Environmental Pollution 167 (2012) 148–154

Contents lists available at SciVerse ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Quantifying the impacts of socio-economic factors on air quality in Chinese cities from 2000 to 2009

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ARTICLE INFO

Article history:
Received 16 November 2011
Received in revised form
1 April 2012
Accepted 8 April 2012

Keywords:
Socio-economic factors
Air quality
Urban environment
Urbanization
Variation partitioning
Environmental treatment

ABSTRACT

Socio-economic factors have significant influences on air quality and are commonly used to guide environmental planning and management. Based on data from 85 long-term daily monitoring cities in China, air quality as evaluated by AOFDAQ-A (Annual Occurrence Frequency of Daily Air Quality above Level III), was correlated to socio-economic variable groups of urbanization, pollution and environmental treatment by variation partitioning and hierarchical partitioning methods. We found: (1) the three groups explained 43.5% of the variance in AOFDAQ-A; (2) the contribution of "environmental investment" to AOFDAQ-A shown a time lag effect; (3) "population in mining sector" and "coverage of green space in built-up area" were respectively the most significant negative and positive explanatory socio-economic variables; (4) using eight largest contributing individual factors, a linear model to predict variance in AOFDAQ-A was constructed. Results from our study provide a valuable reference for the management and control of air quality in Chinese cities.

1. Introduction

Urban areas are hot spots that drive environmental change (Grimm et al., 2008). The unprecedented rate of urban growth over the past century has had an enormous global impact (Brown, 2001). Although cities only cover 2.8% of the Earth's terrestrial surface, they are the major consumers of natural resources, the major producers of pollution waste, and the focus of most other human activities, many governments realize that much of the sustainability debate has an urban focus (Breheny, 1992; Marquez and Smith, 1999).

As cities are wholly created by humans (Whitney and Adams, 1980; Hope et al., 2003), the ecology and environment in and around cities reflects social, economic, and cultural influences (Liu, 2001). For example, income and education are robust determinants of household air pollution (Papineau et al., 2009), urban population density can influence total passenger vehicle emissions (Marshall et al., 2005), and economic development has positive contribution to environmental quality (Xepapadeas and Amri, 1998). However, other reports found that when GDP increases, the larger scale of production leads directly to more pollution and more environmental damage (Zugravu et al., 2008). After all, according to Ewing et al. (2007), compact development could achieve a reduction of greenhouse gas emissions by up to 10% by 2050. Moreover, additional reductions may result from employing other strategies such as transit investment, fuel pricing, and parking (Bandeira et al., 2011).

In light of these significant influences of socio-economic factors, cities should be designed and managed to reduce environmental degradation (Marquez and Smith, 1999). At least 24% of greenhouse gas emissions sources are amenable via more enlightened urban planning and design principles and programs, increasing to 54% if transport, housing and commercial buildings are included (Marquez and Smith, 1999). Information is then needed on the technological and planning options available and how much these can help to reduce emissions and at what cost (Mediavilla-Sahagun and ApSimon, 2006). By determining their power to explain the variance in air quality, socio-economic indices could be more practically and expediently used to connect air quality control with urban planning and policy making. Such an approach should be transparent to both the responsible authorities and to the affected public (Mediavilla-Sahagun and ApSimon, 2006). Yet relative

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doi:10.1016/j.envpol.2012.04.007

studies on the contribution of policy and planning to explain the variance in air quality have only been sporadically reported (Bandeira et al., 2011).

Air pollution in Chinese cities has become one of the top environmental concerns. As a typical developing country, China has an urban population of 621.86 million, accounting for 46.56% of the total population (Editorial Board of China Statistical Yearbook, 2010). In the last two decades, knowledge on air pollution has improved considerably as funding for environmental research has increased (Florig et al., 2002; Chan and Yao, 2008). Air quality monitoring systems have been installed in over 200 cities, some of which began monitoring in the year 2000, and the number of monitored cities continues to increase. The daily reports of air quality in the monitored cities provide important basic data for air quality research.

Socio-economic factors are always important in macro-control of national environmental pollution, and are used to guide environmental treatments. In this research, we hypothesized that air quality in cities is affected by the interrelated socio-economic factors that characterize the human disturbance. The air quality of 85 cities covering all provinces in mainland China with the exception of Tibet were assessed with respect to 21 environmental factors divided into three groups i.e. urbanization, pollution and environmental treatment. Specifically, we posted the following research questions: (1) Do the methods of partitioning analysis applicable to distinguish the relative importance of socio-economic variable groups to air quality? (2) To what extents the contributions of pollution, urbanization and environmental treatment account for variations in urban tree transpiration? (3) Which socio-economic variables are the most important predictors of urban air quality? The results from this research provide insights into the causal socio-economic variables of urban air quality, and provide valuable references for the management and control of air quality in Chinese cities.

2. Materials and methods

2.1. Study sites

Air quality samples were collected at 85 long-term daily monitoring sites (see Appendix A), covering all provinces in mainland China with the exception of Tibet, for which socio-economic data were unavailable. Most of the monitoring sites were in relatively developed cities in each province. The location and monitoring effort for each site is shown in the Appendix A. A map showing the distribution of these sites in China can be seen in the Ministry of Environmental Protection of the People's Republic of China website (MEPPRC, http://www.zhb.gov.cn; Chinese National Environmental Monitoring Centre, 2010). As monitoring at different sites began at different times, the monitoring periods also varies between sample sites (see Appendix A).

2.2. Data

2.2.1. Air quality

To quantify air quality, an air pollution index (API; National Bureau of Statistics of China, 2008) has been in use at the monitoring sites since 1997. Daily average API values of all the monitoring cities are reported at the official website (http://www.zhb.gov.cn). Based on the API, ambient air quality of monitored cities are classified into five levels and also reported on the MEPPRC website (Table 1). These reports provide overviews of air quality across mainland China.

API reporting requires monitored daily average air quality data to be converted into integer values (Jiang et al., 2004). API is measured as the maximum pollution sub-index of pollutants by the following formula (National Bureau of Statistics of China, 2008):

$$\mathrm{API} = \mathrm{Max}\{I_1, I_2 ... I_x ... I_n\}$$

where I_x is the air pollution index for pollutant X, and n is the number of pollutants.

For pollutant X, I_x is calculated by the following formula:

$$I_x = \frac{(C_x - C_{x,j})}{C_{x,j+1} - C_{x,j}} (I_{x,j+1} - I_{x,j}) + I_{x,j}$$

Where $C_{x,j} < C_x \le C_{x,j+1}$, C_x is the concentration of pollutant X (mg/m^3), $C_{x,j}$ is the threshold concentration of pollutant X for level j that is $\le C_x$, $C_{x,j+1}$ is the threshold concentration for level $j+1$ that is $\ge C_x$, $I_{x,j}$ is the index of pollutant X for level j, and $I_{x,j+1}$ is the index for level $j+1$.

For the indices for different levels of pollutants, see the published technical manual for urban ambient air quality daily report and forecast in China (National Bureau of Statistics of China, 2008).

The pollutants in the daily report include daily average concentrations of SO_2, NO_2, PM_{10} and CO, and eight hour (9:00–17:00) averaged concentration of O_3 (National Bureau of Statistics of China, 2008). Since the API is simply the maximum value of the normalized concentrations at a given site, the various pollutants are ascribed equal importance in describing the overall air quality (Liu and Chan, 2002). Technical details concerning the monitoring sites, monitoring methods and statistical methods have been described in Automatic Monitoring Technical Specifications of Ambient Air Quality (HJ/T 193-2005; National Bureau of Statistics of China, 2005a), and Manual Monitoring Technical Specifications of Ambient Air Quality (HJ/T 194-2005; National Bureau of Statistics of China, 2005b).

The Annual Occurrence Frequency of Daily Air Quality above Level III (including air quality level I and II, abbreviated as AOFDAQ-A, and not poor air quality levels III, IV and V), which means better air quality when outdoor activity is not affected, is widely used in China for governmental planning and scientific research. In this paper we took daily air quality observation records from 2000 to 2009 (Chinese National Environmental Monitoring Centre, 2010), and calculated the AOFDAQ-A for each city in each year by dividing the total number of days with daily air quality better than level III by the number of days with valid observations.

2.2.2. Socio-economic variables

Socio-economic predictor variables data was collected from the Statistics Yearbook of Cities in China (Urban Socio Economic Survey Division of National Bureau of Statistics of China, 2001–2010). All possible socio-economic predictor factors were tested using linear regression to select those with a significant effect on air quality. According to the results, significant variables were classified into three groups, which are urbanization, pollution and environmental treatment (Table 2). We identified urbanization variables as a separate group because they were related to both pollution and environmental treatment. Where variables were recorded for different periods of time, data were analyzed during separate runs.

2.2.3. Linear regression

Linear regressions were conducted for each explanatory variable to select the significant variables. For each of the linear regressions, an approximately normal distribution of the residuals was proved by QQ-plot of model residuals and boxplot of residuals, and Levene's test was used to test for homogeneity of variances for the residuals.

Using SPSS16.0, a multi-variables linear regression was conducted with the eight most significant and least collinear variables to model the value of AOFDAQ-A. The error term had a normal distribution with a mean of <0.001.

Table 1
Classification criteria of air quality (translated from National Bureau of Statistics of China, 2008).

Air quality index (API)	Air quality level	Air quality condition	At risk population	Health implications
0–50	I	Excellent	Usual outdoor activities	None
51–100	II	Good		
101–200	III	Lightly polluted	Mild aggravation of symptoms among susceptible persons. Generally healthy individuals may also notice some discomfort.	People with breathing or heart problems should restrict physical exercises and outdoor activities.
201–300	IV	Moderately polluted	Moderate aggravation of symptoms and decreased tolerance in persons with heart or lung disease. More widespread symptoms of transient irritation in the healthy population.	Elders and people with existing heart or respiratory illnesses should remain indoors and avoid exercise.
>300	V	Intensively polluted	Healthy people may experience decreased exercise tolerance and adverse symptoms that affect normal activity, in addition to early onset of certain diseases.	Elders and the sick should remain indoors and avoid exercise. Healthy individuals should avoid outdoor activities.