. 2006).

Despite the limitations and uncertainties, our study may provide new information on air pollution-related health effects in the urban and suburban areas of Ningbo, which may have reference significance for other parts of China.

Conclusion

This study provided the investigation of ambient air pollutants and the health risks for the local residents of Ningbo, China. The annual average concentrations of PM_{10}, NO_2 and SO_2 in the urban area were higher than the suburban area. Due to a combination of meteorological conditions and the different emission types of heating sources in the urban and suburban areas, different seasonal variations of PM_{10}, NO_2 and SO_2 were observed. The risk analysis showed that the potential health risks to respiratory disease for all age categories in urban area were higher than in suburban area.

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