Acidification in Tropical Countries
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CHAPTER 8

Acidification in Southeastern Brazil

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8.1 INTRODUCTION

Contemporary studies of the disruption of natural ecosystems by human actions often involve methods determined by local, regional, national, and global concepts of environment. These concepts in turn depend on cultural and historical factors, and specific biological, hydrological, geological, and other factors in the natural environment.

In highly developed countries, concern about air pollution began in cities. In recent years, however, regional studies have also focused on air pollution in rural areas, acidification of rain and snow, degradation of the surface waters, contamination of soils, and pollution of oceans. Pollution studies also are becoming more common in less developed countries as they struggle to develop their industries, social systems, and economies.

In Brazil, environmental concerns are a recent development. Most scientific studies and routine pollution measurements in Brazil are made in and around cities to monitor and restrain the existing pollution. Little attention has been given to dispersion and effects of pollutants in rural areas.

This report describes environmental conditions of the southeastern region of Brazil. Most of the data are recent, incomplete, and, with a few exceptions, refer only to the more industrial and urban areas of the southeastern region. Nevertheless, they constitute a very large part of the data available for the nation of Brazil.

The southeastern region is about 925,000 km^2 in surface area—about 11% of the total surface of the whole country. The area includes four states: São Paulo (248,000 km^2), Minas Gerais (587,000 km^2), Rio de Janeiro (44,000 km^2), and Espírito Santo (46,000 km^2). Brazil's biggest cities, São Paulo and Rio de Janeiro, each have more than 10 million inhabitants. The entire region has more than 50 million inhabitants. The southeastern region is also the most industrialized and economically productive region of Brazil.

Figure 8.1 shows the southeastern region and its most important cities. The relation between urbanization and industrialization is direct: the biggest industrial centers are located in the biggest cities. However, only about 6% of the total region is industrialized. This area comprises a wide band of coastal territory including most of São Paulo state; the metropolitan regions of Rio de Janeiro, Campinas, and Sorocaba; most of the Paraíba valley; and the metropolitan area near Belo Horizonte city. In Figure 8.2 the numbers for each industrial area indicate the total number of plants. No data are available on their use of fossil fuels or their emissions of air pollutants. The industries include: metalworks, chemical industries, food industries, cement, ceramic,

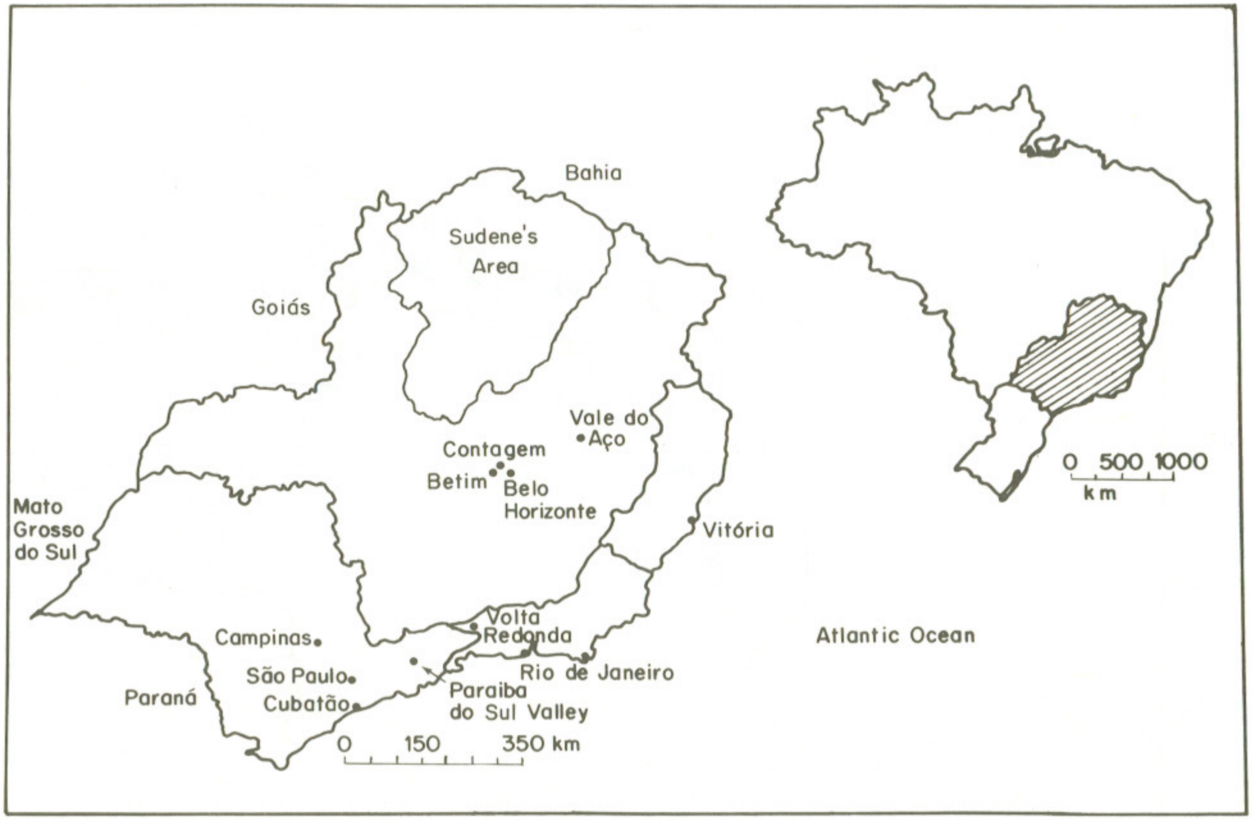

Figure 8.1 Map of the southeastern region of Brazil, showing major cities and locations in Brazil

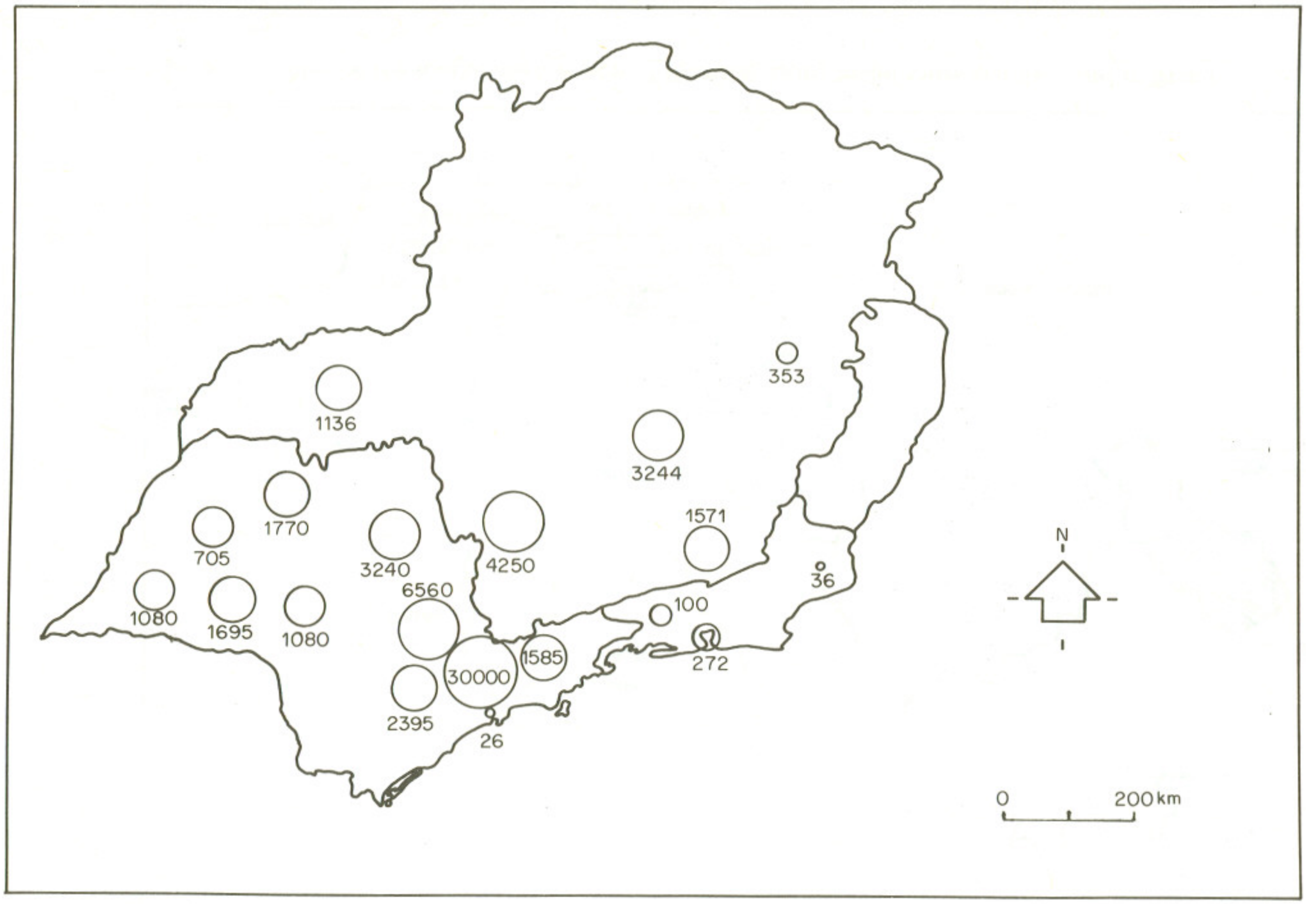

Figure 8.2 Industrial areas of the southeastern region. Numbers in circles indicate number of industrial plants in each region

and producers of non-metallic minerals, pharmaceuticals, and textile and shoe-making industries.

Of the 30,000 industrial enterprises of the Greater São Paulo area, about 50% produce significant amounts of air pollutants compared to nearly all of the enterprises in Rio de Janeiro state. The percentage in Belo Horizonte state is only about 10%.

The data used here come from authorities for pollution control in each of southeastern states: CETESB in São Paulo, the State Organization for Environmental Control (CETEC) in Minais Gerais, and FEEMA in Rio de Janeiro. No data could be obtained for Espírito Santo. The environmental diagnosis of this region is based on incomplete data; thus, any conclusions on environmental conditions drawn from this work must be considered provisional.

These organizations were set up independently and with somewhat different purposes. They all began operations less than 10 years ago, and thus the data are limited and not well coordinated. More complete and well-coordinated data sets on the acidification of the Brazilian environment are expected to become available in the future.

8.2 PHYSICAL AND CHEMICAL CLIMATOLOGY

The position of the southeastern region, between about 15° and 25° south latitude, means that it receives very strong solar radiation, about 0.37 cal/cm^2/min. This strong solar radiation facilitates both rapid evapotranspiration and high rates of photochemical transformation. The southeastern region's rather irregular topography, reaching from sea level to about 1,600 meters, and its close proximity to the Atlantic Ocean, favor relatively large amounts of precipitation.

Winds are dominated by the South Atlantic anticyclone with its high temperature and humidity. The domination of this anticyclone determines the stability of the weather.

Rainy and dry seasons characterize the climate rhythm in southeastern Brazil. The average annual temperature distribution (Figure 8.3) shows the generally warm climate and the influences of latitude, altitude, and proximity to the Atlantic Ocean.

For most of the region, the hottest month is January, and the coolest month June or July. Minimum temperatures in winter result from diminished solar radiation and from more frequent polar air masses. In nearly 60% of the southeastern region at least one month shows an average temperature below 18 °C.

As shown in Figure 8.4, the predominant wind direction is easterly: northeast in Rio de Janeiro state, and east-southeast in São Paulo state (Serra, 1969).

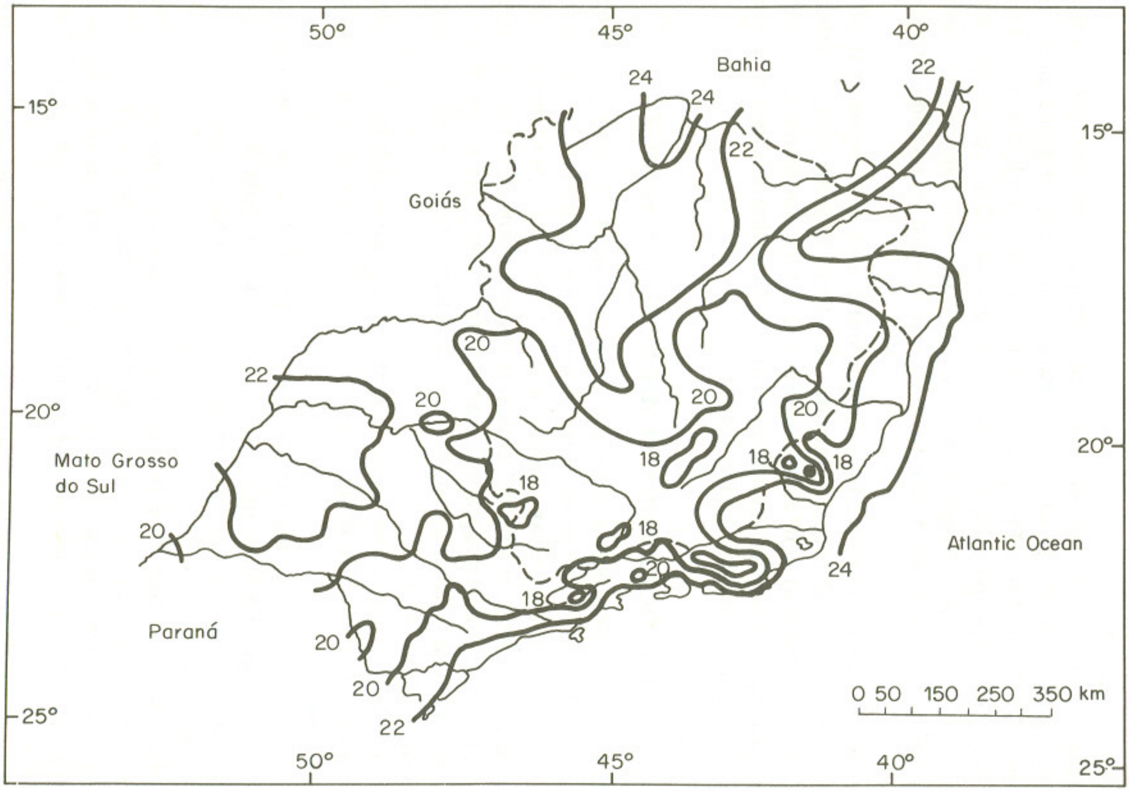

Figure 8.3 Annual average temperatures in southeastern Brazil (Serra, 1969)

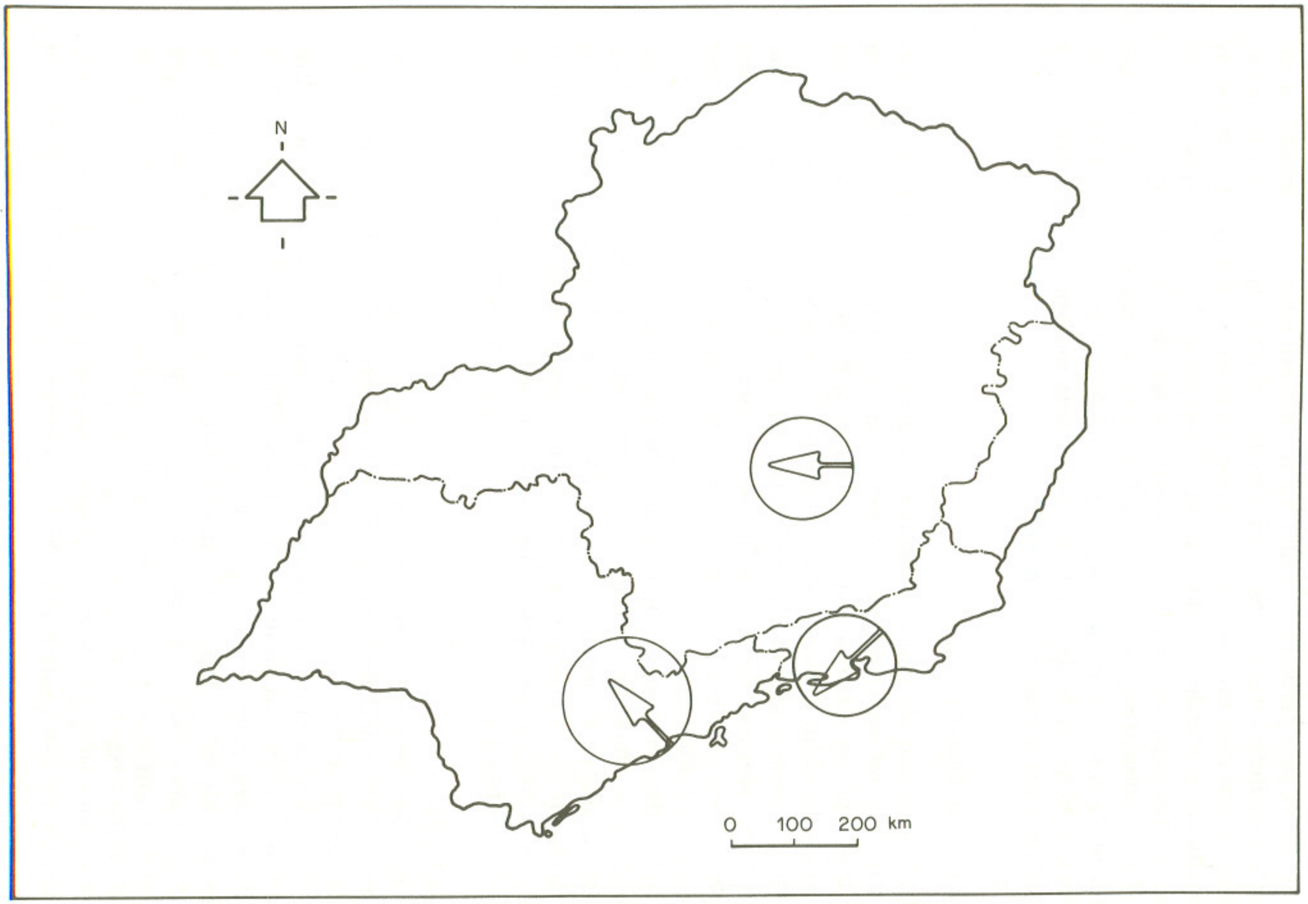

Figure 8.4 Predominant wind directions over the three largest industial areas in the southeast region (Serra, 1969)

The distribution of precipitation across the southeastern region (Figure 8.5) shows two particularly rainy areas: one extending in a southwest-to-northwest direction along the coast, and the second extending in a northwest-to-southwest direction, west of Minas Gerais to Rio de Janeiro. The less rainy Paraíba do Sul Valley (1,200 mm) interrupts these two rainy areas. Most of the southeastern region shows precipitation less than 1,500 mm.

The months of maximum rain are December and January. The minimum precipitation occurs in July, or in June and July. The mean duration of the drought period varies from 0 to 6 months, with most of the southeast having an annual dry season of 2–5 months.

8.2.1 Air Quality

The few existing air quality measurements are concentrated in the southeastern region, but most data are collected within industrial areas. Thus exposure of soils and vegetation in rural areas can only be inferred from data taken in cities. In addition uncoordinated research by independent state organizations has created gaps in the monitoring data and a lack of standardization. For these reasons, the air quality data presented here are for individual states. When possible, however, an attempt is made to synthesize regional air quality information.

Sulfur dioxide is generally measured by the oxygenated water method or coulometry, while the sulfate ion is measured by the lead peroxide plug method, always according to OPS/OMS recommendations. Concentrations of NO_x are determined by a chemical luminescence method. Contents of SO_4^{2-} and NO_3^- in solid suspended matter are measured by the turbidimetric barium sulfate method and the 2.4 xylenol method, respectively.

São Paulo

In this state there are no estimates of air pollutant emissions or of the quantities of sulfur and nitrogen compounds injected into the atmosphere by industrial processes.

Concentrations of SO_2 were measured in 25 cities of the state during two months in 1979, and during six months in 1980. The collections were made daily in most cases, or during a 24-hour period every six days. There are also monthly sulfur deposition rates for 44 cities in this state from July 1978 and December 1979. Amounts of nitrogen compounds were not determined in the atmosphere exept in the Greater São Paulo and Cubatão regions (CETESB, 1985b).

Rainwater NO_3^- and SO_4^{2-} concentrations and pH were determined only in the city of São Paulo and in the Cubatão region (Moreira–Nordemann *et al.*, 1985, 1986).

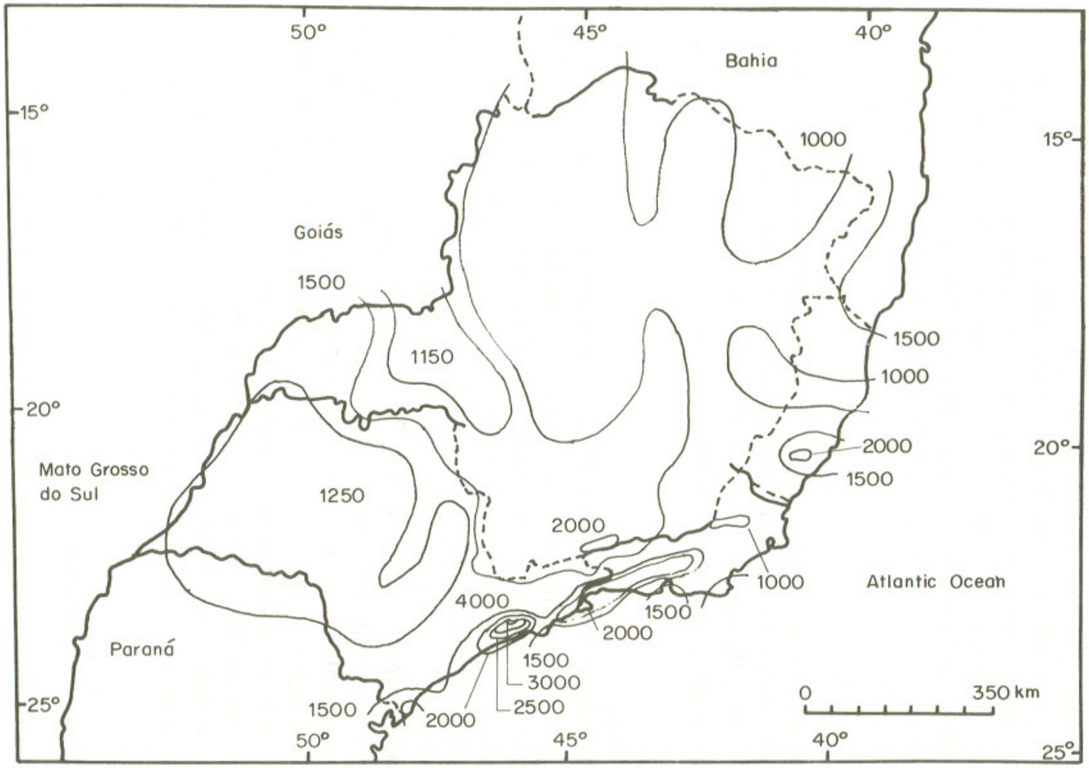

Figure 8.5 Annual precipitation in southeastern Brazil (Nimer, 1972)

Rio de Janeiro
Monthly sulfur deposition rates were measured in 1984 at 32 sites in the metropolitan region and in nine other cities. In the same year, SO_2 concentration was measured in the capital and in two other cities (Niterói and Volta Redonda; FEEMA, 1980, 1984, 1985).

Concentrations of NO_3^- and SO_4^{2-} in particulate matter for Rio de Janeiro city were determined by solubilizing those compounds in deionized water. Rainwater composition (only Na^+, Ca^{2+}, K^+ and Cl^- concentrations) is available for the Floresta da Tijuca (Silva Filho *et al*., 1985a). FEEMA produced estimations of SO_x and NO_x emissions for the whole state.

Espírito Santo
Obtaining data on air quality was not possible. One local metalworks and a mining company monitor gases and particulate matter in some parts of the capital, Vitória, though data are not available. As shown in Figure 8.2, this state is the least industrialized in the entire region.

Minas Gerais
Since the creation of the State Organization for Environmental Control (CETEC) in 1983, continuous air quality studies have been made in three areas of the state: in the 'steel valley' west of the capital, Belo Horizonte; in the so-called 'Sudene Area' (Figure 8.2) in the northern part of the state; and in Belo Horizonte. According to CETEC (1983) these studies are not directly related, and the information they provide is incomplete.

The most important source of air quality information available in this state is the sampling network set up in Belo Horizonte's metropolitan region, where settled dust and sulfur deposition rates were measured at 31 points. In the 'steel valley' only total suspended particles and settled dust concentrations were determined. Finally, in the northern Sudene area, which constitutes about 20% of the area of the state, the same parameters were measured including the sulfation rate (values for sulfur deposition). No other information about air quality or rainwater composition is available.

8.2.2 Emission Inventory

The state organizations responsible for environmental studies usually evaluate the total emission of atmospheric pollutants based on the types and number of industries, amounts of raw materials used, and amounts of fuel oil used. Despite their inadequacies these data give a general indication of air quality conditions.

Estimated SO_2 emissions for the region's three most important industrial centers and for the state of Rio de Janeiro are given below:

Area	Metric tons SO_2/year
Greater Sào Paulo	213,000 (CETESB, 1985a)
Greater Belo Horizonte	136,000 (CETEC, 1985)
Greater Rio de Janeiro	87,000 (FEEMA, 1984)
Rio de Janeiro, state	145,000 (FEEMA, 1984)

The total emissions are rather high, sometimes exceeding the emission densities of some European countries (Swedish Ministry of Agriculture, 1982); In the southeastern states however, attempts are being made to decrease S and N emissions. Rates of sulfur deposition are of special interest because they have been measured in most parts of the southeastern region and provide a reasonable basis for establishing representative data for the whole region.

It is necessary to bear in mind, however, that the available data are not comparable for all parts of the southeastern region—1978/79 for São Paulo and Minas Gerais states, and 1984 for Rio de Janeiro state. Before estimating distributions for the entire region, we first compare the data for specific industrial localities.

The mean deposition of sulfur is about 3 g S/m^2/year in the Belo Horizonte metropolitan area, compared to about twice this value in the Rio de Janeiro metropolitan area. Although the surface areas of the two metropolitan areas are about equal, natural factors, such as climate and relief, are the most important factors determining the environmental picture of the two metropoles. In Rio de Janeiro winds frequently blow from the northeast and drive the air against the Sierra do Mar, thus avoiding dispersion of pollutants, and effectively concentrating them within a few kilometers of the emission source. In Belo Horizonte, by contrast, winds disperse pollutant emissions toward regions that also produce emissions—Betim and Contagem. The areas with the greatest general deposition rates in the southeastern region are west of Belo Horizonte.

Although sulfur emissions were twice as large in Greater Belo Horizonte as in Greater Rio de Janeiro, the values of the sulfur deposition are twice as high in Rio as in Belo Horizonte. The sulfur deposition rate obtained for the fourth industrial area of the southeastern region, Campinas, located a mere 96 km from São Paulo, shows still higher values (8 g S/m^2/year). Data obtained for the whole southeastern region (Figure 8.6) show that the sulfur deposition rate in the steel mill town of Volta Redonda is high. This city is located at the border between Rio de Janeiro and São Paulo, close to the forest reserve of Itatiaia. In industrial parts of São Paulo state, mean monthly values of about 12 g S/m^2/year were registered; in the urban areas the most frequent values vary between 7 and 14 g S/m^2/year. In agricultural regions such values vary between 1 and 2 g S/m^2/year.

Generally speaking, the industrial centers of the southeastern region act as sources of sulfur compounds. Their influence on neighboring regions is important, especially in the areas west of these centers, since the predominant surface winds come from the east (Figure 8.4). Comparing SO_2 measurements for the same period in metropolitan Rio de Janeiro and São Paulo (data for São Paulo state are earlier 1978–1979), Figure 8.7 indicates that the city of Rio de Janeiro has mean SO_2 concentrations as high as those for São Paulo. Among the seven observation points in the Rio de Janeiro metropolitan area, five show annual means exceeding 90 $\mu g/m^3$, while this occurs only at one point among the 22 locations sampled in the São Paulo metropolitan area. Clearly the standard daily SO_2 value (365 $\mu g/m^3$) is frequently exceeded in both cities. The highest SO_2 concentrations in Rio de Janeiro state occur near the Volta Redonda steel mill, where a maximum value of 840 $\mu g/m^3$ of SO_2 was detected.

Although the number of industrial plants in the city of Rio de Janeiro is much lower than in São Paulo (Figure 8.2) the location of the industrial area, together with the climate and relief, determine air quality conditions. This relationship exists in Cubatão, on the east coast just south of the São Paulo metropolitan area. Here only 23 plants account for a mean SO_2 concentration higher than that in the Greater São Paulo area. Campinas, the second largest industrial center of São Paulo, also shows a high average annual SO_2 concentration of 53 $\mu g/m^3$.

Throughout the southeastern region the SO_2 concentration decreases with increasing distance from the big industrial centers. The same regions that show low sulfur deposition rates also show low sulfur concentrations. Thus, in the extreme west of the state of São Paulo, mean SO_2 concentrations remained between 5 and 11 $\mu g/m^3$, with a maximum of 34 $\mu g/m^3$. In some places the mean values oscillated between 3 and 5 $\mu g/m^3$ and the maximum reached only 7 $\mu g/m^3$. These regions have developed largely as agricultural and cattle breeding areas without polluting industries.

8.2.3 General Atmospheric Chemistry Data

Tables 8.1 and 8.2 show the results of soluble NO_3^- and SO_4^{2-} concentrations in particulate matter collected in metropolitan Rio de Janeiro. These data show a gradual trend toward increased concentration, year by year. In addition SO_4^{2-} contents are about five times higher than NO_3^- contents. Much higher values and a very different ratio of S to N were found in metropolitan São Paulo—an annual average value of about 74 μg NO_2/m^3 and about 44 μg SO_2/m^3.

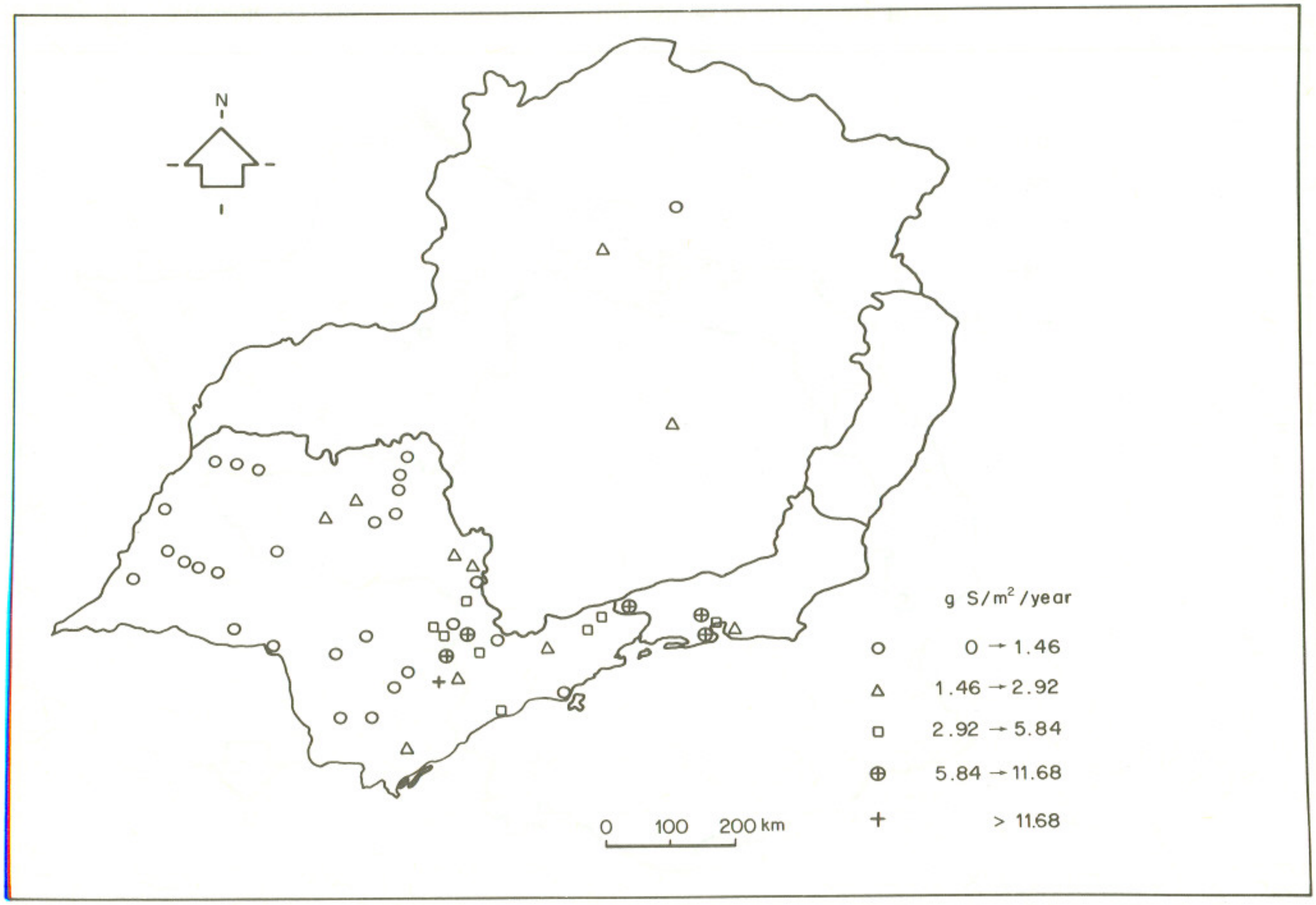

Figure 8.6 Available sulfur deposition rates at measurement stations in southeastern Brazil

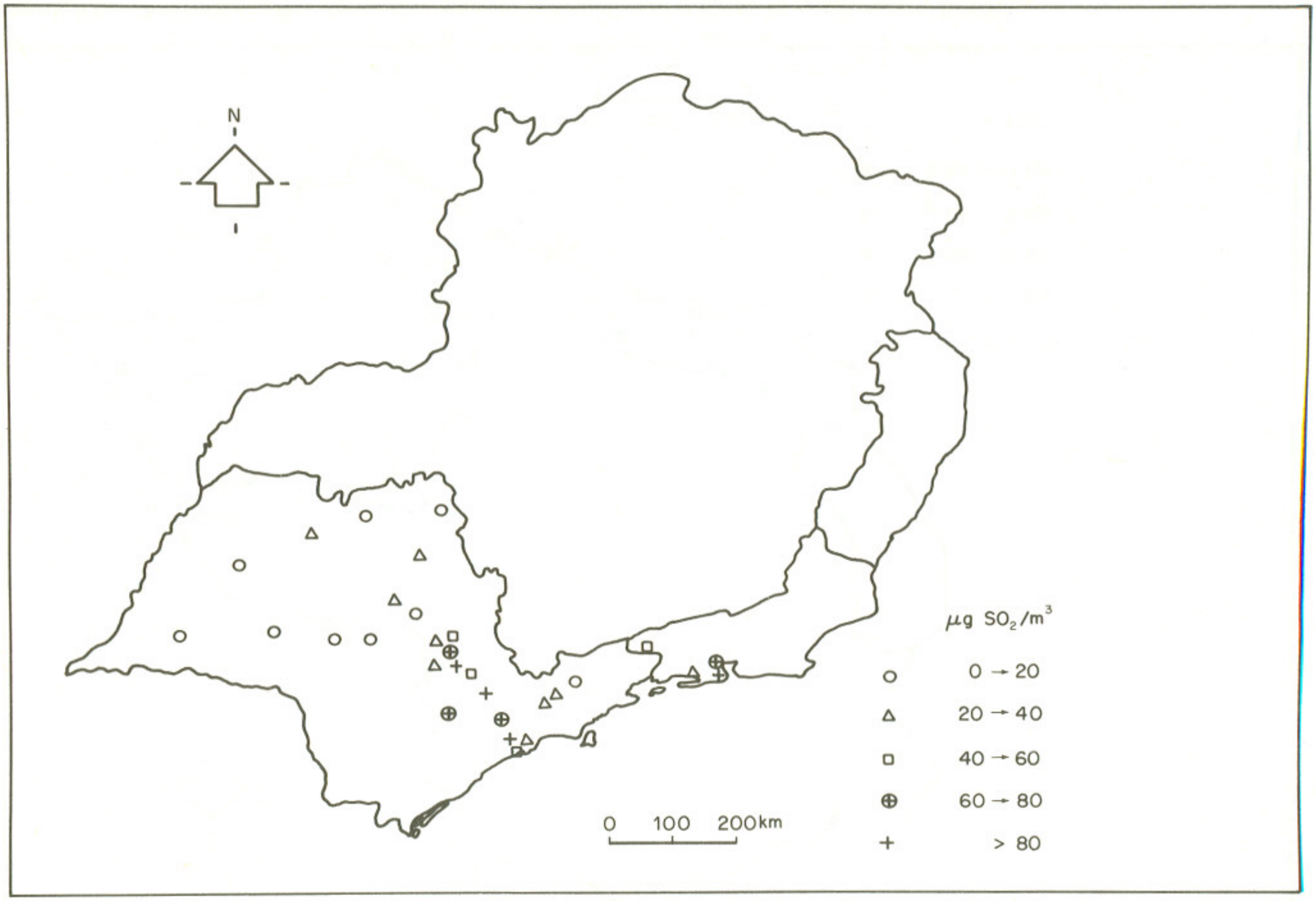

Figure 8.7 Available SO_2 concentrations at measuring stations in southestern Brazil

Taking these results into account we estimate that the deposition rates of sulfur compounds in metropolitan Rio de Janeiro are five times higher than for the nitrogen compounds, while in São Paulo, sulfur compounds are about half as abundant as nitrogen compounds. These preliminary results, should be applied with caution.

Table 8.1 Annual arithmetic means of NO_3^- concentrations in total suspended solids in Rio de Janeiro city ($\mu g/m^3$) (based on unpublished data from archives at FEEMA)

Station	1976	1977	1978	1979
1. Sào Cristòvào	2.7	3.1	3.1	3.4
2. Bonsucesso	—	—	3.6	3.0
3. Penha	2.1	3.0	3.2	3.5
4. Ilha do Governador	2.0	3.2	3.4	3.1
5. Largo do Maracanà	2.7	3.3	3.4	3.0
6. Maracanà	2.1	3.0	2.8	3.0
7. Meier I	2.1	3.0	2.8	—
8. Centro	2.3	3.0	2.9	3.3
9. Copacabana	2.0	2.7	2.5	2.7

Table 8.2 Annual arithmetic means of SO_4^{2-} concentrations in total suspended particulates in Rio de Janeiro city ($\mu g/m^3$) (based on unpublished data from archives at FEEMA)

Station	1976	1977	1978	1979
1. Sào Cristòvào	19.3	21.8	18.8	20.4
2. Bonsucesso	—	—	22.5	18.6
3. Penha	10.3	16.8	16.5	18.7
4. Ilha do Governador	8.9	19.2	15.1	15.1
5. Largo do Maracanà	10.7	18.9	16.4	19.9
6. Maracanà	10.0	16.3	16.4	19.2
7. Meier I	7.7	15.6	16.8	—
8. Centro	9.5	16.9	16.6	18.7
9. Copacabana	7.7	16.6	14.7	18

At two points in Cubatão, another industrial center in São Paulo state, average SO_2 concentrations in 1984 were 36 and 50 $\mu g/m^3$ respectively. The corresponding NO_2 data for these same two points in 1983 were 42 and 22 $\mu g/m^3$. As in Rio de Janeiro, Cubatão has a small number of industrial plants, but the climate and topography near the city have led to deteriorated conditions. There are no data on the deposition rate of sulfur, nor are there evaluations of SO_x emissions for this location.

8.2.4 Chemical Composition of Rainwater

In the entire southeastern region only four studies of precipitation chemistry have been made, all of them in the metropolitan areas of Cubatão and São Paulo (Moreira-Nordemann *et al.*, 1983, 1985), and in Rio de Janeiro (Silva Filho *et al.*, 1985a, b).

8.2.4.1 In Rio de Janeiro

Data on the chemical composition of rainwater in the Tijuca forest, within metropolitan Rio de Janeiro, are shown in Table 8.3. Unfortunately, there are no data on either NO_3^- or SO_4^{2-} concentrations. Contents of Cl^- and Na^+ were high, presumably due to the proximity to the ocean. The average pH value was 4.66, ranging between 4.16 and 6.05. These results are more acid than those reported for the city of São Paulo.

Table 8.3 Input of elements by rainwater in Rio de Janeiro; in tons/km^2/year (Silva Filho *et al.*, 1985a)

Na	2.2
Ca	0.6
K	0.45
Mg	0.53
Cl	4.2

8.2.4.2 In Cubatão

The industrial area of Cubatão is located in the so-called Baixada Santista, a coastal lowland near the port of Santos, about 40 km south of São Paulo city. The area has about 23 industrial sites, including chemical and fertilizer plants, metalworks and an oil refinery. All are large sources of pollutants, emitting gases and particulate matter into the atmosphere and discharging liquid wastes into nearby surface waters.

Two factors intensify environmental degradation here: the types of industries and the industrial zone is compressed between the ocean and the Sierra do Mar. Winds blowing from the sea toward the continent meet the sierra, a natural orographic barrier preventing pollutants from dispersing. As a consequence these emissions include large amounts of aerosol particles that remain suspended in the air and greatly alter the chemical composition of rainwater in the region. Preliminary measurements during the rainy season in December 1982 show that rainwater pH in downtown Cubatão varied from 3.7 to 4.7 while the values in nearby Vila Parisi ranged from 5.8 to 6.8 (Moreira-Nordemann *et al.*, 1983).

From April 1984 to October 1985, 209 rainwater samples were systematically collected in the following areas: Cubatão (DC), Vila Parisi (VP), Santos (S), Alto da Serra de Paranapiacaba (P) and Valley of the River Quilombo (Q) (Moreira-Nordemann *et al*., 1986).

The methods used were checked carefully (Ribeiro Filho, 1975; Ferreira and Moreira-Nordemann, 1985; Tavares *et al*., 1983). Acrylic collectors were used and special care was taken to avoid contamination or evaporation of the samples. The samples were analyzed in INPE and CETESB laboratories. Results indicated that the data were accurate to $\pm 10\%$, or ± 1 μeq/liter, except for SO_4^{2-}, where the precision limits of the turbidometric method were ± 4 μeq/liter.

Due to the quantity and diversity of chemical elements injected into the atmosphere of this region, rainwater in Cubatão and its surroundings can be compared with a 'soup,' a kind of brine of complex composition. Dry deposition certainly influenced the results.

Rainwater pH showed a general tendency toward neutrality. In Vila Parisi pH values >9 were recorded; in Santos the mean value was 6.4 with a maximum and minimum of 7.7 and 5.0 respectively. Only in downtown Cubatão and in Paranapiacaba Hills were pH values of 3.6 recorded; in all other areas minimum values exceeded 4, while the arithmetic mean was greater than 5.5, except at Paranapiacaba Hills where the mean pH value was 4.75. Table 8.4 gives the total ionic contribution of rainwater in tons per km^2 per year for the five areas near Cubatão. These values are expressed as volume-weighted averages using average amounts of precipitation measured at each collection site in the years 1976–1984.

Table 8.4 Total ionic contribution of rainwater (tons/km^2/year) in Santos (S), Vila Parisi (VP), downtown Cubatào (DC), Quilombo River valley (Q), and Paranapiacaba Hills (P). Local mean precipitation in mm for years 1976–1984 (Moreira-Nordemann *et al*., 1986)

	S	VP	DC	Q	P
Na^{2+}	7.1	4.6	4.8	5.1	5.1
Ca^{2+}	3.9	32.7	3.7	4.7	2.7
K^{+}	0.8	6.0	0.8	0.4	0.7
Mg^{2+}	1.5	4.1	1.4	1.2	1.5
Cl^{-}	15.0	14.5	11.3	12.4	13.9
SO_4^{2-}	4.4	56.7	8.6	7.5	6.2
NO_3^{-}	1.5	10.3	2.7	2.0	3.5
NH_4^{+}	0.4	3.8	1.2	0.2	0.8
PO_4^{3-}	1.3	44.8	0.9	0.2	0.3
Mean precipitation (mm)	2,270	2,360	2,490	2,690	3,760

The mean concentration of SO_4^{2-} in precipitation samples was very high in Vila Parisi samples: 24 mg/liter with a maximum value of 305 mg/liter. The mean value obtained in downtown Cubatão is much lower at 3.5 mg/liter but is the second highest value among the five locations in this study. The types of industry in the region and their locations with respect to these two points suggest that industries producing superphosphate fertilizers create the high concentration of sulfur in the Vila Parisi atmosphere.

These results indicate the influence of different sources and microclimates of the region, particularly in relation to amount of rainfall. Even in areas where the volume-weighted mean concentrations were lower, the high rainfall rate 'compensates' the result, emphasizing total quantity of the element deposited as rain. Serra de Paranapiacaba and the valley of the River Quilombo, for example, had the most rain as well as the lowest rainwater ionic strength. Taking into account the two factors mentioned above, the contribution of rain to the Cl^-, Na^+, Mg^{2+} and NO_3^- loading in Paranapiacaba Hills was larger than in downtown Cubatão. On the other hand, Ca^{2+}, K^+, PO_4^{3-}, SO_4^{2-} and NH_4^+ were deposited in higher total quantities in downtown Cubatão than in Paranapiacaba Hills.

8.2.4.3. In São Paulo City

A total of 108 collections were made systematically at a single location in São Paulo city from October 1983 to October 1985, a period coinciding with two rainy and two drought periods. The same collection methods and chemical analyses were used as in Cubatão. The maximum and minimum pH values obtained in 108 determinations were 6.33 and 2.67, with the mean value 5.0. These results show that São Paulo rainwaters are more acid than those in Cubatão and Vila Parisi.

Table 8.5 shows deposition in rainwater. São Paulo precipitation shows high Ca^{2+} and high K^+ concentrations, which are likely due to the large quantity of cement dust in the air. The Ca^{2+} is the third most important chemical species in the total contribution of rainwater in this city. The enrichment of NO_3^-, SO_4^{2-}, NH_4^+, and even Ca^{2+} in precipitation is undoubtedly of anthropogenic origin.

Table 8.5 Total input of ions in rainwater in Sào Paulo city (Moreira–Nordemann *et al.*, 1985)

Ion	Total input (tons/km^2/year)	Ion	Total input (tons/km^2/year)
Na^+	0.3	Cl^-	0.9
Ca^{2+}	1.2	SO_4^{2-}	1.9
K^+	0.3	NO_3^-	2.7
Mg^{2+}	0.3	NH_4^+	1.0

Unfortunately there are no data prior to the industrialization of the region that would allow us to determine the degree of change due to human interference.

8.2.5 SUMMARY

Evidence of significant pollution loading exists in the major industrial centers, especially the three major metropolitan areas of Rio de Janeiro, Belo Horizonte, and São Paulo. These areas cover only 2% of the total area of the southeastern region, but they emit about 450,000 tons/year of SO_2 into the atmosphere. Adding emissions in the state of Rio de Janeiro, total SO_2 emissions in the whole Brazilian southeastern region reach at least 500,000 tons/year.

Among these three capital cities, Rio de Janeiro has the largest pollution problems, in part because of climate and topographical conditions that limit dispersion and confine deposition near emission sources. The highest SO_2 contents and the highest sulfur deposition rates were measured in this city. In addition, pollution caused by motor vehicles is about 35% of the total industrial emissions in Rio de Janeiro.

Using the mean values for sulfur deposition rates in these three industrial centers and their respective surface areas, we calculate a total sulfur deposition of about 30,000 tons/year in Rio de Janeiro, 60,000 tons/year in São Paulo, and 12,000 tons/year in Belo Horizonte.

The low wind speeds observed all over the southeastern region allow the deposition of pollutants near emission sites. Minimum sulfur deposition rates, determined at large neighboring industrial centers, support this argument.

The results of total sulfur deposition rates calculated here suggest that practically all pollutant emissions from Rio de Janeiro city are precipitated *in loco*. In metropolitan São Paulo the calculated deposition rate is slightly more than half of the estimated total emission. In Belo Horizonte total emissions are about four times greater than the total deposition rate obtained; however, the estimated value for total emission in Belo Horizonte seems excessively high.

Another 4% of the total southeastern region is also highly industrialized. Assuming a mean deposition value of 6 g/m^2/year for these areas (a value between the extremes obtained in Campinas and Belo Horizonte), a total deposition of 190,000 tons/year is estimated for all industrial areas.

It is also plausible that the minimum value determined in the southeastern region is representative of the nonpolluted areas, and that 700,000 tons/year are deposited over the entire southeastern region. The sum of these values gives a total deposition of about 1,000,000 tons/year of sulfur over the southeastern region.

These values, although approximate, are probably not unrealistic. Some evaluations show that certain European countries, with less surface area, less industry, and less developed environmental control programs, have total deposition values about equal to or somewhat higher than the ones obtained here.

Concentrations of SO_2 have been obtained at several sites in southeastern Brazil. The mean concentrations of SO_2 in industrialized areas vary between 40 and 100 $\mu g/m^3$, with Rio de Janeiro and São Paulo showing the highest mean value. A minimum value of 3 $\mu g/m^3$ of SO_2 was determined in non-industrialized locations of the region. This result is high compared with the 0.15 $\mu g/m^3$ level determined by Lawson and Winchester (1978) for non-industrialized regions in the Brazilian inland. They consider that even the latter value may be well above natural levels.

Evaluating emissions of nitrogenous compounds for the region is impossible due to the lack of data. We know that the NO_2 emissions in Greater São Paulo are twice as high as the SO_2 emissions, and that the same ratio was found for rainwater, in which mean NO_3^- content was twice as high as mean SO_4^{2-} content. In Rio de Janeiro there is strong evidence that emissions of sulfur compounds are about five times higher than emissions of nitrogenous compounds, a hypothesis that agrees with emissions estimates by FEEMA (1984).

The chemical composition of rainwater in Cubatão reflects the pollution conditions of that region: all ions are present with high concentrations at the five sampling points. The diversity of pollutant sources and the chemical and physical properties of the matter injected into the atmosphere produce a highly variable pattern of rainwater chemical composition in Cubatão. Time distribution of the rain is also important: during dry periods rainwater samples have very high concentrations, and during rainy periods samples are much more dilute.

Although the total concentration of anions is higher than that of cations, pH values, especially in Vila Parisi, show a neutral rather than acid tendency. Minimum values lower than 4 were recorded; however, mean values are usually more than 5. This result seems normal, although it is possible that some unmeasured ions in the atmosphere might have helped neutralize the rainwater.

Rainwater samples from São Paulo tend to be acid, a fact that is beginning to affect surface water in the region. The ion concentrations have shown a strong enrichment in NO_3^-, SO_4^{2-}, Ca^{2+}, and NH_4^+, in this order.

The high concentration of Ca^{2+} is likely due to airborne cement dust from the many buildings under construction. This agrees with concentrations of the same element, which are also high in airborne particulate matter.

As a whole, the southeastern region of Brazil is heavily polluted, and the trend will worsen in the future. The results of this case study show the need for a program to guide further industrial development. One possibility is to 'cap' total emissions by limiting the number of polluting industries to those which already exist.

8.3 HYDROLOGY

The southeastern region of Brazil presents a very rich hydrographic network. However, studying its physical and chemical characteristics is difficult due to the lack of data on both river flow rates and water quality. These factors are essential to calculate the total quantity of products flowing through the basin. In most cases, the rivers have been altered by dams, which supply electricity and water for urban and industrial use. These rivers also receive wastes from domestic and industrial activities. Official monitoring studies on chemical parameters are aimed mainly at determining water quality indexes for human and agricultural use. The rivers are rarely submitted to scientific surveys because they have been altered so completely by human influences.

The most important basins of this region are the Paraíba do Sul, the Paranapanema, the Tietê, the São Francisco, and the Grande (Figure 8.8). In general, the flow rates of these rivers depend on the rainfall distribution, showing summer maximum and winter minimum.

8.3.1. São Francisco River

The headwaters of the São Francisco River are located in the Sierra da Canastra, Minas Gerais. This river flows into the northeastern region to the Atlantic Ocean, after running 3,161 km. It drains 670,000 km^2 and is the most extensive among the exclusively Brazilian basins. Its regime is determined by the climatic conditions—well irrigated by the rains in its higher part, semihumid and semiarid in its medium section, and humid again in the coastal zone. The highest mean discharge is in January. Maximum precipitation occurs in December. In Manga, near the Bahia state border, the river flow varies between 225 m^3/sec and 10,500 m^3/sec with a mean value of 1,840 m^3/sec. Two large dams in the higher reaches of the São Francisco River provide water for irrigation.

Measurements of NO_3^-, NH_4^+, and SO_4^{2-} concentrations, and pH were obtained at several points along the São Francisco River and its tributaries in November–December 1982 and January 1983. Table 8.6 shows maximum and minimum values obtained for SO_4^{2-} and NH_4^+ in these rivers.

8.3.1.1. pH measurements

Measurements of pH along the São Francisco River are between 7.8 and 4.8, the highest values being for the high course, before the Tres Marias dam.

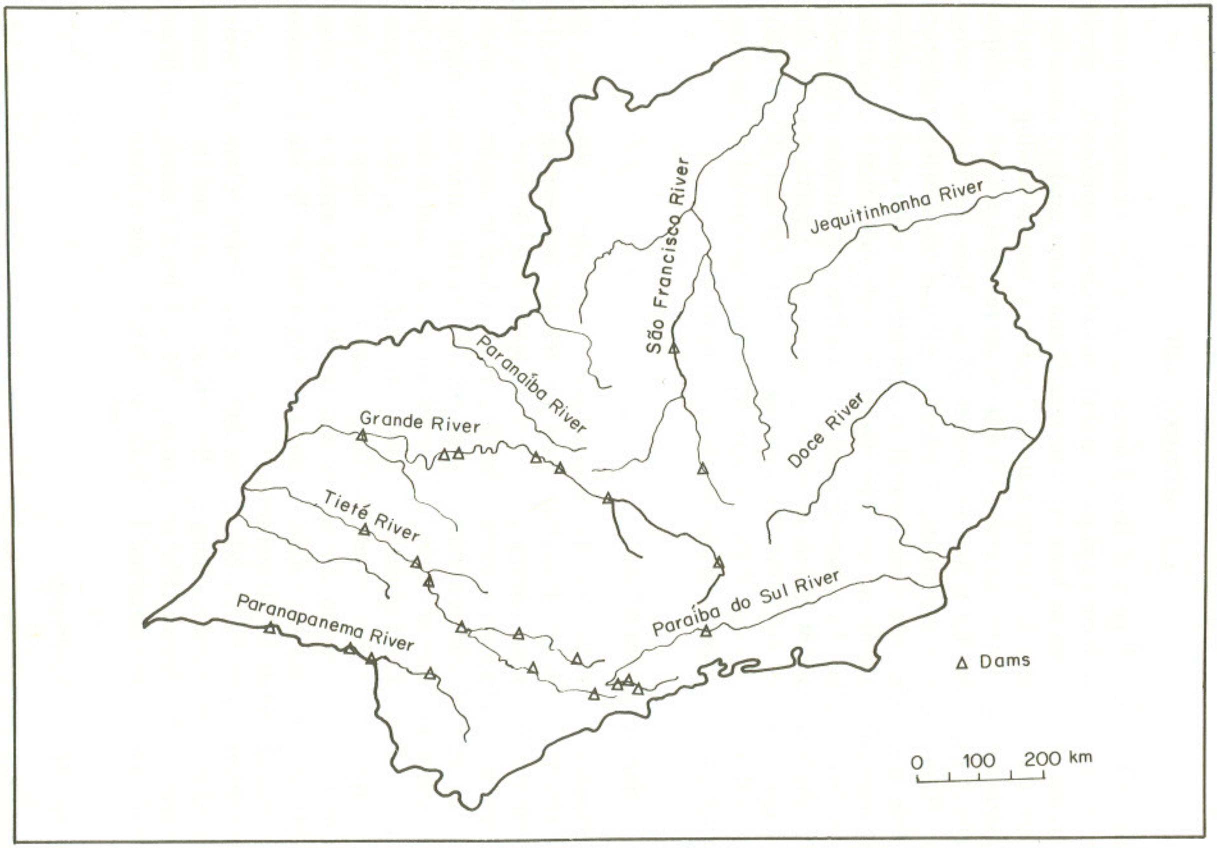

Figure 8.8 The rivers and dams of southeastern Brazil

At Manga in the northeast the pH was 6.5. Since industrialized areas in Minas Gerais are generally located far from the river, this decrease in pH is probably caused by drainage from acid soils or the release of fertilizers used in agricultural activities. There is no evidence that the acidification is due to contributions of the tributaries, because their pH values were always more than 6.2 (Table 8.6).

Table 8.6 The Sào Francisco river and tributaries (T); minimum and maximum values based on one sample per year (1982–1983) at several points on each river (unpublished data from CETEC archives, 1981–1983)

River name	pH	SO_4^{2-} (mg/liter)	NH_4^+ (mg/liter)
Sào Francisco	4.8–7.8	<1.0–16.2	0.1–0.5
Sào Miguel (T)	7.6–7.7	<1.0–2.7	<0.1–0.5
Parà (T)	7.2–7.6	<1.0–5.0	0.1–0.3
Lambari (T)	7.3–7.5	<1.0–3.0	—
R. das Velhas (T)	6.5–8.7	<1.0–55.0	<0.1–2.1
R. Jequitaí (T)	7.1–8.0	1.2–2.3	0.1
Pacuí (T)	7.2–7.8	1.8–2.1	<0.1–1.0
Prata (T)	6.5–7.0	—	0.1–0.2
Verde Grande (T)	6.2–8.2	12.4–16.1	—
Urucuia (T)	6.2–6.5	—	<0.1–0.1
Abaeté (T)	7.9	—	0.3
Pandeiros (T)	7.2–7.6	<1.0	—
Paracatu (T)	6.3	—	<0.1–0.1
Paraopeba (T)	6.5–7.5	<1.0–6.0	<0.1–3.9

8.3.1.2 SO_4^{2-} Concentrations

A value of 2.7 mg/liter was measured near the origin of the river, although the 1982 value was less than 1.0 mg/liter. Thus SO_4^{2-} concentrations increase after the confluence with the Rio das Velhas, which has the highest SO_4^{2-} concentrations of the basin. At São Romão, the mean flow of the São Francisco River is 1,470 m^3/sec. This means that about 6.12×10^4 tons/year of SO_4^{2-} are present in this river, if the measurements are represented as mean values. At the last station, Manga, this value is between 12×10^4 and 24×10^4 tonnes/year based on a mean flow of 1,840 m^3/sec. Silva (1984) found SO_4^{2-} concentrations between 2 and 4 mg/liter at the Manga sampling point of the São Francisco River, values considered representative for Manga.

The most polluted tributary of the São Francisco River is the Rio das Velhas, which crosses the urban area of Belo Horizonte. Near this city, the river contains 3×10^4 tons/year of SO_4^{2-} and the value increases to 5×10^4 tons/year near its mouth. A comparison of these values with those for the São Francisco River itself, clearly shows that most of the SO_4^{2-} in the São Francisco River comes from the Rio das Velhas.

The Rio Verde Grande, the northernmost tributary, shows 16.2 mg/liter of SO_4^{2-} which gives a drainage of 4.5×10^3 tons/year given a mean flow of 28 m^3/sec. Concentrations of 12.4 mg/liter were obtained in this river in 1982. The Rio Jequitaí drains about 1,750 tons/year of SO_4^{2-}. These results must be regarded with caution because they were derived using only one SO_4^{2-} concentration measurement per year (1982–1983).

Other São Francisco tributaries such as the Prata and Pacuí rivers have shown high concentrations of SO_4^{2-}, but flow measurements are not available for these sampling points.

8.3.1.3 NO_3^- and NH_4^+ Concentrations

All measurements of NO_3^- were lower than 1.0 mg/liter. Thus, further discussion is not useful.

Concentrations of NH_4^+ are variable and much lower than SO_4^{2-} contents. Concentrations lower than 0.01 mg/liter and up to 0.50 mg/liter were obtained along the river in 1983. In the high basin a value of 4,000 tons/year of NH_4^+ is obtained, whereas at the last station, Manga, the value reaches 6,000 tons/year.

For the Rio das Velhas the measured concentrations are generally higher, reaching 2.13 mg/liter after crossing through urban Belo Horizonte.

The Rio Verde Grande and the Rio Jequitaí evacuate 350 tons/year and 90 tons/year, respectively. In general, the NH_4^+ concentrations in all the tributaries are not very high. The Lambari River and Pará River are responsible for a total drainage of 580 and about 1,000 tons/year, respectively, of NH_4^+ into the São Francisco River waters.

8.3.2 Paraíba do Sul River

With its origin in the Sierra do Mar, in São Paulo state, this river crosses Minas Gerais state before flowing into Rio de Janeiro toward its mouth at the Atlantic Ocean. The Paraíba do Sul results from the confluence of the Paraitinga and Paraibuna rivers, which have dams on their high reaches. The Paraíba River supplies water to 27 cities, but it also bears the cities' wastes. According to CETESB (1984), municipal pollution is greater than industrial pollution. Seventy-eight percent of the basin area is covered by pastures; its draining area is about 57,000 km^2 and its length is 1,145 km. Flow rates between 180 m^3/sec and 5,400 m^3/sec were recorded in Campos, at the river's mouth. Dams and artificial lakes are found along its course.

River pH measurements and NO_3^- and NH_4^+ concentrations were determined in São Paulo and Minas Gerais states in 1981, 1982 and 1983 (Table 8.7). Measurements for the lower basin (Rio de Janeiro) are shown in Table 8.8.

8.3.2.1 pH Measurements

In the higher basin (São Paulo state) values ranged between 6.2 and 6.8. Beyond the border, between Minas Gerais and Rio de Janeiro states, the river waters show pH values ranging between 6.7 and 7.4, higher than previous values. Tributaries of this river also show pH values greater than 6.6 (Tables 8.7 and 8.8).

8.3.2.2 SO_4^{2-} Concentrations

As shown in Table 8.7, a range between <1.0 and 5 mg/liter of SO_4^{2-} contents was determined in tributaries of the Paraíba do Sul River, Minas Gerais state. The results are incomplete, and no conclusions can be drawn.

Table 8.7 Paraíba do Sul river and tributaries (T), Sào Paulo (SP) and Minas Gerais (MG) states.

River name	pH	NO_3^- (mg/liter)	NH_4^+ (mg/liter)	SO_4^{2-} (mg/liter)
Paraíba do Sul (SP)*	6.2–6.8	0.4–1.8	0.2–0.4	–
Jaguari (SP-T)*	6.4–7.1	0.3–1.6	0.2–0.3	–
Paraibuna (MG-T)†	6.7–7.2	–	0.3–1.6	4.0–5.0
Pomba (MG-T)†	6.8–7.4	–	0.1–0.3	<1.0–1.5

* Minimum and maximum mean values obtained for 1981, 1983 and 1984 in monthly measurements (CETESB, 1981–1984)
† Values obtained in 1983 (unpublished data from CETEC archives)

Table 8.8 Paraíba do Sul basin and tributaries (T), in Rio de Janeiro state (unpublished data from archives at FEEMA)

River name	pH 1984–1985 (min–max)	N-total (mg/liter) (min–max) 1982–1983	NH_4 (mg/liter) (min–max) 1982–1983
Paraíba do Sul	6.1–6.9	0.55–1.44	–
Pirapetinga (T)	–	0.370–2.053	–
Piraí (T)	6.9	1.118–3.902	–
Piabanha (T)	6.6–6.9	–	0.4–2.2
Canal Cacomanga (T)	–	–	0.217–3.412
Canal Campos-Macaé (T)	–	–	0.722–14.265
Saquarema (T)	–	–	0,452–12.677

8.3.2.3 NO_3^- and NH_4^+ Concentrations

Values for the higher basin show NO_3^- contents between 0.4 and 1.8 mg/liter, corresponding to mean values obtained by CETESB between 1981 and 1984. There are no results for the middle and lower courses. Using the mean discharges and mean concentrations at Santa Branca and Caçapava, an NO_3^- discharge of 1,050 tons/year estimated for the first station and 2,700 tons/year for the second. The increase must be related to the waste streams or air emissions from the major industrial plants in the Paraíba do Sul Valley. At Queluz, the last sampling point, 1,840 tons/year of NO_3^- and 350 tons/year of NH_4^+ appear to be drained by the river. The highest concentrations for these two compounds, 1.8 and 0.5 mg/liter respectively, were also determined at Queluz.

For the lower basin, in Rio de Janeiro state, only maximum and minimum values were obtained in 1984. These data suggest a total nitrogen content between 4,900 and 12,800 tons/year is drained by this river at Volta Redonda.

8.3.3 Tieté River

The sources of the Tieté River and its most important tributaries are located in crystalline areas of the Paulista Highlands (Planalto Paulista) on the continental Sierra do Mar. Its basin covers an 84,170 km^2 draining area. The high basin, which extends from the source to metropolitan São Paulo, is located on crystalline rock lands across rural areas. Thirty percent of the higher basin area is agricultural land, and another 30% is reforested. Only about 1.3% remains covered by natural vegetation, which formerly extended over the Paulista Highlands. The Tieté River provides 28% of the São Paulo urban water supply, and receives about 300 tons of organic matter daily. After crossing São Paulo city, the river receives additional pollutants from agricultural chemicals and fertilizers used near the lower and low-medium portions of the river. All along the Tieté are dams and associated hydroelectric plants.

Table 8.9 shows the pH values, and NO_3^- and NH_4^+ mean concentrations measured in the Tieté River and some of its tributaries. The CETESB performed measurements monthly between 1981 and 1984. The pH values range from 5.9 to 7.5, the higher values obtained for sampling points located after the river crosses metropolitan São Paulo. Higher concentrations of NO_3^- and NH_4^+ are also found for these points and for tributaries draining the area, e.g. the Tamanduateí, Buquirivu Guaçu, Pinheiros, and Cotia rivers. Industrial and domestic waste discharged in the rivers produces these results. More dilute concentrations occur at sampling points near the mouth of the Tieté River, apparently due to sewerage treatment plants. Nitrogen compound concentrations and discharge measurements have been obtained for rivers of this basin.

Table 8.9 Tiete River and tributaries (T); minimum and maximum values obtained during 1981, 1983 and 1984 in monthly measurements (CETESB, 1981–1984)

River name	pH (min–max)	NO_3^- (mg/liter)	NH_4^+ (mg/liter)
Tiete	6.2–7.5	0.1–4.5	0.1–8.2
Biritiba-Mirim (T)	6.3–6.4	0.4–0.6	0.04–0.14
Jundiaí (T)	5.9–6.3	0.2	0.03–0.14
Taiacupeba (T)	6.6–6.9	0.1–5.8	0.13–1.08
Buquirivu-Guacu (T)	6.4–6.6	5.8–9.3	0.96–2.24
Represa Juqueri (T)	6.4–7.0	0.3–1.9	0.06–1.86
Pinheiros (T)	6.6–6.8	0.4–1.5	4.95–15.84
Tamanduateí (T)	6.7–7.6	0.1–2.2	13.44–25.93
Jacaré-Guacu (T)	6.1–6.9	0.1–0.6	0.05–0.27
Jacaré-Pepira (T)	7.0–7.3	0.8–0.9	0.12–0.18
Piracicaba (T)	6.9–7.1	0.9–1.2	0.18–0.70
Cotia (T)	6.8–6.9	0.4–0.6	1.20–7.39
Sorocaba (T)	6.5–7.1	0.6–2.7	0.14–1.87

8.3.4 Paranapanema River

The Paranapanema's source is in the extreme southwest of São Paulo state. It flows into the River Paraná and is about 900 km long with a basin draining area of 45,690 km^2. This is one of the most important tributaries of the Paraná River, showing a great variation in mean discharges and a subtropical regime marked by three maxima, corresponding to summer, fall, and winter periods. The CETESB surveys show excellent water quality, although some waste discharges from food industries, distilleries, paper mills, and cellulose plants occur. Nevertheless, this region is mainly agricultural, with 14% as reforested areas and 10% as natural forests. In the lower basin, 41% of the surface is pasture. Seven important dams and hydroelectric plants are located along its flow.

Paranapanema basin waters show pH values between 6.5 and 7.40, and NH_4^+ contents between 0.12 and 0.25 mg/liter. Assuming that mean discharges measured in the lower and higher basins are 60 and 1,200 m^3/sec, respectively, and taking into account mean concentrations of NH_4^+ in these points, a total amount of about 400 tons/year of NH_4^+ can be determined in the higher Paranapanema River course, compared with 4,500 tons/year near its mouth. Using the same procedure with NO_3^- measurements for these same sampling points, values of about 1,800 and 22,000 tons/year are obtained. Higher NO_3^- and NH_4^+ contents are easily obtained in the whole basin, as shown in Table 8.10.

8.3.5. Grande River

The Grande River headwaters are located in the Sierra da Mantiqueira, in Minas Gerais state. Its drainage area is about 122,000 km^2, 60.8% of which is in Minas Gerais state. This river shows a typical tropical regime, with minimum flows in September. Its mean discharge is 912 m^3/sec near the source and 1,733 m^3/sec at the middle course. Results for pH and N compounds measured in points along this basin are similar to those for others in this region (Table 8.11).

8.3.6 Summary

The differences in nitrogen and sulfur concentrations observed in river waters of the southeastern region of Brazil cannot be explained by geological, pedological, or climatic factors. Higher NO_3^-, NH_4^+ and SO_4^{2-} contents were determined in rivers crossing urban and industrial areas, the same areas that also present a polluted atmosphere.

Table 8.10 Paranapanema basin and tributaries (T), Sào Paulo state. Minimum and maximum mean values obtained for 1981, 1982 and 1983 in monthly measurements (CETESB, 1981–1984)

River name	pH	NO_3^- (mg/liter)	NH_4^+ (mg/liter)
Paranapanema	6.5–7.2	0.4–1.1	0.12–0.23
Taquari (T)	6.7–7.4	0.5–0.6	0.13–0.25
Pardo (T)	7.3–7.4	0.7–0.9	0.15–0.18
Itararé (T)	6.5–7.3	0.5–0.9	0.08–0.17

Table 8.11 Grande basin and tributaries, Sào Paulo state; minimum and maximum mean values obtained in 1981, 1982 and 1983 in monthly measurements (CETESB, 1981–1984)

River name	pH	NO_3^- (mg/liter)	NH_4^+ (mg/liter)
Grande	6.8–7.2	0.3–0.35	0.01–0.04
Sapucaí-Mirim (T)	6.9–7.2	0.5–0.7	0.05–0.13
Pardo (T)	6.6–7.1	0.5–0.8	0.03–0.17
Turvo (T)	6.6–6.9	0.4–0.9	0.06–0.15
Preto (T)	6.6–6.7	1.2–1.7	0.08–0.10

In agricultural areas, mainly in the interior of the country, NO_3^- and NH_4^+ concentrations were low, generally less than 0.5 mg/liter. These results are actually lower than those in rivers of Venezuela (Sanhueza *et al.*, 1988) and in African rivers (Livingstone, 1963). Low NO_3^- and NH_4^+ concentrations might be due to low nitrogen concentrations found in soils of this region.

The rivers of southeastern Brazil generally show pH values higher than 6.0, and thus no indication of acidification. Values higher than pH 7 were determined in very polluted river waters.

8.4 SOILS

8.4.1 Geology

The Sierra do Mar dominates the eastern part of southeastern Brazil. In the state of Espírito Santo, Precambrian gneisses are the most important type of bedrock, often intermixed with different lithographic formations. Occasional limestone layers appear, as well as granites (Vitória) and schistose rocks, generally quartzites. Decomposition of some rocks has been intense, creating cliffs and valleys. With the exception of the Baixada Fluminense, the entire state of Rio de Janeiro belongs to the Sierra do Mar orographic system, in which gneisses dominate and are often mixed with a layer of limestone, granite, or dolomite. Granites generally occur on the top of the Sierra, and quartz veins frequently cut the gneisses. Basic eruptive rocks, mostly diabases, form narrow dikes in the entire Sierra do Mar.

The Baixada Fluminense (Oliveira and Leonardos, 1978), a group of islands that broke off from the Sierra do Mar, were linked again to the continent when the Quaternary plain moved up. Rio de Janeiro state also includes decomposed Precambrian rocks and beaches, and Holocene lowlands, on which the capital city is built. There are also magnesium-rich eruptive rocks in several places, and Quaternary rocks in the coastal plains and beach ridges.

The crystalline region of the Sierra do Mar stretches toward the state of São Paulo maintaining consistent features. In the Vale do Paraiba schistose gneisses predominate, alternated with dolomite layers.

The Sierra do Mantiqueira, in southeastern Minas Gerais state, shows less degradation than coastal Sierra do Mar, and has not suffered strong granitization. These two Sierras meet in the extreme southeast of Minas Gerais state and become one Sierra. Important exploitations of minerals are found in the northern part of the Sierra da Mantiqueira.

Quartzites, phyllites and schists can be found in several regions of the states of São Paulo and Minas Gerais. In the São Francisco River basin are Silurian limestone and slates with quartz veins. The limestone region supplies fertile soils, although water shortages cause problems.

A sequence of sedimentary rocks begins in Goias state and extends south and west, covering a large part of the state of São Paulo. Here sedimentary rocks and basaltic lavas form series containing sandstones, shales, compacted clay, and several conglomerates. There are igneous rocks at the borders of the states of Rio de Janeiro, São Paulo, and Minas Gerais. In these four states, the Barreiras series, Tertiary sedimentation, forms several basins.

The Precambrian shield, with acid rocks, dominates in the states of Espírito Santo and Rio de Janeiro, and a large part of Minas Gerais and eastern São Paulo. These rocks gave birth to generally acid soils with a high Si and Al content and low Ca, with the exception of limestone regions. Among the major cations, Ca is the most abundant.

8.4.2 Soil Characteristics

The soils of the southeastern region are highly variable. This part of Brazil corresponds to the upland soil regions, and, according to the *Soil Map of the World* (FAO–UNESCO, 1971) the most common soils are Orthic Acrisol and Ferralsols, followed by Acric Ferralsols. Rhodic Ferralsols also occur in São Paulo and Minas Gerais states. Recent erosion cycles have removed much of the surface layers, especially in coastal Brazil. In the central region (cerrado) soils are well preserved, especially those under forest.

Detailed studies of the soils are available for each state of the southeastern region (Department of Agriculture, 1960–1972), and the following descriptions of principal soils are based on those reports. Where possible, the corresponding nomenclature used in the FAO–UNESCO report is also given. The pH values are measured in water, and other data were obtained following classical analytical methods generally used in soil analysis.

8.4.2.1 São Paulo

Thirty percent of the state's soils have latosolic B horizons, and 41% have textural B horizons. Other types include Hydromorphic, Alluvials and Lithosols. Soil profiles presenting B textural horizons include mainly red-yellow podsolic (Orthic Acrisol), but also 'Mediterranean soils' and 'terra roxa estruturada' (Eutric Nitrosol).

They are generally deep, usually between 0.7 and 1.2 meters. Clay contents are usually higher than 15%; pH is between 4.4 and 6.4, with values above 4.9 most common. Cation exchange capacity (CEC) is between 2 and 17 meq/100 g (measured at pH 7). Calcium is usually the dominant cation.

Nitrogen contents in these soils are generally low, between 0.4% and 0.20%, except in 'Mediterranean soils,' which present N concentrations between 0.20 and 0.50, and 'terra roxa estruturada' in which N contents sometimes reach 0.30%.

The second group, B latosolic, includes dark red Latosols (Orthic Ferralsol), 'terra roxa legítima,' red-yellow Latosol, and red humic soils. These soils are deeper, generally between 1.5 and 4.0 meters, also with clay contents greater than 15%. Their pH values are frequently between 4.5 and 5.5 and CEC between 1 and 6 meq/100 g; again Ca is the most abundant cation. Nitrogen contents in these soils often exceed 0.10%.

Organic matter contents for all soil types are low, usually about 1%, but in terra roxa legítima the value is generally greater than 1%. These soils formed from diabasic magma decomposition. Other types, such as Hydromorphic, make up 2.5% of the state's surface. They are not well developed, are generally flooded, and have high organic matter contents. Most of the hilly surface of São Paulo is occupied by forests; most of the level or gently sloping lands by sugar cane plantations.

8.4.2.2 Rio de Janeiro

Red and yellow Latosols represent 36% of the surface of this state, and associated soils occupy 23% of the area; Podsols occur in 4%; Hydromorphic soils, 11% (Humic Podsol); and alluvials, dunes, Regosols, and Lithosols compose 12% of the total surface. Red and yellow Latosols present deeper profiles, generally more than 3 meters; high clay contents, between 20% and 30%; pH values between 4.3 and 5.3; and CEC between 3.5 and 7.8 meq/100 g. Black-yellow Latosols have higher CEC, between 10 and 21.3 meq/100 g, but are more acid, pH 4.5, and compose only 2% of the state's surface.

Hydromorphic soils are shallower, and the only available profile shows lower clay content (9%), pH 5.2, and CEC 4.1 meq/100 g. Podsolic soils are deeper (>2 m) with lower clay contents (6%), CEC between 3.5 and 8 meq/100 g (mainly 3.7), and pH between 4.8 and 6.0. Nitrogen contents in these soils are between 0.10 and 0.40%; values higher than 0.15% are usual, except for podsolic soils where values between 0.08 and 0.14% are found.

8.4.2.3 Espírito Santo

This state has two principal types of soils: red-yellow Latosols and red-yellow Podsols. There are no available chemical data; only pH values, between 5 and 6, were determined.

8.4.2.4 Minas Gerais

Soils in this state resemble those in São Paulo. Detailed studies have been made in the northern and southern parts of the state, while less complete data are available for the remaining area.

Among the soils in Minas Gerais are latosolic B horizon (red-yellow Latosol), latossolo roxo (dark red Latosol), and soils with textural B horizons (red-yellow Podsols), terra roxa estruturada, and other types of less developed soils. Soils with latosolic B horizons are generally acid; low in nutrient reserves; low in Ca, Mg, K, and P contents; and have high Al concentrations. Among the group with B textural horizons, the terra roxa estruturada (eutric nitrosol) offers good physical and chemical conditions for agriculture, and is the better soil type in Minas Gerais, though low in P content.

In the north, humic red-yellow Latosols and red-yellow Latosols are most common, followed by red-yellow Podsols and Regosolic Latosols. Red-yellow Latosols, plateau phase, have clay contents exceeding 20%, but lower organic matter contents, about 1%. The pH values are between 4.6 and 5.1, and CEC between 6 and 11 meq/100 g. Total nitrogen concentrations are between 0.09 and 0.22. Under forest, these soils have higher clay contents, exceeding 20%, and pH between 4.2 and 4.9. CEC and N contents are also higher: between 12 and 30 meq/100 g and between 0.14% and 0.68% respectively.

Podsolic soils are less acid, with pH values between 6.0 and 6.2, but have lower CEC, between 8 and 11 meq/100 g. Total organic matter is about 2% and clay contents about 5% in the surface; total N contents vary between 0.14 and 0.20% Regosolic Latosols are also less acid, with pH values between 4.9 and 7.0, and have lower CEC values, between 4.5 and 7 meq/100 g. Total organic matter is about 1%, and total N contents are about 0.10%.

In the southern part of this state, red-yellow Podsols predominate, followed by red-yellow Latosols. High clay contents, between 33% and 67% are found in the surface horizons of Podsolic soils, and pH values are always higher than 5.5. Total organic matter is greater than 2%, and total N contents greater than 0.25%. CEC values are between 13 and 17 meq/100 g. Red-yellow Latosols are poor in clay contents, between 15% and 24% in the surface; CEC values are lower, about 10 meq/100 g; pH is between 4.3 and 4.9; N contents about 0.20%; and total organic matter reaches 3% in the surface.

8.4.3 Vegetation

From its semiarid areas to its superhumid areas the southeastern region shows diverse vegetation cover. The current vegetation cover is greatly changed from the original, after four centuries of progressively accelerated settlement, urbanization, and industrialization. These changes are illustrated by the following data taken from Magnani's (1983) study of forest degradation in Brazil:

State	Percentage of area covered with forest AD 1500	AD 1980
Espírito Santo	90	2
Minas Gerais	45	3
Rio de Janeiro	97	13
São Paulo	85	6

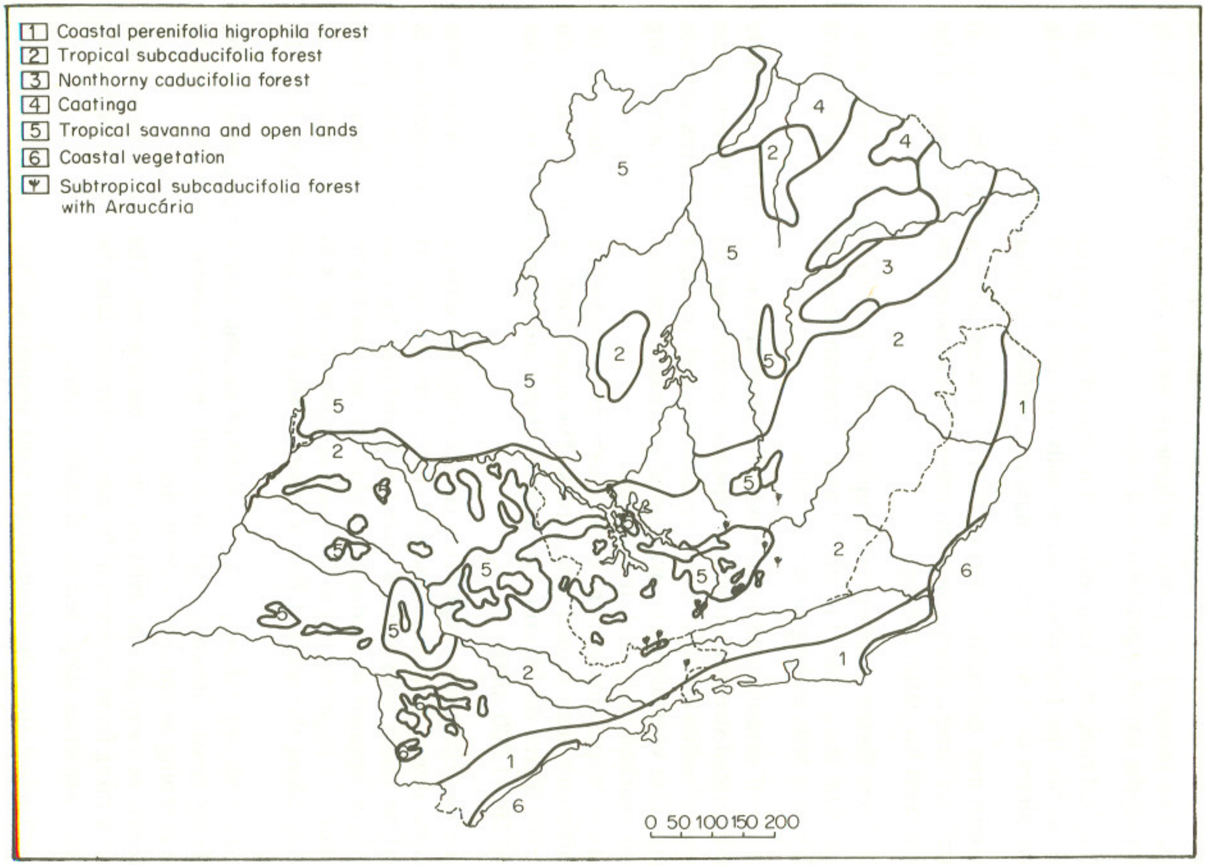

Figure 8.9 The vegetation of southeastern Brazil (Alonso, 1977)

According to Alonso (1977), the southeast shows the following original vegetal formations (Figure 8.9).

1. Coastal perenifolia higrophila forest. This dense forest area was highly variable due to abrupt changes in soil, climate and topography in coastal areas. The intensity of human settlements led to rapid deforestation. Only traces of the native vegetation exist today.

2. Tropical subcaducifolia forest. This vegetation type persists in a few small areas within the hedgeland, where soils are moist. On the continental side of the Sierra do Mar region, climate determined its presence.

3. Nonthorny caducifolia forest. This formation is drier than the tropical caducifolia forest. Only some stretches of brushwood are left; most of the area is used for cattle raising.

4. Caatinga (brushwood-covered region). The Caatinga region is more exuberant than the semiarid northeast and is predominantly arboreous. Drought in this area lasts as long as six months.

5. Tropical savanna and open lands. Tropical savannas appeared in nearly uninterrupted stretches, the interruptions consisting of Galeria forests, areas of tropical subcaducifolia forest, brushwood, and, on higher surfaces, campos limpos. This vegetal overlay was found in areas of semihumid climate, having clearly marked rainy and dry seasons.

Two subtypes are known: underbrush distributed either continuously, or in tuffs; and deep-rooted small trees. The open lands are in the Sierra do Mar, the Sierra do Mantiqueira and the thorn area (Espinhaço) at altitudes above 900–1,000 meters.

6. Coastal vegetation. Vegetation covers along the coast can be divided into beaches, dunes, salt marshes, and mangrove swamps. Beach vegetation is found on sandy coastal soils that are inundated by tides and waves; dune vegetation appears immediately behind the beaches toward the inland. Dune vegetation is important both for its development and its fixation functions. It is found along the coast of Rio de Janeiro, São Paulo, and northern Espírito Santo.

Salt marsh vegetation occupies a strip of variable width along most of the southeast coast, showing vegetation with physiognomic diversity. ranging from creeping to shrubby formations.

Mangrove swamps still exist in some coastal areas. They form in marshy soils resulting from deposits of tenuous sediments into the bottom of basins, and into estuaries subjected to brackish waters.

7. Subtropical subcaducifolia forest with araucária. This vegetation occurs in milder climates and deeper, richer soils. The Brazilian pine (*Araucária*

augustifolia) is characteristic of the southern Brazilian forest.

More than other regions, southeastern Brazil has suffered most from destructive human activities resulting in accelerated deforestation, the injection of pollutants, and an imbalance within the regional ecosystem.

A marked example of these changes is on the slopes of the Sierra do Mar in Cubatão, where the vegetation is vanishing, possibly due to air pollution from the heavy industry located there. This speculation needs confirmation by studies in progress.

8.4.4 Summary

In regions with high precipitation levels, a pH less than 5 and a CEC less than 6 meq/100g in the top of the profiles can be considered as a criterion for determining soil sensitivity to acid deposition. Though there are no studies of this region related to acidification or anthropogenic changes in soils, pH and CEC values can be used to derive information about the sensitivity of soils.

Soils of southeastern Brazil are usually naturally acid, with low cation exchange capacities and low calcium contents. This, along with the criterion mentioned above, implies that many soils in this region would be sensitive to acid deposition. The podsolic soils of Rio de Janeiro state, with pH values higher than 6 but very low CEC values, are probably also sensitive to acid rain.

Other possible abuses of soils include: the extensive use of fertilizers without control or systematic measurements to indicate possible long-term effects on soils; biomass burning, currently common throughout the southeastern region, where soils are naturally poor in organic matter; overuse of fertilizers, which would compromise surface and groundwater quality; and erosion, mainly of soils developed on hills and mountains. Several research organizations are conducting systematic studies on soil use and conservation in the southeastern region of Brazil.

8.5 GENERAL CONCLUSIONS AND RECOMMENDATIONS FOR RESEARCH

This case study of the potential effects of airborne chemicals in southeastern Brazil is characterized by several features of Brazilian natural and cultural history. Since the urban areas of this region are industrialized and polluted, state and municipal authorities place a high priority on monitoring in urban areas. Many gaps and shortcomings in available scientific information became apparent in the preparation of this case study. Thus, the following general conclusions are somewhat provisional and the list of recommendations for research fairly long. In the short term, fulfilling these recommendations is expensive. In the long term, however, it will be even more expensive not to fulfill them. The southeastern region of Brazil needs a better understanding of both the public health and ecological consequences of its own continuing economic development.

8.5.1 General Conclusions

1. The climate of the southeastern region of Brazil is generally warm with distinct wet and dry seasons of variable length, depending on the locale. Amounts of precipitation vary about four-fold from humid coastal areas to relatively more arid inland areas. Large parts of the region experience water deficits during one to six months of the year. Thus, river flow rates tend to have very large seasonal differences, and vegetation is subject to seasonal extremes of both water stress and nutrient availability.

2. Wind speeds in the southeastern region tend to be moderate or low, causing pollutants to be deposited near emission sites. Wind direction is generaly easterly. Thus pollutants are carried inland from industrial areas, which are concentrated near the Atlantic coast.

3. The southeastern region is the most densely populated and heavily industrialized region of Brazil. Most of the population is concentrated in cities and towns covering only about 2% of the region's land area. An additional 2% of the land contains industrial facilities, which are near the cities and towns. These facilities are powered mainly by fossil fuel combustion processes and release large amounts of sulfur, nitrogen oxides, and other pollutants into the atmosphere.

4. As in many other developing countries, relatively severe air and water pollution has occurred and has been accepted by people of the region in the interest of encouraging economic development. Widespread public concern about environmental problems and well-designed scientific studies of air and water pollution have been initiated only recently.

5. Most air pollution research in the southeastern region has been in urban areas where direct toxicity to human beings was of greater concern than indirect effects on aquatic or terrestrial ecosystems.

6. The principal emission sources for acidic and acidifying sulfur and nitrogen air pollutants in the southeastern region are heavy industries—metal smelting and metal working industries, electric power plants, fertilizer and heavy chemical industries. Biomass burning and animal waste disposal are the principal sources of air pollution outside urban areas.

7. Sulfur emissions and deposition densities in southeastern Brazil are roughly comparable with those in many parts of Europe and North America, varying from about 3–5 grams of sulfur dioxide per square meter per year in remote areas, to as high as 10 grams per square meter per year in urban areas.

8. Nitrogen emissions and deposition densities are not as well characterized as those for sulfur. However, the ratio of airborne sulfur to airborne nitrogen compounds in some urban areas appears to vary greatly from one locale to another—S/N ratio ranges from about 5 : 1 to 1 : 2.

9. Many soils of the southeastern region are slightly acidic (pH values ranging from 4.5 to 6.8, mostly lower than 5), and have very low cation exchange capacities (ranging from 4 to 17 milliequivalents per 100 grams of soil). These characteristics make the soils vulnerable to acidification by airborne acidic and acidifying substances.

10. The major rivers of the southeastern region show pH values between 6.0 and 7.5. Thus, there is little or no evidence of acidification of either soils or surface waters.

11. During four centuries of settlement, urbanization, and industrialization, most of the diverse native forest vegetation in all four states of the southeastern region has been cut or burned to make way for agricultural crops and managed forests. Regional air pollution is believed to contribute to the deterioration of native forest vegetation, though this has not been proved. Damage to planted crops and forests is not conspicuous.

12. The continuing economic development of the southeastern region requires a stronger sustained research commitment to understand the public health and ecological consequences of continued change to the chemical climate of the region.

8.5.2 Recommendations for Research

1. Environmental monitoring activities by the states and municipalities of the southeastern region should be coordinated to facilitate regional comparisons of results and environmental conditions.

2. Permanent monitoring networks should be established in selected rural and urban areas to determine spatial and temporal gradients in precipitation chemistry and the concentrations of airborne gases, fine aerosol particles, and coarse particulate matter. The chemical constituents of interest should include pH and conductivity, amounts of major cations and anions, amounts of organic acids, sulfur dioxides, nitrogen dioxide, ozone, ammonia and nitric acid vapors, and, if possible, heavy metals in air and precipitation.

3. Permanent monitoring networks should be established to measure seasonal and multiannual trends in the flow rates and chemistry of both headwater streams and major rivers. The chemical constituents of interest for protection of surface waters should include pH, conductivity, alkalinity, amounts of major nutrient cations and anions, and selected heavy metals.

4. Permanent monitoring networks should be established to determine long-term changes in the chemistry of soils and groundwater aquifers.

5. Epidemiological investigations should test current hypotheses about the

influence of airborne chemicals both on public health and on the health and productivity of managed forests and agricultural crops of the region.

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REFERENCES

Alonso, M.T.A. (1977). Vegetation. *In Geography of Brazil*, Vol. 3: 91–116. IBGE, Rio de Janeiro.

CETEC (1983). Environmental Diagnosis of Minas Gerais State. State Organization for Environmental Control CETEC/SPT-010 ISSV-0100-9540. Minas Gerais Technological Center.

CETEC (1985). Data from CETEC archives (unpublished). State Organization for Environmental Control

CETESB (1981). Inland water quality of Sào Paulo state. Environmental Technologies Center CETESB, Sào Paulo.

CETESB (1984). Inland water quality of Sào Paulo state. Environmental Technologies Center CETESB, Sào Paulo.

CETESB (1985a). Estimation of air quality in the inland and coastal region of Sào Paulo state, October 1977–June 1980. Environmental Technologies Center CETESB, Sào Paulo.

CETESB (1985b). Estimation of air quality in Greater Sào Paulo and Cubatào regions. Environmental Technologies Center CETESB, Sào Paulo.

Department of Agriculture (1960). Exploration survey of the soils of Sào Paulo state. National Center of Agronomical Teaching and Research, National Service of Agronomical Research.

Department of Agriculture (1962). Exploration survey of the regional soils under influence of the Furnas Dam. Bulletin No. 13 of the National Service of Agronomical Research.

Department of Agriculture (1968). Exploration ofthe soils that occupy the lower part of the Macl'ae colony nucleus. Technical Bulletin No. 5, Pedology and Soil Fertility Team.

Department of Agriculture (1968). Exploration survey of the soils of the Rio de Janeiro state and of the federal district. Bulletin No. 11 of the National Service of Agronomical Research.

Department of Agriculture (1970). Exploration survey of the soils of the Mean Jequitinhonha region. Minas Gerais Technical Bulletin No. 9, Pedology and Soil Fertility Team.

Department of Agriculture (1972). Short study of the soils in Espirito Santo state, in the northern Paraná and in the southern Mato Grosso, for classification and correlation. Technical Bulletin No. 20, Pedological Research Division.

FAO-UNESCO (1971). South America. In *Soil Map of the World*, Vol. IV, 88–127.

FEEMA (1980). Chlorides, sulfates and nitrates in Rio de Janeiro. State Environment Engineering Foundation Bulletins, FEEMA, Rio de Janeiro.

FEEMA (1984). Water and air quality in Rio de Janeiro state. State Environment Engineering Foundation Department of Pollution Control, Rio de Janeiro (unpublished).

FEEMA (1984). Data from FEEMA archives (unpublished). State Environment Engineering Foundation

(FEEMA) (1985). Strategy for controlling sulfur dioxide emission in Rio de Janeiro state. State Environment Engineering Foundation Department of Pollution Control, Rio de Janeiro (unpublished).

Ferreira, C. and Moreira-Nordemann, L.M. (1985). Ion contents in the precipitation of Salvador, BA. *Brazilian Geosciences Magazine*, 3, 9–13.

Lawson, D.R. and Winchester, J.W. (1978). Sulfur and trace element concentration relationships in aerosols from the South American continent. *Geophys. Res. Lett.*, **5**, 195–198.

Livingstone, D.A. (1963). Chemical composition of rivers and lakes. Geological Survey Paper 440G. US Government Printing Office, Washington, DC, USA

Magnani, A. (1983). Forest degradation in Brazil and in Rio de Janeiro state. FBCN Bulletin No. 7(2), Rio de Janeiro.

Moreira-Nordemann, L.M., Bertoli, J.R.L., Cunha, R.C. and Palombo, C. (1983). Preliminary chemical analysis of rainwater of Cubatào. Environmental impacts. Brazilian symposium of hydrology and hydrological resources. INPE-2857-PRE/396, Blumenau (SC).

Moreira-Nordemann, L.M., Forti, M.C., Andrade, F. de and Orsini, C.M. (1985). Ionic composition of rainwater in Sào Paulo city. Brazilian symposium of hydrology and hydrological resources, November.

Moreira-Nordemann, L.M., Lopes, J.C., Danelon, O.M., Forti, M.C., Espirito Santo, C.M. and Sardella, D.D. (1986). Characterization of rainwater in Cubatào. Final report prepared for CETESB. INPE-3965-RPE/515.

Nimer, E. (1972). Southeastern Brazilian regional climatology: Introduction to the dynamic climatology. Contributing to a Brazilian regional geography. *Rev. Bras. Geog.*, **34**, 3–48.

Oliveira, A.I. and Leonardos, O.H. (1978). *Geology of Brazil*, third edition. High School of Agriculture of Mossoro.

Ribeiro Filho, A. (1975). Sodium, calcium, potassium and magnesium behavior in atmospheric precipitation of the Paraguacu basin. Bahia. M.Sc. thesis, UFBa: 75 pages.

Sanhueza, E., Cuenca, G., Gomez, M.J., Herrera, R., Ishizaki, C., Marti, J. and Paolini, J. (1988). Characterization of the Venezuelan environment and its potential for acidification. In Rodhe, H. and Herrera, R. (Eds.) *Acidification in Tropical Countries*. SCOPE 36, 197–255. John Wiley and Sons, Chichester, England.

Serra, A. (1969). *Climatological Atlas of Brazil*. Department of Agriculture.

Silva, A.B. (1984). Hydrological, hydrochemical and morpho-structural analysis of the Jaiba karstic aquifer, northern Minas Gerais state. Ph.D. thesis, Institute of Geosciences, Sào Paulo University: 190 pages.

Silva Filho, E.V., Brown, I.F., Paula, F.C.F. and Ovale, A.R.C. (1985a). Acid rain and atmospheric input of elements in the Tijuca forest. Rio de Janeiro state, Geotec 1, Congress of Geology and Technology.

Silva Filho, E.V., Ovale, A.R.C. and Brown, I.F. (1985b). Nutrient balance in tropical rainy forests. Tijuca National Park, Rio de Janeiro. Water and Terrestrial Ecosystems symposium, Sào Paulo, September.

Swedish Ministry of Agriculture and Environment (1982). *Acidification Today and Tomorrow*.

Tavares, M.F.M., Vieira, B.M. and Moreira-Nordemann, L.M. (1983). Ion chemical analysis of rainwaters in natural regions. Correlation with atmospheric aerosols. Brazilian symposium of hydrology and hydrological resources, Blumenau, September. 1983.