Acidification in Tropical Countries
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CHAPTER 10
Acidification in Southwestern China

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10.1 INTRODUCTION

Acidification has emerged as an environmental issue of increasing concern in China, particularly in the southwest. Since the late 1970s an increasing number of institutes for environmental sciences and meteorology in cities such as Beijing, Shanghai, Chongqing, and Guiyang have been collecting rainwater samples and measuring their acidity and chemical composition. In November 1981, the First National Symposium on Acid Rain was held in Beijing, China, with the Institute of Environmental Chemistry, Chinese Academy of Sciences presiding. The following year the Chinese National Environmental Protection Office (EPO) organized and sponsored two research projects concerning acid rain: 'Nation-wide Survey of Acid Rain' and 'Research on the Formation and Effects of Acid Rain in Southwestern China.'

A large number of environmental monitoring stations have participated in the first project, and the second was undertaken by the Institute of Environmental Chemistry and the Institute of Atmospheric Physics of the Chinese Academy of Sciences in cooperation with the local environmental institutes of Guizhou province and Chongqing city, Sichuan province.

In order to increase our understanding of acidification in China and provide a reliable basis for environmental decision making a new, comprehensive and multi-disciplinary Five-Year Research Program (1986–1990) has been developed as one of the nations's top priority research programs. It covers nearly all major aspects of acid rain phenomena: sources, formation mechanisms in and below clouds, contribution of long-range transport of pollutants, ecological and other adverse effects, control options, and monitoring techniques. Scientific workers from institutes under the Chinese Academy of Sciences, EPO, universities, and the meteorological system will work together while the State Science and Technology Commission will take responsibility for organizing and coordinating interdisciplinary and interagency activities (Zhao and Lixuen, 1985).

This report focuses on acidification and related problems in southwestern China, particularly Guizhou province. Figure 10.1 shows the location and range of the study area.

10.2 AIR POLLUTION IN CHINA

Coal combustion is responsible for most of the atmospheric pollution in China, especially in big cities. Particulate matter and sulfur dioxide are the two most significant pollutants (Zhao, 1984).

In 1982, about 620 million tons of coal equivalent were consumed for energy production in the country; coal accounted for 74% of the total (Table 10.1). An estimated 40% of the coal consumed was for industrial, commercial, and domestic use in cities with an area less than 0.5% of the entire country. Thus air pollution in China occurs mainly in cities.

Most of the coal used in cities is burned in medium-sized and small furnaces with low stacks that cannot be equipped with devices for removing SO_2 from flue gas. Thus, under unfavorable meteorological conditions heavy air pollution often occurs in these areas.

Concentration of airborne particles stays high during the year throughout the country (Table 10.2). Apart from fly ash from coal combustion, wind-blown soil dust is another primary source for total suspended matter. A general survey made in northern cities showed that the contribution of natural dust is 40% in winter and 60% in summer, while in southern cities it is estimated to be about one-third of the total due to the humid weather.

Emissions of SO_2 from coal combustion in 1985 amounted to about 13 million tons (Hancheng, 1986). In cities that burn high-sulfur coal and

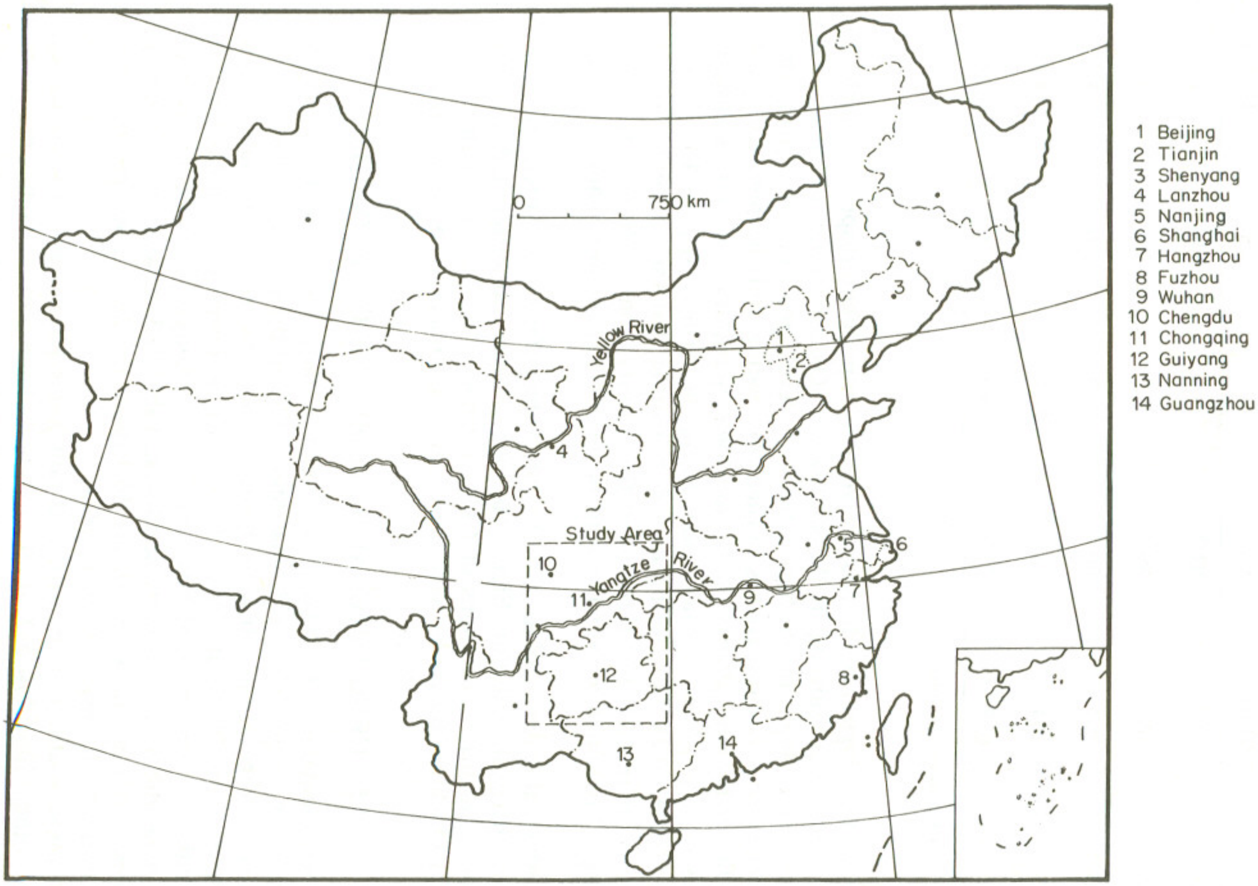

Figure 10.1 Map of the People's Republic of China

Table 10.1 Energy production in China (Chinese Statistical Bureau, 1983)

Year	Total 10^6 tce	Percentage of total			
		Coal	Oil	Gas	Hydro
1953	54	94.3	3.8	0.02	1.8
1962	165	89.2	6.6	0.9	3.2
1970	293	80.9	14.7	0.9	3.5
1975	454	71.8	21.1	2.5	4.6
1982	619	73.9	18.7	2.6	4.8

tce = tons coal-equivalent.

have meteorological conditions unfavorable to pollutant dispersion, such as Chongqing and Guiyang in the southwest, SO_2 concentrations in air are always rather high. In northern cities, SO_2 levels generally rise during the winter season as more coal is burned for heating and the meteorological conditions become adverse. Sulfur dioxide concentrations in most southern cities, rural areas, and northern cities during the off-heating period are rather low (Table 10.2). Monitoring data demonstrate that the concentration of NO_x in air remains low throughout the country, commonly not exceeding 50 $\mu g/m^3$ (counted as NO_2), except in the vicinity of busy main streets in big cities.

Unfavorable meteorological and topographical factors are often responsible for heavy air pollution. Figure 10.2 demonstrates atmospheric dispersion capacity in different regions of China (Dahai *et al.*, 1982). Guizhou and eastern Sichuan provinces have the lowest atmospheric dispersion capacity.

10.3 GEOGRAPHICAL DISTRIBUTION OF ACID RAIN

Environmental monitoring data gathered thus far demonstrate that acid rain does occur in some parts of China. About 90% of the sampling sites with an annual average pH of rainwater below 5.6 are situated to the south of the Yangtze River (Zhenran, 1985). Those with the lowest rainwater pH are in the cities of Chongqing, Sichuan province and Guiyang, Guizhou province, and in neighboring areas in the southwest. Table 10.3 shows rainwater acidity in some cities of China, and Figure 10.3 shows the distribution of rainwater pH in the southwest in August 1982.

In those southern cities with acid rain, some have heavy SO_2 pollution, while others have low SO_2 levels. In some of the northern cities there are high SO_2 emissions with serious pollution, but no acid rain. Beijing and

Table 10.2 Atmospheric pollution levels in some Chinese cities

Region	City, year		July average	December average	Annual average	Reference
Total Suspended Particulates ($\mu g/m^3$)						
North	Beijing,	residential, 1983	251	552	383	Ministry of Health, 1984
		clean, 1983	177	290	236	Ministry of Health, 1984
	Shenyang,	residential, 1983	206	821	517	Ministry of Health, 1984
		clean, 1983	125	314	245	Ministry of Health, 1984
South	Shanghai,	residential, 1984	227	172	212	Ministry of Health, 1985
		clean, 1984	141	116	151	Ministry of Health, 1985
	Guangzhou,	residential, 1984	116	204	161	Ministry of Health, 1985
		clean, 1984	96	132	92	Ministry of Health, 1985
	Guiyang,	residential, 1982	863	840	898	Zhao and Xiong, 1988
		clean, 1982	160	147	159	Zhao and Xiong, 1988
	Chongqing,	residential, 1982	480	870	610	Zhao and Xiong, 1988
		clean, 1982	–	130	60	Zhao and Xiong, 1988
SO_2 ($\mu g/m^3$)						
North	Beijing,	residential, 1983	17	354	127	Ministry of Health, 1984
		clean, 1983	6	52	186	Ministry of Health, 1984
	Shenyang,	residential, 1983	13	209	132	Ministry of Health, 1984
		clean, 1983	15	72	47	Ministry of Health, 1984
South	Shanghai,	residential, 1984	14	109	68	Ministry of Health, 1985
		clean, 1984	9	12	16	Ministry of Health, 1985
	Guangzhou,	residential, 1984	64	55	57	Ministry of Health, 1985
		clean, 1984	15	19	18	Ministry of Health, 1985
	Guiyang,	residential, 1982	403	419	393	Zhao and Xiong, 1988
		clean, 1982	64	109	88	Zhao and Xiong, 1988
	Chongqing,	residential, 1982	170	380	260	Zhao and Xiong, 1988
		clean, 1982	20	40	20	Zhao and Xiong, 1988

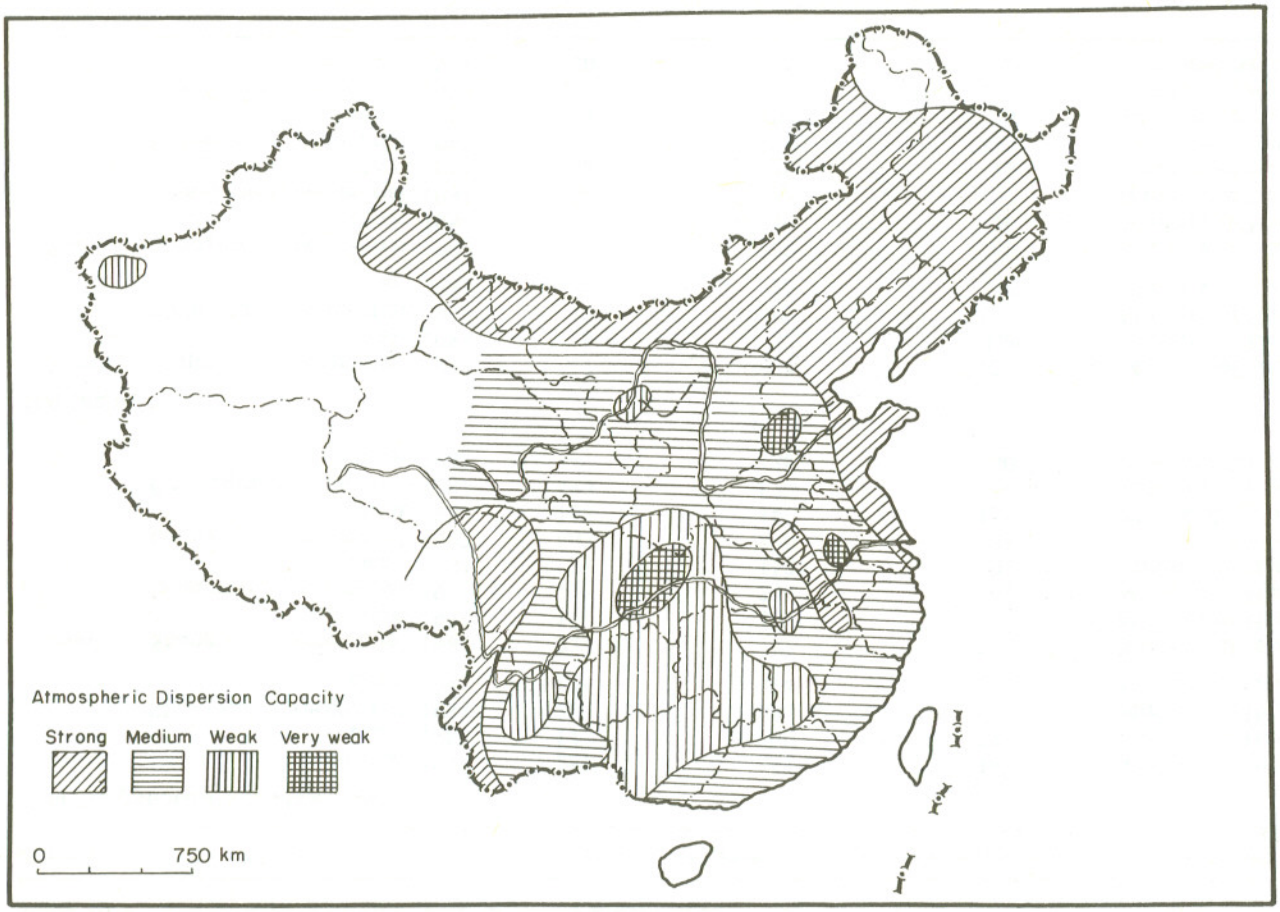

Figure 10.2 Atmospheric dispersion capacity of China based on mean wind speed frequency (Dahai *et al.*, 1982)

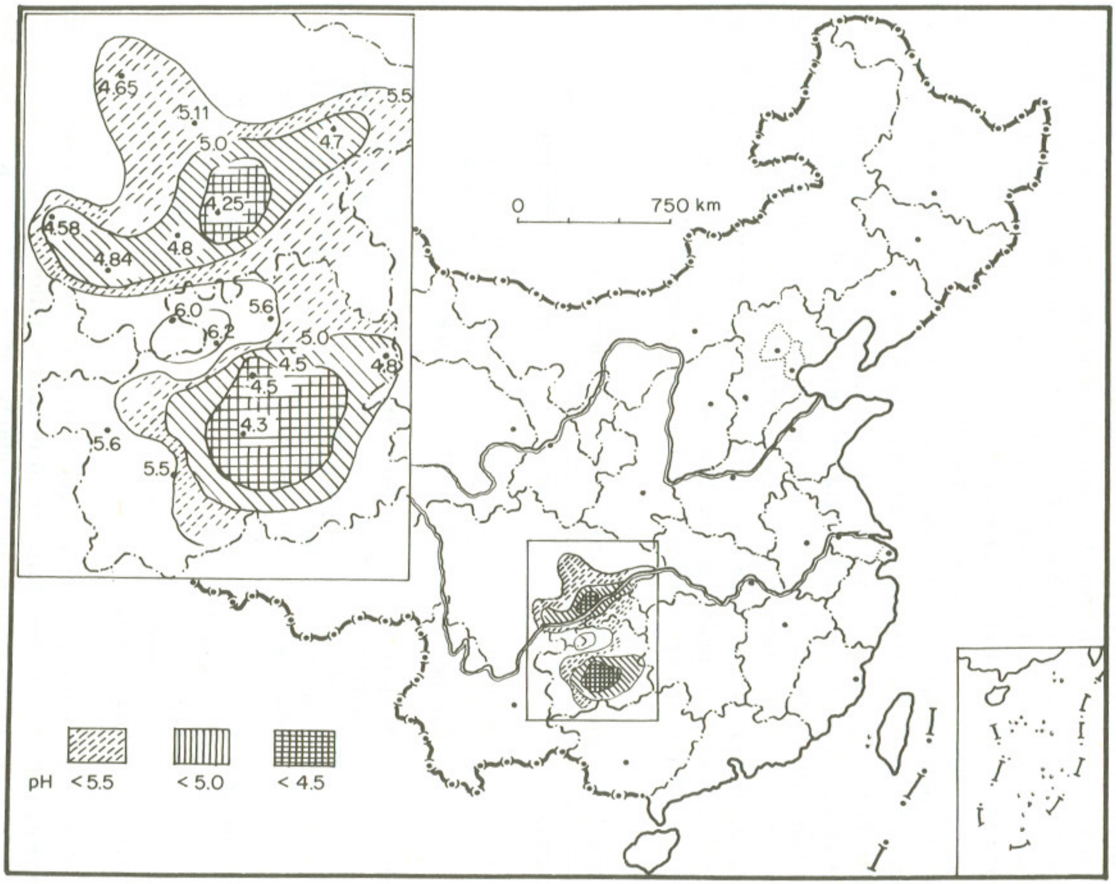

Figure 10.3 Geographic distribution of rain pH in southwest China, August 1982

Tianjin are typical examples. It can thus be inferred that formation of acid rain depends not only on the presence of SO_2, but also on other factors (Zhao *et al.*, 1985).

Spatial distribution of acid rain is, in most cases, similar to that of SO_2; that is, heavy in urban areas but light in suburban and rural areas. Thus, it may be speculated that the acid rain in China is mainly sulfuric acid from local SO_2 emissions. Contribution of long-range transport of acidification substances has not been documented.

Table 10.4 shows the chemical composition of acid rain and nonacid rain in some cities of China. In Chongqing and Guiyang anions and cations in rainwater generally have similar concentrations (differences of less that 10%). The measured conductivity is approximately equal to that calculated (Table 10.5). Figure 10.3 shows the geographic distribution of rain pH.

Table 10.4 indicates that the concentration of $C1^-$ is more or less similar to that of Na^+, implying that the two elements may originate mainly from seasalt, but contribute little to acidity. The major anions are SO_4^{2-}, while Ca^{2+} and NH_4^+ are major cations. This means that rain acidity is determined by the relative strength of SO_4^{2-} on the one hand and Ca^{2+} and NH_4^+ on the other.

Table 10.3 Average rainwater pH in several Chinese cities

Location	City	Year	pH	References
North	Beijing	1981	6.8	Zhao *et al.*, 1985
	Tianjin	1981	6.26	Zhao *et al.*, 1985
	Lanzhou	1981–1982	6.85	Pin *et al.*, 1983
South	Nanjing	June–Nov. 1981	6.38	Mulin *et al.*, 1984
	Hangzhou	Sept.–Dec. 1981	5.10	Mulin *et al.*, 1984
	Wuhan	Jan.–July 1983	6.44	Yanyi and Dehui, 1983
	Fuzhou	May 1982	4.49	Tianlin *et a.*, 1984
	Nanning	May–Dec 1981	5.74	Mulin *et al.*, 1984
Southwest	Yibin	1982	4.87	Zhao *et al.*, 1985
	Chongqing*	1982	4.14	Zhao *et al.*, 1985
	Guiyang*	1982	4.02	Zhao *et al.*, 1985

* Volume-weighted averages

A comparison of the chemical composition of acid rain and nonacid rain reveals that they do not differ much in concentrations of the anions SO_4^{2-} + NO_3^- but in the content of the cations Ca^{2+} + NH_4^+ + K^+. Thus, the formation of acid rain depends not only on the acid present in rain, but also to a great extent on the amount of alkaline matter acting as a neutralizing agent, which perhaps plays a decisive role in the resulting acidity of precipitation.

Table 10.4 Concentration of major ions in rainwater samples (microequivalent per liter)

Ions	North (1981)			South (1982–1984)				
	Beijing, urban	Beijing, suburban	Tianjin, urban	Guiyang, urban	Guiyang, suburban	Guiyang, rural	Chongqing, urban	Chongqing, rural
pH	6.8	—	6.3	4.07	4.42	4.58	4.14	4.44
H^+	0.2	—	0.5	84.5	37.9	26.3	72.4	36.3
SO_4^{2-}	273.1	131.0	317.7	411	281	167	307	165
NO_3^-	50.2	16.0	29.2	21	25.3	15.9	31.6	18.0
Cl^-	157.4	178.9	183.1	8.2	11.8	21.1	15.0	23.9
NH_4^+	141.1	76.1	125.6	78.9	49.2	50.6	106	64.1
Ca^{2+}	184.0	124.5	287.0	231.2	198	87.7	110	42
Na^+	140.9	117.8	175.2	10.1	11.2	5.9	51.4	45.4
K^+	40.2	24.6	59.2	26.4	10.5	7	7.4	23.4
Mg^{2+}	—	—	—	56.5	44.6	29.4	48.3	18.3
$\Sigma(-)$	480.9	325.9	530.0	440.2	318.1	204	353.6	206.7
$\Sigma(+)$	508.3	343.1	647.0	487.6	351.4	206.9	395.5	229.5

Table 10.5 Theoretical and measured conductivity (μmho/cm)

City		Theoretical	Measured
Chongqing,	urban	67	66
	suburban	42	46
Guiyang,	urban	80	66
	rural	21	20

10.4 AIR POLLUTION IN GUIZHOU PROVINCE

Guizhou and Sichuan provinces are located in southwestern China with the Qinling Mountains to the north and the Hangduan Mountains to the west. These mountains prevent cold north and southwestern air currents from the Bay of Bengal from entering this region. The sea is some distance away and the typhoons do not reach this far inland, so the region has a very low air dispersion capacity. Consequently, most air pollutants produced in the area are removed by wet and dry deposition within the same region.

Coal is the main energy resource in Guizhou and is burned mainly in cities in small stoves and medium-sized boilers with low smokestacks. The coal mined and used in the area has a sulfur content as high as 3–5%, the highest in China.

Most of the cities of Guizhou are located in river basins or valleys with weak winds making pollutant dispersion difficult. Temperature inversion is also common in Guiyang. For example, inversion appears 8 of every 10 days, and nearly every day from October to May. At that time SO_2 levels may reach 0.5–1.0 mg/m^3.

Generally speaking, SO_2 concentrations in air in central Guizhou are higher in urban areas than in suburban and rural areas. The SO_2 concentration in air decreases rapidly with distance from the city and reaches about 20–50 μg/m^3 in rural areas and 13 μg/m^3 in Fanjin Mountain, a natural reserve far away from human activities in Guizhou (Xiong *et al.*, 1986). However, SO_2 levels in winter are 2–3 times those in summer, both in cities and in suburban areas.

Concentrations of NO_x tend to be lower than SO_2 concentrations by 1–2 orders of magnitude. In the urban areas of Guiyang, for example, the average NO_x concentrations in 1981 were 14 μg/m^3 in the spring, 34 μg/m^3 in the summer, 44 μg/m^3 in the autumn, and 10 μg/m^3 in the winter.

10.5 ACID DEPOSITION IN GUIZHOU PROVINCE

Rain samples have been collected and analyzed for acidity and chemical composition in Guizhou since 1981. Figure 10.4 shows the location of rain sampling sites in 1983–1984. The Environmental Monitoring Center of Guizhou measured pH at 11 sites while pH, conductivity, and nine chemical constituents of event rain samples at nine GIEP sites (Table 10.6) were measured by the Guizhou Institute of Environmental Science and the Institute of Environmental Chemistry, Chinese Academy of Sciences.

Table 10.6 Mean precipitation pH and ionic concentrations at some GIEP sites in Guizhou province, 1984 (units: μeq/liter)

Site	pH	SO_4^{2-}	NO_3^-	Ca^{2+}	NH_4^+
Guiyang, urban	3.95	444	10.3	256	57
Luizhang, rural	4.68	143	9.1	165	30
Keyang, rural	4.56	163	20.8	132	87
Shisun, rural	4.65	97	15.9	73	38

Note: Wet-only sample for each rain event; volume-weighted averages

In general SO_4^- concentrations in rain in urban areas range from 200 to 400 μeq/liter, about the same as in other regions (see Chongqing, Beijing, and Tianjin in Table 10.4). Concentrations of SO_4^{2-} in suburban and rural areas are much lower, generally in the range of 80–150 μeq/liter. Rather high SO_4^{2-} levels in rainwater for 1984 in rural areas may be due to abnormal weather patterns. Concentrations of NO_3^- are in the range of 10–12 μeq/liter, an order of magnitude lower than for SO_4^{2-}. There is almost no perceivable difference between urban and rural areas. It may be concluded therefore, that NO_3^- contributes little to precipitation acidity in this area.

Table 10.7 shows monthly averages of rain pH at some sites in central Guizhou in 1984. It is clear that acidity is high in winter but low in summer, high in urban areas but low in rural areas. This is similar to the temporal and spatial distribution of many air pollutants.

Snow has lower acidity than rain, as shown by measurements made in Guiyang (Table 10.8). This might be explained by the fact that the washout efficiency of snow is lower for gaseous SO_2 and higher for particles than that of rain (Xiong *et al*., 1984).

The seasonal and annual wet sulfur depositions have been calculated on the basis of respective rainfall amounts. Acid deposition does not differ much between winter and summer except at a few sites that have slightly higher values in winter. Sulfur deposition is also about the same in winter and in summer.

Table 10.7 Mean monthly precipitation pH at different sites in Guizhou, 1984

Site	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Guiyang, urban	3.9	4.0	3.8	4.1	4.0	4.5	4.5	4.1	3.7	3.8	3.7	3.4
Luizhang, rural	4.3	4.4	4.4	4.2	4.5	4.9	4.9	4.6	4.8	4.3	5.4	5.4
Keyang, rural	4.3	4.1	4.2	4.6	4.6	5.4	5.1	4.5	4.5	4.6	4.5	4.3
Shisun, rural	5.9	4.3	3.9	4.7	4.3	5.1	4.7	4.5	4.4	4.5	4.7	4.7

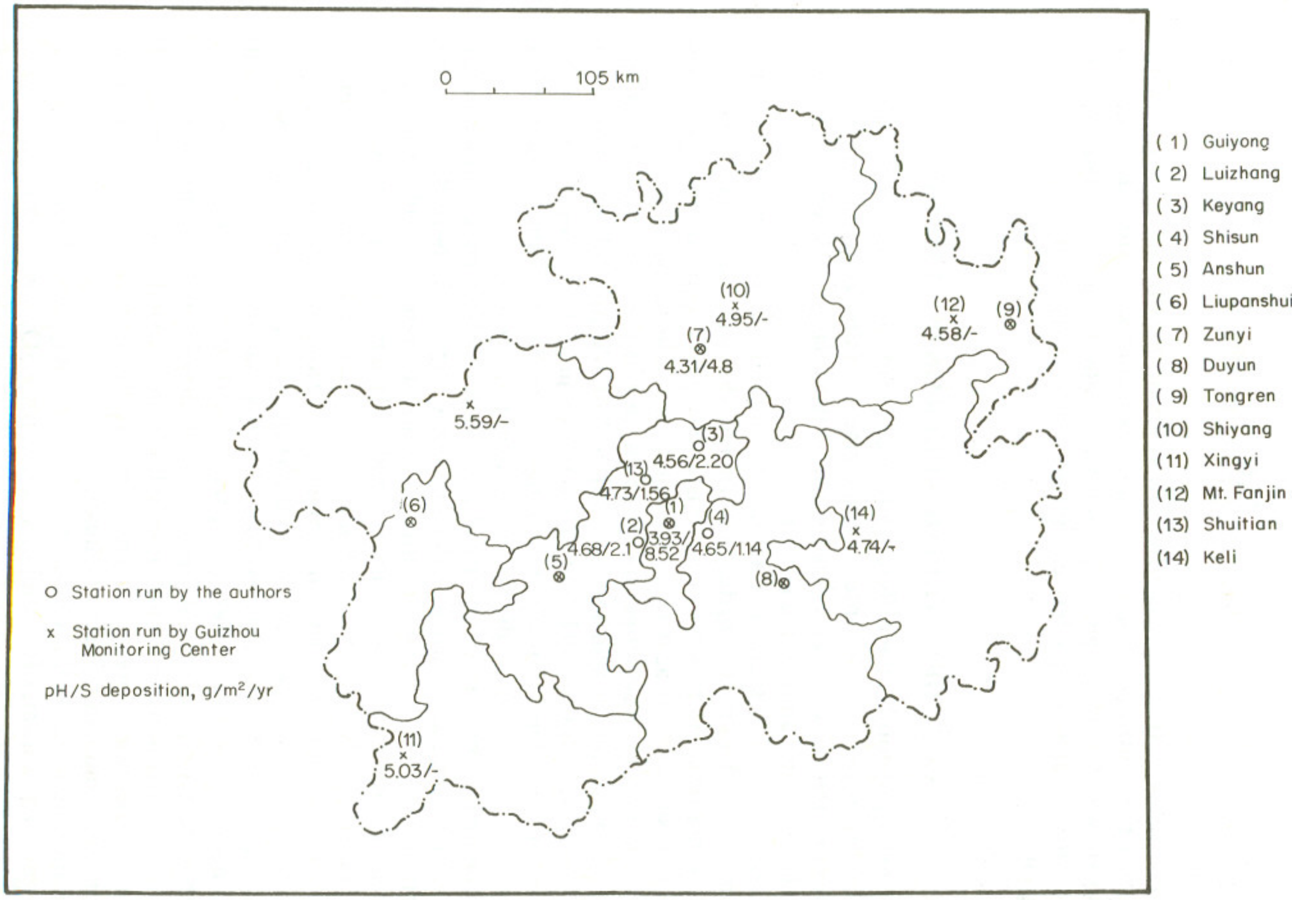

Figure 10.4 Location of precipitation chemistry stations in Guizhou province, 1983–1984

Figure 10.5 is a map of sulfur deposition calculated using the simple model formulated by Rodhe (Rodhe, 1972):

$$di(r) = \frac{4f_1Q}{\pi r_{01}} \cdot \frac{1}{r} e^{-r/r01}$$

where $r_{01} = 300$ km, considering low emission height and high precipitation in the southwest. For comparison, measured wet sulfur deposition is also shown. The total calculated sulfur deposition is greater than real wet deposition values with a few exceptions, particularly in areas containing a big city.

10.6 FORMATION OF ACID RAIN IN GUIZHOU

As noted previously, the difference between acid rain and nonacid rain depends mainly on cation content rather than on anion content (Table 10.4). Thus precipitation acidity is determined by the balance between sulfuric and nitric acids, and ammonia and alkaline dust.

Table 10.9 shows concentrations of ammonia in the air of Guiyang, Chongqing, Beijing, Chengdu, and Tianjin (Shuwei and Yugin, 1985). A difference of about a factor of ten exists among NH_3 concentrations in cities with versus without acid rain. This finding is consistent with ammonium levels in rain in these cities, and gives an idea of the role played by atmospheric ammonia in acid rain formation. Volatilization of ammonia from soil increases with soil pH. Soil pH in the Beijing/Tianjin region lies in the range of 7–8, while in Guizhou the range is 5–6. This explains why ammonia concentration is high in the north and low in the south.

The pH and buffering capacity of particulates in Guiyang are much lower than in Beijing, as shown in Table 10.10 and Figures 10.6–10-8, where the vertical axis gives the acid quantity consumed by buffering substances, and the horizontal axis the acid quantity added. When the slope of the buffering curve equals 1, all the acid added is consumed by alkaline matter in particles and the pH does not change. Zero slope means that the sample solution no longer possesses any buffering capacity. It may be concluded from Table 10.10 and Figures 10.6–10.8 that samples from Guiyang and Chongqing have low buffering capacities, with the exception of particles with a diameter greater than 7 μm. These findings imply that, in addition to high SO_2 emissions, low atmospheric buffering capacity can be considered another, perhaps more important, factor in the formation of acid rain in central Guizhou and eastern Sichuan.

Experiments on below-cloud scavenging of SO_2 carried out in Guiyang suggest that rainwater H^+ primarily comes from SO_2 absorbed by raindrops. This is indicated by the similar spatial and temporal distributions of H^+ and

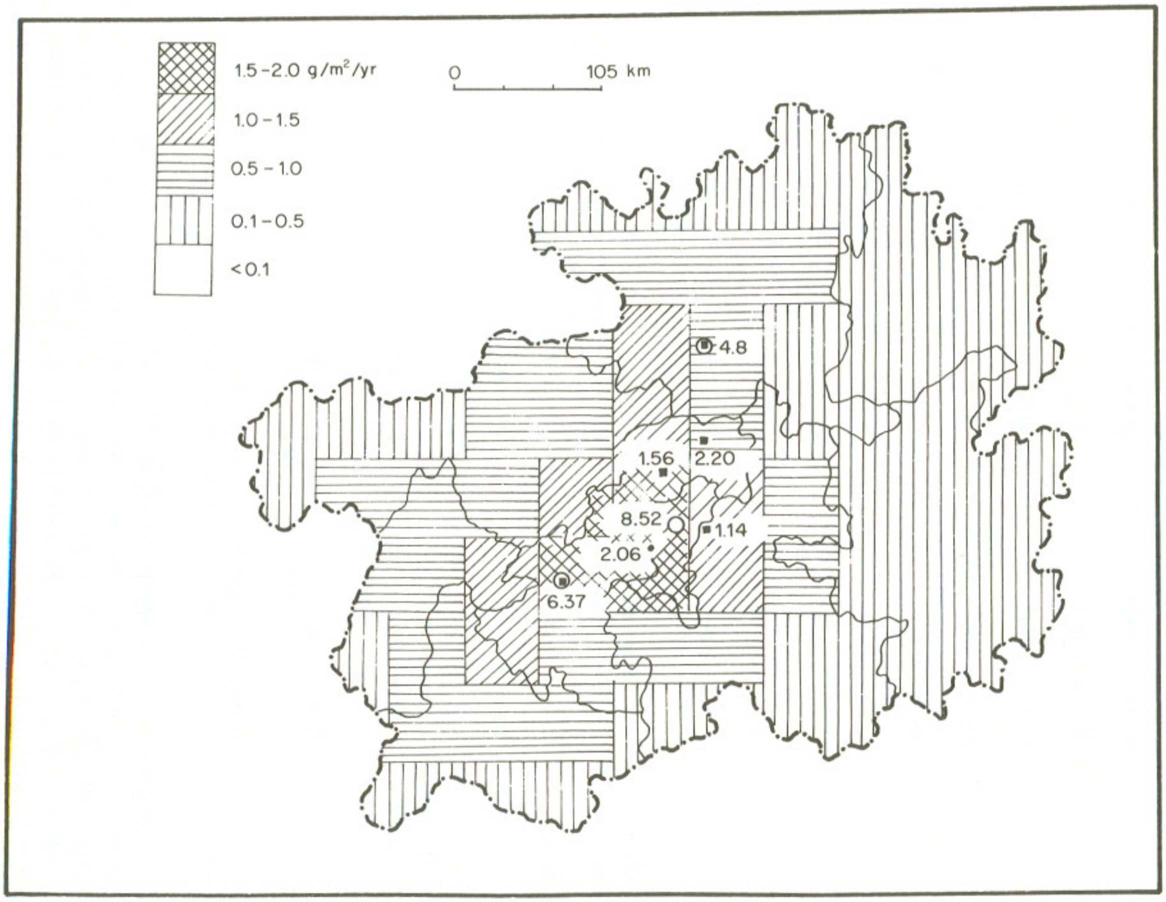

Figure 10.5 Estimated sulfur deposition; figures on map indicate measured wet deposition of sulfur, 1982–1984

Table 10.8 Acidity of rain and snow in urban areas of Guiyang

Date	Weather	pH
8 Dec., 1982	Rain	3.3
9 Dec., 1982	Rain	3.5
10 Dec., 1982	Rain	3.5
11 Dec., 1982	Rain	3.6
26 Dec., 1982	Snow	4.5
6 Jan., 1983	Rain	3.2
7 Jan., 1983	Rain	3.6
9 Jan., 1983	Snow	5.8
12 Jan., 1983	Snow	5.7
15 Jan., 1983	Rain	3.5

Table 10.9 Measured gaseous ammonia in air

Region	City		Year/month	Mean NH_3 (ppbv)	No. of samples
North	Beijing		July 1984	44	10
	Tianjin		July 1984	23	4
Southwest	Chongqing,	urban	Sept. 1984	5.18	16
		rural	Sept. 1984	0.81	4
	Guiyang,	urban	Sept. 1984	3.36	20
		rural	Sept. 1984	2.0	4
	Chengdu,	urban	Sept. 1985	4.8	2

HSO_3^-, two products of the dissolution of SO_2 into raindrops (Figure 10.9) (Zhao *et al.*, 1985). The same experiments indicate, however, that more than two-thirds of the sulfur in rainwater may originate from the washout of sulfate aerosol rather than gaseous SO_2. Monitoring data demonstrate that there are approximate spatial and temporal correlations between sulfate and nitrate in rain, and sulfur and nitrogen oxides in air at ground level.

Concentrations are high in urban areas and during winter, but low in rural areas and during summer. Measured acidity of samples of cloud and rain collected at altitudes of 3,000–5,000 meters above ground at the same sites is apparently lower than that of rain samples collected at ground level.

Table 10.10 pH of sample solution of particles in different size ranges (Spring 1985)

City		Sampling duration (hour)	Diameter (μm)				
			>7	7–3.3	3.3–2	2–1.1	<1.1
Chongqing,	urban	24	7.55	6.37	5.16	4.94	4.49
	rural	24	5.27	4.87	4.97	4.95	4.66
Guiyang,	urban	48	6.37	5.59	5.31	4.86	4.32
	rural	48	6.40	5.80	5.15	4.92	4.58
Beijing,	urban	24	8.24	7.75	7.48	6.64	7.20

Note: Anderson high-volume cascade impactor, 566 liters/min, filter Whatman-41. Sample volume for each filter 200 ml (48 hours), 100 ml (24 hours), blank pH 5.14.

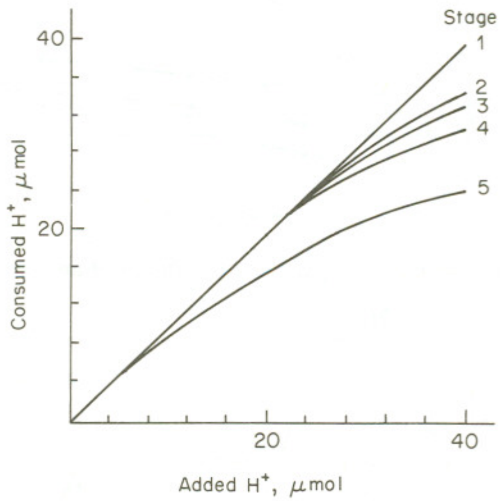

Figure 10.6 Buffering curve of particles of different diameters for Beijing suburban sites Stage 1: >7 μM 2: 7–3.3 3: 3.3–2 4: 2–1.1 5: <1.1

These facts suggest that acid rain in southwestern china is caused mainly by local emission sources. Nevertheless, data from remote regions in Guizhou suggest that precipitation chemistry may be affected in areas several hundred kilometers away from large cities with large emissions.

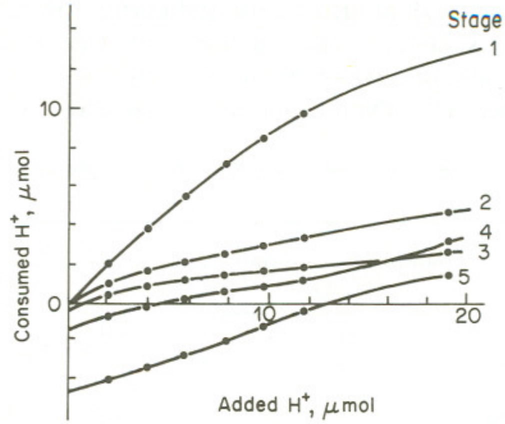

Figure 10.7 Buffering curve of particles of different diameters for Guiyang urban site

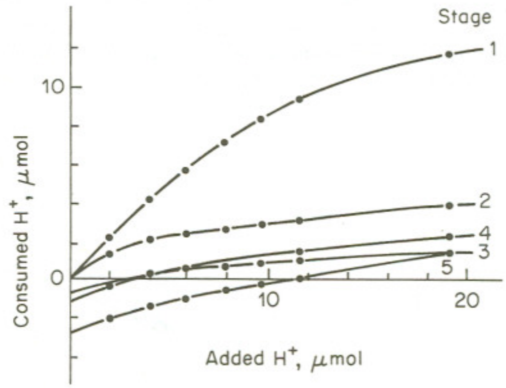

Figure 10.8 Buffering curve of particles of different diameters for Guiyang rural site

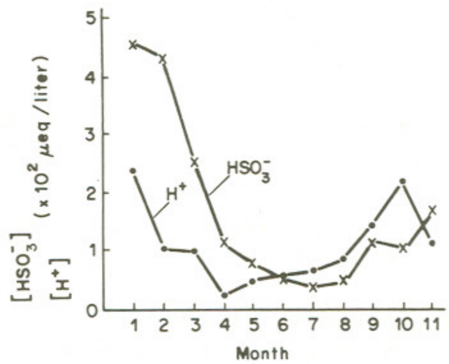

Figure 10.9 Monthly mean concentration of S(IV) and H^+ in rain for Guiyang, 1983.

10.7 ENERGY CONSUMPTION AND ANTHROPOGENIC SO_2 EMISSIONS IN GUIZHOU

Figure 10.10 and Table 10.11 show anthropogenic emissions of SO_2 and NO_x for six southern provinces of China.

Figure 10.11 demonstrates anthropogenic emissions of SO_2 in different prefectures and cities of Guizhou in 1983. The SO_2 emitted from Guiyang, Anshuen, Zunyi, and Duyun, four big cities in central Guizhou, accounts for about half the total SO_2 emissions in the entire province. In the central area, which covers one-third of Guizhou province and includes the four big cities, SO_2 emissions account for more than 80% of the total.

Coal accounted for about 76% of the total energy consumption of Guizhou in 1983 and hydroelectric power about 13%. Energy consumed for domestic and commercial use composes about 30% of the total but is regarded as the major air pollution source in cities. Due to rich coal reserves, a large quantity of coal is burned for heating in Guizhou, and is the major source of the urban air pollution problems.

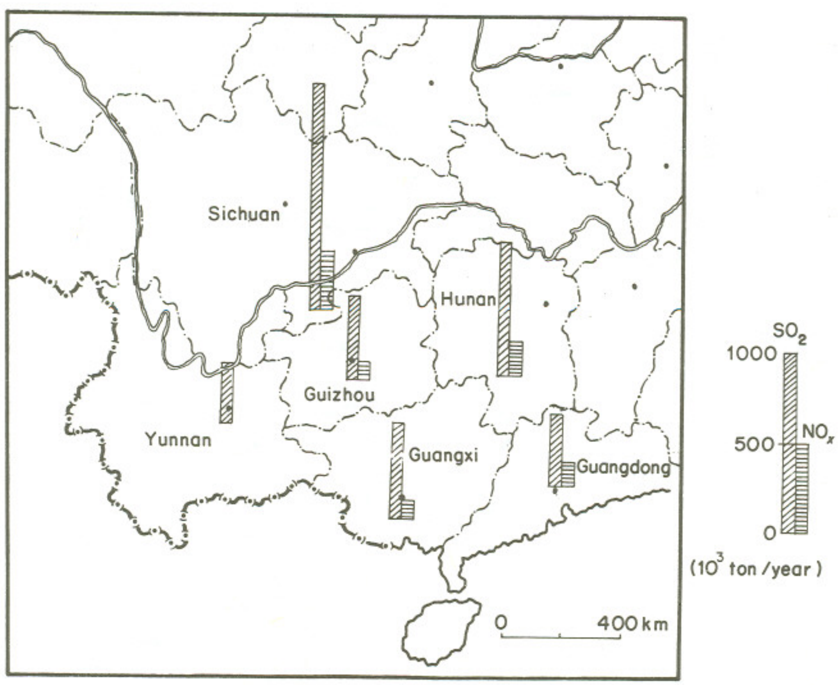

Figure 10.10 Anthropogenic emissions of SO_2 and NO_x for six southern provinces of China

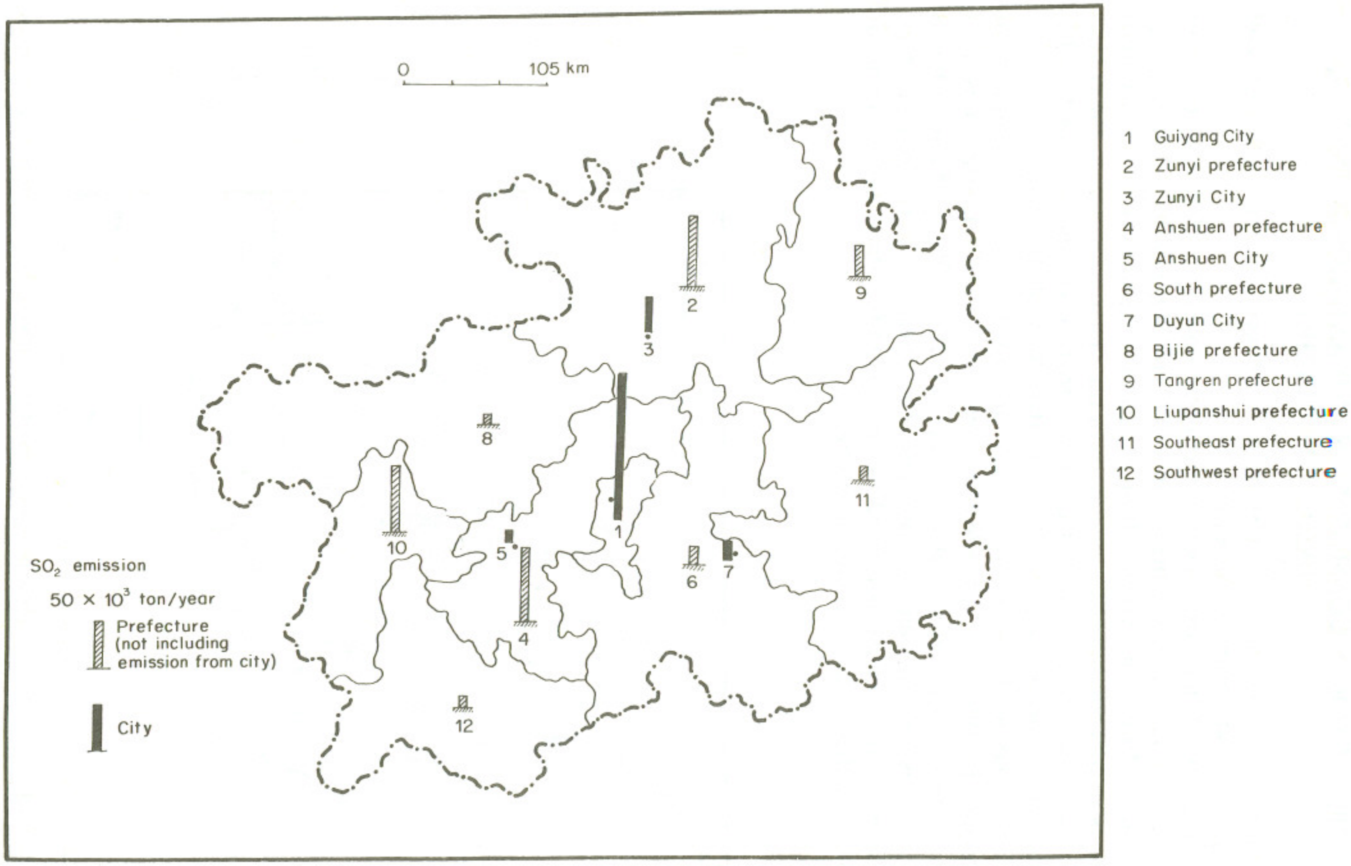

Figure 10.11 Annual anthropogenic SO_2 emissions in different prefectures of Guizhou, 1983

The coal mined in Guizhou is high in sulfur content. On the average, coal for domestic and commercial use has a sulfur content of 2.3–5.3%, and coal for industries 4.3–7.2%. Coal consumed for domestic use in the large cities of central Guizhou, such as Guiyang, Zunyi and Duyun, generally has a slightly higher sulfur content of about 4%.

Table 10.11 Annual anthropogenic SO_2 and NO_x emissions in six southern provinces of China

Province	Emission (10^3 ton)		Emission density (tons/km^2)	
	SO_2	NO_x	SO_2	NO_x
Guizhou, 1983	530	100	3.0	0.6
Sichuan, 1981	1,490	210	2.6	0.4
Yunnan, 1981	370	–	1.0	–
Guangxi, 1981	580	100	2.4	0.4
Hunan, 1981	801	260	3.8	1.2
Guangdong, 1981	365	75	1.7	0.3
All of China	13×10^6	–	<2	–

10.8 PHYSICAL GEOGRAPHY OF GUIZHOU AND EASTERN SICHUAN

Guizhou has an area of more than 170,000 km^2 and a population of 27.8 million. Rising between the Sichuan and Guanxi basins, the entire province is called the Guizhou Plateau. 80% of Guizhou is mountainous. Due to folds, faults and erosion, the plateau is intersected with mountains, hills basins, and valleys, giving it a very rugged topography. Limestone is found in numerous caverns and underground streams.

Guizhou has a humid, subtropical monsoonal climate with warm winters, mild summers, and little seasonal contrast. It has a mean annual temperature of 15–17 °C and a mean annual precipitation of 900–1,500 mm and more overcast days than any other part of the country; the area around Guiyang averages 220 cloudy days per year. (The translation of Guiyang is 'a place where sunshine is a pleasure.')

Sichuan can be divided into two major topographical areas, the Sichuan Basin (eastern Sichuan) and the western Sichuan Plateau. The Sichuan Basin is enclosed on four sides by mountains and the Yunnan–Guizhou Plateau.

It has a humid subtropical monsoonal climate, with mild winters, hot summers, plentiful rainfall and mist, high humidity, and less sunshine (China Handbook Editorial Committee, 1983).

Figures 10.12 and 10.13 provide a general description of Guizhou's physical geography and can serve as a basis for assessing effects of acid rain on ecological systems of the province.

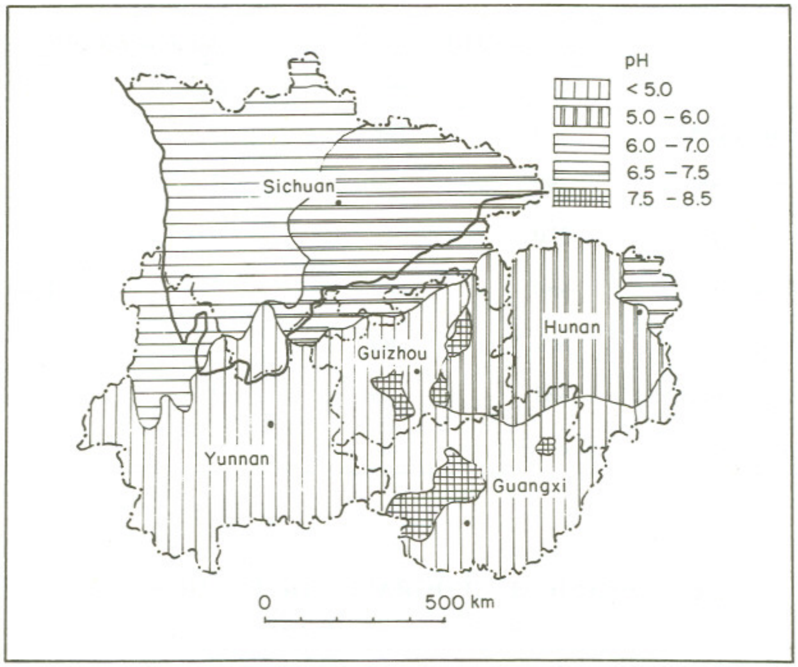

Figure 10.12 Map of soil pH of China (Runhua *et al.*, 1985)

10.9 PRELIMINARY ASSESSMENT OF RESOURCES POTENTIALLY AT RISK IN GUIZHOU AND NEIGHBORING PROVINCES

10.9.1 Soils

Runhua *et al*. (1985) developed a map of soil sensitivity for southern China, including Guizhou, Sichuan, Hunan, and Guangxi provinces, using soil cation exchange capacity (CEC) and soil pH as two parameters and taking residuum into account (Table 10.12) (Runhua *et al*., 1985). Guizhou

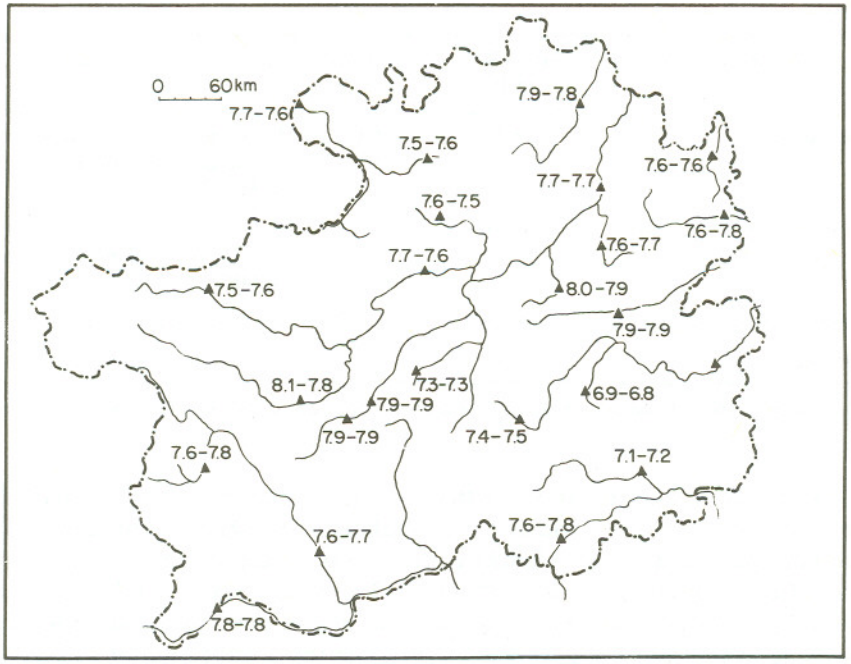

Figure 10.13 Mean surface water pH in Guizhou, 1981–1984

soil can be classified as slightly sensitive to acid rain, while Sichuan soil is basically non-sensitive. Runhua *et al*. (1985) pointed out that:

> Acid rain has been recorded in many cities in south China. Very low pH rain also occurred in some cities. To make the situation even more severe, more than 60% of the entire study area belongs to sensitive and slightly sensitive groups. Poor soil management may possibly accelerate acidification, impoverish soils and lead finally to the collapse of the whole ecosystem.

Acidic soil in southwestern China is mainly Oxisol with low cation exchange capacity and low buffering capacity. Oxisols have been reported to have large anion adsorption capacities (Tianren, 1985), which may reduce sensitivity to acidification or delay effects. Another investigation found that soil in urban areas is generally lower in pH and base saturation than soil in rural areas, and that 'recent data show that the cumulative effect of acidic precipitation has damaged susceptible vegetation as well as soil fertility in the urban district [of Chongqing] where the annual mean pH value of precipitation is 4.12' (Borong, 1985).

Table 10.12 Sensitivity to acid deposition of soils in southern China (Runhua, 1985)

Soil sensitivity	Soil CEC (meq/100g)	Soil pH	Type of residuum
Sensitive	10	6.0	Silica-ferrum residuum or silica–aluminum residuum >80%*
Slightly sensitive	10–16	5.0–7.0	Silica–ferrum residuum or silica–aluminum residuum >60%
Generally non-sensitive	16–25	6.0–7.0	Carbonate residuum >60%
Non-sensitive	25	7.5	Carbonate residuum >80%

* Figures represent the percentage of the area of residuum in the entire area researched.

Field experiments demonstrate that the pH of acidic soil could be made to decrease under frequent additions of simulated rain (pH 3) during the whole growing period of wheat (Yanchi *et al*., 1985). In the southwest, rainfall is plentiful, amounting to more than 1,000 mm/year. In general, the more rainfall, the larger the amount of wet acid deposition and the stronger the leaching in the soil. These processes promote the acidification of the soil.

Acidic yellow soil covers 40% of the Guizhou province. Laboratory tests demonstrate that yellow soil possesses a strong buffering capacity (Ruenxian and Guotei, 1986). Table 10.13 shows the pH and conductivity of leaching solutions into soil and effluent solutions from soil. Effluent solutions from the tested soil samples maintain a rather stable pH value of 5.01–5.21 regardless of the initial pH of the leaching solution. As seen in Table 10.13 the conductivity of effluent solutions is much lower than, and closely correlated

Table 10.13 Buffering capacity of yellow soil in Guizhou (Ruenxian *et al*., 1986)

Leaching solution		Elusion solution	
pH	Conductivity ($\mu\mho$/cm)	pH	Conductivity ($\mu\mho$/cm)
3.8	120.0	5.01	30.0
4.2	46.0	5.17	15.0
5.55	3.1	5.21	12.0
6.9	41.0	5.17	19.0
8.15	380.0	5.04	200.0

to, the leaching solution added to the soil sample. Yellow soil has a strong absorbing capacity for ions, probably both cations and anions, in leaching solutions. Thus, acid rain may not have a significant acidifying effect on the yellow soil or surface waters in Guizhou in the near future.

10.9.2 Forests and Crops

There are vast forests in the mountain areas of the northwestern Sichuan Basin and Guizhou is one of China's best-known spruce producers. A few reports cite evidence of forest damage in Chongqing city (Sichuan province) and suggest that long-term exposure to acid rain might be partly responsible, at least indirectly, for the damage found there.

On Nanshan Mountain in the south of Chongqing, about 20 km from urban areas, two thousand hectares of *Pinus massoniana* 'Masson Pine' have been planted. In 1982, dieback began and about half have withered so far. It seems likely that the remainder will also be affected. One report (Shuwen *et al*., 1985) holds that: 'diseases and insect pests are the direct cause of the forest dieback, while air pollution and acid rain are the inducers for the explosion of diseases and insect pests.'

Another survey (Chuying, 1985) carried out in the Chongqing area put forward the following ideas:

(1) rain pH is a dominating factor affecting growth and yield of *Pinus massoniana* in the region of Chongqing.

(2) Acid rain primarily damages needles of *Pinus massoniana*. The chlorophyll content of *Pinus massoniana* in the region with rain pH > 4.5 was higher than that in the region with rain pH < 4.5.

(3) Total biomass and net production were, respectively, 40.81 tons/ha, 2.23 tons/ha/year for 18-year olds in regions with rain pH < 4.5, and 103.74 tons/ha, 8.72 tons/ha/year for 19-year olds in regions with rain pH > 4.5.

(4) Damage of acid rain to the biological productivity was estimated as 52–59%.

Forests in Guizhou are probably experiencing similar injuries. Surveys in progress will provide more information.

On several occasions in Chongqing, large areas of paddy rice have suddenly turned yellow after a rain of pH < 4.5. The causes have not been clearly determined. Field experiments on wheat growth under simulated acid rain in Chongqing's rural farmland showed that in the middle and late growth periods, rainfall of pH 3.5 might cause acute injury to wheat and decrease yield and quality. Simulated acid rain of pH 4.5 could also inhibit wheat growth and eventually lower yields.

10.9.3 Water

Hydrochemical data on streams in the southwest show that at present none can be regarded as acidified. No noticeable changes in stream chemistry could be found after comparing data from 1981 with that of 1984. However, HCO_3^- concentrations in a few stations in southeastern Guizhou seem to be lower than in other parts of the province. It is not yet clear whether acidified streams exist in mountains known to be vulnerable to acidification.

10.9.4 Materials

In southwestern cities with heavy acid rain, such as Guiyang and Chongqing, metals, concrete and stone works are undergoing rapid and severe corrosion. In Guiyang and Chongqing, metal structures are scraped of rust and painted once every 1–3 years. Shells of buses are generally replaced every 1–2 years. Structural components made of stainless steel become rusty after a few years. Some concrete works built in the 1950s have corroded in such a manner that the gravel is exposed. It is estimated that the corrosion depth reaches 0.5 cm in less than 30 years. Atmospheric SO_2 and acid rain are both possible causes of materials damage; however, surveys revealed that the surface directly facing the prevailing wind, and thus receiving more acid rain, was more significantly corroded.

Nanjing in Jiangsu province is a city very similar to Chongqing and Guiyang in terms of temperature, humidity, and rainfall, but with far less air pollution and rain acidity. The rate of metal corrosion there is apparently lower than in Chongqing and Guiyang by at least a factor of two. The difference in the corrosion of concrete works is even greater; buildings completed in the 1930s in Nanjing remain unaffected.

10.10 TRANSPORT OF ANTHROPOGENIC EMISSIONS

Acid rain in Guizhou can be considered a predominantly local phenomenon. This is due to low emission heights and frequent rains which rapidly scrub acidifying substances from the air. Therefore, most of the acid deposition seems to occur in urban areas where emission sources are concentrated and in adjacent suburban and rural regions. Apart from the reasons mentioned in the foregoing discussion, this concept was confirmed by cluster analysis based on rain chemistry in different monitoring sites.

Cluster analysis based on ionic contents in rainwater divides the sampling sites of Chongqing and Guiyang into two groups and further divides urban and suburban sites into subgroups (Zhao *et al.*, 1986). This implies a clear difference in precipitation chemistry between two cities only a few hundred kilometers apart and even between urban and suburban areas of the same city.

It should be stated that long-distance transport of air pollutants is by no means nonexistent. Levels of SO_2 in air and SO_4^{2-} in rainwater and particulates measured at the top of Fanjin Mountain (a natural reserve in northeastern Guizhou) (Figure 10.4), reach 13 $\mu g/m^3$, 18 μeq/liter, and 8 $\mu g/m^3$ respectively. These values are low, but higher than global background readings. Thus, the air quality of Fanjin Mountain is markedly influenced by dense emission areas located several hundred kilometers away in central Guizhou, Hunan province or eastern Sichuan (Xiong *et al.*, 1986).

Although long-distance transport of acidifying substances probably does not yet play a significant role with respect to acid rain formation, many large coal-fired power plants and factories with tall stacks will be built in the near future. Consequently, sulfur emissions will probably increase considerably, despite control measures. Should this happen, sulfur may be transported some hundreds or even thousands of kilometers, endangering the ecosystems of vast areas.

Figure 10.14 shows emissions and prevailing surface winds in relation to sensitive regions in southern China. Large rural areas in the southwestern Guizhou and Yunnan provinces might be victims of sulfur emissions generated in central Guizhou, Hunan, and eastern Sichuan. There is almost no acid rain to date in Yunnan province due to its low industrialization and use of coal with a low sulfur content. On the other hand, its soil is highly sensi-

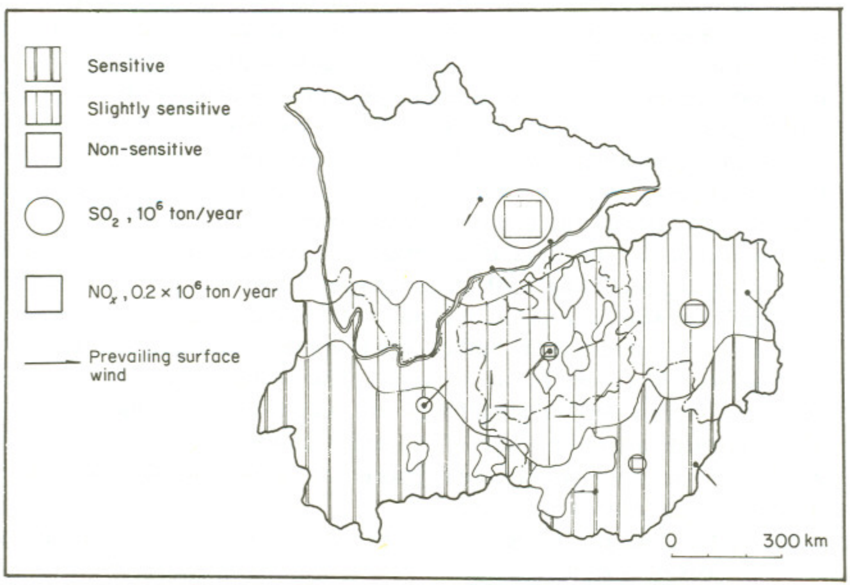

Figure 10.14 Emission sources and prevailing winds in relation to sensitive regions in southern China

tive to acidification and 'has been called a botanical garden' for its abundant plant life of 15,000 plant species, more than any other province in China. It is one of the country's three major forest areas, with more than nine million hectares yielding many precious timbers (China Handbook Editorial Committee, 1983). Serious attention should be given to consequences related to the possible long-distance transport of sulfur emitted from central Guizhou, Hunan, and eastern Sichuan.

10.11 CONCLUSIONS

During the course of the case study, some gaps in knowledge and weaknesses in research were found. The most important ones seem to be a lack of information on rural areas, particularly concerning damage to ecosystems caused by acid deposition. In order to obtain a better understanding of acid deposition, acidification of the environment, and the ecological effects in Guizhou and southwestern China, the following recommendations are made:

1. Design and implement a monitoring network covering the whole study area with sampling sites in rural and background areas. It should be equipped with reliable automatic wet-only precipitation samplers and run by qualified personnel. All the samples collected should be preserved, treated, and analyzed using national or international standards. Air pollutants, such as SO_2, NO_x, and aerosol, should also be monitored regularly.
2. Organize and conduct a comprehensive survey of soils, waters and forests in the study region to see whether acidification and damage already exist, to assess the sensitivity of soils and waters in various parts of the region, and to estimate the potential risk to the ecosystems.
3. Research the major pathways of acid rain formation, the relative contributions of local and distant sources, as well as of different source types. Measure acidity and the chemical composition of clouds and fog.
4. Devise a reliable inventory of emission sources and quantities of sulfur and nitrogen, including both anthropogenic and natural sources. It is reported that wood is a dominant fuel in the vast countryside of Guizhou, amounting to about seven million cubic meters each year. In addition, a large area of forest burns annually. Therefore, sulfur and nitrogen generated from wood burning, forest fire, and natural biological activities may constitute a large portion of the sulfur and nitrogen budgets for the whole province and should not be ignored when studying the acidification problem, especially in rural areas.
5. Measure the background levels of sulfur and nitrogen oxides in air and identify possible origins.
6. Try to measure or estimate the dry deposition of sulfur and its effects on ecosystems and materials.

7. Set up special classes in universities to train technicians for collecting, handling, and analyzing samples in order to obtain reliable data. Encourage more scientists to take part in research. Establish standard procedures and methods of sample collection and chemical analyses in order to obtain reliable and comparable data.
8. Work out a plan for further studies of the acidification problem in southwestern China including at least the Guizhou, eastern Sichuan, Hunan and Yunnan provinces. Considering the potential risk of ecological damage in this region and the large number of questions that remain to be answered, the work of this case study should be only the beginning.

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