Journal of Global Environment Engineering, Vol. 7, pp. 47-61, 2001

SULFUR DIOXIDE EMISSIONS AND COUNTY-LEVEL DISTRIBUTIONS IN CHINA

Hongwei Yang[1]
Yuzuru Matsuoka[2]
Tomohiro Matsuo[3]

Abstract

This paper presents the development of a county-level inventory system for sulfur dioxide emissions in China based on detailed and reliable investigations. Specific data for 269 and 381 large point sources are included in 1990 and 1995, respectively. The methodology for the extraction of provincial level area source emissions and the disaggregation from provincial total into county-level emissions is discussed in detail. The total sulfur dioxide emissions are 18.99 million tons in 1990 and 23.70 million tons in 1995. 23% and 28% of the national total emissions are identified as large point source emissions in 1990 and 1995, respectively. The geographic distributions of sulfur dioxide emissions at 2137 counties and county-level cities are also provided in this paper as a result of our studies.

KEYWORDS: *inventory, sulfur dioxide, China, GIS*

1. Introduction

Air pollution is one of the most important environmental issues in the developing countries, especially in their urban areas. Air pollutants emissions are usually closely related to energy utilization activities. For example, most of the sulfur dioxide (SO_2) emissions in China are from coal combustion. In China's ninth five-year plan for state economic development, the so-called "two control zones" for SO_2 emissions control and acid rains control have been considered as a national-wide strategy to protect the regional environment. Some preliminary countermeasures are being taken to mitigate air pollutants. Every year the State Statistics Bureau of China and State Environmental Protection Administration of China publish the national total air pollutants emissions. However, more detailed information for the distributions of these air pollutants is not available in China. The geographic distributions are very important scientific foundations for the assessment of air pollutants and design of countermeasures.

Many Asian countries are now undergoing a period with high economic growth and environmental issues are becoming more and more important to realize a sustainable economy. Recognizing the importance of this issue, many researchers have studied the situation of air pollution

[1] Dr. Eng., Energy Research Institute, Beijing, China.
[2] Dr. Eng., Professor, Dept. of Environment Eng., Kyoto University, Kyoto, Japan Dept. of Environment Eng., Kyoto University, Kyoto, Japan.
[3] Dept. of Environment Eng., Kyoto University, Kyoto, Japan.

in this region (H. Akimoto and H. Narita, 1994; R. Arndt et.al.,1997; S. Fujita et.al., 1991; N. Kato, 1996; Y. Matsuoka, 1992; D.G. Streets and S. T. Waldhoff, 2000; T. Wang et.al., 2000). In the case of studies about China, more detailed investigations are required as China is a large country with big varieties among different provinces. For example, both the advanced and backward technologies are being implemented in China for the production of the same product. Another reason is that the statistics system in China is also undergoing an improvement process. The more we use the direct emission data such as emissions from large point sources, the more we can reduce the uncertainties for the inventory studies. The specific feature of this study is that it is based on detailed and reliable investigations for major large point sources in China. Large point source data in five major emission-intensive sectors were collected. Allocation of area sources is based on actual activity indexes by each county, including population, industrial GDP, transportation volumes, etc. So the emissions are closely related with the economic and energy activities in the local regions. Geographic distributions of SO_2 emissions at county level are also presented in this paper.

2. Methodology

Similar to most of the countries, sources of air pollutants in China consist of point sources, area sources and line sources (mainly for transportation sector). However, large variation exists among different regions in China. Considering the availability of the necessary data for inventory studies, we assume that air pollutants are emitted from large point sources and area sources (including line sources) in this study.

2.1 Emissions from Large Point Sources

Estimation of large point source emissions is based on the collected data and the related technological information, including data for fuel combustion technology, production processes of a product, production quantity, technology level, and energy consumption by fuels for large point sources. There are two approaches to estimate emissions from large point sources: first, multiplying energy consumption by the related emission factors by fuels; and second, multiplying production volume by the related emission factor for that process. The former approach is mainly applied to the estimation of emissions from thermal power plants and iron and steel plants, while the latter is mainly applied to the estimation of emissions from nonferrous metal plants and cement plants. The emission factors are calculated plants by plants based on collected information (performances of the fuel combustion facilities used in the plant, production processes, quality of fuels used, etc.).

Emission from a large point source can be estimated using the following equations:

— Approach 1: multiplying energy consumption by emission factors:

$$Q^{PS} = R^{PS} \times \sum_k (E_k^{PS} \times f_k^{PS}) \tag{1}$$

— Approach 2: multiplying production volume by emission factor for the process:

$$Q^{PS} = R^{PS} \times V^{PS} \times f_v^{PS} \tag{2}$$

where

Q^{PS}	Emission of a large point source
R^{PS}	Release rate of the air pollutants after removal process from the plant (fuel pre-processes outside the plant are not included)
E_k^{PS}	Energy consumption of the k-th fuel type of a large point source
f_k^{PS}	Emission factors of the k-th fuel type
V^{PS}	Production volume of a large point source
f_v^{PS}	Emission factor of the product (process)
k	Fuel type

2.2 Emissions from Area Sources

In this study, we present county-level distributions for area source emissions in China. The administrative classification in China is in the series of state, provinces, prefectures and counties. There are 2137 counties (including county-level cities) in China. It is very difficult to collect all information at county-level due to the difficulties of data unavailability. However, it is important to know where the air pollutants are being emitted in order to estimate the impacts of the pollution. To solve this problem, we developed a methodology that can disaggregate the emissions from provincial level into county-level distributions. First we calculate the area source emissions at provincial level based on provincial energy balance tables; and then allocate the province's area source emissions into area source emissions at each county in the province by selecting appropriate proxy intensity indexes of emissions (see Figure 1). Of course, data availability is an important element to decide which index should be adopted.

Emissions from area sources were estimated based on energy consumption related to the anthropogenic activities and the large point source emissions that we have already investigated. Both national level and provincial energy balance tables are available in China from the State Statistics Bureau (1998). Emissions from provinces are calculated based on the information about energy consumption in these statistical materials by the following equation:

$$Q_j^{AS} = \sum_k (E_{j,k}^{AS} \times f_{j,k}^{AS}) \tag{3}$$

where

Q_j^{AS}	Emissions of the air pollutants of j-th sector in the region (province) from area sources
$f_{j,k}^{AS}$	Emission factor of the air pollutants of the j-th sector and k-th fuel type from area source emissions, including the effect of removal process
$E_{j,k}^{AS}$	Energy consumption of the j-th sector and k-th fuel type from area sources, and is calculated with $E_{j,k} - \sum_{PS \in j} E_k^{PS}$
$E_{j,k}$	Total energy consumption of the j-th sector and k-th fuel type by area and point sources

$PS \in j$	All the point sources belong to the j-th sector
j	Sector
k	Fuel type

More detailed information about the approaches to obtain the emission factors by fuels ($f_{j,k}$) will be discussed in section 3 of this paper.

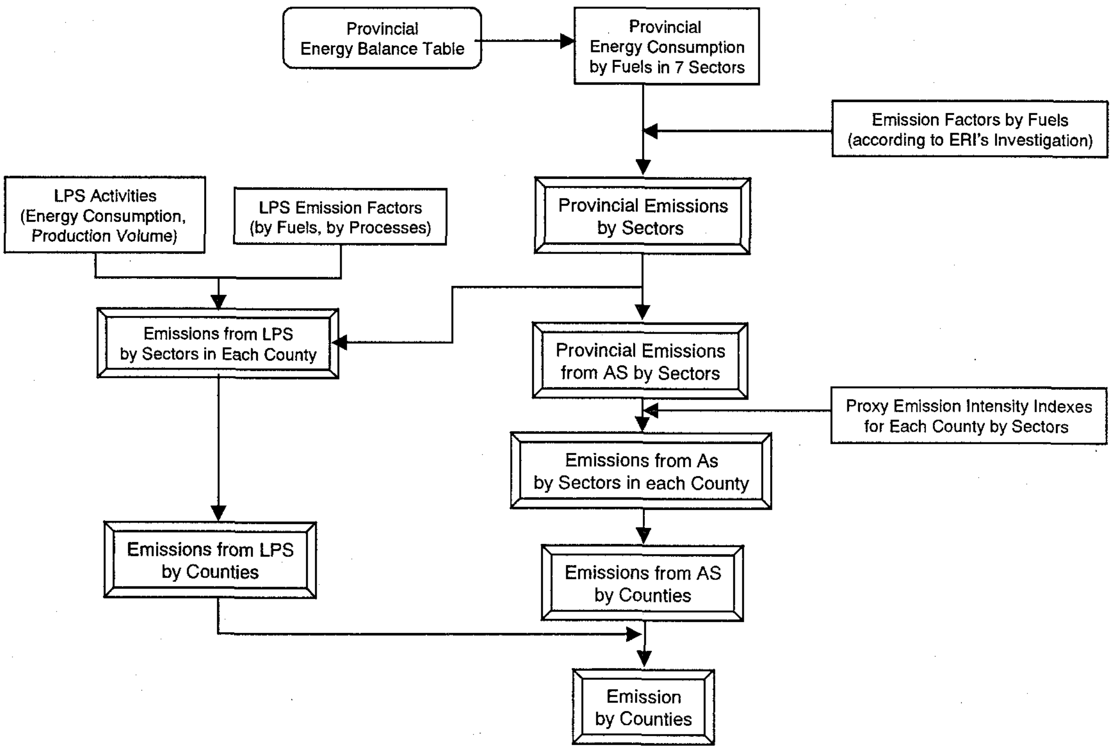

Figure 1. Schematic diagram of the estimation process

The emission of each province estimated by equation (3) is that from area sources in each sector of the province. The total emission from sector j in the province is:

$$Q_j = Q_j^{AS} + \sum_{PS \in j} Q_j^{PS} \tag{4}$$

The provincial area source emissions are allocated to the area source emissions at county level. This allocation is performed by sectors in the province using the allocation index which is the best available driving force to the local pollutant emissions in the addressed sector, as indicated in the following equation:

$$Q_i^{AS} = \sum_j (Q_j^{AS} \times \frac{I_{i,j}}{\sum_i I_{i,j}}) \tag{5}$$

where

$I_{i,j}$ Emission intensity index for sector j in county i

2.3 Total Emissions by Counties

After the disaggregation of area source emissions from provincial level to county level, the total emission of a county i can be obtained by summing up the point source emission and area source emission, as indicated by equation (6):

$$Q_i = \sum Q^{PS} + Q_i^{AS} \tag{6}$$

where, the first term on the right side of the equation is total point source emissions and the second term is the total area source emissions in that county.

3. Data Collection and Calculation Result

The main objective of the inventory system we proposed in this paper is to estimate the sulfur dioxide emissions and their distributions at county level in China in 1990 and 1995. To apply the above methodology, a large number of necessary data were collected.

3.1 Emissions from Large Point Sources

In China, coal utilization is the most important source for SO_2 emissions, which takes about 90 percent of the national total SO_2 emissions (State Environmental Protection Administration, 1996a). Thermal power generation, cement production, iron and steel making, sulfuric acid production and non-ferrous metallurgy are the major large point sources of SO_2 emissions in China. In this study, large point sources data for major thermal power plants, iron and steel plants, nonferrous metal plants, cement plants and sulfuric acid plants are collected based on the investigations by Energy Research Institute (Hu and Yang, 2000). Large point sources in this study means the key SO_2 emitters in electric power generation and industrial sectors (see Table 2). The number of large point sources we investigated is 269 in 1990 and 381 in 1995, respectively. The data for large point sources mainly include activity data, emission factors and the related descriptions for the technologies or facilities in service. The activities consist of energy consumption by fuels and production volumes (or electric power generated). The emission factors are described as emission factors by fuels and emission factors by processes. Table 1 lists the major information sources for large point sources in this study. Table 2 shows the number of large point sources in this study. Fuel pre-processes such as coal washing, oil refinery, and mixing of desulfurization agents are outside of the plants, so the release rate R^{PS} in equation (1) does not include the effects from such kind of fuel pre-processing activities.

Table 1. Sources for LPS data

LPS Data	Sources
Thermal power plants	*1.* China Electric Power Statistical Yearbooks (State Power Corporations, 1990, 1995). *2.* Handbook for Industrial Pollutants and Emission Factors (State Environmental Protection Administration, 1996b). *3.* Inquiry to State Power Corporations.
Cement plants	*1.* China Building Materials Statistical Yearbooks (State Building Materials Bureau, 1991, 1996). *2.* Inquiry to State Building Materials Bureau. *3.* Inquiry to China Society of Building Materials Industry. *4.* Handbook for Industrial Pollutants and Emission Factors (State Environmental Protection Administration, 1996b).
Non-ferrous plants	*1.* Inquiry to State Metallurgy Industry Bureau. *2.* Handbook for Industrial Pollutants and Emission Factors (State Environmental Protection Administration, 1996).
Sulfuric acid plants	*1.* China Chemical Industrial Statistical Yearbooks (State Chemical Industry Bureau, 1991, 1996). *2.* Inquiry to State Chemical Industry Bureau. *3.* Handbook for Industrial Pollutants and Emission Factors (State Environmental Protection Administration, 1996b).
Iron and steel plants	*1.* China Iron and Steel Statistical Yearbooks (State Metallurgy Industry Bureau, 1991, 1996). *2.* Inquiry to State Metallurgy Industry Bureau.

Table 2. Number of large point sources in this study

	1990		1995	
	Number of Plants	Share of Production (%)***	Number of Plants	Share of Production (%)
Power Plants*	95	67	150	68
Iron & Steel Plants	89	98	89	90
Non-ferrous Plants	12	59	12	58
Cement Plants	73	11	73	11
Sulfuric Acid Plants**	-	-	51	42
Total	269	-	381	-

Notes: * capacity for electric power generation ≥ 300 MW.

** annual production volume ≥ 80000 tons.

*** share of production in the national total.

Table 3. Sulfur contents of coal used by thermal power plants in China

Sulfur Content of Coal (%)	Share of Coal (%)	Share of Sulfur (%)
< 1.0	46.3	16.8
1.0-2.0	35.0	38.2
2.0-< 3.0	10.0	18.2
3.0-< 4.0	4.7	12.0
4.0-5.0	1.9	6.3
> 5.0	2.1	8.5

Source: ERI (1999).

According to the survey by Energy Research Institute (ERI, 1999), the sulfur contents of coal for thermal power generation are listed in Table 3. Table 4 and Table 5 show the estimated results for large point source emissions in 1990 and 1995. As the sulfur content of coal varies in different regions, in this study the calculation of SO_2 emissions is based on the investigations of the actual sulfur content of coal used by each large point source plant (ERI, 1999). In the case of the calculation of area source emissions, provincial level average data of sulfur content rate of fuels by sectors have been adopted. The estimated emissions from the large point sources we investigated are 4.45 million tons and 6.62 million tons in 1990 and 1995, respectively. The shares of these large point source emissions in the national total SO_2 emissions are 23% and 28% in 1990 and 1995, respectively.

3.2 Emissions from Area Sources

Provincial level area source emissions can be obtained based on the provincial energy balance tables (State Statistics Bureau, 1998) and the sums of large point source emissions in the provinces. Some modifications to the energy balance tables were required to calculate the total emissions and also to allocate the area source emissions. Energy consumption in the form of heating (L20 in the energy balance table) and electricity (L21 in the energy balance table) have been replaced by the consumption of coal, oil and gas according to the statistical data for power generation and heat (State Power Corporations, 1995). In the provincial energy balance tables, seven major sectors are defined as: agriculture, forestry and fisheries; industry; construction; transportation; commerce; residential; and the others. Then, industrial sector is divided into fifteen sub-sectors. The fuel types used in all the sectors are defined according to the classification in energy balance tables. In China's energy balance tables, energy consumption is classified into the following 17 kinds of fuels besides the above mentioned heating and electricity: 1) raw coal; 2) washed coal; 3) other washed coal; 4) briquettes; 5) coke; 6) coke oven gas; 7) other gases; 8) other coking products; 9) crude oil; 10) gasoline; 11) kerosene; 12) diesel; 13) fuel oil; 14) LPG; 15) refinery gas; 16) other petroleum products; 17) natural gas.

For area source emissions, we have no detailed information about SO_2 removals, so we estimate the value of release rate in each sector based on the inquiry on unburned ratios and the specific situation for SO_2 removals by sectors and provinces (State Environmental Protection Administration, 1991, 1996). Table 6 shows the estimated release rate of SO_2 emissions in 1990 by sectors. Emission factors by fuels can be derived from release rates by using equation (7). As listed in the energy balance tables, the effects of pre-processes for some fuels are considered when determining the emission factors by fuels.

$$f_{j,k}^{AS} = T \times S_{j,k} \times R_{j,k}^{AS} \tag{7}$$

where

T	Conversion factor from sulfur to SO_2, which is constant: T = 2.0
$S_{j,k}$	Average sulfur content of the k-th fuel type at the j-th sector
$R_{j,k}^{AS}$	Sulfur release rate of the k-th fuel type at the j-th sector

We use several indexes to allocate provincial sectoral emissions among counties. First the provincial emissions are divided into area and point source emissions using equation (4). Then provincial sectoral emissions are divided as mentioned in equation (5) by using specific proxy emission intensity indexes.

For residential sector, energy activities are closely related to the number of population, so population in each county (State Statistics Bureau, 1992, 1996a) served as the proxy intensity index in residential sector.

Similarly, industrial emissions are closely related to the production processes. Industrial GDP values (State Statistics Bureau, 1992, 1996a) in each county are used.

For transportation sector, the situation is a little bit complicated due to the unavailability of transported volumes for each county. First we divide the emissions in this sector into two parts — one part from large and medium cities (231 cities) and another part from other areas (small cities and counties) — by using the share of transportation volumes of the large and medium cities to the provincial total (State Statistics Bureau, 1999). Then the part for large and medium cities is allocated to each city by transportation volumes of each city; and the other part is allocated by population in each county (small cities and counties).

3.3 Total Emissions

The total emissions for each county are calculated by summing up the point source emissions and area source emissions in that county. The result of SO_2 emissions at county level according to our study is shown in Figure 4. The emissions in each province are listed in Table 7. In 1990, the top 5 provinces for SO_2 emissions are Shangdong, Sichuan, Jiangsu, Liaoning and Hebei, which take more than 40% of the national total. While in 1995, the top 5 provinces are the same ones in 1990, but the order by emissions changes to be Shangdong, Sichuan, Jiangsu, Hebei and Liaoning, and the share in national total maintains almost the same as 1990 level. Statistics from SEPA is also listed in Table 7. Note that LPS data of sulfuric acid in 1990 are not included in this study as the related data are not available. However, emission from sulfuric acid LPS is only a minor part in the national total. In 1995, SO_2 emission from sulfuric acid LPS contributed 0.11% of the national total. The differences of this study and the SEPA's data mainly come from the fact that SO_2 emissions from township and village enterprises (TVEs[4]) are not included in SEPA's statistics. Figure 2 shows the comparison of total SO_2 emissions by this study and some of the other studies. The trend of SO_2 emissions from 1990 to 1995 indicated by different studies is very similar. However, the estimated total SO_2 emissions in this study are relatively lower than that by other studies. This difference mainly comes from the contribution of large point sources. Through our investigation, we found that the actual SO_2 emissions from a large point source plant are affected by the actual oxidation rate of fuels (especially coal that is more difficult to have a complete combustion) and the desulfurization measures (such as additional coal washing by a thermal power plant who buys ordinary steaming coal from the market and re-processes it by itself, and other measures like simply adding lime or other agents that help to reduce the generation of SO_2 in the combustion process) in that plant.

Table 4. Large point source emissions in 1990 (10000 ton-SO_2)

Province	Thermal Power	Iron & Steel	Nonferrous	Cement	Total
Beijing	9.30	3.38	0.00	0.08	12.76
Tianjin	7.20	1.48	0.00	0.00	8.68
Hebei	25.56	3.48	0.00	0.50	29.54
Shanxi	20.29	2.01	1.67	0.00	23.97
Inner Mongolia	13.69	2.18	0.00	0.13	16.00
Liaoning	26.63	9.04	12.91	1.06	49.64
Jilin	6.90	0.54	0.00	0.00	7.44
Heilongjiang	17.50	0.48	0.00	0.57	18.55
Shanghai	24.95	3.41	0.00	0.21	28.57
Jiangsu	27.00	1.78	0.00	0.19	28.97
Zhejiang	11.40	0.44	0.00	0.19	12.03
Anhui	14.47	3.81	3.69	0.54	22.51
Fujian	4.37	0.37	0.00	0.00	4.74
Jiangxi	3.51	0.71	0.30	0.22	4.74
Shangdong	38.13	1.56	0.00	0.25	39.94
Henan	22.30	0.89	0.00	0.18	23.37
Hubei	5.76	4.38	1.90	0.45	12.49
Hunan	5.02	1.23	9.42	0.39	16.06
Guangdong	15.63	0.68	0.97	0.50	17.78
Guangxi	3.11	0.38	0.00	0.61	4.10
Hainan	0.00	0.00	0.00	0.00	0.00
Sichuan	16.62	3.02	0.00	0.90	20.54
Guizhou	5.60	0.60	0.00	0.19	6.39
Yunnan	3.37	0.64	1.73	0.33	6.07
Tibet	0.00	0.00	0.00	0.00	0.00
Shaanxi	10.11	0.22	0.00	0.24	10.57
Gansu	2.99	0.65	8.74	0.36	12.74
Qinghai	0.06	0.20	0.00	0.00	0.26
Ningxia	3.50	0.04	0.00	0.00	3.54
Xinjiang	2.33	0.34	0.00	0.23	2.90
Total	347.30	47.94	41.33	8.32	444.89

[4] Township and village enterprises (TVEs) refer to those farmer-owned small-scale enterprises that locate in rural areas in China.

Table 5. Large point source emissions in 1995 (10000 ton-SO_2)

Province	Thermal Power	Iron & Steel	Nonferrous	Cement	Sulfuric Acid	Total
Beijing	8.70	4.93	0.00	0.05	0.00	13.68
Tianjin	9.15	1.64	0.00	0.23	0.04	11.06
Hebei	36.80	4.21	0.00	0.15	0.03	41.19
Shanxi	38.75	2.22	2.20	0.32	0.07	43.56
Inner Mongolia	19.57	2.36	0.00	0.01	0.03	21.97
Liaoning	30.29	9.34	19.04	1.04	0.35	60.06
Jilin	12.21	0.69	0.00	0.15	0.00	13.05
Heilongjiang	23.36	0.41	0.00	0.30	0.03	24.10
Shanghai	32.37	5.19	0.00	0.16	0.14	37.86
Jiangsu	53.26	1.83	0.00	0.14	0.31	55.54
Zhejiang	18.29	0.46	0.00	0.28	0.06	19.09
Anhui	27.88	4.65	4.07	0.48	0.17	37.25
Fujian	6.82	0.36	0.00	0.09	0.00	7.27
Jiangxi	6.22	1.33	0.39	0.05	0.13	8.12
Shangdong	54.91	2.22	0.00	0.43	0.06	57.62
Henan	33.20	1.18	0.00	0.17	0.10	34.65
Hubei	10.74	4.17	1.94	0.40	0.14	17.39
Hunan	12.41	1.30	14.40	0.14	0.20	28.45
Guangdong	24.91	0.89	0.86	0.21	0.15	27.02
Guangxi	4.13	0.52	0.00	0.77	0.03	5.45
Hainan	0.00	0.00	0.00	0.00	0.00	0.00
Sichuan	27.80	3.67	0.00	0.53	0.23	32.23
Guizhou	10.42	0.74	0.00	0.17	0.00	11.33
Yunnan	6.65	0.76	1.48	0.10	0.24	9.23
Tibet	0.00	0.00	0.00	0.00	0.00	0.00
Shaanxi	14.63	0.26	0.00	0.09	0.03	15.01
Gansu	4.34	0.93	10.99	0.06	0.03	16.35
Qinghai	0.00	0.17	0.00	0.01	0.00	0.18
Ningxia	7.34	0.04	0.00	0.02	0.00	7.40
Xinjiang	5.24	0.42	0.00	0.03	0.00	5.69
Total	540.39	56.89	55.37	6.58	2.55	661.79

Table 6. SO_2 release rates (%) by sectors in China in 1990

Sector	Coal	Oil	Gas
Coal Industry	82.0	89.0	92.0
Petroleum Industry	83.0	89.0	92.0
Power Industry	90.0	89.0	92.0
Iron and Steel	44.3	89.0	92.0
Nonferrous Metallurgy	85.0	89.0	92.0
Fertilizer Industry	50.0	89.0	92.0
Heavy Chemical Industry	30.1	89.0	92.0
Cement Production	40.4	89.0	92.0
Other building Material	70.0	89.0	92.0
Machinery	83.0	89.0	92.0
Food	82.0	89.0	92.0
Textile	82.0	89.0	92.0
Paper making	82.0	89.0	92.0
Other light Industry	82.0	89.0	92.0
Construction	85.0	89.0	92.0
Transportation	82.0	89.0	92.0
Commercial	85.0	89.0	92.0
Other service sector	85.0	89.0	92.0
Residential	75.5	89.0	92.0

Sources: ERI (1999); State Statistics Bureau (1998).

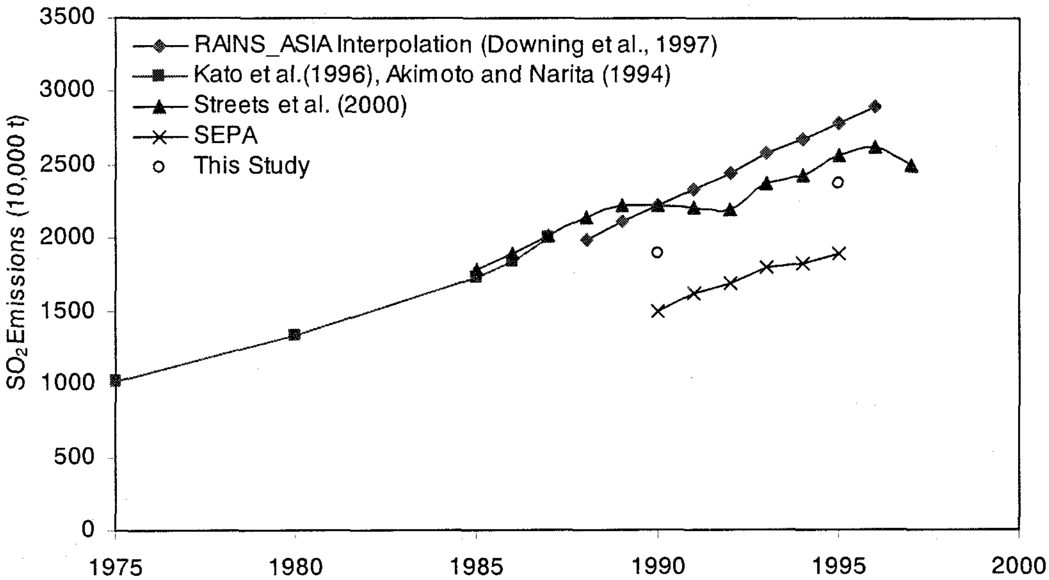

Figure 2. Comparison of total SO_2 emissions in China

3.4 Integrating the Results with GIS

In the above sections, we focus on the "quantity"of our estimation. However, to understand the regional characteristics of the emissions is also an important issue to assess their environmental impacts and prepare recommendations for future countermeasures. Accordingly, in this study, in order to understand regional characteristics of the SO_2 emissions, we made digital maps that indicate the geographic distributions of these emissions by using a geographical information system (GIS). As an example, the distributions of SO_2 emissions from Iron & steel large point sources and total SO_2 emissions at county-level are displayed in Figure 3 and Figure 4. We have presented similar results of GIS maps at the 5th AIM Workshop (Yang et al., 2000).

Table 7. Estimation of SO_2 Emissions in China (10000ton-SO_2)

Province	1990				1995			
	Large Point Sources	Area Sources	Total	Total (SEPA)*	Large Point Sources	Area Sources	Total	Total (SEPA)*
Beijing	13	26	39	34	14	29	43	38
Tianjin	9	16	25	22	11	25	36	33
Hebei	30	81	111	89	41	100	141	116
Shanxi	24	74	98	78	44	79	123	101
Inner Mongolia	16	47	63	53	22	64	86	74
Liaoning	50	76	126	97	60	80	140	109
Jilin	7	24	31	26	13	26	39	32
Heilongjiang	19	23	42	32	24	22	46	34
Shanghai	29	23	52	42	38	21	59	49
Jiangsu	29	111	140	100	56	118	174	92
Zhejiang	12	42	54	44	19	47	66	54
Anhui	23	25	48	38	37	22	59	49
Fujian	5	12	17	12	7	17	24	17
Jiangxi	5	34	39	30	8	38	46	36
Shangdong	40	193	233	193	58	214	272	232
Henan	23	41	64	49	35	48	83	66
Hubei	12	56	68	56	17	52	69	54
Hunan	16	51	67	55	28	42	70	56
Guangdong	18	37	55	40	27	44	71	56
Guangxi	4	76	80	60	5	93	98	76
Hainan	0	2	2	1	0	4	4	2
Sichuan	21	157	178	148	32	218	250	223
Guizhou	6	54	60	50	11	76	87	72
Yunnan	6	27	33	23	9	37	46	36
Tibet	0	0	0	0	0	2	2	2
Shaanxi	11	78	89	59	15	98	113	80
Gansu	13	31	44	36	16	36	52	42
Qinghai	0	4	4	3	0	4	3.8	3
Ningxia	4	13	17	13	7	22	29	23
Xinjiang	3	17	20	16	6	34	40	35
Total	445	1454	1899	1499	662	1710	2370	1891

* Statistics from State Environmental Protection Administration (1991, 1996).

Figure 3. Iron & steel large point sources in China (1995) (unit: t-SO_2)

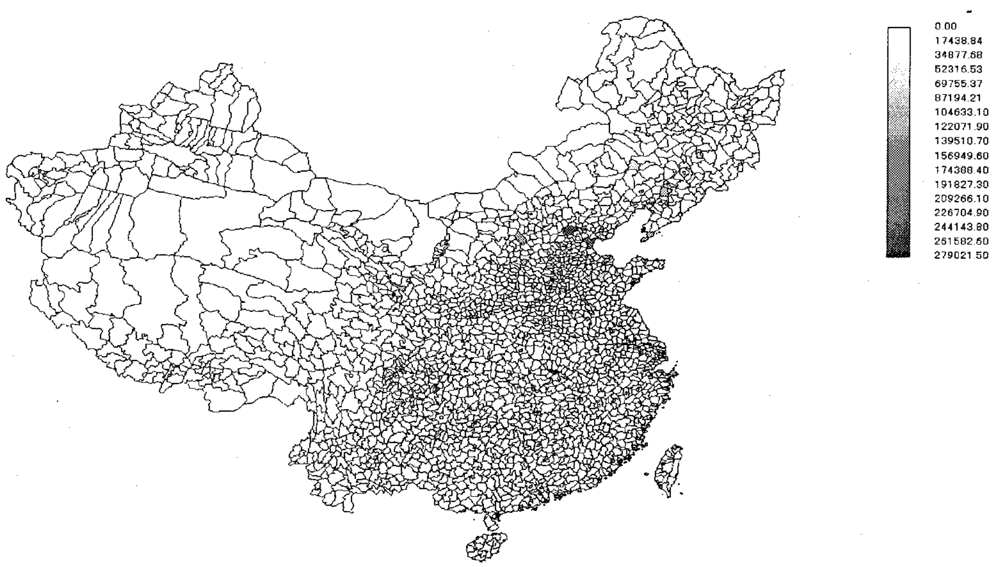

Figure 4. Total SO_2 emissions at county level in China (1995) (unit: t-SO_2)

4. Conclusion

In this study we estimated total SO_2 emissions in China in 1990 and 1995. Total emissions have been divided into large point source emissions and area source emissions. Large point source emissions are obtained through detailed investigations for the most important 269 and 381 large-scale plants in China, sharing 23% and 28% of the national total SO_2 emissions in 1990 and 1995, respectively. Area source emissions have been further disaggregated into county-level distributions by utilizing appropriate allocation indexes that can indicate the SO_2 emissions in the local region. Indexes used in this study include the industrial GDP, transportation volume and population at each county. The estimated total SO_2 emissions in China by this study are 18.99Mt and 23.70Mt for 1990 and 1995, respectively. As the methodology of SO_2 estimation in this study is directly from the energy related activities, it covers wider range than SEPA's published statistical data for the same period. As mentioned above, about 1/4 to 1/3 of the total SO_2 emissions in this study are the contributions from large point sources whose emissions are affected not only by the sulfur contents in fuels but also by the actual oxidation rate of fuels and the simple desulfurization measures adopted in these plants. This has resulted in a moderate emission volume compare to the estimated results by other studies.

Further efforts are required to improve the present studies on inventory. These may include the investigations to obtain more detailed information about the key technologies and facilities that are being applied by the large point sources. It is important and significant to establish a stable and concrete relationship between energy system and environment system in order to identify and assess the countermeasures for air pollution control in China.

References

Akimoto, H., H. Narita (1994): Distribution of SO_2 and NOx in Asia: emission inventories, Atmos. Env. 28, 213 – 225 pp.

Arndt, R., G. Carmichael, D. Streets, N. Bhatti (1997): Sulfur dioxide emissions and sectorial contributions to sulfur deposition in Asia, Atmos. Env. 31, 1553– 1572 pp.

Downing, R.J., R. Ramankutty, J. Shah (1997): RAINS-ASIA: An assessment model for acid deposition in Asia, The World Bank.

ERI (1999): The investigation of large point source emissions and distributions, Energy Research Institute Report.

Fujita, S., Y. Ichikawa, R. Kawaratani, and Y. Tonooka (1991): Preliminary inventory of sulfur dioxide emission in East Asia, Atmos. Env. 25A, 1409 – 1411 pp.

Hu, X., H. Yang (2000): Introduction on the methodology for compiling SO_2 emission inventory of China, AIM project report, AIM China Team, China.

Kato, N. (1996): Analysis of structure of energy consumption and dynamics of emission of atmospheric species related to the global environmental change (Sox, NOx, and CO_2) in Asia, Atmos. Env. 30, 757 – 785 pp.

Matsuoka, Y. (1992): The impacts of anthropogenic SOx emissions on the global environment,

Environmental System Research, 20, 142 – 151 pp. (in Japanese)
State Building Materials Bureau (1991): China Building Materials Statistical Yearbook 1991, China Building Materials Industry Press (all the statistics pages).
State Building Materials Bureau (1996): China Building Materials Statistical Yearbook 1996, China Building Materials Industry Press (all the statistics pages).
State Chemical Industry Bureau (1991): China Chemical Industry Statistical Yearbook 1991, China Chemical Industry Press (all the statistics pages).
State Chemical Industry Bureau (1996): China Chemical Industry Statistical Yearbook 1996, China Chemical Industry Press (all the statistics pages).
State Environmental Protection Administration (1991): China Environmental Statistical Yearbook 1991, China Environmental Statistical Yearbook Press (all the statistics pages).
State Environmental Protection Administration (1996a): China Environmental Statistical Yearbook 1996, China Environmental Statistical Yearbook Press, 492 – 493 pp.
State Environmental Protection Administration (1996b): Handbook for Industrial Pollutants and Emission Factors, China Environmental Science Press, 22pp, 32pp, 36pp, 63pp, and 102pp.
State Power Corporations (1990): China Electric Power Statistics 1990, China Electric Power Press, (all the statistics pages).
State Power Corporations (1995): China Electric Power Statistics 1995, China Electric Power Press, 688 –689 pp.
State Statistics Bureau (1992): China Rural Economic Statistics 1990, China Statistics Press, 2 - 239pp.
State Statistics Bureau (1996a): China County Level Economic Statistics, China Statistics Press, (all the statistics pages).
State Statistics Bureau (1996b): China Statistical Yearbook 1996, China Statistics Press, 746 - 749pp.
State Statistics Bureau (1998): China Energy Statistical Yearbook 1991-1996, China Statistics Press, 171 – 403 pp.
State Statistics Bureau (1999): Urban Statistical Yearbook of China, China Statistics Press, 339 – 354 pp.
Streets, D., N. Tsai, H. Akimoto, K. Oka (2000), Sulfur dioxide emissions in Asia in the period 1985 – 1997, Atmos. Env. 34, 4413 – 4424 pp.
Wang, T., L. Jin, Z. Li, K. Lam (2000), A modeling study on acid rain and recommended emission control strategies in China, Atmos. Env. 34, 4467 – 4477 pp.
Yang, H., Y. Matsuoka, T. Matsuo (2000): The disaggregate of China's SO_2 emissions into county-level distributions, the 5th International AIM Workshop, Tsukuba, Japan, March 2000.