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Impact of Ambient Air Pollution on Public Health under Various Traffic Policies in Shanghai, China[1]

CHANG-HONG CHEN#, HAI-DONG KAN+,2, CHENG HUANG#, LI LI#, YUN-HUI ZHANG+,
REN-JIE CHEN+, AND BING-HENG CHEN+

#Shanghai Academy of Environmental Sciences, Shanghai 200233, China;
School of Public Health, Fudan University, Shanghai 200032, China

Objective To investigate the potential impact of ambient air pollution on public health under various traffic policies in Shanghai. **Methods** The exposure level of Shanghai residents to air pollution under various planned traffic scenarios was estimated, and the public health impact was assessed using concentration-response functions derived from available epidemiological studies. **Results** Our results showed that ambient air pollution in relation to traffic scenarios had a significant impact on the future health status of Shanghai residents. Compared with the base case scenario, implementation of various traffic scenarios could prevent 759-1574, 1885-2420, and 2277-2650 PM_{10}-related avoidable deaths (mean-value) in 2010, 2015, and 2020, respectively. It could also decrease the incidence of several relevant diseases. **Conclusion** Our findings emphasize the need to consider air pollution-related health effects as an important impact of traffic policy in Shanghai.

Key words: Air pollution; Traffic; Public health impact

INTRODUCTION

Road traffic is an important source of outdoor air pollution worldwide, contributing to fine particulate matter, carbon monoxide, and oxides of nitrogen. Recent epidemiological and animal studies suggest that exposure to traffic air pollution is associated with cardio-respiratory mortality and morbidity[1-3]. Several impact assessment studies of traffic air pollution have been initiated and completed by local, national and international organizations and institutions[4], highlighting the impact of traffic air pollution on public health. For example, the World Health Organization (WHO) estimated that 6% of deaths per year in Austria, France, and Switzerland are due to air pollution, and half of these deaths are linked to traffic fumes. The cost of treating diseases associated with traffic pollution across the three countries amounts 1.7% of their gross domestic product, exceeding the costs arising from traffic accidents[4].

Shanghai is a rapid-developing city and the cause of air pollution has changed from the conventional coal combustion to the mixed coal combustion/motor vehicle emission due to the rapid increase of motor vehicles within the city. Clearly, traffic policies in Shanghai will have a significant effect on the future local air pollution and health of Shanghai residents. The present study, was to evaluate impact of ambient air pollution on public health under various traffic scenarios in Shanghai.

MATERIALS AND METHODS

Scenarios of Traffic Policies and Air Pollutant Concentrations

Scenarios related to this study included base-case (BC), implementation of strict emission standard for new vehicles (scenario 1 below), and comprehensive vehicle pollution control (scenario 2 below). Details of the scenarios are described below:

● Under BC scenario, vehicle CO, VOC, NOx, and PM emissions in the whole city will increase to 1.563 million tons, 117 000 tons, 111 900 tons, and

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[2] Correspondence should be addressed to Hai-Dong KAN. Box 249, 130 Dong-An Road, Shanghai 200032, China. Tel/fax: 86-21-6404-6351. E-mail: haidongkan@gmail.com

Biographical note of the first author: Chang-Hong CHEN, male, Director and Professor, Atmospheric Science Institute, Shanghai Academy of Environmental Sciences.

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15 900 tons by 2020, approximately by 2.7, 1.4, 1.3, and 1.3 times higher than those in 2004, respectively.

- Under scenario 1, bus and taxi sectors take the lead in implementing GB III emission standard in 2006, GB III standard will be implemented for all new vehicles in 2007, GB IV standard will be implemented in advance in 2009. By 2020, the vehicle CO, VOC, NOx, and PM emissions in the whole city will be 742 000 tons, 82 800 tons, 54 700 tons and 8 500 tons, which will be reduced by 53%, 29%, 51%, and 46% as compared with those under BC scenario.
- Scenario 2: By integrated implementation of strict emission standard for new vehicles, reinforcement of I/M program and acceleration of old vehicle elimination, vehicle CO, VOC, NOx, and PM emissions in the whole city will become 574 000 tons, 70 600 tons, 50 500 tons, and 7 100 tons by 2020, which will be reduced by 23%, 15%, 8%, and 17% as compared with those under strict standard implementation scenario. The vehicle CO and VOC emissions in the whole city can be kept at the level of 2004, and NOx and PM emissions can be reduced by half as compared with the level of 2004.

This project uses ADMS-Urban model to link emission scenarios and pollutant concentrations. This model is the most complex one among the atmospheric dispersion model systems developed by Cambridge Environmental Research Consultants Ltd. (CERC, Ltd.), including point source, line source, area source, volume source and grid source models, embedded with chemical conversion and physical dispersion mobility modules. It can simulate synchronously the influence of the primary pollutant, secondary sulfate aerosol and ozone pollution resulting from the emission from industrial, civil and road transportation pollution sources in the urban area. One advantage of ADMS-Urban is that it can be used jointly with a geographical information system (GIS). It also features concepts based on Monin Obukhov length and boundary layer height, which make the boundary layer structure be defined with the directly measurable physical parameters. Therefore, it can express the dispersion process changing with the height more exactly, and simulate pollutant concentration distribution more accurately and reliably.

Human Exposure Level to Air Pollution

The year of 2004 was selected as the base period in this analysis. Air quality changes in 2010, 2015, and 2020 were estimated under the following scenarios: BC, implementation of strict emission standard for new vehicles, and comprehensive vehicle pollution control.

In this assessment, Shanghai was divided into four kilometers by four kilometers grid cells, and the changes in population exposure level and incidence of adverse health effects in each cell were estimated. Total health outcomes associated with air pollution in Shanghai were equal to the sum of grid-cell-specific changes of health outcomes.

Traffic-related air pollution consists of a mix of different pollutants (e.g. NO_2, PM_{10}, total suspended particles, fine particle, CO). In the present analysis, PM_{10} was selected as an indicator of air pollution to estimate the relevant health effects, since PM_{10} has the strongest epidemiological evidence among all air pollutants to support its association with adverse health effects. Our choice of indicator pollutant is also in line with other similar assessments of traffic-related air pollution[4].

All people living in Shanghai (excluding Chongmin County) were considered the exposed population in this analysis. An estimate of the number of Shanghai residents in each 4 km × 4 km grid cell was then made based on the population data collected from the Shanghai Bureau of Statistics. By combining the PM_{10} level and population size in each cell, we estimated the population exposure level to air pollution under various scenarios of traffic policy in Shanghai.

Estimation of Health Effects

Since most epidemiological studies linking air pollution and health endpoints are based on a relative risk model in the form of Poisson regression (Fig. 1), the cases at a given concentration C, could be given by:

$$E = \exp(\beta \times (C - C_0)) \times E_0 \qquad (1)^{[5]}$$

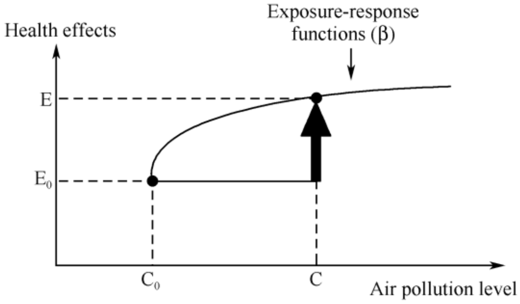

FIG. 1. Model to derive the number of cases under different scenarios[5].

where C and C_0 are the air pollutant concentration under one specific scenario and baseline scenario, respectively, and E and E_0 are the corresponding health effect cases under concentration of C and C_0. The health effect (benefit/damage) under the scenario with respect to baseline scenario is the difference between E and E_0. The value could be obtained if the following data components are available: exposure-response functions (β), population exposure levels (C and C_0), and baseline rate (E_0). The following sections would explain each of these components in details.

The final results of this analysis were given as the comparison of health effects under one specific scenario with respect to BC scenario in 2010, 2015, and 2020.

The selected health outcomes associated with PM_{10} exposure included long term mortality, chronic bronchitis, hospital admission (respiratory and cardiovascular systems), outpatient visits (internal medicine and pediatrics), and other diseases (acute bronchitis, asthma attack).

Exposure-response functions link air quality changes and heath outcomes. The preference for this analysis was to select E-R functions from Chinese studies whenever they were available[6]. Only when the selected endpoints could not be found in Chinese literatures, the results of international peer-reviewed literatures were used. If there were several studies describing the E-R function for the same health endpoint, we used the pooled estimate to get the mean and 95 percent confidence interval (CI) of the coefficient.

RESULTS

By combining the air quality level and population size in each cell, we estimated the population exposure level to PM_{10} under different scenarios in Shanghai. The percentages of population exposed to different levels of PM_{10} in 2010, 2015, and 2020 are summarized in Table 1. It should be emphasized that the PM_{10} level in Table 1 was much lower than the actual PM_{10} level in Shanghai, because in the present study, only PM_{10} from the traffic source was assessed. PM_{10} from other sources, such as coal-combustion, natural sources, construction sites, *etc*, was not included.

The PM_{10} exposure-response coefficients (mean and 95% CI) in our analysis are listed in Table 2.

TABLE 1

Population Exposure to PM_{10} Level under Various Scenarios in 2010, 2015, and 2020 (%)

PM_{10} Level (μg/m^3)	2010			2015			2020		
	BC	Scenario 1*	Scenario 2**	BC	Scenario 1*	Scenario 2**	BC	Scenario 1*	Scenario 2**
<10	44.51	53.56	65.72	42.58	67.96	77.91	40.22	73.00	87.04
10-20	33.75	33.84	34.28	35.33	32.04	22.09	33.17	27.00	12.96
20-30	21.74	12.60		22.09			26.62		
Total	100	100	100	100	100	100	100	100	100

Note. *Scenario 1: implementation of strict emission standard for new vehicles. **Scenario 2: comprehensive vehicle pollution control.

TABLE 2

Exposure-response Coefficients Used in the Analysis[6]

Health Endpoints	Population	Relative Risk (95% CI)
Total Mortality	Adults (⩾30 yrs)	1.0430 (1.0260, 1.0610)
Chronic Bronchitis	Total Population	1.0460 (1.0150, 1.0770)
Respiratory Hospital Admission	Total Population	1.0130 (1.0010, 1.0250)
Cardiovascular Hospital Admission	Total Population	1.0095 (1.0060, 1.0130)
Outpatient Visits (Internal Medicine)	Total Population	1.0034 (1.0019, 1.0049)
Outpatient Visits (Pediatrics)	Total Population	1.0039 (1.0014, 1.0064)
Acute Bronchitis	Total Population	1.0460 (1.0000, 1.0920)
Asthma	Children (⩽15 yrs)	1.070*
Asthma	Adults (⩾15 yrs)	1.0040 (1.0000, 1.0080)

Note. *95% CI was not provided in the original paper.

The excess cases in each scenario with respect to the BC scenario were computed based on the change in population exposure levels to PM_{10} under each scenario, exposure-response functions, and baseline rates for the health outcomes. The mean and 95% CI of the results in each year are shown in Table 1.

Traffic policy could have a significant impact on the future health status of Shanghai residents. Compared with BC scenario, implementation of scenario 1 (implementation of strict emission standard for new vehicles) and scenario 2 (comprehensive vehicle pollution control) in Shanghai could prevent 759-1574, 1885-2420, and 2277-2650 avoidable deaths (mean value) in 2010, 2015, and 2020, respectively. It could also decrease the substantial cases of relevant diseases.

TABLE 3

Health Benefits from Various Scenarios with Respect to BC Scenario in Shanghai in 2010, 2015, and 2020 (Mean and 95% CI)

	2010		2015		2020	
	Scenario 1*	Scenario 2**	Scenario 1*	Scenario 2**	Scenario 1*	Scenario 2**
Long-term Mortality	759	1 574	1 885	2 420	2 277	2 650
	(459-1 077)	(951-2 232)	(1 140-2 674)	(1 463-3 433)	(1 377-3 230)	(1 602-3 760)
Chronic Bronchitis	1 617	3 352	4 015	5 155	4 851	5 646
	(455-2 779)	(943-5 761)	(1 130-6 900)	(1 450-8 859)	(1 365-8 337)	(1 588-9 703)
Respiratory Hospital Admission	417	864	1 035	1 328	1 250	1 455
	(32-801)	(66-1 661)	(80-1 990)	(102-2 555)	(96-2 404)	(112-2 798)
Cardiovascular Hospital Admission	286	592	709	911	857	997
	(154-417)	(319-866)	(382-1 037)	(490-2 555)	(461-1 252)	(537-1 458)
Outpatient Visits	28 904	59 926	71 774	92 151	86 714	100 929
-internal Medicine	(16 351-41 456)	(33 901-85 951)	(40 604-102 945)	(52 131-132 170)	(49 055-124 372)	(57 097-144 761)
Outpatient Visits	3 001	6 222	7 452	9 568	9 003	10 479
-pediatrics	(1 071-4 931)	(2 220-10 224)	(2 659 –12 246)	(3 414-15 722)	(3 212-14 794)	(3 739-17 220)
Acute Bronchitis	55 446	114 955	137 684	176 772	166 342	193 611
	(19 089-91 802)	(39 578 –190 333)	(47 403-227 965)	(60 861-292 683)	(57 270-275 414)	(66 659-320 564)
Asthma Attack	962	1 994	2 388	3 066	2 885	3 358
(<15 Years)	(590-1 355)	(1 223-2 809)	(1 465 –3 365)	(1 881-4 320)	(1 770-4 065)	(2 060-4 731)
Asthma Attack	4 965	10 295	12 330	15 831	14 897	17 339
(⩾15 Years)	(2 419-7 512)	(5 015-15 574)	(6 007-18 654)	(7 713-23 949)	(7 257-22 536)	(8 447-26 231)

Note. *Scenario 1: implementation of strict emission standard for new vehicles. **Scenario 2: comprehensive vehicle pollution control.

DISCUSSION

Traffic air pollution and health constitute one of the biggest challenges to the sustainable economic development in Shanghai. This study provided an opportunity for Shanghai to look into future environmental tasks. The approaches we have used are also in line with those employed elsewhere and widely employed in heath-based risk assessment. The results illustrate that an effective traffic policy would play an active role in the reduction of air pollutant emission, improvement of air quality and promotion of public health.

Quantification of the impact of air pollution on public health has increasingly become a critical component in policy decision. Analyzing the timpact of ambient air pollution on public health in a community remains a challenge, given the gaps in scientific knowledge about the health effects of air pollution, and the wide range of uncertainties involving many parts of the process.

It is still unclear which constituents of traffic emissions are responsible for the observed adverse effects on people’s health. Knowledge about such indicators would be very useful in implementing mechanisms by which air pollutants are controlled. Most epidemiological studies have concentrated on the classical air pollutants, such as black smoke[7], nitrogen dioxide[8] or particulate matter[9]. A few studies have investigated the effects of ultra-fine particles on public health[10-11]. Choice of the indicator depends on the application of source apportionment, health risk assessment or transportation-flow management. Possible indicators of exposure to particulate matters from traffic in urban areas might include black smoke and ultra-fine particles.

Also, it is still difficult to estimate the population's exposure to transport-related air pollution, which limits the precision with which the effects can be quantified. Estimating this exposure as correctly as possible requires knowledge about where the people spend their time and what pollution levels prevail in these microenvironments. The quantity of passing traffic, the distance from a road to a residence, weather conditions and time spent in different traffic modes contribute to the overall exposure level[12-13]. Health risks are expected to become elevated in people living and working near busy roads or commuting in heavy traffic, or both. Also, intake of pollutants varies among such road users as drivers, bicyclists and pedestrians. Most commonly used estimates of population exposure levels are based on fixed monitoring sites and do not reflect the spatial and temporal variability of personal exposures.

Our current estimation of the impact of traffic air pollution on public health under various scenarios was conservative due the following three reasons. Firstly, in the present analysis we only selected PM_{10} as the indicator of traffic-related air pollution, which would probably overlook the adverse health effects of exposure to other air pollutants (e.g. NOx, CO, and ozone), thus underestimating the effects of traffic air pollution on public health. Although PM_{10} may be a good indictor of air pollution, there is evidence that other pollutants, such as ozone, nitrogen oxides, and sulfur dioxide, *etc.*, may exert independent effects on health[14]. In addition, we could not include estimates of synergistic effects of various air pollutants, or of co-factors such as pollen and other allergens. Secondly, the model we used could only deal with primary PM_{10} and NOx, thus leading to underestimation of the secondary PM_{10} effects on health. A previous study showed that ammonium sulfate and nitrate account for a substantial ratio of fine particles in Shanghai[15]. Thirdly, in the selection of relevant health endpoints, we only focused on the outcomes that could be quantitatively estimated and translated into monetary values for further assessment. Some endpoints, such as sub-clinical symptoms and decrease in pulmonary function, were not included in this analysis, although they are associated with air pollution exposure. We did not estimate cancer risk linked to exposures to ambient air pollution, although a recent cohort study in USA has suggested their association[16].

Studies with new designs are needed to address the effect of emissions from diesel-powered vehicles on public health. It was reported that emissions from vehicles with heavy-duty diesel engines are more relevant to the adverse health effects than those from cars with light-duty engines[17]. Specific differentiation between light-duty and heavy-duty vehicles requires study populations who are exposed different diesel sources. Studies are needed to understand the effects of new pollution constituents, such as trace elements from automobile catalytic converters (platinum, palladium, and rhodium) on public health. Air pollution is much more associated with stop-and-go traffic and car traffic, rather than with moving traffic and truck traffic[17].

In conclusion, air pollution has severe impacts on public health in Shanghai. In a century moving toward sustainable economic development, close collaboration between public health and traffic policy makers will achieve success in preventing avoidable health hazards.

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