A Critical Review of Air Pollution Research in China over the last decade

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ABSTRACT

Critical Review of Air Pollution Research in China over the last decate

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It is estimated that more than 40% of the coal consumed in China is for industrial, commercial and domestic uses in cities with an area less than 0.5% of the whole country. This means that at present air pollution in China concentrated mainly in cities. In recent years China mined and consumed about 620 million tons of coal a year. About 84% of this coal was burned in factories and homes. Therefore, it is estimated that the total amount of sulfur dioxide emitted to the atmosphere each year exceeds 15-18 million tons. The main pollutants in China are particles and SO_2. The particle emissions in China are much higher than in U.S., however more SO_2 and NO_x are emitted in the U.S. than in China. Because more coal is consumed in the north, air pollution in northern Chinese cities is higher than in cities of south China , especially in winter.

Beijing is a city with typical coal-burning pollution which becomes worse under certain meteorological conditions. It is estimated that the residential coal-burning may be the most important source of pollution in Beijing and in other coal-burning cities in China, since 300 $\mu g/m^3$ of TSP may originate from coal burning.

On larger spatial scales, the emissions of SO_2 may cause acid rain, SO_2 emissions and the atmospheric buffering capacity, or more specifically the nature of the soil, brings about the current geographical distribution of acid rain in China.

Chapter 1

Introduction

Air pollution is generally acknowledged to be one of the major problems faced by the urban areas of China. The increased use of coal in recent years has contributed to the deterioration in air quality, and there is a growing concern that, as energy use in general, and coal use in particular grows during the next few years, the levels of air pollution in the cities and industrial areas might become worse. Faced with this situation, the Chinese environmental authorities have initiated measures and research during the last 10 years to halt the deterioration and improve air quality. At present, China produces and consumes about 620 million tons of coal a year; see Table 1-1. About 84% of this coal is burned in industries and for domestic uses. Around 60% of the particulate material and 80% of the sulfur dioxide in the atmoshere is attributed to coal burning. (Ye Yi-sen and Lu Zhan-huan, 1982). It is estimated that the total amount of sulfur dioxide emitted to the atmosphere each year exceeds 15-18 million tons. (Wu Bing-lin and Guan Ju-gen, 1981) In comparison 21.4 million tons of SO_2 were emitted in the U.S. in 1984. Total annual particulate emission was about 20 million tons in 1983 in China, which does not include wind blown dust. At the same time 8.5 million tons of particulate matter were emitted in the U.S. The annual emission of NO_x in China was about 6 million tons in 1983. Approximately 11% of the global NO_X emissions of 53 million tons/year were contributed by China, while the U.S. emitted 19.1 million tons of NO_X that year(see Figure 1-1).

Suspended particulate matter is the major pollutant in China. Other pollutants of concern are sulfur oxides. Nitrogen oxides have not been considered an environmental problem yet, but the Chinese ambient air quality standards are probably exceeded along main streets in large Chinese cities.

It is estimated that more than 40% of the coal consumed for industrial, commercial and domestic uses in cities was used in less than 0.5% of the country's land area. This means that in China air pollution at present occurs mainly in cities and suburban areas. In addition, the coal consumption is increasing very fast (see Table 1-1), thus increasing the potential for urban pollution. The air pollution in the cities of northern China is more severe during the winter, because more coal is burned and the meteorological dispersion is poor at that time. In the southern part of the country the high levels of particulate material and sulfur dioxide in the atmosphere are due to the relatively poor quality of the coal. The sulfur content of some coal is as high as 3-5%, in the south but only 1.3-1.5% in the North. Hence, the acidic precipitation is directly linked to the combustion of the local fossil fuels. Table 1-2 shows the percentages of fuels used for energy in major Chinese cities, the percentage of coal burning is the highest among energe supplies.

In regions with low atmospheric buffering capacity, acid rain is a likely consequence. It should be noted that there is a relatively large natural background of dust in China. Background dust levels are higher in northern than in southern China (Kinzelbach, 1982). A general survey made in Beijing shows that contribution of natural dust to total particulate level is 40% in winter and 60% in summer, while in southern cities

it is estimated to contribute less than one third of the total. The pH of soil in North China is 7-8, therefore, ammonia is released in large quantity from soil in North China. Both factors, ammonia and alkaline dust comprise the buffering capacity which netralizes the acidity of the rain in North China. Since the pH of soil in South China is 4-6, the buffering capacity, hence, is rather weak, and acid rain does occur in southwestern part of China.

The natural dust in Beijing is due to both local sources and long distance transport. The dust transported from dry areas (the northwestern part) of China passes North China and blows over the Pacific ocean. This is an important factor in the air quality of North China including Beijing (Wang 1982). Wind blown dust mainly increases the concentrations of coarse particles but does not have a significant effect on levels of fine paticles. Regarding local dust sources which include lime, cement dust, and wind blown dust. Wang (1985)found that the enrichment of [Ca] was quite high: the concentration of [Ca] was 10.4 $\mu g/m^3$ during 1980 and 1981 in Beijing, and 90% of which may come from the sourses of lime and cement dust. Hence, these local sources are important there.

Table 1-3-A shows ambient air quality standard in China and Table 1-3-B is that in U.S. The maximum allowable annual mean concentrations of SO_2, CO, O_3 and NO_x for both countries are about the same. However, the maximum allowable concentration of particulate matter at any time in China is 500 $\mu g/m^3$. This value is greater than 260 $\mu g/m^3$ which isn't allowed to be exceeded more than once per year in the U.S.

Air quality of nine American cities in Table 1-4-B was chosen to compare with that of nine Chinese cities in Table 1-4-A. Although the air quality of these cities were not recorded in the same year, they still can be compared with each other. Not only the dust concentration of these nine Chinese cities were much higher than those of American cities but also the concentration of SO_2 over most of the nine Chinese cities were higher by a factor of up to 20 compared to American in cities except Fuzhou, Nankin and Shenyang (see figure 1-2). Since the main fuel in China is coal, it is important to investigate the contribution of coal burning to air pollution. This effort should include the chemical and physical characterization of both industrial and domestic coal burning particulate emissions. It should also include a study of the relationship between source location and transport of pollutants.

China has achieved some success in environmental protection. For example, 70% of chimneys were equipped with soot trappers, more than 6 million hectares have been reforested in green belts, and gas rather than coal cooking was popularized. Over the past ten years, scientists in China have been concerned with acid rain in the cities of Chongjing and Guiyang and the regions on Beijing and Tanjing. Although for these regions research has progressed, for many regions of China the scientific data are not yet available. Because Chinese scientists have only recently entered this area of research, the Chinese government is interested in developing international cooperation to extend its scientific data base. In this thesis I will review and analyse the status of air pollution in China determined from scientific, technical and general publications. The goal is to use this collective information to explain what is now known about air

pollution in China, and use this information to develop a reseach program to answer some of the more urgent guestions that are emerging.

The plan of the thesis is to consider urban pollution in general (Chapter 2) and review two specific cases: Beijing and Tianjing (Chapter 3). Next, the effects of industrial emissions from urbon areas over larger spatial scales are consided. This regional SO_2 pollution may cause acid rain. The general problem and specific cases are consided in Chapter 4. Some general conclutions and research goals are discussed in Chapter 5 and 6.

Fig. 1-1 The emission comparison between American and China

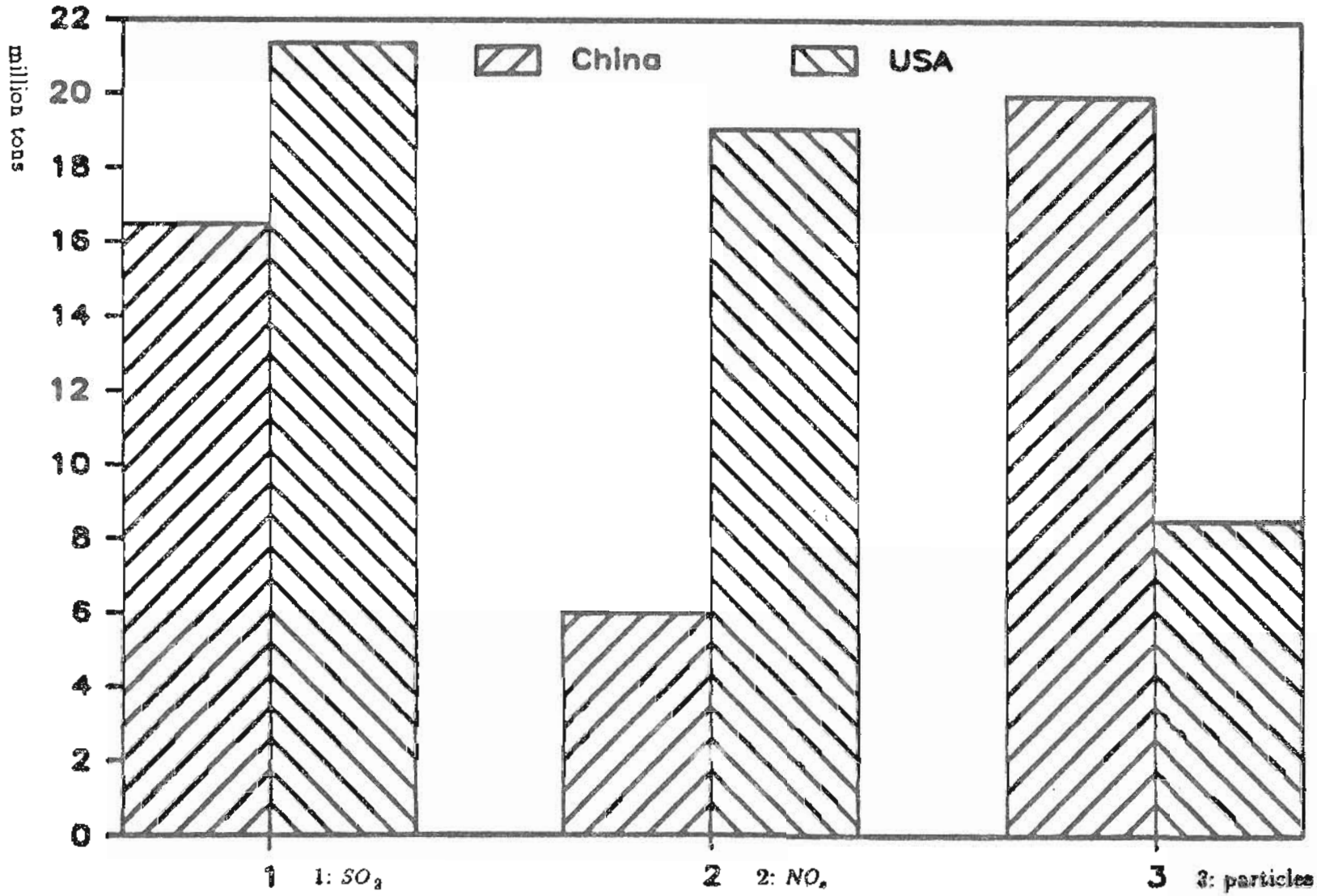


Figure 1-2 The comparison of SO_2 concentration level between American cities and Chinese cities (Wolfgang,1982)

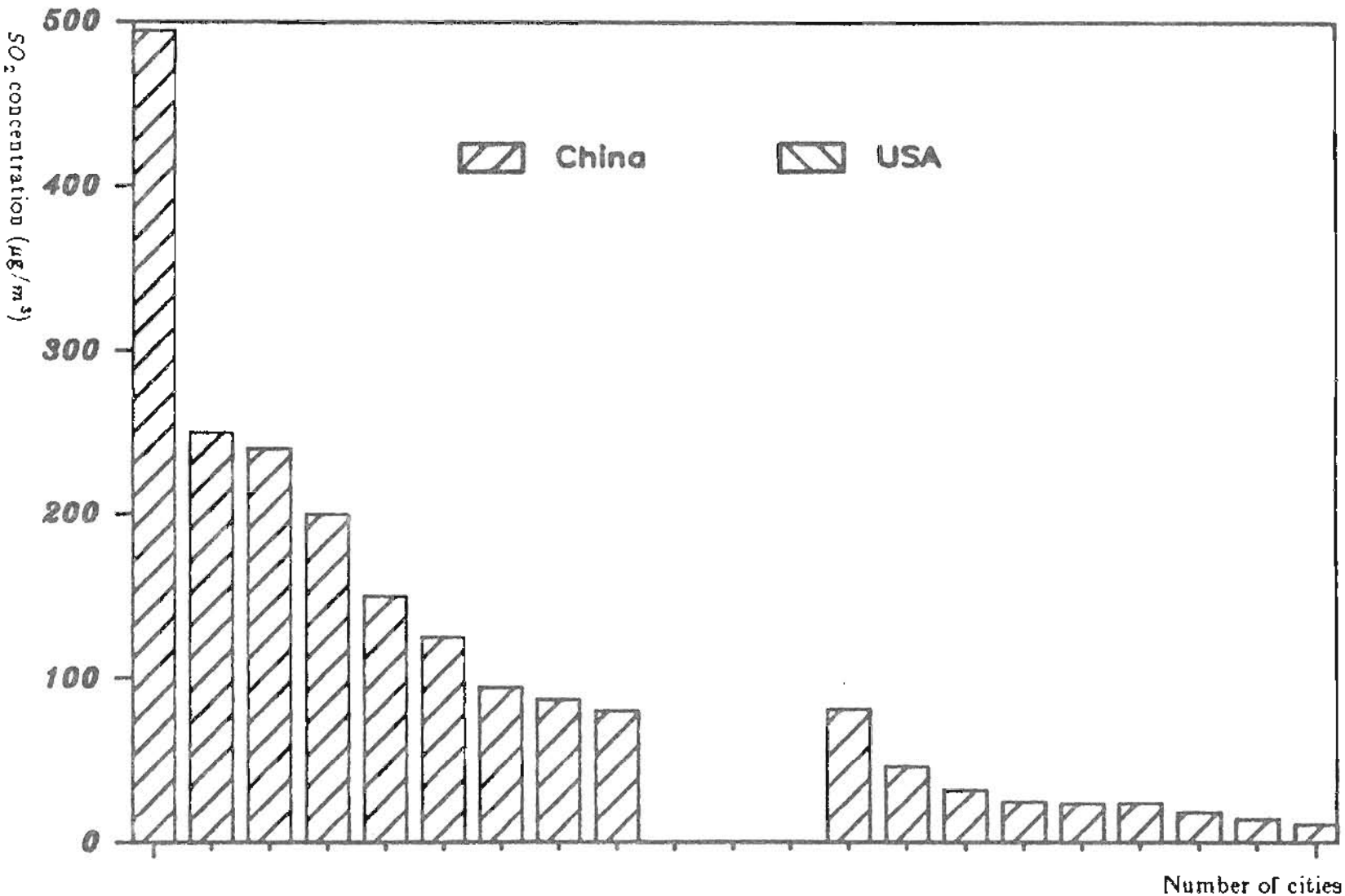


Table 1-1. Important economic indicators for the People's Republic of China and the production of coal.

Year	Population (million)	Per capita consumption			Power generation capacity (W/person)
		Grain (all value in kg)	Coal	Steel	
1949	536	207	60	0.3	3.3
1957	640	298	204	8.4	7.0
1966	771	279	348	19.5	17.9
1970	846	287	387	21.0	22.9
1976	962	296	507	23.9	38.4
1978	1004	294	598	31.0	45.0
1985	1122	357	812	60.0	96.3

Values in this table are either taken from or calculated on the basis of data appearing in the contributions of A G Ashbrook, Jr, W Clarke and V Smil in *Chinese Economy Post-Mao* (reference 12). The 1985 values were calculated on the basis of the official Chinese plans and using J S Aird's population estimate.

(wolfgang,1982)

Table 1-2. Relative contribution of coal, oil, and natural gas to the energy supply of different Chinese cities.

City	Coal (%)	Oil (%)	Natural gas (%)
Cities in the north			
Beijing	72.2	22.3	5.5
Tianjin	55.0	41.4	3.6
Shenyang	54.3	38.5	7.2
Harbin	53.6	45.0	1.4
Baotou	85.2	9.5	5.3
Cities in the south			
Hangzhou	79.6	19.1	1.3
Chongqing	78.4	6.1	15.5
Guangzhou	82.0	17.8	0.2
Guilin	91.8	8.2	0.
Mao Ming	2.6	81.4	16.0

From Environment Protection Office, Working Group on Standards (1982b).

(T.A. Siddiqi,1984)

Table 1-3-A Ambient air quality standard in China.

Polluttant	Time period	Ambient standard ($\mu g/m^3$) Class I	Class II	Class III
Total suspended particles (TSP)	Daily average	150	300	500
	Maximum at any time	300	1000	1500
Particulates $< 10\mu$ in diameter	Daily average	50	150	250
	Maximum at any time	150	500	700
SO_2	Annual daily average	20	60	100
	Daily average	50	150	250
	Maximum at any time	150	500	700
NO_X	Daily average	50	100	150
	Maximum at any time	100	150	300
CO	Daily average	4000	4000	6000
	Maximum at any time	10,000	10,000	20,000
Photochemical oxidant (O_3)	Hourly average	120	160	200

From Environment Protection Office, Working Group on Standards (1982a).

(T.A. Siddiqi,1984)

Table 1-3-B United States National Ambient Air Quality Standards

Air Contaminant	National Standard[a]	Maximum Allowable Annual Mean Concentrations: AAM[c] $\mu g\ m^{-3}$	AAM[c] ppm	AGM[d] $\mu g\ m^{-3}$	Maximum Allowable Short-Period Concentrations and Averaging Times[b]: $\mu g\ m^{-3}$	$mg\ m^{-3}$	ppm	Averaging Times
Oxidant[e] (Ozone)	Primary				240		0.12	1 hour
	Secondary				240		0.12	1 hour
Carbon Monoxide	Primary[e]					10	9	8 hours
						40	35	1 hour
	Secondary[e]					10	9	8 hours
						40	35	1 hour
Nitrogen Dioxide	Primary	100	0.05					
	Secondary	100	0.05					
Sulfur Dioxide	Primary	80	0.03		365		0.14	24 hours
	Secondary				1300		0.50	3 hours
Particulate Matter	Primary			75	260			24 hours
	Secondary			60	150			24 hours
Lead	Primary				1.5			Quarterly
	Secondary				1.5			Average

[a] National Air Quality Standards as presented in the Code of Federal Regulations, 40, Protection of Environment, Part 50, sec 50.4 to 50.11, July 1, 1974, U.S. Government Printing Office, Washington, D.C., 1974. Primary Standard—Necessary to protect the public health (sec 50.2). Secondary Standard—Necessary to protect the public welfare and the environment from known or anticipated adverse effects of a pollutant (sec 50.2).

[b] Not to be exceeded more than once per year (for ozone, the average number of days per year above the standard must be less than or equal to one).

[c] AAM—Annual Arithmetic Mean.

[d] AGM—Annual Geometric Mean.

[e] Both the eight-hour and one-hour standard must be met.

(J.H.Seinfeld)

Table 1-4-A. SO_2 concentration data on major Chinese cities and comparable cities in U.S.A.

Location in China	SO_2 ($\mu g/m^3$)	Location in U.S.A.	SO_2 ($\mu g/m^3$)
Beijing	200.	Washington D.C.	32.
Shanghai	125.	New York	46.
Shenyang	87.	Pittsburg	81.
Chongqing	495.	Los Angelos	14.
Lanzhou	250.	Houston	18.
Taiyuan	240.	Kansas City	25.
Nanking	94.	Boston	24.
Xuzhou	150	Atlanta	24.
Fuzhou	80.	Portland	11.

[Wolfgang 1982 and National Aerometric Data Bank 1986]

Table 1-4-B TSP concentration on major Chinese cities and comparable cities in U.S.A.

Cities in U.S.A.	TSP ($\mu g/m^3$)			Cities in China	TSP ($\mu g/m^3$)
	Arit	Geo	Gsd		
Washington D.C.	52.	49.	1.4	Beijing	870.
New York	59.	56.	1.4	Shanghai	410.
Pittsburg	62.	55.	1.6	Shenyang	512.
Los Angeles	91.	87.	1.4	Chongqing	1240.
Houston	63.	56.	1.5	Lanzhou	1320.
Kansas City	61.	52.	1.8	Taiyuan	1000.
Boston	59.	55.	1.4	Nanjing	195.
Atlanta	61.	57.	1.4	Xuchou	1260.
Portland	62.	53.	1.7	Fuzhou	1730.

[Wolfgang 1982 and National

Aerometric Data Bank 1986]

Chapter 2

Status of Air Pollution

China began to monitor air pollution in the 1970's, although the Institute of Environmental Protection in Shenyang started to analyze some of the trace gases in the 1950's.

In some cities TSP, SO_2, NO_x and particles were monitored. The methods used were as follows:

TSP: Filter sampling and weighing

SO_2: Assayed by Pararosaniline Hydrochloride

NO_x: Assayed by Naphthylethylenediamine Chloride

Dustfall: Collecting dust box.

Figure 2-1 and 2-2 shows the distribution of levels of particulate matter and dustfall in Chinese northern and southern cities and indicates that the particulate pollution in northern cities is more severe than that in the Southern cities(Wang Ming-xia,1983).

As mentioned earlier, it is estimated that the present emission of SO_2 in China is around 18 million tons, so China contributed about 12% of the global SO_2 emissions of 1.5×10^8 tons/year.

In Figure 2-3 it is shown that concentrations of SO_2 in cities in southern China and northern China are quite similar, the reason is described later.

Figure 2-4 displays that the annual average NO_x concentration in 26 Northern cities is about 10 $\mu g/m^3$ higher than 29 Southern cities.

The Figure 2-1, 2-2, 2-3, 2-4, and Table 2-1, 2-2 all lead to the conclusion that the main pollutants in China are particles and SO_2 and that air pollution in northern Chinese cities is greater than in southern Chinese cities. This pollution is caused mostly by coal burning.

The main reason for air pollution in the north being greater than that in the south is that more coal is consumed in northern cities, especially in the winter. In addition, vegetation cover is less in northern cities than southern cities, and therefore the levels of wind blown dust are higher in the North.

It is interesting to note that the differences in SO_2 concentrations between the northern and southern regions are not large (See Fig.2-3). This characteristic of SO_2 pollution can be understood by analyzing the type of coal consumed in these two regions. The coal used in south-western part of China contains higher sulfur (3% to 5%) than the coal used in northern China, while more coal is burned in northern China. The two effects tend to balance each other and produce comparable levels of SO_2 pollution in both northern and southern cities.

As a developing country, China has been working on air pollution only in the last ten years. Chinese scientists have been conducting research in the region between Beijing and Tianjin, and in the south-western part of China. They have applied dispersion models in Beijing, Shenyang, Jiling and other regions. They also have used a Chemical Mass Balance model to calculate the distribution of pollution sources in Beijing.

Chinese authorities urge factory managers and workers to devise more economical processes for production and to collect waste of every sort for processing or recycling. Factories are asked to reduce emissions of black smoke and SO_2. But, it seems that they have a long way to go before they can claim success.

In the next chapter air pollution in Beijing and Tianjing is examined in more detail.

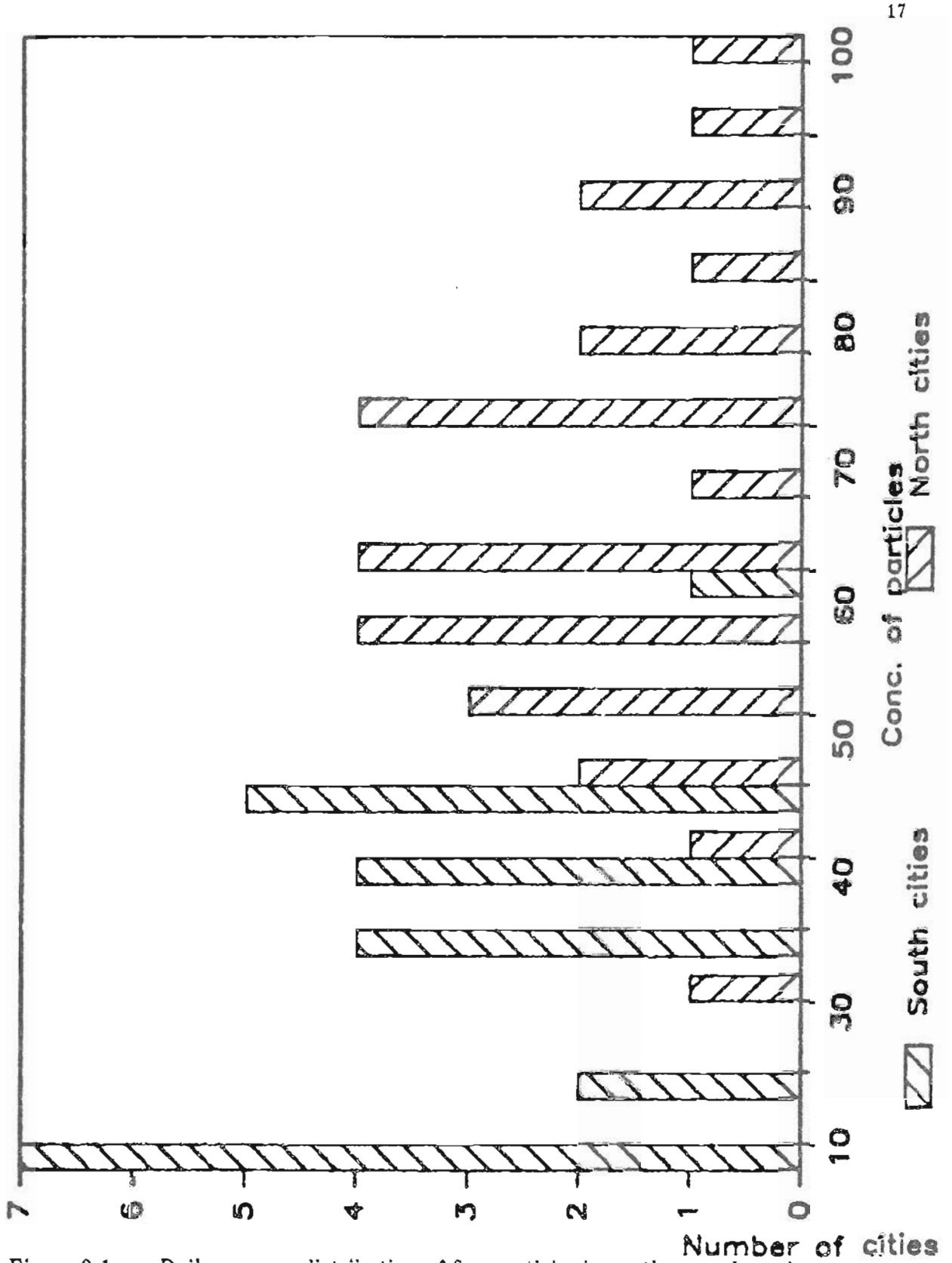
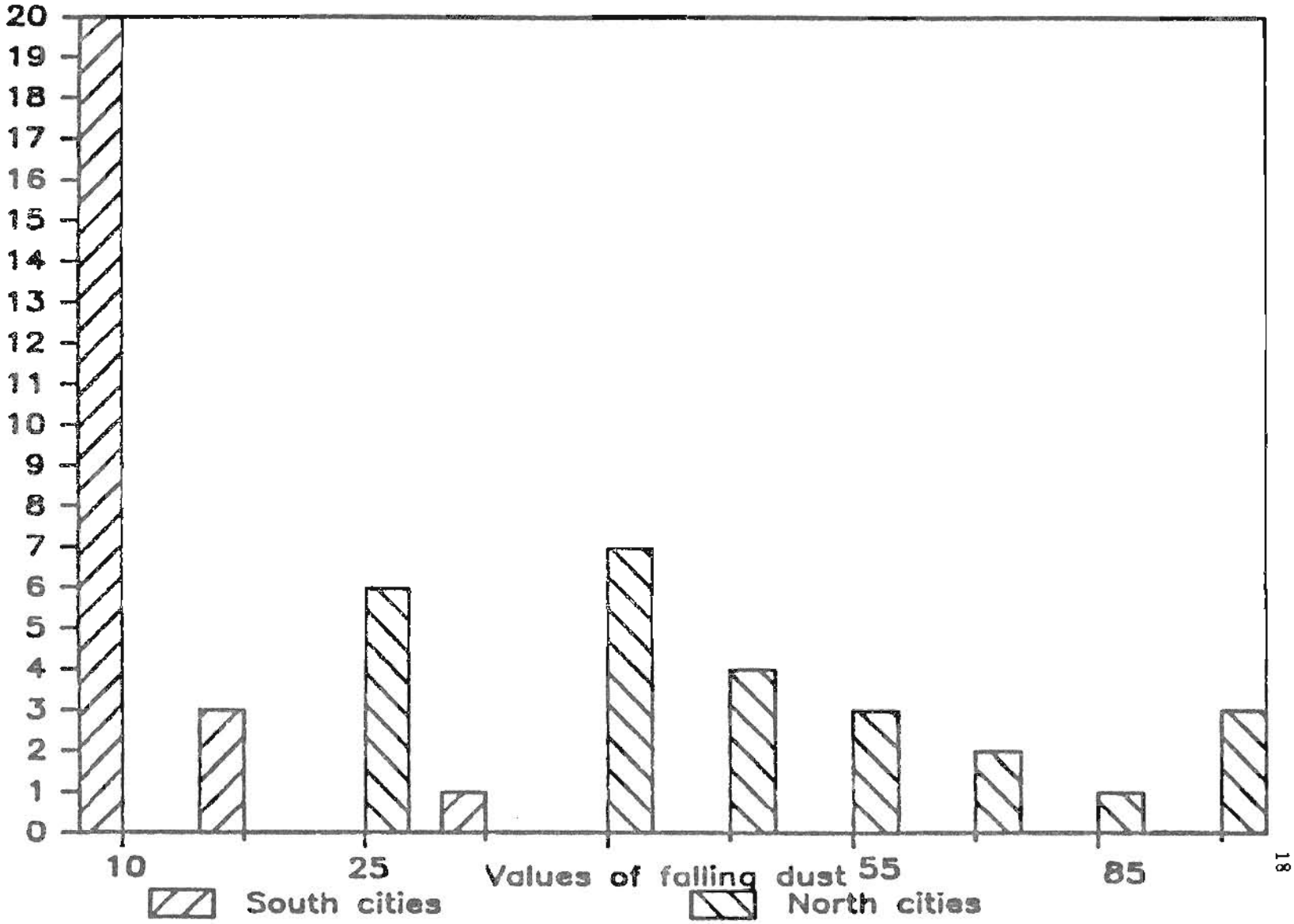


Figure 2-1 : Daily average distribution of fine particles in northern and southern cities (Wang Ming-xia, 1983)

Figure 2-2 : Distribution of falling dust in southern and northern cities



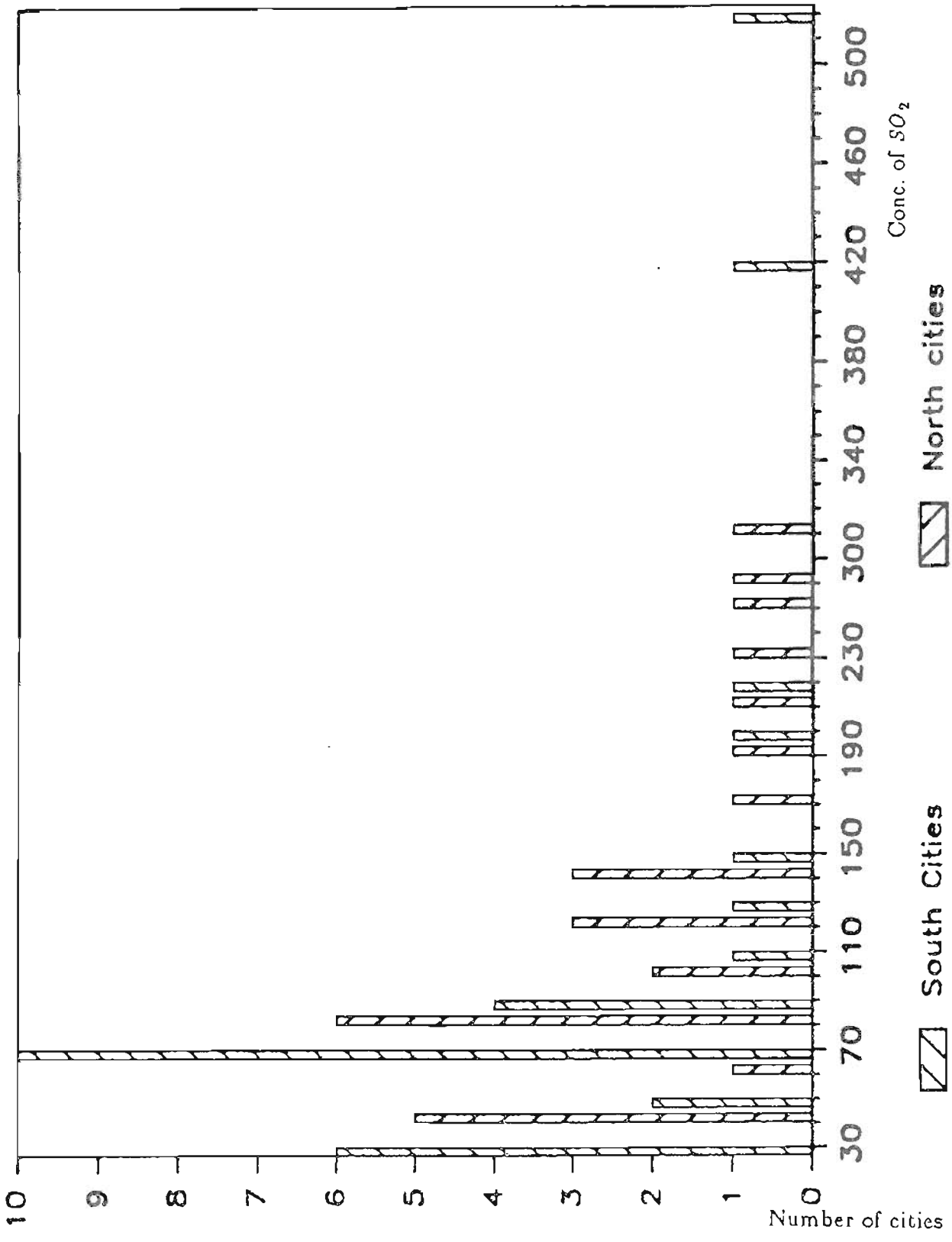


Figure 2-3 Distribution of daily average SO_2 in southern and northern cities

Figure 2-4 . Distribution of daily concentration of NO_X in southern and northern cities

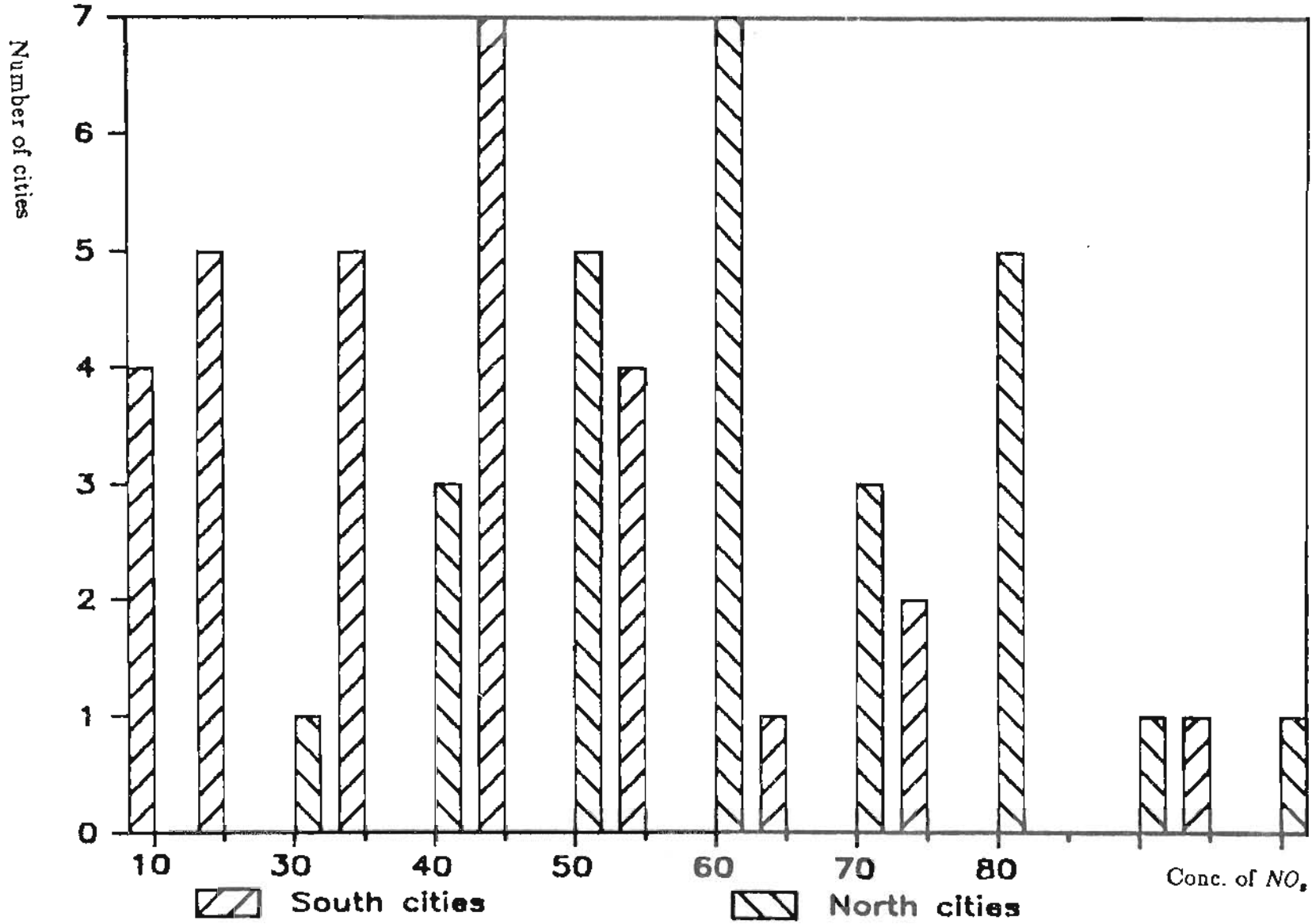


Table 2-1. Measured levels of air pollutants in the polluted areas of Chinese cities

Pollutant	Range of measured levels ($\mu g/m^3$)		
	Cities in the north	Cities in the south	Other
Total suspended particles	240-1980	190-950	
SO_2	32-2190	14-780	
(usual range)	100-390	130-320	
NO_X	100-170	20-130	
CO			3000-12,300
O_3			60-210(Lanzhou) 70-80 (Beijing)
Pb			0.10-0.6 (cities in general)
Total deposition of dust (tons/km^2, month)	32.7-93	4.4-103.4	

(T.A Siddiqi,1984)

Table 2-2. Carbon monoxide concentration in some cities of China (in mg/m^3).

City		Type of area			
		Urban	Traffic intersection	Industrial	Control
Beijing	Average	5.5	12.3	5.1	1.3 (Ming Tomb)
	Maximum	35.6	68.	113.	0.7 (Bai Hwa Hill)
Shenyang	Average	7.72	8.08	5.99	4.97(Qing Tomb)
Lanzhou	Average	10.2		4.2	
Nanjing	Average	3.03	2.39	1.14	1.15

From Environment Protection Office, Working Group on Standards (1982b).

(T.A. Siddiqi,1984)

Chapter 3

Urban pollution

(Beijing and Tianjing)

3.1. Introduction

Beijing is a city with typical coal-burning pollution which becomes worse under certain meteorological conditions. The air pollution situation, as well as the characteristics of aerosol pollution in Beijing are described in this chapter. After reviewing emission sources, the conclusion is drawn that residential coal-burning may be the most important source of pollution in Beijing and other coal-burning cities.

3.2. Beijing

3.2.1. Geographical and meteorological factors

Beijing is situated at the northern apex of the triangular North China Plain and lies at an elevation between 30 to 40 meter above sea level. To the north lies the fringe of the Mongolian plateau; to the northeast rises the Yen Shan mountain range, part of which forms the eastern part of what is known to geologists as the "Bay of Beijing" the concave arc that circles the Beijing low land from the northeast to the southwest.

The city was built at the edge of this plateau, which opens onto the great plain to the south and east, and between two rivers (Yung-ting and Chao-Bai), which eventually join and empty into the Gulf of Chihli. Beijing is a natural gateway to the long distance land communication route between the north China plain and the northern edge of the plateaus.

The general air circulation in Beijing is from the northwest throughout the year. Maritime effects on Beijing are meager. The climate is a continental monsoon type that occurs in the temperate zone. Winter is cold and dry because of the Siberian air that passes over the Mongolian plateau and moves southward into Beijing. In the summer, the warm and humid air from the southeast penetrates into North China, bringing Beijing most of its annual precipitation.

Generally there are more southerly winds in the day and northerly or northwesterly winds at night.

The annual mean temperature of the city is 12 C. In the average year there are 132 days of freezing temperature in Beijing. The mean amount of precipitation is 76 cm with 75% of the annual total falling in the summer months from June to August.

3.2.2. Visibility change in Beijing

3.2.2.1. The change of solar radiation

The radiation of the sun at ground level in Beijing has been decreasing since 1963. This is the result of increasing aerosol pollution. Because the air in Beijing is dry, the humidity is approximately constant(Pan Gen-di,1982).

Figure 3-1 shows the trend of air pollution from 1957 to 1979. The main features of the trends may be explained as follows: from 1960 to 1962, the withdrawal of Russian support resulted in a reduction of industrial activities and therefore on increase of solar radiation as shown in the curve. At that time, Beijing had normal and good air quality. The solar radiation decreased during 1964-1966, because of the fast development and reindustrialization. Hence, air quality deteriorated. During the period of 1967-1971, the air quality improved again due to the anti-industrial policies of the Cultural Revolution. As a result, some of factories were shut down, the output of production decreased and the industrialization also decreased. From 1972 and especially from 1976, when the Gang of Four was thrown out, the solar radiation measured on the ground started decreasing again signaling renewed industrial development and higher particulate pollution levels. On the whole, the air quality deteriorated and the emission of particles increased over the span of the solar radiation measurements.

3.2.2.2. The change of visibility

Figure 3-2 shows that the distribution of smoke pollution in Beijing. Figure 3-3 shows that the smoke pollution increases from 6:00 A.M. and the pollution is high from 6:00 A.M. to 10:00 A.M. After that the pollution decreases.

It can be noted from Figure 3-4 that pollution is heavy in the heating season (winter). It also shows that a visibility of less than 4 km occurs on 15 days from September to March, and on 20 days in Dec. and Jan. There are only 10 days in April and August of such visibility.

The daily duration of smoke pollution lasts longer in autumn and winter. The smoke lasts from early morning until afternoon. Sometimes it lasts the whole day. But the smoke is diluted in summer after 10 A.M.

3.2.3. Characteristics of aerosol

3.2.3.1. The distribution of aerosol concentrations over Beijing.

Scientists in Beijing set up 12 monitoring stations from 21, Oct. 1981 to 1, Nov. 1981, and from 23, Nov. 1981 to 4, Dec. 1981, over the whole of Beijing. The samples were collected four times per day at a height of 7-8 meters using 2 hour sampling periods(Zhao Mingyu,1983).

The horizontal aerosol distribution shown in Figure3-5 has an elliptic form and the direction of its major axis is NW-SE. The center of the high concentration is near the Dongjiao Power Plant with average value 980 $\mu g/m^3$; the zone of this concentration is about 2-3 km in diameter. The average yearly concentration of aerosol in Zhonguanzhun area is 300 $\mu g/m^3$ because of the high density of population (see Figure 3-8). Usually the concentration of particulate pollution in Beijing is higher than that in the suburbs.

Wang and his colleagues have found that the spatial distribution of atmospheric aerosol is nonuniform in the horizontal direction and stratified in the vertical(Wang,1984). This experiment was done above Mi Yun Reservoir by a airplane on Sep. 1982. The navigation was from SW to NE at the same altitude with speed at 240km/hr, each flight distance being approximately 22km, and then flew back to the

original point for the investigating route of next height. Flying altitudes of the investigation were at 500, 750, 1000, 1500, 2000, 3000 and 3800 m, and the directions of each navigation were identical. The whole experimental area was above the Mi Yun Reservoir. Since there were very few sources of pollutants, the investigated result represented the regional characteristics of the atmosphere in Beijing suburbs. The results chinese scientists got is that the aerosol is a mixture of particles with four size distributions, (0.01-0.05, 0.15-0.3, 0.5-1, and 5-10 μm), so that the size distribution function of the aerosol should be multimodal composed of four normal functions.

It has also been found that, with increasing altitute, the size distribution becomes narrower, and the number of particles in the coarse mode decreases.

However, the change of concentrations of particles is discrete (see Figure3-6). From 1000 m to 1500 m, the concentration of particles drops sharply; total concentration of the particles at 1500 m is five times less than that at 1000 m, and concentration of coarse particles decreases by a factor of 30. But above 1500 m the change is slow. The concentration of particles remains the same between 1500 m and 2000 m, and then decreases slowly from 2000 m to 3000 m. The concentrations of particles are more or less the same from 3000 m to 3800 m. These observations imply that the distribution of aerosol is stratified, especially between 1000 m, and 1500 m in altitude. Particles accumulate around 1000 m, and form an aerosol layer with high concentrations of particles.

The particle distributions in the horizontal direction are ellipsoids whose principle axes all have the same directions and whose origins coincide(Figure 3-7). The diameters

of this distributions are from approximately 1km to several ten km in the horizontal and a few hundred to thousand meters in the vertical(Wang,1984).

3.2.3.2. The change of aerosol concentration with time

There is an obvious regularity in the daily change of aerosol concentration, the concentration in the daytime is high (south wind) and it is low at night (north wind), since north wind is stronger and more coal is burned at day time.

The change of daily air pollution is bimodal, meaning that the concentrations of pollutant in the morning (6:00-9:00AM) and evening (5:00-8:00PM) are higher than that in the afternoon and at midnight. The highest concentration during a day occurs in the morning(Su Wi-han,1985). At this period the concentration of SO_2 is 3-5 times heavier than the daily mean concentration; Concentration of CO is 2-3 times larger, while concentration of TSP is 0.5-1 times greater than daily mean concentration.

Wang measured the concentration of TSP at 596 $\mu g/m^3$ in March, and 338 $\mu g/m^3$ in April of 1984. But there is no great difference between the meteorological conditions of March and April based on the statistical data in China. The the processes of rain washout and dry deposition are similar for these two monthes and also there are no great differences in industrial activity and transportation. Therefore, the difference of the total mass concentration of aerosol between March and April may be caused by coal burning. This also seems to indicate that winter space heating can contribute 300-500 $\mu g/m^3$ to ambient levels of TSP, since the heating period stops around the middle of March in Beijing.

From Figure 3-8 it shows that fine particle aerosol concentration in winter and spring are higher than they are in summer and autumn. The ratio of the heating period over the non-heating period is around 1.9 (range from 1st, January to 4th, March, 1981). Wang Anpu's measurements show that the concentration change of both fine and coarse particles in the heating season and the non-heating season were similar in different areas in 1984 (Wang Anpu and Yong Chulian, 1984).

3.2.3.3. The meteorological influence in Beijing

Observations have confirmed that the urban air pollution has a close relationship with wind direction and velocity, rainfall, stability and inversion near the ground.

Usually, during the periods with strong north winds after the passing of a cold front, a clear air period will exist in Beijing, since the inversion layer is weak and thin, and the wind speed is higher, and the mixed layer is unstable. Turbulent dispersion and horizontal transport are strong at the same time. The strong north wind comes from the north area bringing clean air which reduces pollutant concentrations.

On the other hand, the following conditions can cause the periods of heavy pollution in Beijing.

i) winds around the Beijing area are controlled by a slow moving anticyclone in the upper atmosphere. The high pressure moves easterly out of the sea and is separated into typical northern China saddle fields; in addition, local wind fields form a weak convergence field centered at Beijing, the wind speed is less than 3 m/s and calm.

ii) Inversion layer

The inversion is continuous below 300 m, lasts days and nights, and causes heavy air pollution.

iii) Horizontal wind field

For lack of horizontal advection transport, pollutants are accumulated in the urban areas.

It has been found that during times of heavy pollution when the concentration of elements reached the first peak, the emission of pollutants from three industrial sources (suburbs of west, southwestern and southeastern direction) overlap in Beijing city and its north suburb. Later, the pollutants are sent in a northwestern direction out of Beijing. During this period the south suburb of Beijing is seldom influenced by the industrial sources. This is because the distribution of regional air pollution is largely influenced by local horizontal wind fields(Zhao Deshan,1983).

The aerosol concentration from the southeastern suburb to the Lang-Fen area is heavy. This is because of local circulation. On the other hand, the aerosol pollution is reduced by continued wet precipitation(Zhao Mingyu,1983).

3.2.3.4. The adsorbtion of the airborne particles

Toxic and harmful metals and chemical compounds are absorbed on the airborne particles[See Table 3-1 (A,B,C)]. It can be seen from these tables that although TSP concentration might be high, the concentration of metals are not. It can be found, however, that levels of both organic substances and benzopyrene tend to be high. In addition, concentration of benzene-soluble organic substances are higher in urban than suburban areas, and higher in the mornings and evenings than other times of the days.

This indicates that organic substances in TSP mainly originate from household coal combustion(Zhao Dianwu,1986).

3.2.4. Emission information

The main source of increased air pollution in Beijing is caused by coal burning.

The annual coal consumption in Beijing was approximately 1 million tons in 1949. It increased 20 fold from 1949 to 1979. The annual rate of increase was about 10%. The coal consumption in 1980 was 77% of the total fuel consumption in Beijing. Some of this coal was not desulfated and pretreated. Residential consumption of coal, including residential heating, cooking, and commercial heating, constitutes some 15% of the total coal consumption.

The Beijing Environmental Protection Institute has calculated that monthly coal consumption in the heating season was 30% greater than that in the non-heating season, and the contribution of residential coal burning was 63 times greater than that of coal-fired power plants. The coal consumption in downtown in 1980 was 8.7% of the total coal consumption of the whole city. However, the downtown area is only 0.5% of all Beijing.

During winter, small-sized furnaces and household stoves, 1,500,000 units, in use in Beijing, emit TSP at a rate of about 22 tons/day (or 8,000 tons/year). This has already become the main source of the air pollution in Beijing (From "People's daily" on 12/4/1985). Because most of the residents cook and heat with coal, indoor air pollution is even heavier than outdoor pollution, sometimes concentration of SO_2 indoor

could be 500 $\mu g/m^3$ (Tai Qi-shen,1984).

Since the space heating season ends in March, the difference between the TSP concentrations in Beijing in March and April suggests that about 300 $\mu g/m^3$ originated from coal burning for space heating in March. Based on the limited wind direction data, Wang (unpublished data) has estimated March levels of TSP at 500 $\mu g/m^3$ for the suburban areas and $>$ 900 $\mu g/m^3$ for the suburbs plus central city inputs in March. The corresponding April levels are about 200 and $>$ 400 $\mu g/m^3$. This also seems to indicate that winter space heating can contribute 300-500 $\mu g/m^3$ to ambient levels of TSP(J. Daisey,1983).

Aerosol composition measured from coal-burning in China is similar to that from coal-fired power plant in the U.S.(Table 3-4). We suspect that the samples in China could have been collected near the coal-fired power plants. It is known that aerosol composition from coal-fired power plant is significantly different from that of residential coal-burning(Table 3-5 and 3-6) Data on the composition of residential coal burning in Beijing is not yet available.

The emissions from industries can be considered as continuous point sources with constant emission rates. However, the TSP readings in Beijing in March and April have a difference of 300$\mu g/m^3$. For this reason, the TSP values measured could be contributed from residential coal-burning instead of coal fire power plants, or other industry.

The wind-blown dust is another source of air pollution in Beijing. On the average there are 33 days of high dust levels per year. In one study the concentration of coarse particles in the case of wind-blown dust were over 100 times greater than clean air in

Xing Long (near the great wall). Whereas concentration of fine particles were only a few times greater than air in Xing Long in this case(Wang,1982).

There are more than 120,000 automobiles in Beijing. But the contribution of this source is not as significant as soil and coal burning. During periods of heavy traffic, the concentration of CO can reach very high level, and the concentration of NO_x could reach 300-700 $\mu g/m^3$ on the main roads of the city(Tai Qishen,1984).

3.3. Applications of the CMB model to Beijing aerosols

Wang (1983) used a CMB model to analyze the contribution of various sources to the measured aerosol concentrations in Beijing. The conclusions of Wang and co-workers as discussed earlier are very important and useful. However, this analysis has several uncertainties which could have affected the conclusions. The most significant uncertainty of the CMB model which Wang worked out is that it neglected organic and elemental carbon components which comprised 80% in emissions from residential space heating with coal in U.S.A.(J. A. Cooper,1984), and the sample site may have been near the coal-fired power plants, and not representative of the residential area.

Another uncertainty of the Chinese CMB model is that the source characterizations were not sufficient (see Table 3-2, 3-3 and 3-4). Since Zhong-Lian Chen came to the conclusion that the soil source contributed 48.0% of the total pollutant concentration, while coal burning contributed 22.9%, it seemed that 70% of the contribution come from soil and coal burning. It also should be noted that Wang thought that 50% of the contribution to ambient aerosols was due to soil and coal burning. This

conclusion should be verified.

Altogether there are 16 elements for the CMB model in China. Some significant elements were missed for coal burning pollution: Na, As, and Ba. The other uncertainty of the Chinese CMB model is that the total mass of every sample was not measured. Therefore, it is not possible to assess quantitatively the error in the CMB estimation used there. The last uncertainty is that the background concentration was not taken into account.

Although Wang's research leaves many unanswered questions about the sources of air pollution in Beijing, It still will be very helpful in the planned Beijing aerosol characterization stady.

3.3. Tianjing

Tianjing is an industrial city with a population of about 5 million. It is about 200 KM away from Beijing, and it is near the beach.

Tianjing is another typical coal burning city. Since coal is the main fuel, the air is polluted moderately at noon, and more seriously in the morning, no matter whether in winter or summer. The reduction of visibility in Tianjing with coal as fuel probably is the synergistic effect produced by sulfate and relative humidity. It is estimated that the average reaction rate from SO_2 to $SO_4^{=}$ is around 2.3 1.1%/hr. and 1.5%/hr. in winter. The life time of SO_2 is about 17-34 hours and the transport distance of SO_2 is 17-340km(Su Weihan,1982).

According to the "People's Daily" (22, Jan. 1986) many scientists who have been working on air pollution in Tianjing for last three years have estimated that if people do not cut down the emission of TSP and SO_2 in Tianjing, there may be a major smog incident over the next 20 years similar to those in London. They also found that half of the aerosol comes from soil dust and automobiles.

3.4. Conclusion

Decreasing visibility and solar radiation in Beijing shows that the concentration of particles is increasing since the annual coal consumption rate has risen to approximately about 10%. The distribution of the average aerosol concentration in Beijing has an elliptic form and the direction of its major axis is NW-SE. The spatial distribution of the atmospheric aerosol is non-uniform in horizontal direction and stratified in vertical direction. Heavy air pollution occurs under the following typical conditions: a slow moving anticyclone at the upper atmosphere, continuous inversion below 300m and calm wind field near the surface. It is estimated that residential coal-burning may be the most important source of pollution in Beijing and in other coal-burning cities in China. To characterize present pollution sources, especially coal burning sources, CMB modeling may be useful.

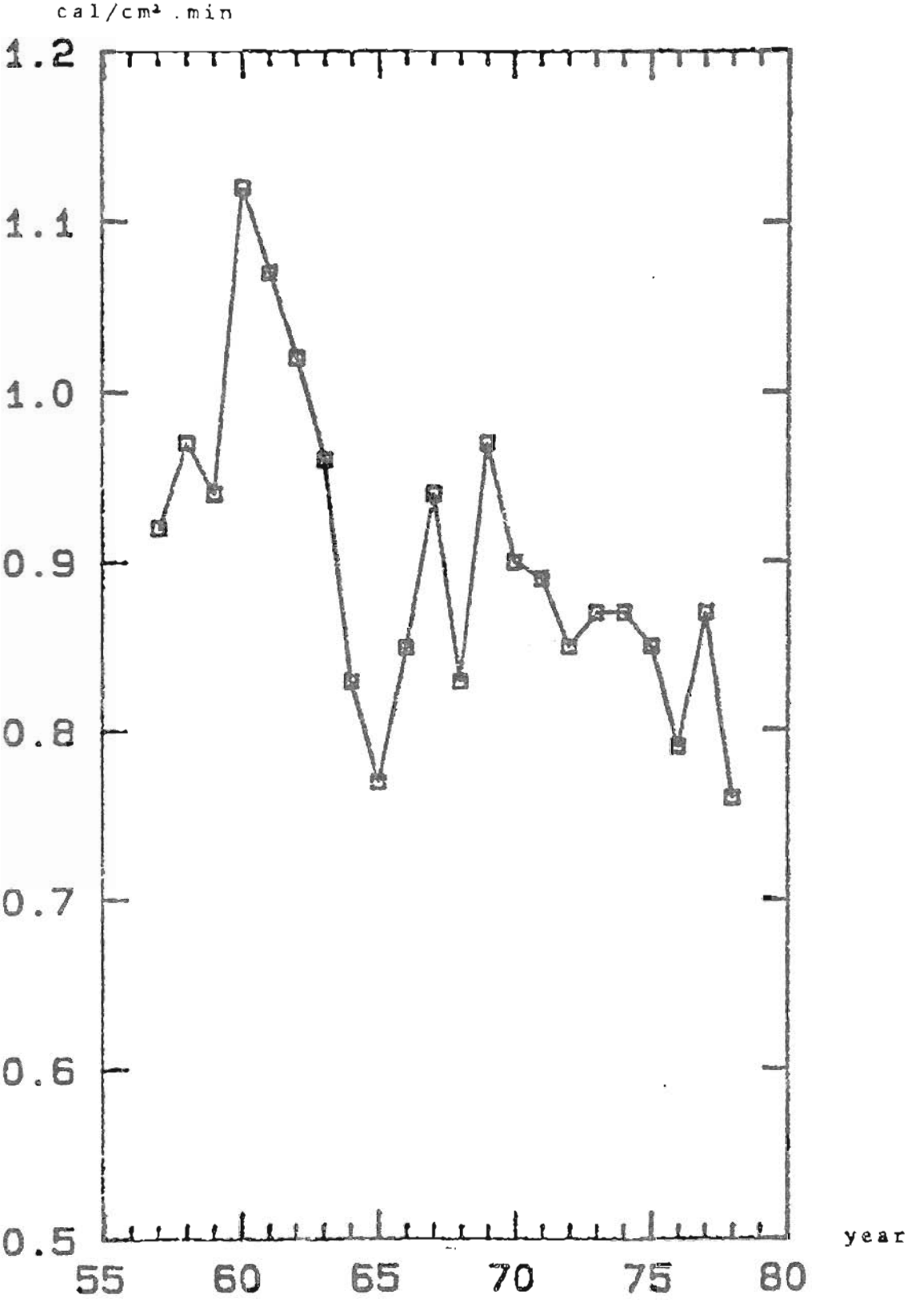


Figure 3-1 The solar radiation reaching the ground in Beijing

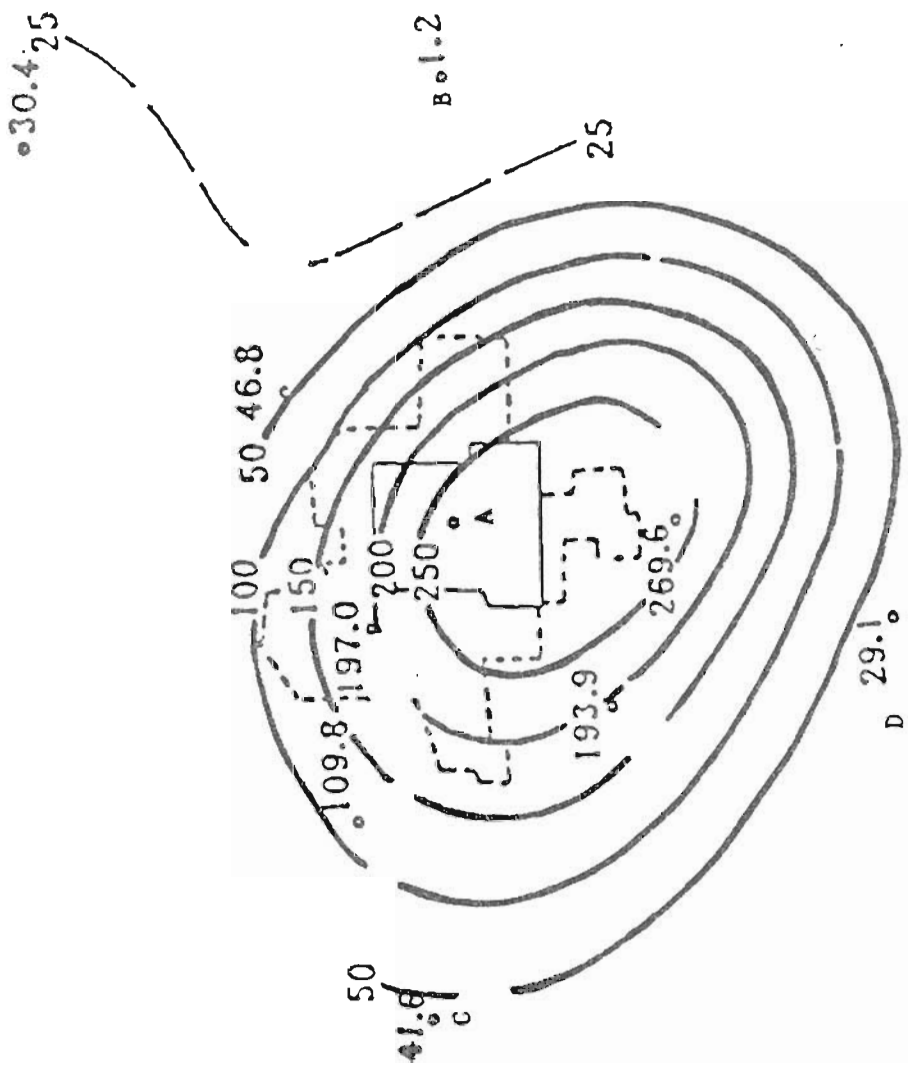


Figure 3-2. Smoke information on Beijing area.

[Average smoke days from 1961-1970].
A: Tian An-men. B: Tong Xian.
C: Men Tou-gou. D: Da Xin. (Lin,1980

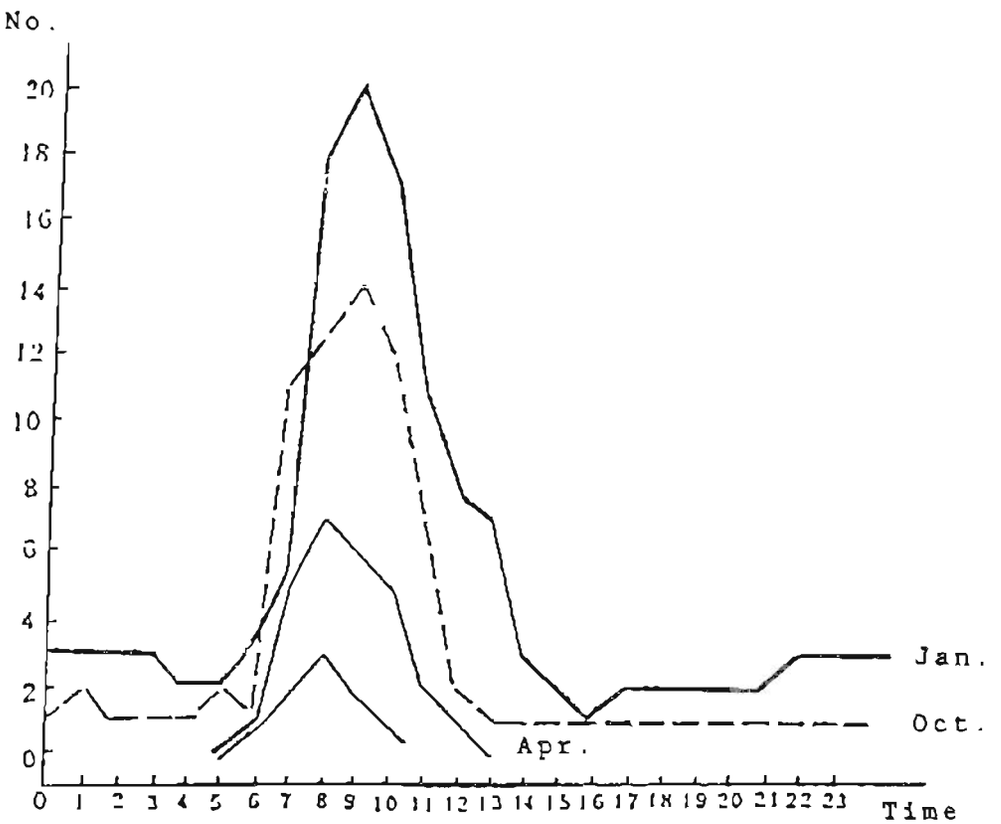
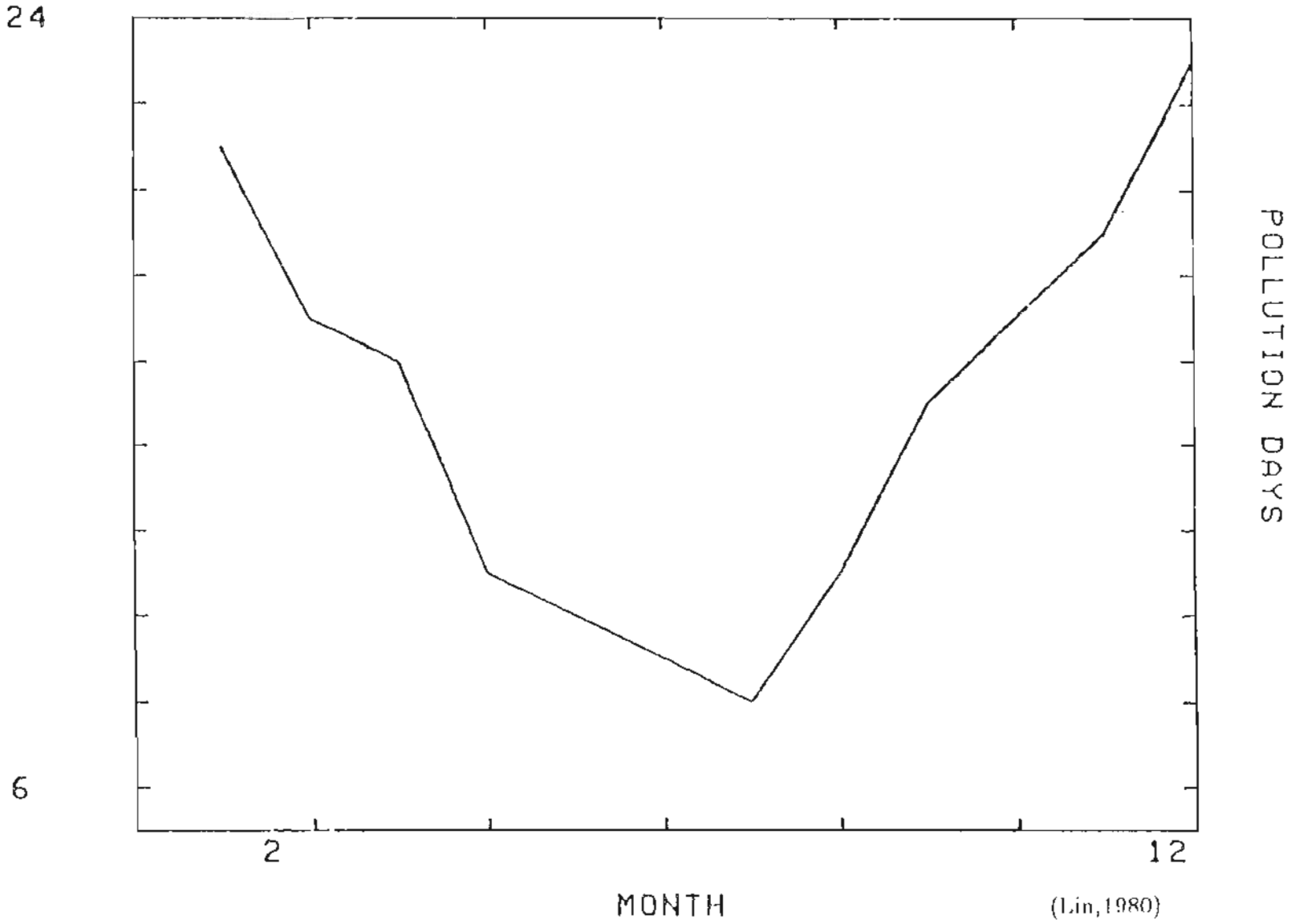


Figure 3-3. Frequency of visibility less than 4km in winter of Beijing.

(Lin,1980)

Fig. 3-4. Number of smoke pollution days every month.



(Pollution day means the visibility is less than 4km at that day.)

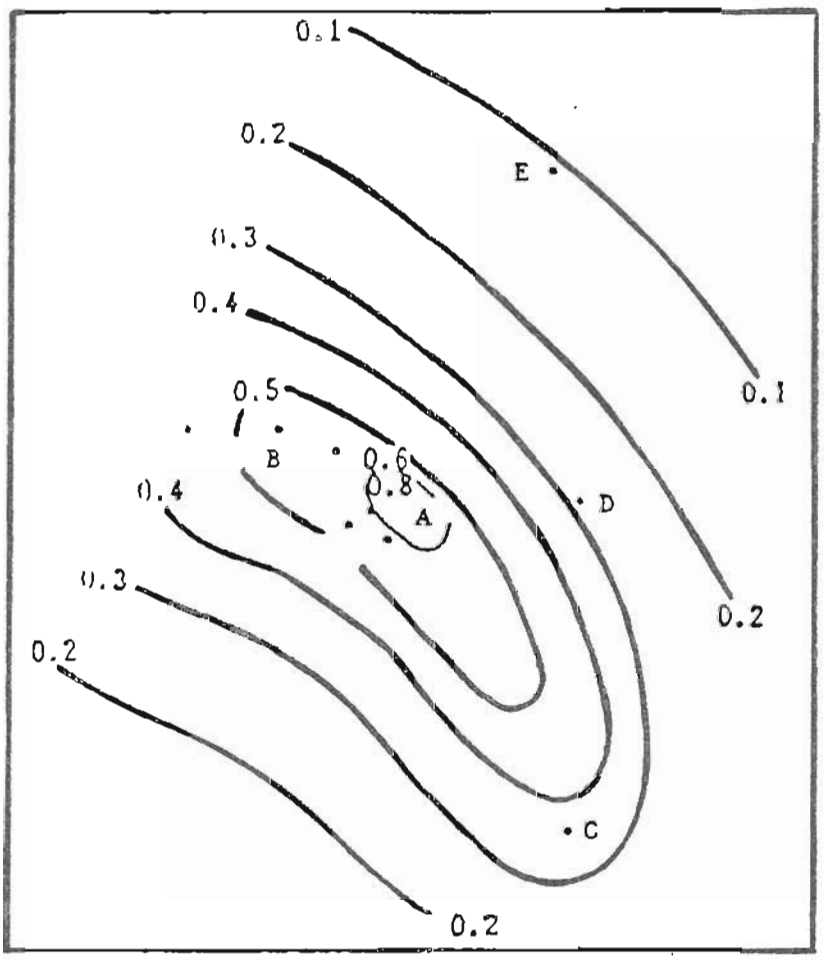


Figure 3-5. The distribution of concentration of aerosol in Beijing. mg/m³

A: Power station.
B: Zhou Guanzhun.
C: Lang Fang.
D: Tong Xian.
e: Huai Rou.

(Zhao Ming-yu,1983)

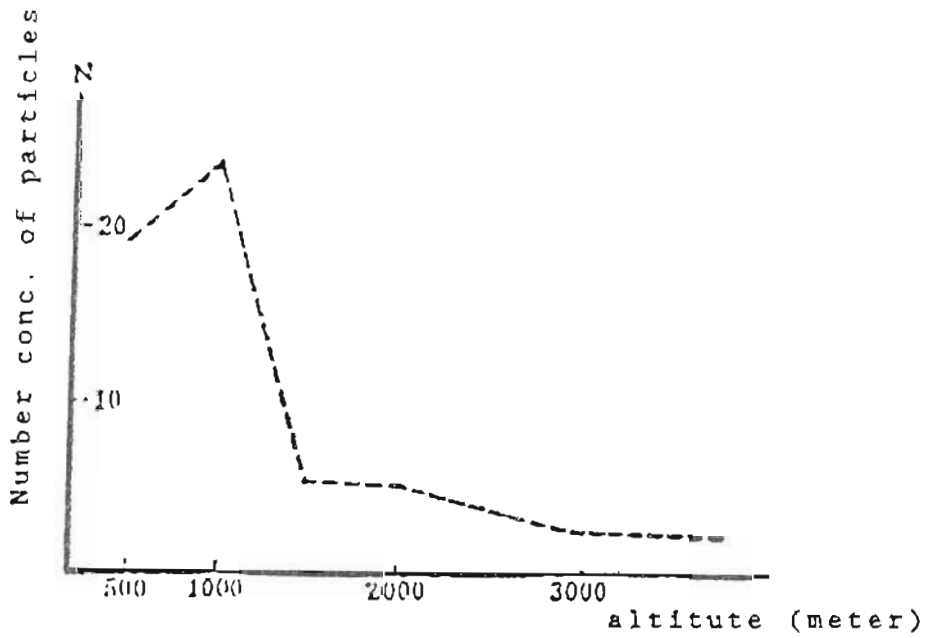
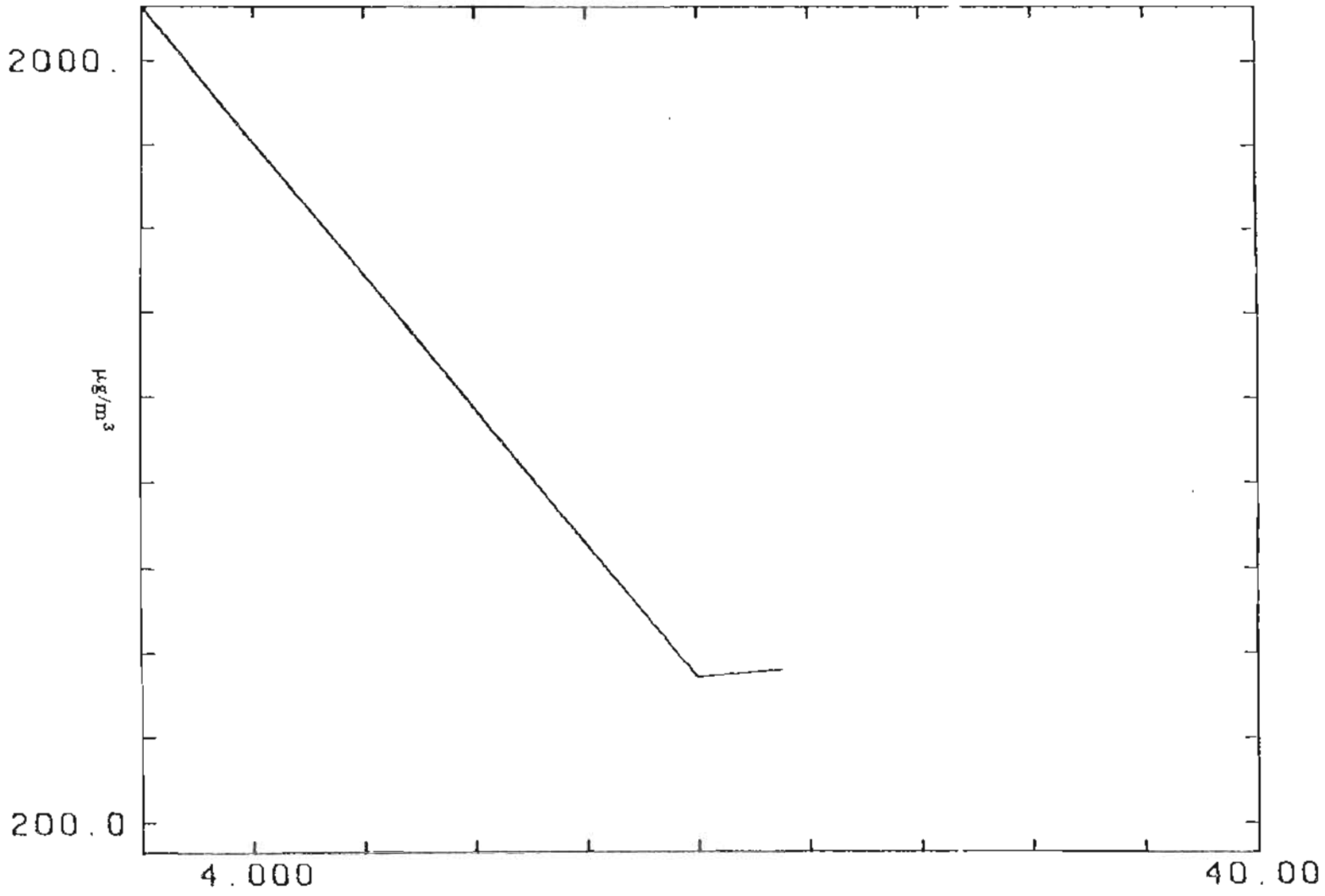


Figure 3-6. The Change of concentration of aerosol in atmospherewith change of height

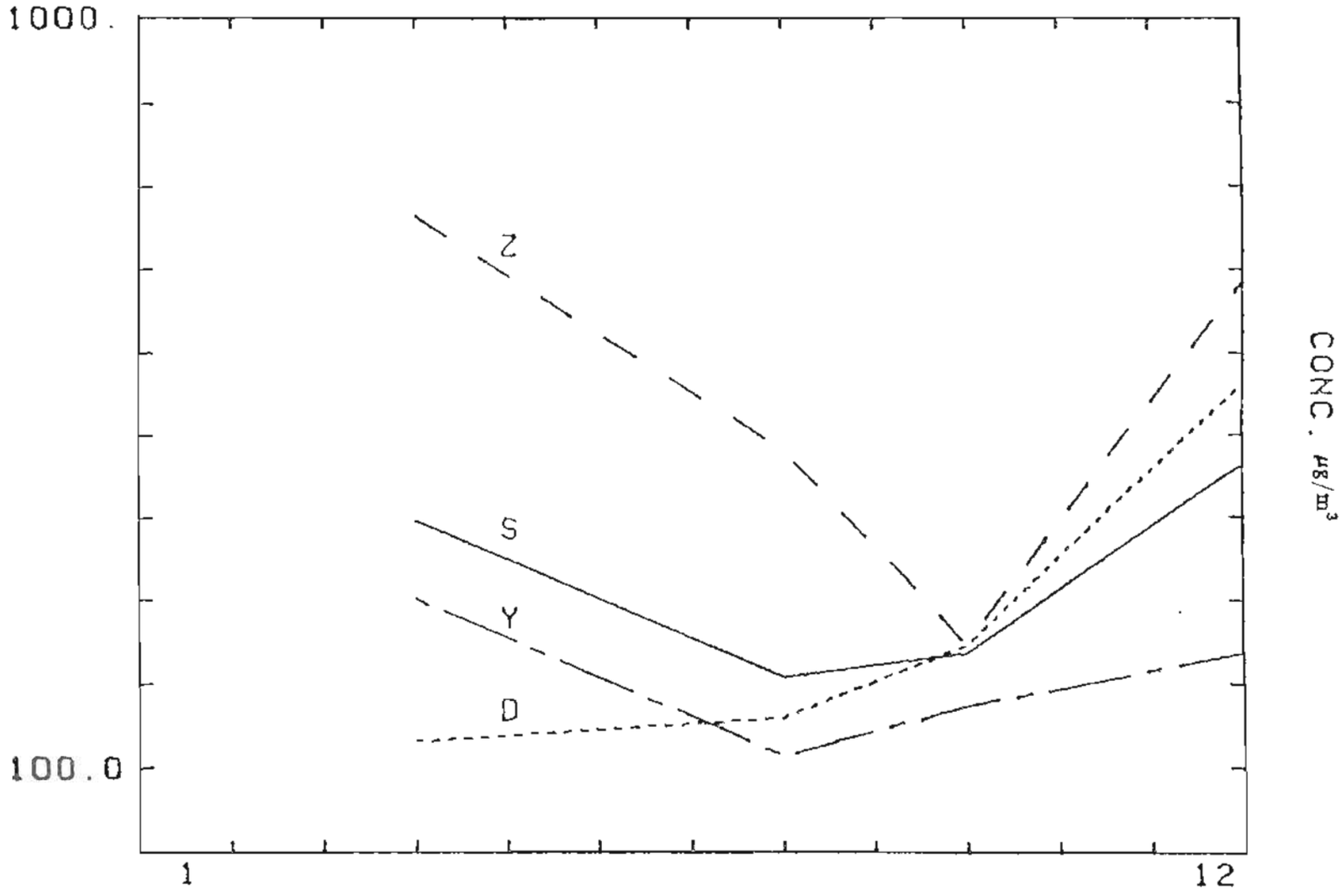
(Wang,1984)

Figure 3-7. The change of concentration of aerosol in horizontal direction



(Wang, 1984)

Figure 3-8. Concentration of particles in Beijing in 1981



(Wang An-pu,1984)

Name of sites: Z: Zhonguanzhun. S: Shougang.
Y: Youse. D: dondan.

Table 3-1-A Concentration of benzene-soluble substances in airborne particles in Beijing.

Site	Date	Con. of particle ($\mu g/m^3$)	Benzene-soluble substances (weight %)
Institute of Environmental Chemistry	81.4.2–3	552.6	5.8
	81.8.12–13	259.0	6.9
Huairou Reservoir	81.8.25–26	78.2	12.8

* From Reference

Table 3-1-B Concentration of BaP in airborne particles in some cities.

Cities	Years	BaP (ng/m^3)	Reference
Beijing	1980.9–1981.4		4
Clean area		4.9	
Residential		29.3	
Industrial		266	
Nanjing	1976		5
Clean area		1.5	
Residential		7.3	
Shanghai	1977	2.9–58	5

Table 3-1-C Concentration of heavy metals in airborne particles in Beijing, 1981 ($\mu g/m^3$).*

Date	Pb	Cu	Zn	Cd	Mn	Fe	As	No. of samples
Average of March	0.28	0.075	0.37	0.004	0.41	14.6	0.022	6
Average of February	0.27	0.065	0.273	0.003	0.19	4.9	0.013	6

* From Reference (Zhao, 1986)

Table 3-2 The contribution concentrations of elements from different sources (mg/m^3)

Conc. (mg/m^3) \ Source / Element	Soil	Coal burning	Petro-chemical	Wood burning	Auto-mobile	Calcu lated	measure	Calcul-ated Meas-ure Error
Pb	0.0008	0.011	0.030	0.137	0.087	0.28	0.28	0
Cu	0.0020	0.010	0.077	0.0027	—	0.093	0.075	−0.018
Zn	0.0042	0.0020	0.152	0.203	0.0015	0.35	0.37	0.01
Mn	0.058	0.38	0.009	0.001	—	0.45	0.41	−0.04
Fe	3.04	11.27	0.20	0.011	0.005	14.52	14.60	0.01
As	0.0001	0.021	0.0020	0.0004	—	0.026	0.022	−0.004
Cd	0.00001	0.0042	0.00025	0.0025	—	0.007	0.004	−0.003
Al	4.955	15.91	0.042	0.024	—	20.93	31.39	10.46
Si	16.72	19.02	—	—	—	36.34	65.85	29.51
K	1.58	2.08	0.042	0.71	—	4.41	9.05	4.64
Ca	2.22	1.46	0.76	0.020	0.0013	4.47	26.80	22.33
Ti	0.27	0.973	0.002	0.003	—	1.25	1.00	0.25
V	0.0082	0.007	2.15	0.00005	—	2.16	2.10	−0.06
Cr	0.005	0.002	0.005	0.0008	—	0.014	0.019	0.005
Br	0.00015	0.0025	0.005	0.0027	0.0037	0.014	0.012	−0.002
TSP	50.0	101.5	11.2	2.3	0.3	305	407	102

(Wang 1983)

Table 3-3 Source contribution of particulate matter

Contribution % source / Element	Soil	Coal burning	Petro-chemical	Wood burning	Auto-mobile	Sulfate	Unknown
Pb	0.3	3.9	12.8	48.9	34.6	0	0
Cu	3.5	10.7	82.8	2.9	0	0	0
Zn	1.2	0.7	42.2	56.4	0.4	0	0
Mn	8.6	90.7	1.3	0.1	0	0	0
Fe	20.8	77.2	1.8	0.1	0	0	0
As	0.8	73.8	20.0	3.1	0	0	0
Cd	0.2	60.3	3.6	36.0	0	0	0
Al	15.8	50.7	0.1	0.1	0	0	33.3
Si	25.4	29.8	—	—	0	0	44.8
K		23.0	0.5	7.3	0	0	51.3
Ca	8.3	5.4	2.8	0.1	0	0	83.4
Ti	14.2	51.2	0.1	0.2	0	0	34.2
V	0.4	0.30	99.4	—	—	—	—
Cr	42.8	14.3	35.7	5.7	—	—	—
Br	1.1	17.8	35.7	19.3	26.4	0	0
TSP	13.1	22.3	2.5	0.5	0.1	28.5	33.0

(Wang,1983)

Table 3-4. Comparison of Coal Burning Sources

term / % by WT / element	China coal burning	U.S.A. coal fired power plant		U.S.A. residential(space heating coal)	
		fine	coarse	fine	TSP
Al	15.657	15.609	14.205	--	1.275
Si	19.330	23.837	22.872	—	1.275
K	2.049	1.304	1.436	—	<
Ca	1.438	1.235	1.514	—	2.100
Ti	0.959	0.967	1.008	—	0.075
Fe	11.103	8.491	9.524	—	1.650
As	0.021	0.081	0.036	—	0.030
Mn	0.374 [21]	0.043	0.046 [22]	—	0.007 [22]

(Table 4-1,4-2,4-5 and 4-6)

1-Jun-85

Table 3-5. SOURCE LIBRARY

SOURCE: COAL-FIRED POWER PLANT
SCC: 1-01-002-01
CONTROLS: ESP

PROFILE: 11201
RANKING: 3321
RATING : B

SPECIES NUMBER	SPECIES NAME	FINE <2.5 UM		COARSE 2.5-10UM		TSP <30 UM	
		% BY WT	UNC	% BY WT	UNC	% BY WT	UNC
4	BE	NA	NR	NA	NR		
5	B	NA	NR	NA	NR		
9	F	NA	NR	NA	NR		
11	NA	NA	NR	NA	NR		
12	MG	NA	NR	NA	NR		
13	AL	15.679	0.789	14.205	0.742		
14	SI	23.837	1.192	22.872	1.191		
15	P	0.620	0.114	0.279	0.060		
16	S	3.305	0.180	0.656	0.043		
17	CL	0.094	0.041	0.102	0.013		
19	K	1.304	0.069	1.436	0.076		
20	CA	1.235	0.090	1.514	0.093		
21	SC	<	NR	<	NR		
22	TI	0.967	0.050	1.008	0.053		
23	V	0.079	0.007	0.066	0.006		
24	CR	0.058	0.004	0.051	0.003		
25	MN	0.043	0.003	0.046	0.003		
26	FE	8.491	0.428	9.524	0.496		
27	CO	<	NR	<	NR		
28	NI	0.049	0.004	0.032	0.002		
29	CU	0.031	0.003	0.027	0.002		
30	ZN	0.069	0.005	0.045	0.003		
31	GA	0.027	0.003	0.021	0.002		
32	GE	<	NR	<	NR		
33	AS	0.081	0.006	0.036	0.003		
34	SE	0.036	0.003	0.005	0.001		
35	BR	0.000	0.007	0.000	0.002		
37	RB	0.009	0.002	0.012	0.001		
38	SR	0.124	0.007	0.159	0.009		
40	ZR	0.076	0.003	0.035	0.007		
47	AG	0.022	0.010	0.002	0.004		
48	CD	0.012	0.013	0.000	0.006		
50	SN	0.000	0.020	0.011	0.008		
51	SB	NR	NR	NR	NR		
55	CS	<	NR	<	NR		
56	BA	0.000	0.098	0.098	0.040		
58	CE	<	NR	<	NR		
80	HG	0.000	0.006	<	0.003		
82	PB	0.036	0.006	0.025	0.003		
201	OC	NA	NR	NA	NR		
202	EC	NA	NR	NA	NR		
203	SO4	NA	NR	NA	NR		
204	NO3	NA	NR	NA	NR		
SUM(%)		56.284		52.267		0.000	

NOTES: OC = ORGANIC CARBON : EC = ELEMENTAL CARBON : NA = NOT ANALYZED : NR = NOT REPORTED
< = LESS THAN DETECTION LIMIT
OTHER NOTES :BITUMINOUS COAL. REF. 52.

(John.A. Cooper,1984)

13-Jun-85

Table 3-6. SOURCE LIBRARY

SOURCE: RESIDENTIAL SPACE HEATING-COAL
SCC: NONE
CONTROLS: NONE

PROFILE: 43201
RANKING: 1121
RATING : D

SPECIES NUMBER	SPECIES NAME	FINE <2.5 UM % BY WT	FINE <2.5 UM +-	FINE <2.5 UM UNC	COARSE 2.5-10UM % BY WT	COARSE 2.5-10UM +-	COARSE 2.5-10UM UNC	TSP <30 UM % BY WT	TSP <30 UM +-	TSP <30 UM UNC
4	BE							NA		NR
5	B							0.120		NR
9	F							<		NR
11	NA							0.007		NR
12	MG							0.540		NR
13	AL							1.275		NR
14	SI							1.275		NR
15	P							0.105		NR
16	S							NR		NR
17	CL							<		NR
19	K							<		NR
20	CA							2.100		NR
21	SC							<		NR
22	TI							0.075		NR
23	V							0.030		NR
24	CR							0.007		NR
25	MN							0.007		NR
26	FE							1.650		NR
27	CO							0.007		NR
28	NI							0.090		NR
29	CU							0.060		NR
30	ZN							0.300		NR
31	GA							<		NR
32	GE							<		NR
33	AS							0.030		NR
34	SE							<		NR
35	BR							<		NR
37	RB							<		NR
38	SR							0.030		NR
40	ZR							<		NR
47	AG							0.900		NR
48	CD							<		NR
50	SN							0.105		NR
51	SB							0.405		NR
55	CS							<		NR
56	BA							0.105		NR
58	CE							<		NR
80	HG							<		NR
82	PB							0.015		NR
201	OC							40.000		NR
202	EC							40.000		NR
203	SO4							NA		NR
204	NO3							NA		NR
SUM(%)		0.000			0.000			89.238		

NOTES: OC = ORGANIC CARBON ; EC = ELEMENTAL CARBON ; NA = NOT ANALYZED ; NR = NOT REPORTED
< = LESS THAN DETECTION LIMIT
OTHER NOTES : AVERAGE OF TWO TESTS. WARM AIR FURNACE BURNING HIGH-ASH BITUMINOUS COAL
REF. 51.

(John.A. Cooper,1984)

Chapter 4

Regional Pollution: Acid Rain

4.1. Introduction

Acid rain in south-western part of China is posing a serious threat to densely populated areas of south China. A survey conducted between 1982 and 1983 showed that acid rain ($pH < 5.6$) is concentrated in the southwest in Sichuan, Guizhou, Jianxi and Hunan provinces. The governmental authorities are paying great attention to this problem.

There has been widespread speculation that acid rain is the main cause of environmental damage. For example, the forests on south mountain of Chongqing have been dying since 1982, half of them are dead. The others are in danger of extinction. Many needles of young trees on the south mountain showed the typical syndromes of sulphur dioxide injury. Such phenomena were more apparent as trees were closer to cities or against the wind. There were only chronic effects (as opposed to acute).For trees which were distant from cities or did not receive direct wind. The chronic effects include slow growth of pines and early abscission of needles. These effects on pines can still be observed in the southern parks which are away from cities. Generally, tree growth became slower under continuous exposure to acid rain and eventually many weakened trees died from disease or insect infestation within a few years

in some areas of Sizhuan province. Chinese scientists also discovered serious corrosion of metal and concrete works in Chongqing.

In the cities of Chongqing, Nanchan, Qingdao, Guiyang, Nanning and Hangzhou, 50 per cent of the annual precipitation has pH less than 5.6 according to a report by the news agency Xinhua ("China Daily" July, 1985).

Both acid rain and heavy SO_2 pollution occur in many southern cities. Some northern cities have high SO_2 concentration levels, but no acid rain. Beijing and Tianjin are two typical examples. It can be inferred that formation of acid rain depends not only on presence of enough SO_2, but also on other factors such as atmospheric buffering capacity which can play an important role. Generally speaking, acid rain is heavy in urban areas and light in suburban and rural areas. Looking at the whole country, pH of rain is higher in the north and lower in the south (See Table 3-5, pH is from 7 to 4) reflecting the soil pH (See Figure 3-10). This implies that the precipitation pH is related to local soil pH since half of the TSP is contributed by soil(Chen,1985).

In this chapter, the regional pollution of Guiyang-Chongqing area is introduced first, then this acid rain region is compared with non-acid rain region of Beijing-Tianjing.

4.2. Guiyang

In 1981 the Environmental Institute in Guiyang decided to look into the causes of acid rain there. They set up several gas-monitoring stations in and around the city. The results obtained from June to November of 1981 are briefly summarized below: The mean pH of rain varied from 3.80 to 4.50 with the minimum value 3.44; The SO_2 in the air varied from 150 to 700 $\mu g/m^3$ with maximum value 3000 $\mu g/m^3$).

They found that in general, the concentration of SO_2 in the air decreases as the pH of rain decreases, and that the concentration of SO_2 in the air decreased when it was raining (see Table 4-1 and Figure 4-1 and 4-2).

4.3. Chongqing

4.3.1. Introduction

Three years of data in Changqing have shown that the rainfall pH was quite low (average is 4.14), and the frequency of acid rain (pH $<$ 5.6) was high. The following data were observed by two stations, one of which is in the city and the other in the suburb. In the city the average pH of rain was 4.12 (from 3.43 to 6.28). The frequency of acid rain was 94.8%. In Beipei (suburb), the annual pH rainfall was 4.47 (from 3.80 to 5.65), and the frequency of acid rain was 95.5%.

Figure 4-3 shows that occurrences of rain pH values between 3.5 to 4.0 were more frequent inside the city than outside the city, and that the acidity of rain in the center of the city was higher and decreased gradually toward the suburb. Moreover, the

annual average pH of rain deceased from 1981 to 1983 in the city. The frequency of pH between 3.5 to 4.0 increased from 1981 to 1983 as shown in Figure 4-5.

4.3.2. Source of acid rain

It is shown from Table 4-6 that $[SO_4^{=}]$ is the most important anion responsible for acid rain, the second most important is $[NO_3^-]$, we can also see that the concentration of $[SO_4^{=}]$ was higher in the city than in the suburb.

The concentration of $[Ca^{+2}]$ was the highest in the city, however, in the suburb, the concentration of $[NH_4^+]$ was higher.

Observations on pollutants originating from low smokestacks and in rain samples collected in clouds at high altitutes show that the acidity of rain probably comes mainly from below-cloud scavenging of SO_2. Figures 4-11 and 4-12 show that pH value of ground rainfall has a high correlation with the sulfur content in the rain samples. This indicates that ground rainfall pH is determined by the dissolution of SO_2(Zhao Dianwu). Since $[SO_4^{-2}]$ was 87% of the total anions, the heavy SO_2 pollution and strong acid rain occured in urban areas. The acidity of rain may probably comes mainly from below-cloud scavenging of SO_2.

In addition, the cluster analysis based on ionic contents in rainwater divides sampling sites of Chongqing into two respective groups and further divides urban and suburban sites into different subgroups. This result implies that there exists a clear difference in precipitation chemistry between urban and suburban areas of the same city(See Figure 4-9). It can be concluded that acid rain in Chongqing is caused by local

emission of SO_2. The contribution of long range transport of SO_2 might not be significant.

In 1983 Zhao Dianwu and Xong Jiling found the correlation equation between $S(IV)$ and $S(VI)$ in Pung Shua-zhi site of Guiyang city as follows:

$[SO_4^{=}]=2.68\ [S(IV)]+311$, ($\mu$eq/l)

r=0.60 n=77 (See Fig. 4-13)

From the above equation, we see that $[SO_4^{-2}]$ does not come mainly from S(IV) according to figure 4-13 shown, S(IV) only accounts for about 30% of total$[SO_4^{-2}]$. The situation in other sites (for example in Chongqing) was simular to this. Therefore, the concentration of SO_2 in the air was not the only source of acid rain. Since $[SO_4^{-2}]$ has a good correlation with $[Ca^{+2}]$ and $[NH_4^{+}]$ there, it can be estimated that the majority of sulfate in raindrop comes from the washout of particles in the air(Zhao,1985).

Most acid rain in Chongqing is from local emission. The high concentration of SO_2 in the air results from local coal burning. About 70% of the industrial and household energy comes from coal burning, and the sulfur content in the coal is 4.5%. The total emission of SO_2 in Chongqing in 1982 was 600,000 tons, the density of coal consumption was 55,000 ton/km^{2}year.

Xu Yu et al.(1982) stated that the pH of rain in May and April is higher than that of other months since cold air which brings basic particles from the north is blown to Chongqing in that period. It seems that the aerosol in the air can both increase or decrease the pH of rain depending on ambient conditions.

The following formula was found:

$$\text{pH of rain} = 4.4033 - 0.4732 \cdot C$$

where C is the concentration of particles(μeq/l). Therefore, we know that the acid rain is a total result of rain and ambient dust concentration Since the pH of particles in the air of Chongqing is lower, the rainfall there, hence, can not be neutralized(Table 4-8).

4.3.3. A review

From another paper(Chen,1984), Xu Yu and other authors have assumed that there might be long distance transport of SO_2 in north western part of Chongqing.

In 1981 from April to October, the Environmental monitoring station in Chongqing collected 204 samples under different wind directions(Xu Yu, 1982). At the site of Guanying-qia pH was 4.13, but in Shapin-ba it is 4.36, since there are no local pollution sources there, these authors came to the conclusion that the mass of air from the northwest brought acidic pollutants there. This means that long distance transport of SO_2 may happen in the northwestern part of Chongqing (see Table 4-2). When the two group samples of NW with NNW direction and of NNE with NNW direction are compared as shown in Table 4-2-B, it seems that t-tests tend to give few significant results. Since $t'_{calculated}=1.87$ is greater than $t_{critical}(0.05)=1.58$, and $t'_{calculated}=1.25$ is less than $t'_{critical}=1.83$. This indicates that such situations might occur occasionally, and the contribution of long distance transport is probably not be significant in the NNW direction of Chongqing.(Suedelov & Cochran).

Furthermore, when the other two group samples(Table 4-2-C) are compared with each other, the combination of direction may also be concerned to occur by chance since $t'_{calculated}$=1.06 is less than $t_{critical}(0.05)$=1.92 between the samples of SSW and NNW direction. It also was not significant in the comparison of the average of S, SSW and SW direction with the average of WNW, NW, NNW and N direction since $t'_{calculated}$=1.02 is less than $t_{critical}(0.05)$=1.75. Therefore, it might be difficult to take long distance transport into account in Chongqing.

4.4. Comparison between the region with acid rain and those without acid rain in China

4.4.1. Chemical composition of acid rain in some areas of China

It can be seen from Table3-5 that $[SO_4^{-2}]$ dominates the anions, while $[SO_4^{-2}]$ and $[NH_4^+]$ are major cations. But, it also can be seen that the concentration of $[SO_4^{-2}]$ in different areas does not differ greatly. For $[Ca^{+2}]$, $[NH_4^+]$ and $[K^+]$, there are large differences of concentration among the sites sampled. Therefore, the acidity of rain is determined not only by the concentration of acidity in rain, but also by the concentration of basic particles.

Table 4-5 indicates that the equivalent concentration of $[Cl^-]$ is more or less similar to that of $[Na^+]$ implying that they may originate mainly from the sea. Zhao Dianwu suggested in 1985 that the formation and the spatial distribution of acid rain must be in close relation to natural factors, particularly the nature of soils in various

regions.

4.4.2. Buffering capacity in the air

It is important to study the relationship of particles to acid rain to understand why about 90% of the sampling sites with annual average pH of rainwater below 5.6 are located at the south of the Yangtze river(See Figure 4-14).

Figure 2-3 shows that concentration of SO_2 among cities in south and north China are quite similar, but concentration of fine particles and NH_3 in the air are higher in the northern cities than in the southern cities (Figure 2-1, 2-2 and Table 4-7).

Reports indicate that soil dust makes up about half of the particle concentrations. Soil pH in the Beijing-Tianjin region lies in the range of 7-8, while in Chongqing-Guiyang region it lies in the range of 5-6. This explains why ammonia concentration is high in the north and low in the South. Therefore, as shown in Table 4-8, particle's pH in Beijing is higher than that in Guiyang and Chongqing. The mean pH of particulates is 8.20 in Beijing (12 samples) and 5.82 in Guiyang (26 samples).

Figure 4-6 shows titration curves of particles in Beijing and Guiyang. For comparison, the quantity of acid needed to decrease pH of sample solution to 5.5 has been determined from titration curves and defined as critical buffering capacity C ($\mu eq/l$) as follows:

Beijing (24 samples) C=146 $\mu eq/l$

Guiyang (9 samples) C= 21 $\mu eq/l$

Figure 4-6 shows that Beijing's samples possess the highest buffering capacity, almost seven times that for Guiyang's samples. It can be concluded from Table 4-9, Figure 4-7 and 4-8 that:

(A) Samples in Beijing have the highest buffering capacity. Samples from Chongqing and Guiyang have rather low buffering capacity.

(B) The smaller the particle size, the lower the initial pH value and the buffering capacity.

(C) Particles with small size in Guiyang and Chongqing are more acidic.

(D) Buffering capacity of rural samples is slightly lower than that of urban samples.

The soil is the cause of the difference in buffering capacity.(Zhao, 1986). In northern China the pH of soil is around 7-8. Hence, ammonia is released into the air in large quantities from the alkaline soil and its concentration can be as high as 20 ppbv in the Beijing-Tianjing area, which is about 10 times higher than that in the Chongqing Guiyang area. Considering that both factors, i.e. alkaline soil which contributes half of the particles in the air and the high ammonia concentration, air must retain a strong buffering capacity to neutralize the acidity in the rain. Consequently acid rain seldom occurs in northern China even though the SO_2 level is high in those areas. In southern cities, on the contrary, because the soil is acidic with pH around 5-6 resulting in low emission of ammonia, the buffering capacity of the air is rather weak. Figures 4-10 and 4-14 show a good correspondence between the distribution of soil pH and the geographic distribution of rain pH. The southern cities, therefore, suffer from acid rain

frequently even though the concentration of SO_2 is not very high. But most of the southern cities have no acid rain. So, besides buffering capacity, the geographic and weatherly conditions should be concerned as well. For example, both Chongqing and Guiyang are located at basin areas, this is other reason why acid rain occurs there.

4.4.3. Catalyzed aqueous phase oxidation of sulfur dioxide

Airborne particulates are found at high level in cities throughout the country with abundant Mn, Fe and other metal ions expected to be effective catalysts for the aqueous phase oxidation of SO_2. Zhao suggests that $[O_3]$ and $[H_2O_2]$ may not play a decisive role in SO_2 conversion because of their rather low concentrations in the air and raindrops. For example, measured concentration of total oxidants in the air in Guiyang, 1984, were in the range of 25-56 $\mu g/m^3$, and O_3 in Beijing, 1985, 40-60 ppb.

It is likely that catalytic oxidation on the surface of particles might be the major pathway of SO_2 conversion in clouds, fog and rain(Zhao,1985).

4.5. Discussion

Chinese scientists have concluded that the acid rain in Chongqing and Guiyang is caused by local emission of SO_2. The contribution of long-range transport of SO_2 is not significant, and most of the cities with acid rain in China are probably in the same situation. However, Table 4-11 shows that the pH of rain in Hangzhou is quite low. Based on the geographical conditions in Hangzhou, it should not be polluted by local emissions, because there are no important industrial sources nearby. It's monthly pH

changes are more or less similar to Zhongjang and Jinpu districts of Shanghai. However, Hangzhou is located downwind of Shanghai and Nanjing. It seems that acid rain in Hangzhou has something to do with the long distance transport of SO_2 from Shanghai. So, the idea that in most Chinese cities acid rain is caused by local pollution might not be entirely correct.

Table 4-1, Figures 4-1 and 4-2 show that concentration of SO_2 in the air decreases as pH of rain decreases, and that the concentration of SO_2 in Guiyang decreases when it is raining. Figure 4-11 and 4-12 also show that the pH of ground rainfall in Guiyang has a high correlation with the S(IV) in the rain samples. As a consequence, we might be able to say that the pH decreases due to washout of SO_2 in the air in Guiyang. But the formula

$$[SO_4^{=}] = 2.68[S(\mathrm{IV})] + 311(\mu\mathrm{eg/l}) \quad \text{(Figure 4-13)}$$

reported by Zhao in 1985 indicates that the contribution from SO_2 is not significant to the formation of $[SO_4^{-2}]$.(Zhao,1985). The question arises then, what is the cause of the acidity of rain ? Is it from the washout of particles or from the washout of SO_2 in the air ? This problem needs to be further investigated.

4.6. Conclusions

Chinese scientists have tried to arrive at definitive conclusions based on the following facts.

First, in Chongqing, Guiyang and many other cities, heavy SO_2 pollution and acid rain occur in the urban area and the situation is quite the oppsite in the suburbs.

Second, the acidity of rain comes mainly from below-cloud scavenging of SO_2.

Third, the concentration of SO_2 in the air is mainly from low emission sources, and long distance transport of SO_2 is not significant.

Fourth, acid rain is a total result of rain and ambient dust concentration. Therefore, no acid rain has been found in Beijing and Tianjin although the SO_2 level is high in this region. The pH of the soil brings about the current picture of acid rain in China.

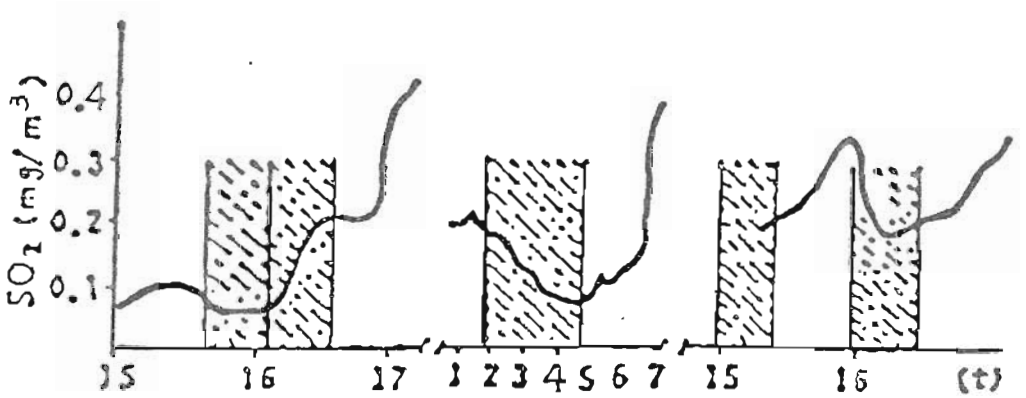


Figure 4-1. The variation of atmospheric SO_2 concentration during rain.

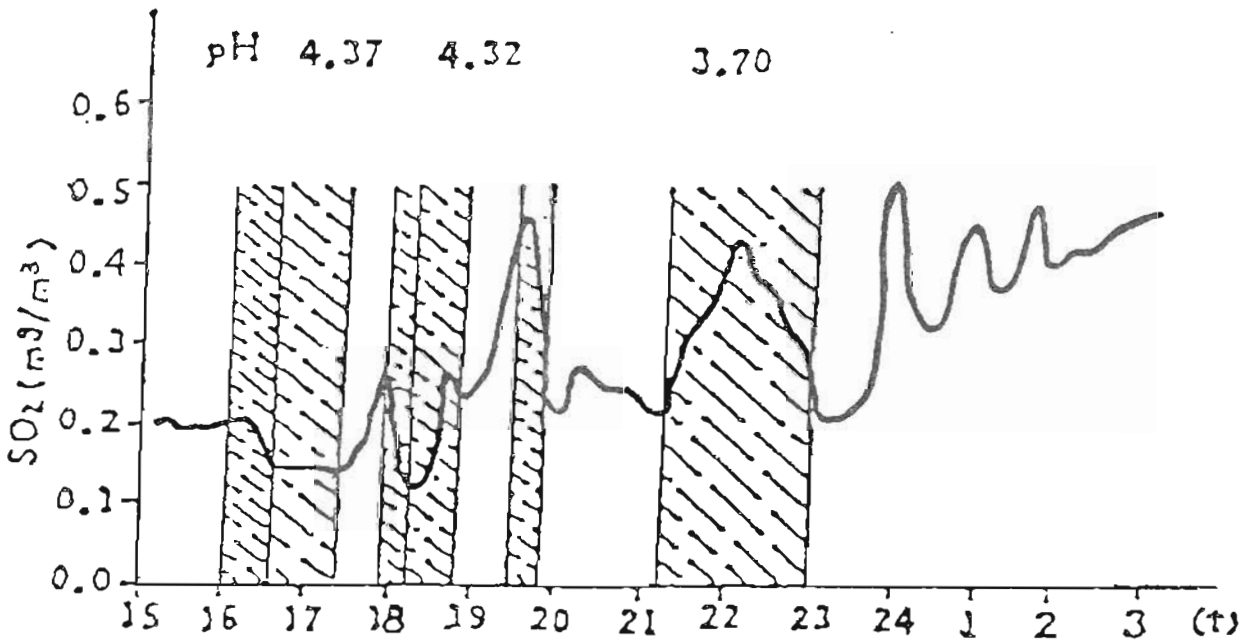


Figure 4-2. The relation between so in the air and PH of rain

(Xiong,1982)

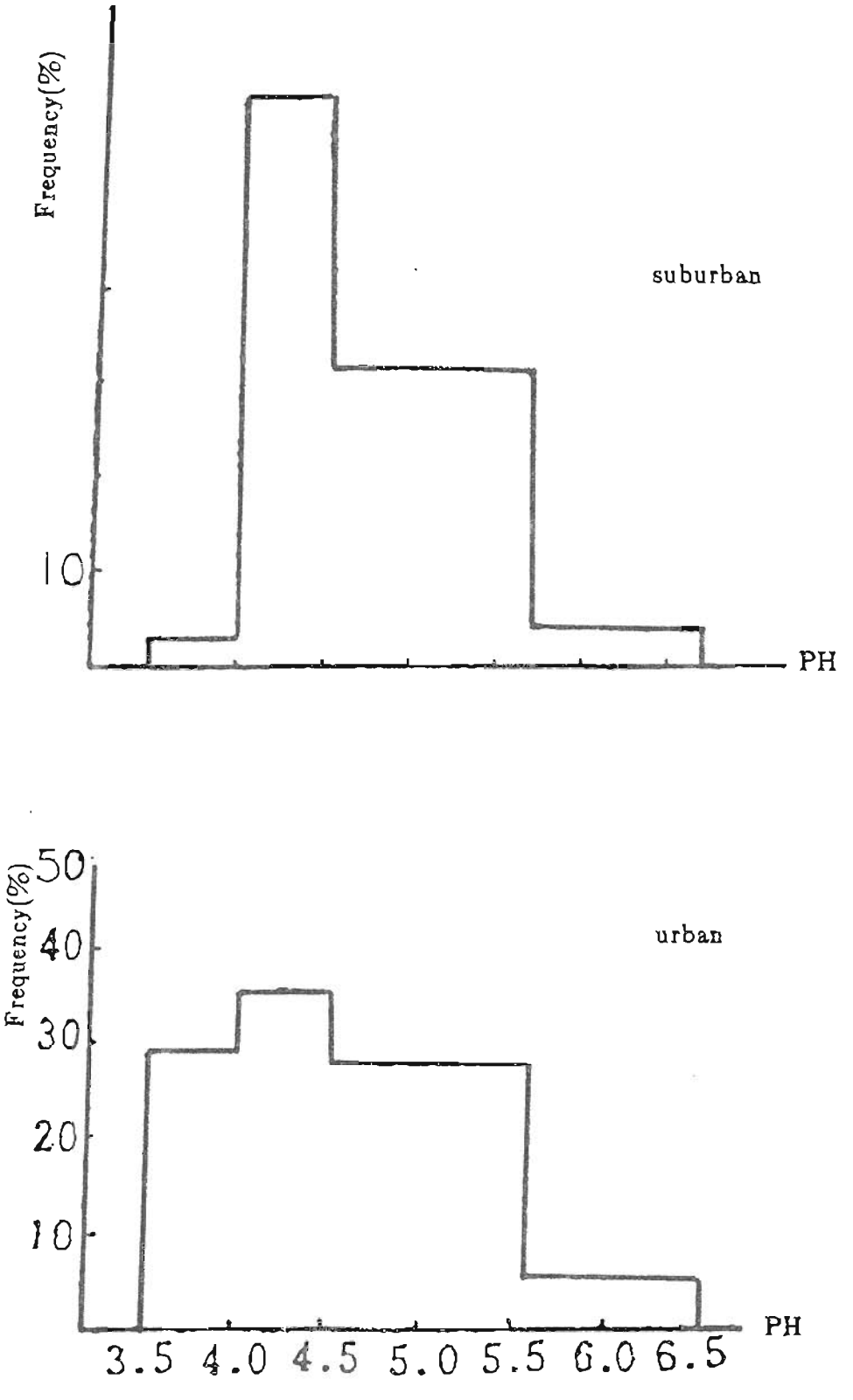


Figure 4-3 The distribution of PH of rain in Chongqing in 1983

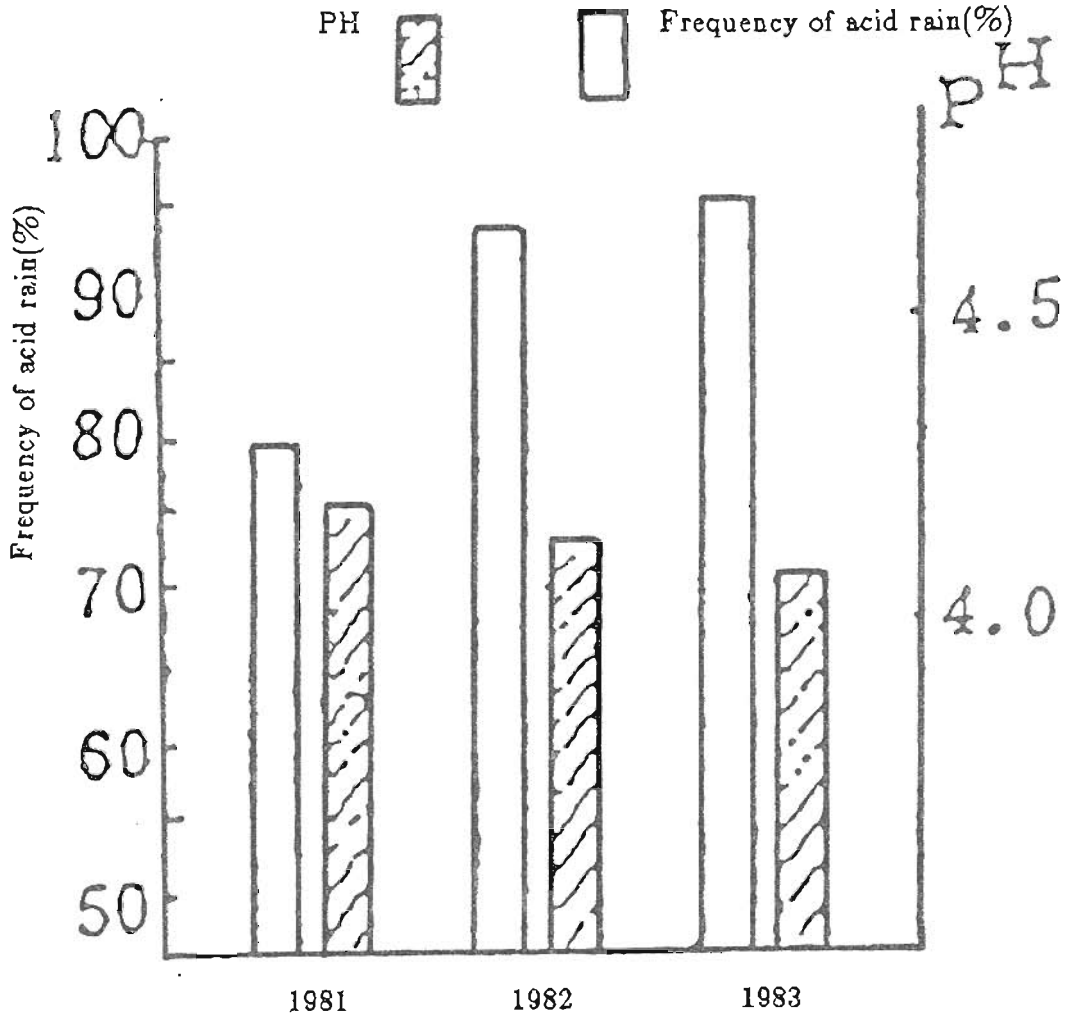


Figure 4-4. Annual average and frequency of pH of rain in urban area in Chong qing

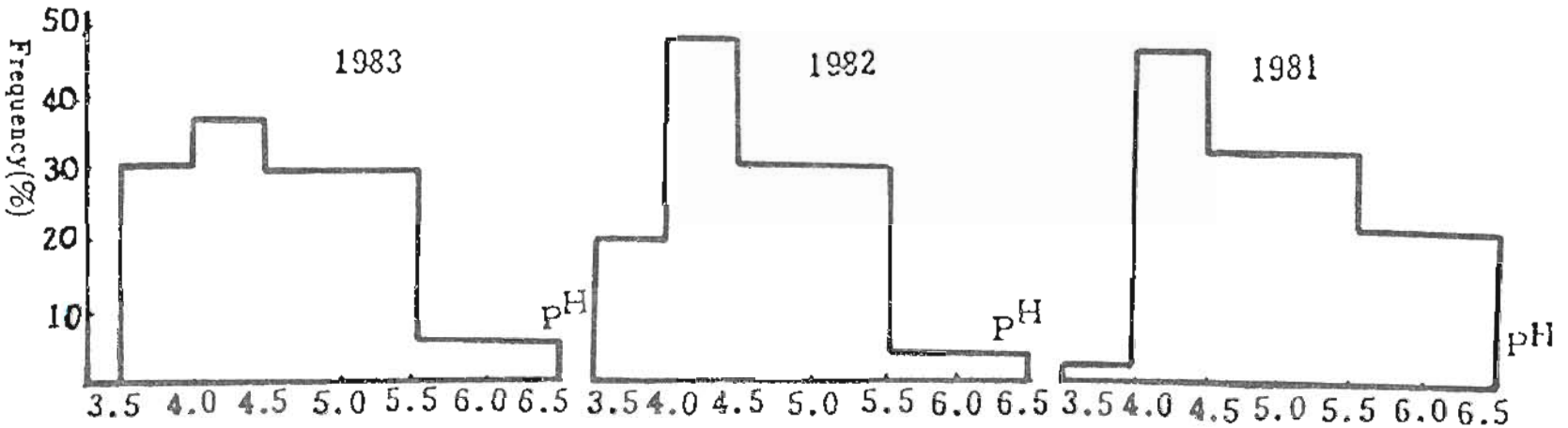


Figure 4-5. The change of frequency of pH of rain with years

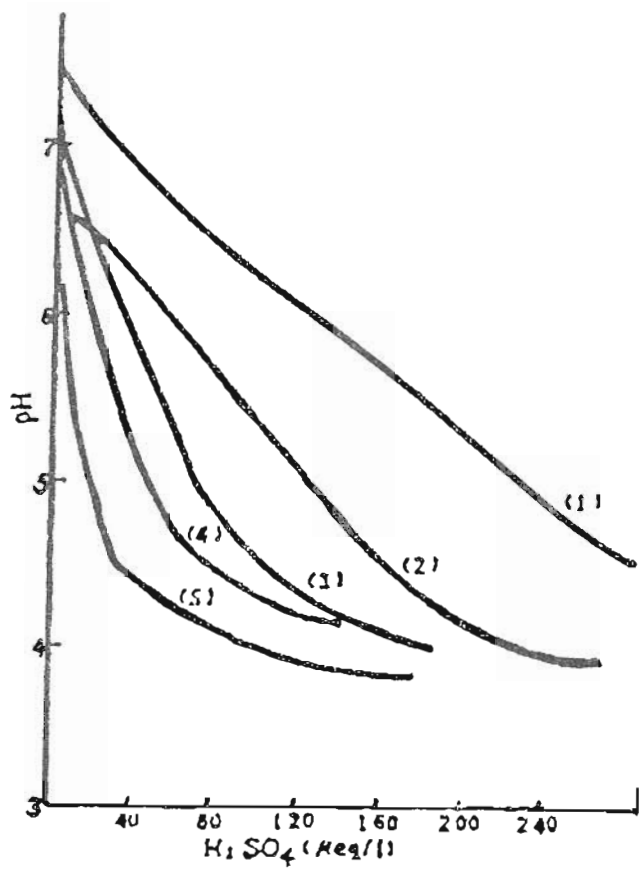


Figure 4-6. Buffering curve of airborne particles.

(1): Beijing samples;
(2): Beijing smoke;
(3): Guiyang samples;
(4): Background of filter;
(5): Boiled deionized water.

(Zhao,1985)

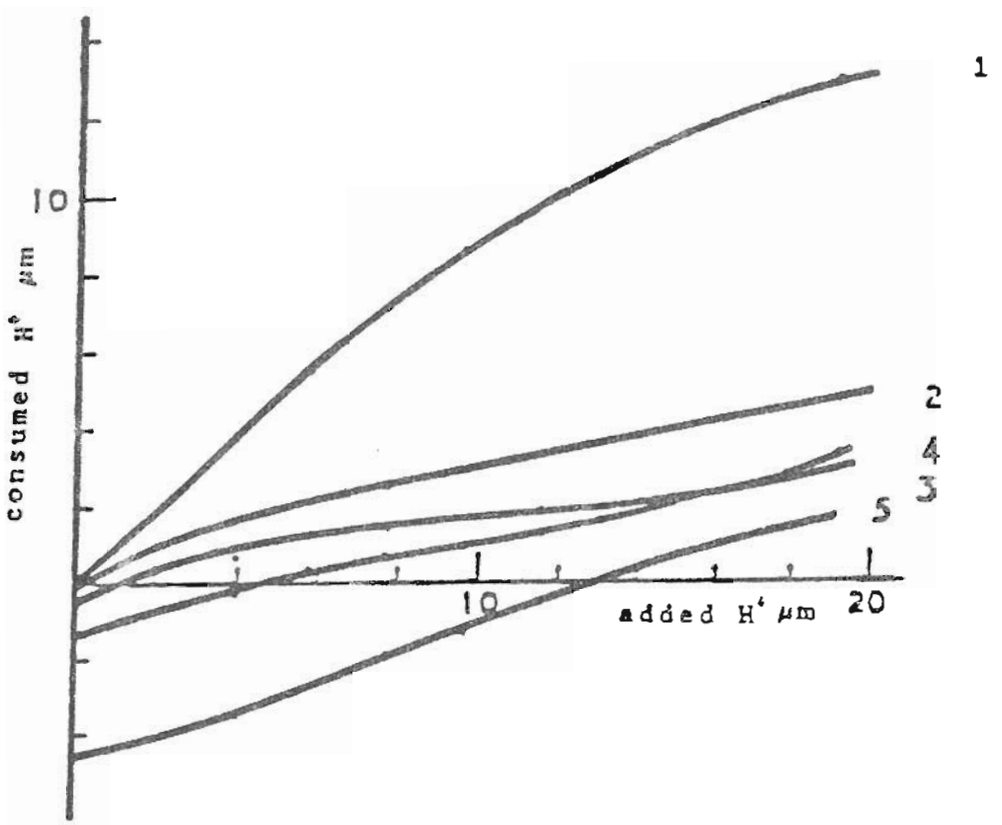


Figure 4-7. Buffering curve of particles of different size distribution for urban sites of Guiyang

(Zhao,1985)

Size range:(μm)

1: >7, 2: 7-3.3,

3: 3.3-2, 4: 2-1,

5: <1.1.

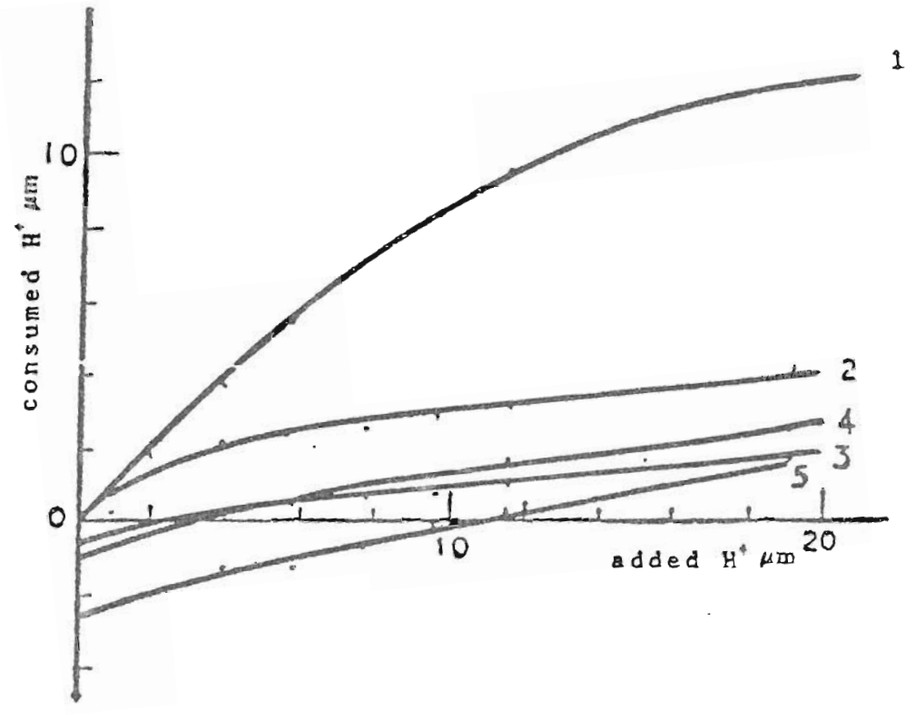


Figure 4-8. Buffering curve of particles of different size distribution for Guiyang suburban sites.

(Zhao,1985)

Size range:(μm)

1: >7, 2: 7-3.3,

3: 3.3-2, 4: 2-1,

5: <1.1.

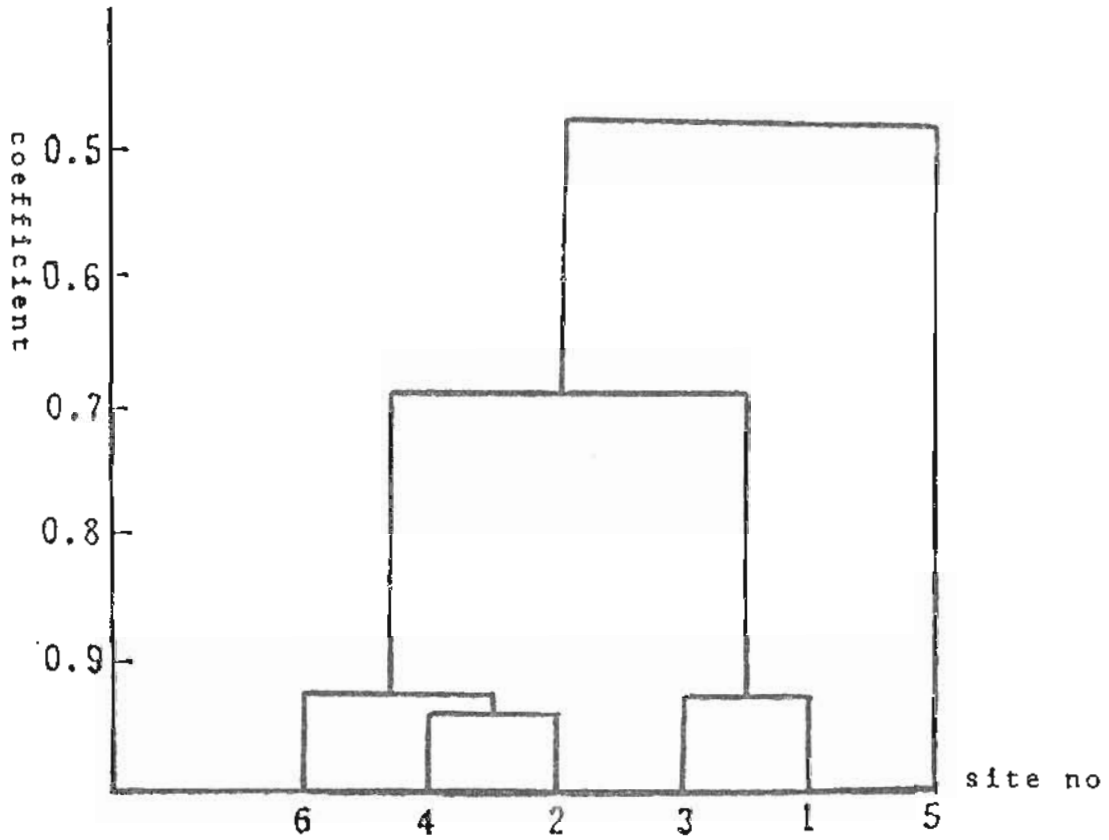


Figure 4-9. Cluster analysis based on ionic contents in rain for Guiyang.5

Number of site: 2,4,6: Urban.
1,3: Northeastern suburban.
5: Southeast suburb.

Figure 4-10 **Map of soil pH of the People's Republic of China.**

(Zhao,1986)

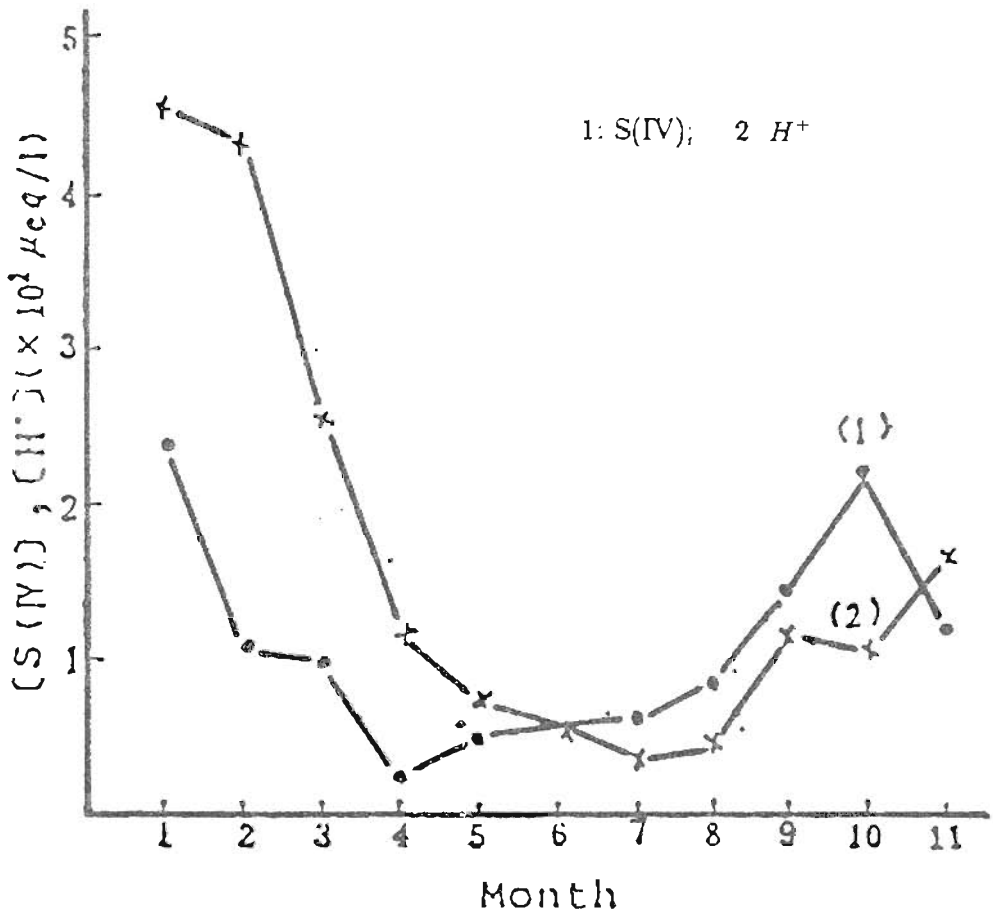


Figure 4-11. Monthly mean concentration of S(IV) and $[H^+]$ in rain in Guiyang (Zhao,1985)

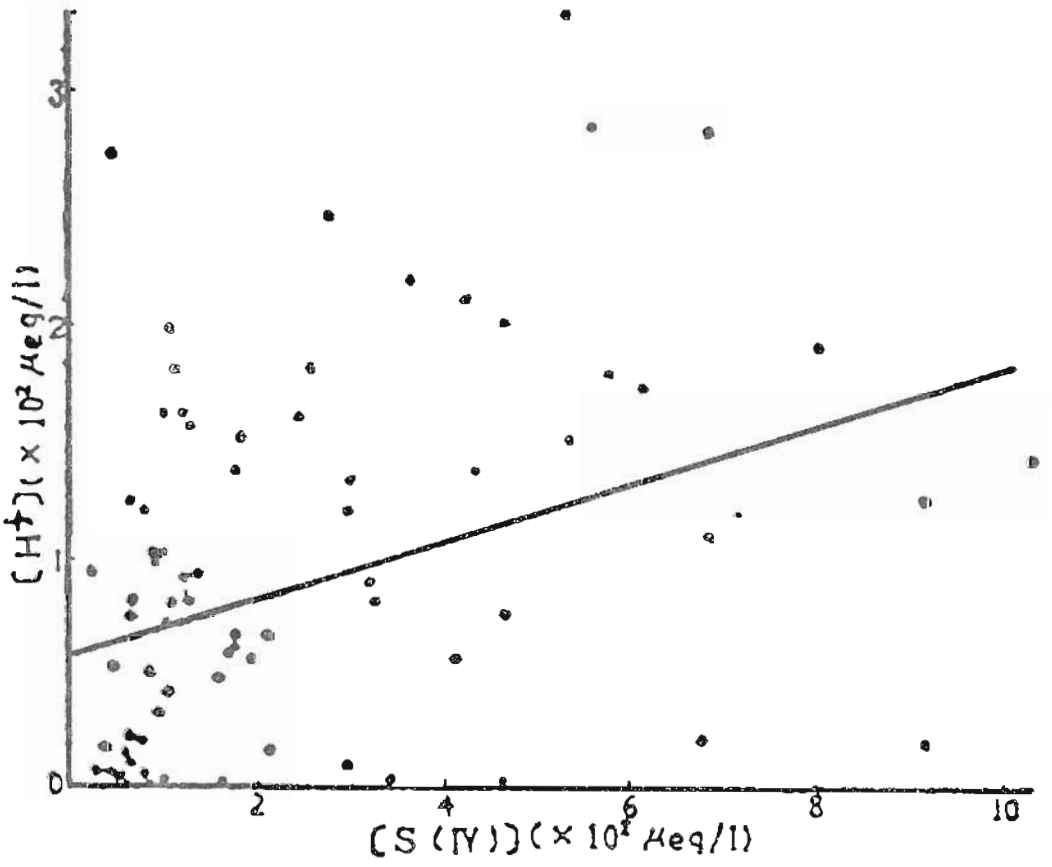


Fig. 4-12 Correlation between S(IV) and H^+ in rain for Guiyang,1983

$$r = 0.43, \quad n = 69$$

(Zhao,1985)

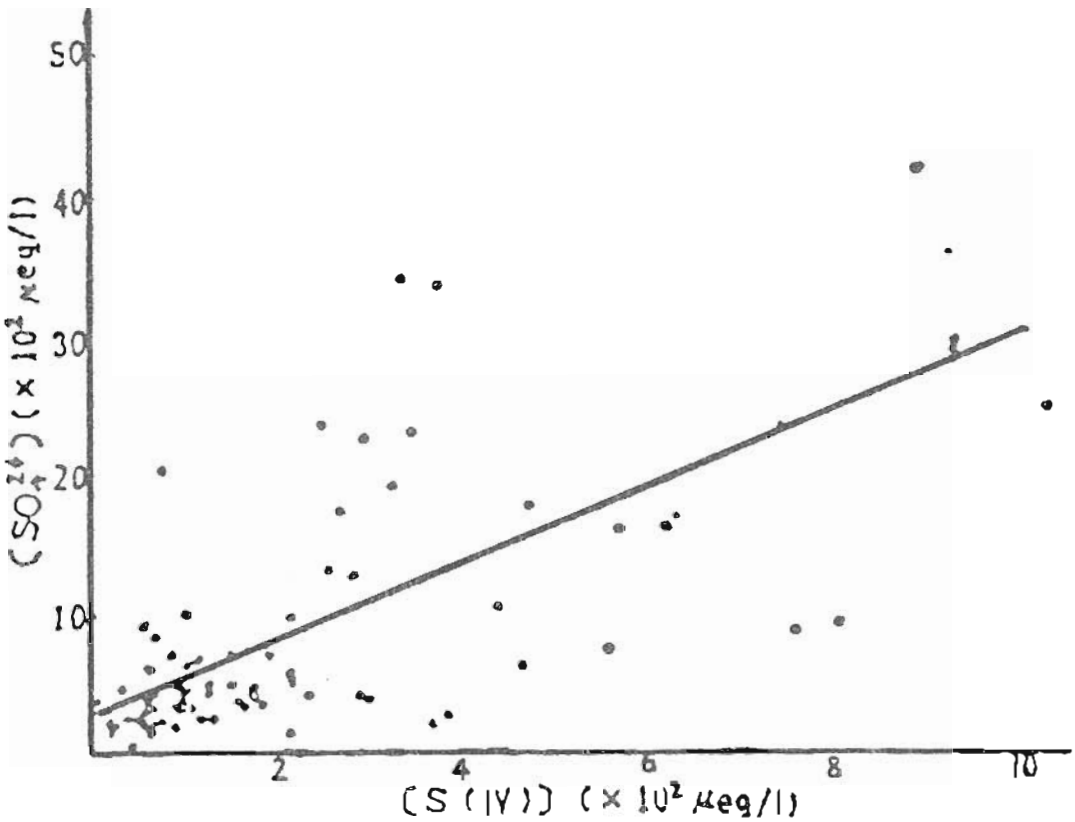


Fig. 4-13 orrelation between S(VI) and S(VI) in rain for Guiyang, 1983

$$[S(VI)] = 2.68[S(IV)] + 311 \quad \mu g/m^3$$

$$r = 0.60, \quad n = 77$$

(Zhao,1985)

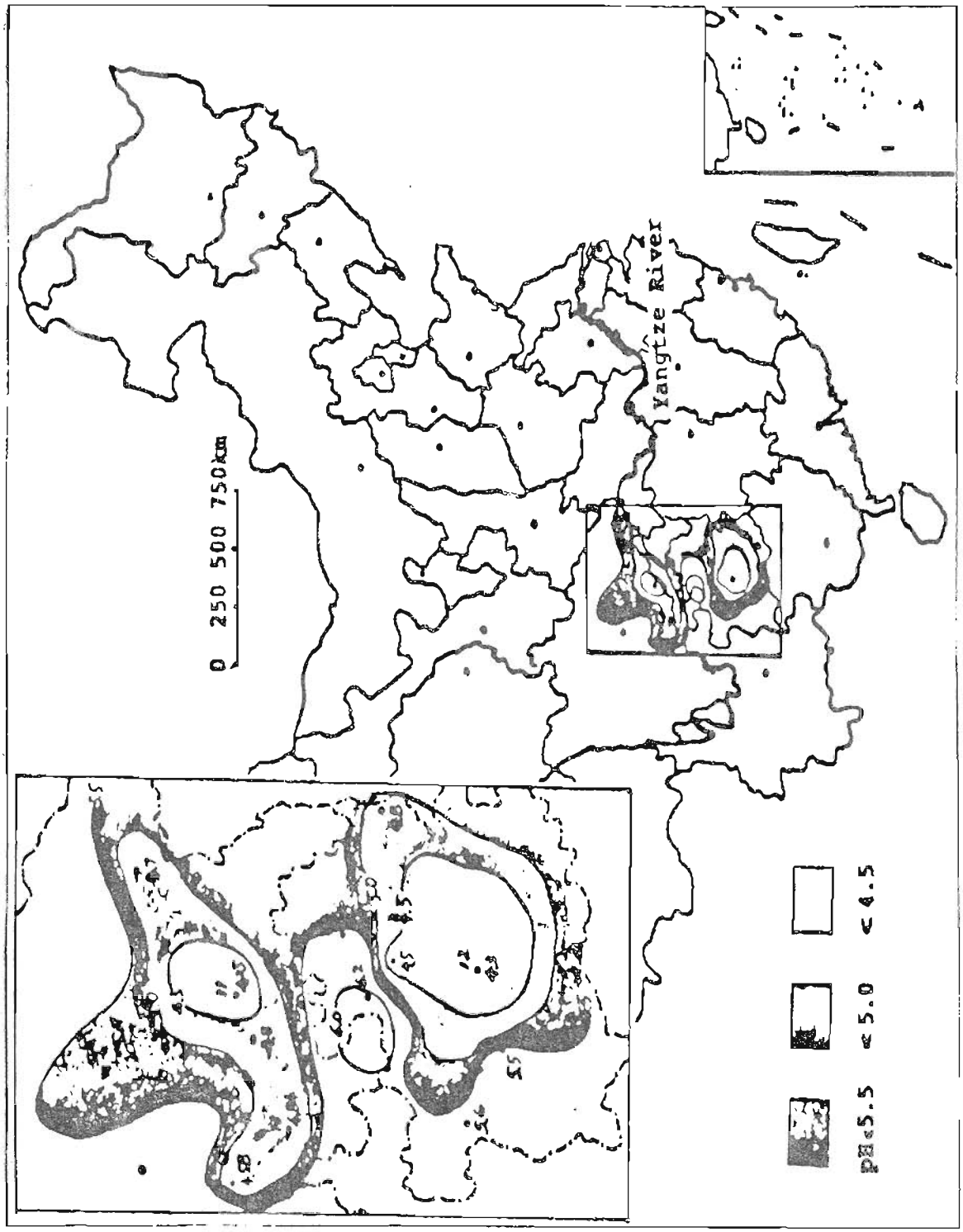


Figure 4-14 Geographic distribution of rain pH in southwest China, August, 1982

(Zhao.1986)

Table 4-1. The relation between concentration of SO_2 and weather (June, 1981)

Date	Conc. of SO_2 (mg/m^3)	Weather situation
9 A.M. (4th)	0.11	raining
11 A.M. (5th)	0.17	raining
9 A.M. (11th)	0.27	raining
9 A.M. (27th)	0.18	raining
9 A.M. (3rd)	0.48	after rain
9 A.M. (7th)	0.65	after rain
9 A.M. (19th)	0.81	after rain

(Xiong,1982)

Table 4-2-A. pH-direction of wind

point \ wind dir.		NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	N	C
guanyinqo	pH	4.31	4.90	4.75	4.32	—	5.10	7.05	5.23	4.45	4.40	—	5.00	4.52	5.18	4.13	4.35	5.00
	n	10	6	3	1	0	1	1	6	7	3	0	1	6	4	11	2	8
	σ	0.37	0.42	0.48	—	—	—	—	0.94	0.50	0.61	—	—	0.51	1.32	0.28	0.14	1.39
shapingba	pH	4.62	4.41	4.27	4.51	4.10	—	4.48	4.64	4.51	4.80	4.53	4.49	4.44	4.53	4.36	4.58	4.40
	n	5	5	3	4	3	0	2	2	8	10	4	3	7	13	20	13	33
	σ	1.10	0.69	0.31	0.85	0.43	—	0.16	0.07	0.97	1.11	0.28	0.53	0.24	0.55	0.71	0.90	0.47
region	pH	4.48	4.68	4.61	4.47	4.10	5.10	5.34	5.06	4.54	4.71	4.53	4.62	4.48	4.68	4.28	4.55	4.52
	n	15	11	6	5	3	1	3	7	15	13	4	4	13	17	31	15	41
	%	7.4	5.4	2.9	2.4	1.5	0.5	1.5	3.4	7.4	6.4	2.0	2.0	6.4	8.3	15.2	7.4	20.1

% : Number of samples in this wind direction over number of total samples.

(Xu Yu,1982)

Table 4-2-B The comparison of two samples from Table 4-2-A

NW (direction)	NNW (direction)
$\bar{X}_1$=5.18 =PH	$\bar{X}_2$=4.13 =PH
n_1=4	n_2=11
$S_1=\sigma_1$=1.32	$S_2=\sigma_2$=0.28
S_1^2/n_1=0.436	S_2^2/n_2=0.007
t' =1.05/0.67=1.58	
t_1(3 d.f.)=2.353	t_2(10 d.f.)=1.812
$t_{0.05}'$ =5% level of t' =1.036/0.443=2.34	
so $t' < t_{0.05}'$	

NNE (direction)	NNW (direction)
$\bar{X}_1$=4.31=PH	$\bar{X}_2$=4.13=PH
n_1=10	n_2=11
$S_1=\sigma_1$=0.37	$S_2=\sigma_2$=0.28
S_1^2/n_1=0.014	S_2^2/n_2=0.007
t' =0.18/0.144=1.25	
t_1(9 d.f.)=1.833	t_2(10 d.f.)=1.812
$t_{0.05}$=5% level of t' =0.0380/0.0208=1.827	
so $t' < t_{0.10}'$	

Table 4-2-C The comparison of two group samples from Table 4-2-A

SSW (direction)	NNW (direction)
$\bar{X}_1$=4.45=PH	$\bar{X}_2$=4.13 =PH
n_1=7	n_2=11
$7S_1=\sigma_1=0.50$	$S_2=\sigma_2=0.28$
$S_1^2/n_1=0.036$	$S_2^2/n_2=0.007$
t' =0.22/0.2069=1.06	
t_1(6 d.f.)=1.943	t_2(10 d.f.)=1.812
$t_{0.05}'$ =5% level of t' =0.0823/0.2069=0.3978	
so $t' < t_{0.05}'$	

S, SSW, SW (average)	WNW, NW, NNW, N (average)
$\bar{X}_1$=4.7=PH	$\bar{X}_2$=4.4334=PH
n_1=15	n_2=23
$S_1=\sigma_1=0.842$	$S_2=\sigma_2=0.577$
$S_1^2/n_1=0.043$	$S_2^2/n_2=0.025$
t'=0.288/0.28=1.02	
t_1(14 d.f.)=1.761	t_2(22 d.f.)=1.717
$t_{0.05}$=5% level of t'=0.119/0.068=1.745	
so $t' < t_{0.05}'$	

Table 4-3. Total Energy Consumption and Its Breakdown in China

Year	Total 10^6 tce	% of Total			
		Coal	Oil	Gas	Hydro.
1953	54.11	94.33	3.81	0.02	1.84
1962	165.40	89.23	6.61	0.93	3.23
1970	292.91	80.89	14.67	0.92	3.52
1975	454.25	71.85	21.07	2.51	4.57
1982	619.37	73.92	18.67	2.56	4.85

Source: Chinese Statistical Yearbook - 1983, p.250

(Zhao,1985)

Table 4-4. Rainwater pH in Some Cities of China

Index	Location	City	Year	pH	Reference
1	North	Beijing	1981	6.8	4
2		Tianjin	1981	6.26	4
9		Lanzhou	1981 -- 1982	6.85	11
10	South	Nanjing	1981.6 - 11	6.38	12
11		Hangzhou	1981.9 - 12	5.10	12
12		Wuhan	1983.1 - 7	6.44	13
13		Fuzhou	1982.5	4.49	14
14		Nanning	1981.5 - 12	5.74	12
15		Yibin	1982	4.87	4
7		Chongqing	1982	4.14	4
8		Guiyang	1982	4.02	4

(Zhao,1985)

Table 4-5. Concentration of Major Ions in Rainwater Samples

(ueq/l)

Index	1	1	2	7	7	8	8
Location	North	North	North	South	South	South	South
City	Beijing, Urban	Beijing, Suburban	Tianjin, Urban	Chongqing, Urban	Chongqing, Suburban	Guiyang, urban	Guiyang, Suburban
Year	1981	1981	1981	1982	1982	1982	1982
pH	6.8	--	6.26	4.14	4.73	4.02	4.73
H^+	0.16	--	0.55	73	18.6	94.9	18.6
SO_4^{2-}	273.13	131.04	317.71	283.0	213.4	345	83.3
NO_3^-	50.23	15.97	29.19	21.5	15.6	9.5	15.6
Cl^-	157.43	178.86	183.14	15.3	9.7	8.9	5.1
NH_4^+	141.11	76.11	125.56	81.4	99.5	63.8	26.1
Ca^{2+}	184	124.5	287	100.6	52.8	149	45.0
Na^+	140.87	117.83	175.22	17.1	23.9	9.8	8.3
K^+	40.23	24.62	59.23	14.8	16.3	9.5	4.9
Mg^{2+}	--	--	--	31.0	14.8	43.4	13.3
$\sum[-]$	480.9	325.9	530.0	327.0	241.9	376.4	103.0
$\sum[+]$	508.3	343.1	647.0	317.9	225.9	370.4	116.2

Source: Reference (Zhao, 1985)

Table 4-6.Measured Gaseous Ammonia in Air

Index	Location	Year	City	Mean NH_3, ppb	No. of Samples
1	North	1984.7	Beijing	44	10
2	North	1984.7	Tianjin	22.8	4
7	South	1984.9	Chongqing	5.17	12
8	South	1984.9	Guiyang	1.7	16

Source: Reference (Zhao,1985)

Table 4-7. Acidity of Airborne Particles in Cities

Index	Location	Year	City	Airflow m^3	Mean pH	No. of Samples
1	North	1984.3	Beijing			
			urban	18.7	8.20	12
			smoke	16.1	7.86	1
8	South	1984.4	Guiyang			
			urban	14.0	5.82	26

Table 4-8. pH of Particles with Different Size Range

Index	City	Size Range, μm				
		> 7	7-3.3	3.3-2	2-1.1	<1.1
1	Beijing, urban	8.24	7.75	7.48	6.64	7.20
8	Guiyang, urban	6.37	5.59	5.31	4.86	4.32
	Suburban	6.40	5.80	5.15	4.92	4.58
7	Chongqing, urban	7.55	6.37	5.16	4.94	4.49
	suburban	5.27	4.97	4.95	4.87	4.66

(Zhao,1985)

Table 4-9 Oxidation Rate of SO_2 and Metal Content in Rainwater Sample

City	Mn μM	Fe μM	Cr μM	Oxidation Rate SO_4^{2-} μM/min	Reference
Chongqing	0.55	1.32	0.005	4.90	9
	0.19	4.20	0.05	1.26	
	0.16	2.48	0.046	0.84	
	0.10	4.34	0.006	0.56	
Guiyang	1.27	<1.25	--	7.42	8
	1.09	<1.95	--	3.84	
	1.09	<1.25	--	3.06	
	1.46	<1.25	--	2.47	
	0.64	<1.25	--	0.20	

(Zhao,1985)

Table 4-10. In 1981 September-December pH of Rainwater in Hangzhou

Month	pH of Rainwater
9	6.33-6.74
10	4.04-6.61
11	3.94-5.56
12	4.74-5.70
Average	5.10

(Wang Mu-lin,1984)

Chapter 5

Future expectations

Based on the national policy of economic development, by the end of this century energy consumption will be doubled and gross national production will be quadrupled. Chinese authorities realize that under present conditions air pollution is a serious and growing problem. A large pollution control effort will be required to keep pollution from getting worse under the projected increases in coal usage.

Chinese authorities now pay great attention to environmental protection. There are many scientists working in this field in China. They have been collecting data over the last ten, even thirty years. The National Data Library of Environmental Background Samples was established by the Chinese Environmental Monitoring Station at the end of 1985.

Chinese scientists have done significant work on air pollution in recent years and used various high quality instruments. The new "open policy" will provide great opportunities for international cooperation which will be greatly benefit both China and the U.S.

The Beijing area is an ideal natural laboratory for investigating coal combustion aerosol because it does not have the complications of transportation or industrial sources for characterizing this aerosol in the urban plume.

For the next fifteen years the following control options are presented(Zhao,1986):

a. Coal preparation-to reduce ash content 50% and sulfur 30%.

b. Dust collection-electrostatic precipitators with efficiencies of 95% and cyclones with efficiencies of 85%.

c. Coal briquet: With sulfur-fixing binder to reduce sulfur emission by 50% for household and small boiler uses.

d. More city gas production and central heating facilities will be built.

e. Coal-burning boilers will be improved.

f. More forestation and grass in the cities will be planted to reduce wind blown dust.

g. Factories that have serious pollution sources will be moved out of the city limits.

Since coal is the dominant energy resource in China and will be used for many years to come, coal will be a major pollution source (Table 4-1-2 A,B) now and in the near future.

CMB modeling would be expected to be useful to characterize present pollution sources especially coal-burning sources and monitor future control efforts. As the United States moves toward greater utilization of coal resources, the information on aerosol composition and concentrations in a coal burning city are especially pertinent (Daisey,1983).

These results may also help in predicting the impact of coal combustion on air quality in other countries now contemplating increased use of coal as an alternative to

oil(John W. Winchester,1981).

Chapter 6

Conclusions

In the first and second chapters this study concentrated on a summary of the air pollution in China. The following conclusions were reached:

1. Air pollution at present in China occurs mainly in cities, particularly in their central areas.

2. The main pollutants of concern in China are particles and SO_2.

3. Air pollution in northern Chinese cities is higher than that in Southern Chinese cities.

4. Concentration levels of airborne particles are high and soil dust accounts for about half of these concentration levels.

Chapter three examined the urban pollution in Beijing, a typical coal burning city, details are summarezed as follows:

1. Lower visibility and solar radiation in Beijing shows that the concentration of particles is increasing.

2. The distribution of average aerosol concentration in Beijing has an elliptic form and the horizontal direction and stratified in the vertical direction.

3. It is found that the spatial distribution of atmospheric aerosol is non-uniform in the horizontal direction and stratified in the vertical direction.

4. The heavy air pollution occurs under the following typical conditions: a slow moving anticyclone at the upper atmosphere, continuous inversion below 300 m and wind field near the surface unfavorable for the horizontal trasfer, exist simultaneously.

5. Residential coal-burning is probably the most important source of pollution in Beijing and in other coal-burning cities in China.

6. CMB modeling would be expected to be useful to characterize present pollution sources especially coal burning sources, and to monitor future control efforts.

Chapter four discusses regional acid rain pollution in China. The following conclutions were drawn:

1. SO_2 in the air is mainly from lower emission sources.

2. Rain acidity comes from below-cloud scavenging of SO_2 emitted from local sources.

3. The atmospheric buffering capacity, (basically the pH of soil), brings about the current picture of geographical distribution of acid rain in China.

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