Vinnytsia National Technical University

Faculty of Construction, Civil and Environmental Engineering

Department of Ecology, Chemistry and Environmental Protection Technologies

MASTER THESIS

«The mechanism of acid rain formation and measures to reduce its impact on the environment»

Student of 2ТЗД-21м group
specialty 183 "Environmental protection technologies"
Jing Wenjing *Wenjing*
Supervisor: PhD, Dr. V. Ishchenko
«20» 06 2024
Reviewer: PhD, Dr. T. Titov
«20» 06 2024

Accepted for defense
Head of the Department ECEPT
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«20» 06 2024

Vinnytsia – 2024

INDIVIDUAL TASK

Vinnytsia National Technical University
Faculty ______Construction, Civil and Environmental Engineering______
Department __Ecology, Chemistry and Environmental Protection Technologies_
Level of study II (master)
Field of knowledge – 18 "Production and technologies"____________________
Specialty –183 "Environmental Protection Technologies"
Study program – "Environmental Protection Technologies"

APPROVED
Head of the Department ECEPT
Prof. V. Petruk
____
27.09 2022

TASK

FOR MASTER THESIS

Jing Wenjing

1.Topic «The mechanism of acid rain formation and measures to reduce its impact on the environment»
supervisor____Vitalii Ishchenko______________________
approved by the order of VNTU on «14» 09 2022 No. 203

2. Deadline for thesis subsmission – 20.06.2024

3. Input data: China's sulfur dioxide emissions: 31.72 million tons per year

4. Content:
Introduction
Preface
1. Overview of acid rain
2. Current situation and distribution of acid rain
3. Formation mechanism of acid rain
4. Acid rain control indicators and acid rain monitoring
5. Impact and harm of acid rain
6. Acid rain prevention and control measures
7. Economic effectiveness of environmental measures
Conclusions
References

5. Illustrations
1. Statistics of precipitation pH value and acid rain frequency from 2003 to 20
2. Proportion and average acid rain frequency of some provinces in 2018
3. Ion equivalent concentration percentage of precipitation in 2018
4. Distribution of acid rain in China
5. The distribution of acid rain in the world

6. Consultants

Chapter	Name and title of the consultant	Signature	
		task is assigned	task is accepte
7 Economical feasibility of environmental measures	Alla Kraevska	Kl	Kl

7. Data of task acceptance "21" 09. 2022

CALENDAR PLAN

No.	Stages of master thesis	Deadline	Notes
1.	Technical task	30.09.2022	викон
2.	Literature review	08.10.2022	викон
3.	Overview of acid rain	15.10.2022	викон
4.	Current situation and distribution of acid rain	31.10.2022	викон
5.	Formation mechanism of acid rain	15.11.2022	викон
6.	Acid rain control indicators and acid rain monitoring	25.11.22	викон
7.	The influence and harm of acid rain	12.12.22	викон
8.	Acid rain prevention and control measures	20.12.22	викон
9.	Conclusions, literature list		

Student Wenjing (signature) Jing Wenjing

Supervisor (signature) V. Ishchenko

ABSTRACT

UDC 504.054

Jing Wenjing “The mechanism of acid rain formation and measures to reduce its impact on the environment”. Master thesis, specialty 183 – “Environmental Protection Technologies”, study program “Environmental Protection Technologies”. Vinnytsia: VNTU, 2024. 90 p.

English language. Bibliogr.: 17 references; 7 figures; 2 tables.

By determining the meaning and characteristics of acid rain, and on the basis of analyzing the formation mechanism of acid rain in the industrial period, the master's thesis introduces the control objectives of acid rain in different regions. It is pointed out that acid rain does serious harm to human production and life, and puts forward effective measures such as perfecting laws and regulations, adjusting energy structure and controlling sulfur dioxide.

Keywords: acid rain, sulfur dioxide, nitrogen oxides, environment.

SUPERVISOR'S REVIEW OF MASTER THESIS

Jing Wenjing «The mechanism of acid rain formation and measures to reduce its impact on the environment»

Acid rains are among the biggest environmental issues. These are formed in every country resulting in water and soil pollution, as well as living organisms damage. Acid rain makes such waters more acidic, which results in more aluminum absorption from soil, which is carried into lakes and streams. Therefore, study on mechanism of acid rain formation and measures to reduce its impact on the environment is highly relevant.

Master thesis contains a thorough analysis of current situation on acid rains in the world, including China. Formation mechanisms of acid rain are analyzed (conditions, factors, etc.). Also, acid rain control indicators are analyzed, as well as acid rain monitoring issues are discussed.

Besides, one should note that acid rain prevention and control measures were prepared.

Master thesis are written at a high level and is of scientific and practical relevance. Master student Jing Wenjing has done all the tasks in time. Therefore, I recommend to accept the master thesis with "A" grade.

Scientific supervisor,
PhD, Head of the Department of Ecology,
Chemistry and Environmental Protection Technologies Vitalii ISHCHENKO

MASTER THESIS REVIEWER'S REPORT

Student: Jing Wenjing

Thesis title: The mechanism of acid rain formation and measures to reduce its impact on the environment

The aim of the thesis of Jing Wenjing was to analyze the environmental problems of acid rain in China and propose feasible control and elimination measures.

The thesis meets the goal and results in a valuable theoretical study and successful practical implementation. The report itself is very well written, using an appropriate language and thesis structure, which makes the thesis easy to follow. Based on the state-of-the-art and state-of-the-practice investigation, it proposes measures for acid rains control and prevention.

The practical part is systematically discussed, including research on impact and harm of acid rains, as well as calculation of the financial profit of environmental measures and research on desulfurization technology.

The following shortcomings can be noted in the master thesis:

- the investigation of climate change impact on acid rains dissemination would be also valuable.

Overall the thesis is very interesting with very high practical value, and is hence in my opinion worth grade A.

Reviewer,
Ph.D., Associate Professor of the
Department of Ecology, chemistry and
environmental protection technologies

Taras TITOV

CONTENT

INTRODUCTION

Relevance. At present, the acid rain is spreading and expanding. The acid rain area has accounted for 30% of China's land area, and has become the third largest heavy acid rain area in the world after Europe and North America. Acid rain is a global disaster that crosses national boundaries and is known as “death in the air”. It has been listed as one of the major environmental problems facing mankind at present (acid rain wreak havoc on water crisis, land desertification, ozone layer destruction, greenhouse effect, soil erosion, forest sharp decline, species extinction and toxic chemical pollution). The rapid development of our economy, especially the rapid development of electric power and steel industry, has led to the increase of sulfur dioxide emissions, resulting in increasingly serious air pollution. Therefore, the control of sulfur dioxide emissions and the formation of acid rain has become the central content of our environmental pollution control work. In this paper, I will summarize the formation mechanism and harm of acid rain, and put forward the corresponding treatment measures.

Connection of master thesis with scientific programs, plans, topics. The master thesis was prepared according to research area of the Department of Ecology, Chemistry and Environmental Protection Technologies in Vinnytsia National Technical University.

The goal of master thesis is to analyze the environmental problems of acid rain in China and propose feasible control and elimination measures.

Tasks of master thesis:

- providing the overview of acid rain;
- analysis of current situation and distribution of acid rain;
- studying the formation mechanism of acid rain;
- study on acid rain control indicators and acid rain monitoring;
- assessment of the influence and harm of acid rain;
- developing acid rain prevention and control measures.

Object of the research – acid rain environmental problems in China.

Subject of the research – environmental pollution parameters of acid rain.

Novelty of the results. Further develop the scientific demonstration to deal with acid rain environmental problems. This will help to reduce the environmental impact of acid rain problems.

Practical value includes putting forward feasible and effective measures to control acid rain.

1 OVERVIEW OF ACID RAIN

The modern Industrial Revolution began with the steam engine. Coal was burned in boilers to produce steam to drive machines. Then coal-fired power plants proliferated, and the amount of coal burned soared. Unfortunately, coal contains impurities sulfur, about one percent, in combustion will discharge acid gas SO_2. The high temperature generated by combustion can still promote the partial chemical changes in the air that supports combustion, the combination of oxygen and nitrogen, and the emission of acid gas NO_x. They are washed and dissolved by rain and snow high up in the sky, and rain becomes acid rain. These acidic gases become impurities such as sulfate, nitrate, and ammonium ions in rainwater.

Acid rain was first identified by M. Ducros, whose 1845 article in the Journal of Pharmaceutical Chemistry confirmed its existence. A later British chemist, Robert Smith, published a paper in 1852 revealing the relationship between acid rain and industrial emissions in Manchester. Smith's pioneering research was largely forgotten until the mid-20th century, when a growing number of scientists from Canada, the United States, and Australia discovered a strong link between air pollution and atmospheric sulfate (SO_4^{2-}) deposition and other chemicals. The concept of acid rain was first proposed by the British chemist RA Smith. In 1872, Smith analyzed the rainwater in the city of London and found that it was acidic, and the rural rainwater contained ammonium carbonate, which was not acidic. Suburban rainwater containing ammonium sulfate, slightly acidic; Urban rainwater contains sulfuric or acidic sulfates and is acidic. So Smith first coined the term "acid rain" in his book Air and Rainfall: The Beginnings of Chemical Climatology.

As the name suggests, acid rain is acid rain, the current general PH less than 5.6 rain called acid rain. It includes rain, snow, hail, fog, dew and other precipitation process, from the point of view of atmospheric pollutant sedimentation and "acid rain" called "acid rain", also known as "acid precipitation", and consider the environmental impact, in order to more fully express the concept of "acid precipitation" environmental problems, Some call it "environmental acidification." In the process of formation and fall, rain and snow absorb and dissolve sulfur dioxide and nitrogen oxides in the air, forming acidic precipitation with a pH lower than 5.6. Acid rain is mainly caused by the man-made release of large amounts of acid into the atmosphere. Acid rain in China is mainly caused by burning large amounts of coal with high sulfur content, which is mostly sulfuric acid rain and less nitric acid rain. In addition, exhaust gas emitted by various motor vehicles is also an important cause of acid rain.

The modern scientific explanation of acid rain as an environmental problem stems from studies in the 1960s and 1970s by Swedish scientist Svante Oden and North American scientist Gene Likens on regional emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x). Their work not only established a link between acid rain and emissions from thermal power plants and other industrial sources, but also demonstrated the effects of acid rain on the ecological environment, such as acidification of water bodies and poisoning of vegetation and fish.

The work of acid rain pioneers made governments, policy makers, the media, and the public aware of the serious ecological damage caused by acid rain, and led to the enactment of the first sulfur dioxide and nitrogen oxide emission reduction laws in North America and Europe. Awareness and policy formulation of acid rain hazards in Asian countries lag behind Western countries, and sulfur dioxide and nitrogen oxide emissions are still rising in some individual countries (e.g. India).

Current global reports show that atmospheric levels of sulfur (S) and nitrogen (N) are still rising in areas close to industry and coal burning. At the same time, the scientific community is generally aware that ammonia (NH_4) and ammonium (NH^{4+}) can also cause ecosystem acidification [1].

Although acid rain is no longer a major focus of the media in North America and Europe, scientists continue to observe and study atmospheric subsidence and the restoration of ecosystems after acid rain events. In recent years, the scientific community has continuously made new progress in the study of acid rain. For example, our understanding of soil-regulated ecosystem restoration has been significantly improved, revealing how plants and animals respond to low sedimentation level and its regulatory factors, and quantifying the rate of ecosystem restoration. Acid rain affects regions on a large scale, and new observations are exploring the ability of ecosystems to recover from such large-scale disturbances. In addition, people are beginning to realize the close relationship between sulfur dioxide and nitrogen oxides and the air pollutants mercury (Hg) and ozone (O_3).

The acid rain area will continue to expand, and the harm to humans will also increase day by day. It has been confirmed that sulfur dioxide and nitrogen dioxide in the atmosphere are the main substances that form acid rain. Among the acid rain components measured in the United States, sulfuric acid accounts for 60%, nitric acid accounts for 32%, hydrochloric acid accounts for 6%, and the rest is carbonic acid and a small amount of organic acid. Sulphur dioxide and nitrogen dioxide in the atmosphere are mainly derived from the combustion of coal and oil, which form acid dissolved in rainwater under the action of oxidants in the air. According to statistics, about 100 million tons of sulfur dioxide and 50 million tons of nitrogen dioxide are emitted into the atmosphere globally every year. Therefore, acid rain is mainly caused by human production activities and life.

At present, three major acid rain regions have formed in the world. China covers Sichuan, Guizhou, Guangdong, Guangxi, Hunan, Hubei, Jiangxi, Zhejiang, Jiangsu and Qingdao and other provinces and cities. The acid rain area with an area of more than 2 million square kilometers is one of the three major acid rain areas in the world. The rapid expansion of acid rain areas in China and the high acidification rate of precipitation are rare in the world. The other two acid rain regions in the world are centered on Germany, France, the United Kingdom and other countries, affecting more than half of Europe, the Nordic acid rain region, and the North American acid rain region including the United States and Canada. The total area of these two acid rain areas is about 10 million square kilometers, and the pH value of precipitation is less than 0.5, and some are even less than 0.4. When acid rain falls, the leaves are severely eroded and the survival of trees is seriously endangered. Also, the ground will acidify. Many bacterial organisms grow in the soil, and these organisms play an extremely important role in the growth of plants. For example, there are as many species of bacteria growing in black soil as the world's population. If the soil is eroded by acid rain, most of the bacteria in the soil will not survive except for a small part. In addition, the nutrients in the soil are lost when dissolved by the acid, which also constitutes a hazard to the trees.

In Canada and Europe, 15% to 60% of forests are eroded by acid rain to varying degrees and wither on a large scale. If this continues, the forest will disappear in the near future. Not only are forests seriously threatened, but soils are also subject to acid erosion, which can also lead to reduced agricultural yields.To that end, we're throwing alkaline lime into acidic soil for neutralization. However, neutralizing with lime is not a foolproof solution, and it cannot fundamentally solve the problem.

In addition, acid rain can easily corrode cement, marble, and rust ferrous metal surfaces. Therefore, buildings are easily damaged, and carvings in parks and many ancient ruins are also susceptible to corrosion. If the harm caused by acid rain is measured in money, the loss is huge, and many losses are irreversible with money.

Acid rain is characterized by a wide range of pollution. It can migrate and spread more than 100-1000 kilometers, causing pollution. Monitoring of sulphur dioxide and nitrogen oxides using simulation tests and measurement has identified sources in the United Kingdom, France, Germany, Poland and the Netherlands as' culprits' in the Scandinavian acid rain problem. Acid rain is a typical example of global pollution and one of the most serious environmental pollution problems in the world.

2 CURRENT SITUATION AND DISTRIBUTION OF ACID RAINS

Since the beginning of this century, the scope of acid rain pollution around the world has been expanding. Acid rain, which originally only occurred in industrially developed countries in North America and Europe, has gradually expanded to some developing countries, such as India, Southeast Asia, and China. At the same time, the acidity of acid rain is gradually increasing. According to the continuous monitoring results of the European Atmospheric Chemistry Monitoring Network in the past 20 years, the acidity of rainwater in Europe has increased by 10%, and the pH of acid rain in Sweden, Denmark, Poland, Germany, Canada and other countries is mostly about 4.3. There are already 15 states in the United States. Acid rain pH is below 4.8.

Anthropogenic emissions of sulfur dioxide worldwide are currently about 160 million tons per year. Nitric acid is formed from nitrogen oxides. Nitrogen oxide gas is mainly produced at high temperature combustion. For example, nitrogen oxides are released in combustion chambers of automobile engines and when fossil fuels are burned at high temperatures. Artificial sources of hydrogen chloride. In addition to factories that use radon chloride, the gas is also released by the incineration of waste (which has high chlorine content in plastics) and the burning of fossil fuels. Although sulfur dioxide and ammonia oxide caused by human activities are about the same amount as those from natural sources (i.e., about 50% each), the amount of sulfur dioxide caused by human activities is more because nature has a limited capacity to clean itself. This is like a person to eat, the stomach again large, let him eat twice the meal, but also the belly. The formation of acid rain by sulfur oxides and nitrogen oxides in atmosphere is a very complicated atmospheric chemical and physical process. If there is no cloud and rain when forming acid material, the acid material will gradually fall on the ground in the form of gravity sedimentation, which is called dry sedimentation, in order to distinguish it from the wet sedimentation such as acid rain and acid snow. Dry fallout combines to form acids when the ground meets water. The acidity of acid clouds and mists, which are not diluted by much larger raindrops, is much more acidic than acid rain. SO_2 and NO_x discharged from pollution sources are the main starting materials for acid rain formation, because SO_2 and NO_x in the atmosphere dissolve in water after oxidation to form H_2SO_4,

HNO_3 and HNO_2, resulting in the decrease of rain pH value. When pH value is lower than 5.60, acid rain is formed.

2.1 Current situation on acid rains in China

China is a big coal-burning country, and coal accounts for 75% of the total energy consumption. In 1980, the national coal consumption was only 600 million tons, but with the development of economic construction, it reached 1.28 billion tons in 1995, more than doubled in 15 years. With the increase of coal consumption, the emission of sulfur dioxide is also increasing. In the 1980s, acid rain in China mainly occurred in Sichuan, Guizhou and Guangdong and Guangxi regions represented by Chongqing, Guiyang and Liuzhou, with an area of 1.7 million square kilometers. By the mid-1990s, acid rain had developed to the vast areas south of the Yangtze River and east of the Qinghai-Tibet Plateau, and the area of acid rain had expanded by more than 1 million square kilometers. The acid rain area in central China, represented by Changsha, Ganzhou, Nanchang, and Huaihua, has become the most seriously polluted area of acid rain in the country. The pH value of annual precipitation in the central area is lower than 4.0, and the frequency of acid rain is as high as 90% degree. East China coastal areas represented by Nanjing, Shanghai, Hangzhou, Fuzhou, Qingdao and Xiamen have also become major acid rain areas in China. Acidic precipitation also occurred in parts of North China and Northeast China. In China's air pollution, acid rain and flying dust are the most important ones. For more than a decade, the problem of acid rain has become increasingly prominent due to increasing emissions of sulfur dioxide and nitrogen oxides. China is now the third largest acid rain region after Europe and North America.

With the rapid development of Asian economy, the Asian region centering on the south of Yangtze River, the east of Qinghai-Tibet Plateau and the vast area of Sichuan Basin has become one of the three major acid rain regions in the world. There is a close relationship between acid rain and energy consumption increase.

With the rapid development of Chinese economy, energy consumption continues to increase year by year, and coal as one of the main energy sources in China, acid rain monitoring began in the late 1970s. In 1974, acid rain was first monitored in Beijing, and then pH of precipitation was monitored in a few cities such as Shanghai, Chongqing, Guiyang. Since 1979, various provinces and cities have carried out monitoring work and projects in this field. Early in the same year, acid rain was first detected in Songtao County in Guizhou province and Changsha City in Hunan province in Fenghuang County. Since then, acid rain has been monitored in most provinces and cities successively. Especially in the summer of 1982, acid rain fell continuously in Chongqing, and the pH value of precipitation was mostly below 4.0. In order to understand the distribution of acid rain and find out the situation of acid rain pollution in China, the national environmental protection department established a national acid rain monitoring network in 1982, establishing 189 observation stations and 52 precipitation sampling points to establish a preliminary acid rain monitoring network. In 1982, the State Department of Environmental Protection found that acidic precipitation began to appear in some parts of north China based on the observation records. The average annual PH value of precipitation acidity is less than or equal to 5.6 in Huangdao and Jinchang in Tianjin, Beijing and Gansu. The cost of acid rain in China is generally divided into four regions: Southwest Central China, East China and South China. However, the acid rain in central China is the most polluted, and the frequency of acid rain distribution in the central city is as high as 90%, which is almost the degree of acid every rain. The former State Environmental Protection Administration organized the acid rain census in 2002 in order to master the acid rain pollution situation and development trend accurately, determine the acid rain pollution areas and levels, and verify the main pollutant composition and characteristics of acid rain pollution in China. The number of cities (districts and counties) monitoring acid rain increased from 111 in 2001 to 556 in 2002. The establishment of the national acid rain monitoring network has accumulated a large number of monitoring data, which provides important data support for Chinese acid rain control and research. By the end of 2018, more than 450 cities had carried out routine precipitation monitoring.

The occurrence of acid rain in China is inseparable from the emission of sulfur dioxide. According to the annual emission of sulfur dioxide provided by the Environmental Bulletin published by the State Environmental Protection Bureau, the emission of sulfur dioxide showed a downward trend from 1997 to 1999. Around 1998, The State Council approved the Division Plan of Acid Rain Control and sulfur Dioxide Pollution Control Zones of the State Environmental Protection Administration, which proposed strict control of sulfur dioxide emissions from the two industries of power and coal in the two controlled zones, thus significantly reducing sulfur dioxide pollutants during this period. The Law of the People's Republic of China on the Prevention and Control of Air Pollution amended in 2000 first proposed the concepts of acid rain control zones and sulfur dioxide pollution control zones. Through unremitting efforts, acid rain pollution has been greatly improved since 2008. Although the Law of the People's Republic of China on the Prevention and Control of Air Pollution amended in 2015 did not mention the content of acid rain, acid rain, as a global atmospheric environmental problem, is still widely concerned, and it is necessary to continue monitoring acid rain. Some studies show that the pH and electrical conductivity of precipitation (EC) had great changes from 2011 to 2016 compared with 1980 to 2000. From 2011 to 2014, equivalent concentrations of Sodium (Na^+), the NO_3^-, SO_4^{2-} respectively from (7.26 ± 2.51), (11.56 ± 3.71), (33.73 ± 7.59) μeq/L increase to (11.04 ± 4.64), (13.59 ± 2.63) and (41.95 ± 8.64) μeq/L, and reduced to 2016 (9.75 ± 2.89), (12.29 ± 4.02), (30.57 ± 7.43)μeq/L. The above change is mainly due to the special treatment of air pollution, which has reduced air pollution. However, in recent years, the rapid development of the domestic economy, the rapid demand for energy and the increase in the number of cars have made the acid pollutants show a rising trend. It is predicted that before 2020, the emission of sulfur dioxide will continue to grow, and this year, the emission of sulfur dioxide has reached about 31.72 million tons.

Because NO_2 is more difficult to control. Its emissions would exceed 20 million tons or so.

Acid rain is spreading rapidly in China. Research shows that the area of acid rain in China has expanded from 1.75 million square kilometers in 1998 to 3.84 million square kilometers in 2009, accounting for about 40% of China's national land area. In this decade or so, the area of acid rain has expanded by more than 2 million square kilometers. And in the acid rain region there is a large movement south of the Yangtze to the northwest across the Yangtze and the Yellow Rivers. According to the test results, the acidity of precipitation in the country remained stable in the 1990s. After 2000, the acidity of precipitation showed an increasing trend. By 2005, the average concentration of sulfate and nitrate in precipitation increased by 12% and 14% respectively. The area of heavy acid rain increased from 4.9% of the total land area in 2002 to 6.1% in 2005. It has brought serious economic losses to China.

In 2018, the pH of the average annual precipitation in 291 cities ranged from 4.49 (Ji 'an, Jiangxi Province) to 8.05 (Tangshan, Hebei Province), with an average of 5.56. The average annual precipitation pH of 63 cities was lower than 5.6, accounting for 21.6% of the total. The average annual precipitation pH of the 12 cities was 4.5-5.0, accounting for 4.1%. The average annual precipitation pH of one city is lower than 4.5, accounting for 0.3% (see Table 1.1). From the analysis of occurrence frequency of acid rain, the average frequency of acid rain in China in 2018 was 11.7%, among which the average frequency of heavy acid rain was 4.7% and that of heavy acid rain was 1.4%. Among 291 cities, 118 cities had acid rain, among which 28 cities had acid rain frequency of more than 50%, accounting for 9.6% of all cities. Zhoushan City of Zhejiang Province had the highest acid rain frequency, accounting for 96.0%. Compared with 2003, the maximum frequency of acid rain occurrence changed from 100.0% to 96.0%, the average frequency of acid rain occurrence decreased by 9.8 percentage points, the proportion of acid rain in cities decreased by 14.8 percentage points, and the acid rain pollution situation was significantly improved.

Table 1.1 – Statistics of precipitation pH value and acid rain frequency from 2003 to 2018

year	PH of annual urban precipitation			Acid rain frequency /%		Acid rain city ratio /%		
	minimum value	maximum value	average value	maximum value	average value	pH<5. 6	4. 5≤pH<5. 0	pH<4. 5
2003	3. 67	8. 05	4. 99	100. 0	21. 5	36. 4	15. 5	6. 2
2004	3. 80	8. 16	4. 87	100. 0	23. 4	40. 9	18. 6	7. 6
2005	4. 02	8. 13	4. 87	100. 0	24. 6	39. 2	15. 5	12. 7
2006	3. 85	8. 58	4. 85	100. 0	25. 6	39. 9	18. 2	10. 3
2007	3. 99	7. 95	4. 92	100. 0	23. 8	39. 5	15. 8	9. 3
2008	4. 04	8. 11	4. 94	100. 0	23. 8	40. 5	16. 8	8. 9
2009	3. 86	7. 97	5. 00	100. 0	22. 0	38. 8	14. 8	7. 2
2010	3. 93	8. 16	4. 96	99. 0	22. 0	36. 1	14. 8	8. 6
2011	4. 19	8. 34	5. 09	100. 0	20. 7	34. 4	15. 1	5. 5
2012	4. 22	7. 94	5. 00	100. 0	22. 0	35. 7	15. 1	5. 5
2013	4. 01	7. 93	5. 18	100. 0	19. 5	30. 9	12. 7	3. 1
2014	4. 19	8. 07	5. 18	100. 0	18. 7	32. 6	15. 1	1. 7
2015	4. 18	7. 81	5. 34	100. 0	15. 6	25. 8	8. 6	1. 0
2016	4. 06	8. 07	5. 40	100. 0	14. 0	22. 0	6. 2	1. 0
2017	4. 51	8. 04	5. 48	100. 0	11. 8	21. 3	6. 5	0. 0
2018	4. 49	8. 05	5. 56	96. 0	11. 7	21. 6	4. 1	0. 3

In 2018, acid rain occurred in 17 provinces, among which 13 provinces had average annual urban precipitation pH lower than 5.6. The provinces most affected by acid rain were Zhejiang, Shanghai and Chongqing. The average frequency of acid rain was 64.7%, 45.0% and 17.2%, respectively. The average annual precipitation pH of 11 cities in Zhejiang Province was all lower than 5.6. In addition, Hunan, Jiangxi, Fujian, Hainan, Guangdong, Guangxi and other provinces were heavily affected by acid rain, with an average frequency of acid rain greater than 19.4% (fig. 1.1).

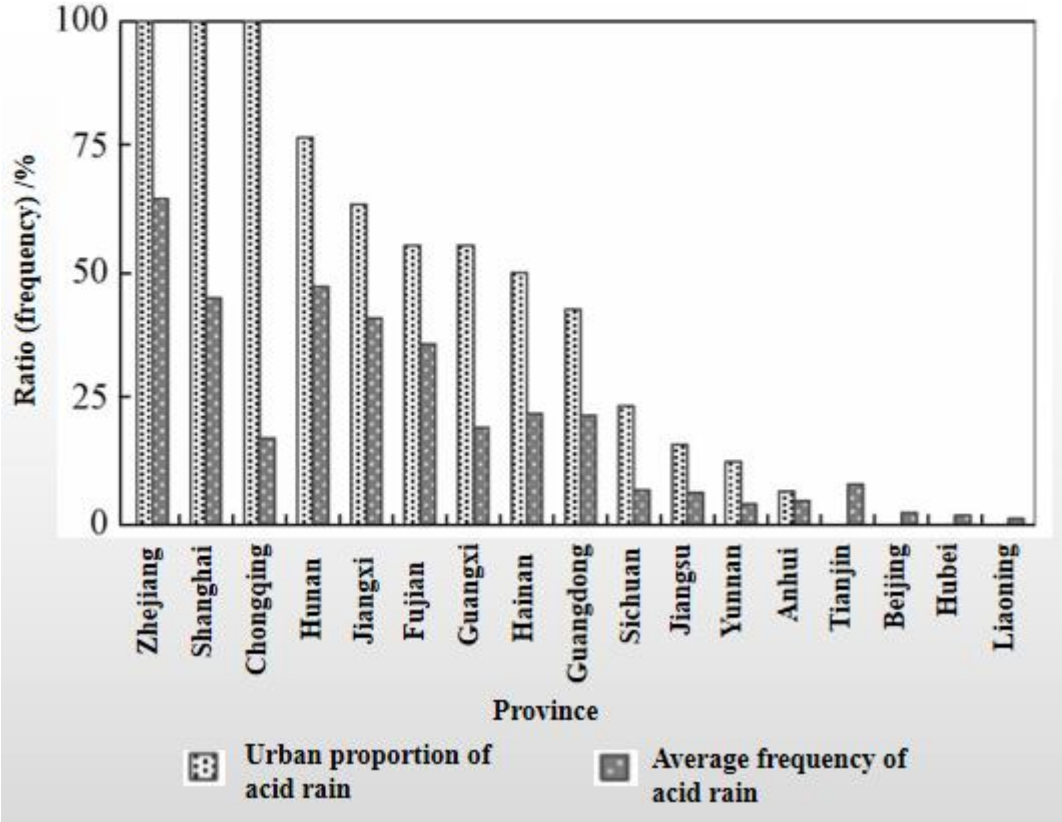

Figure 1.1 – Proportion and average acid rain frequency of some provinces in 2018

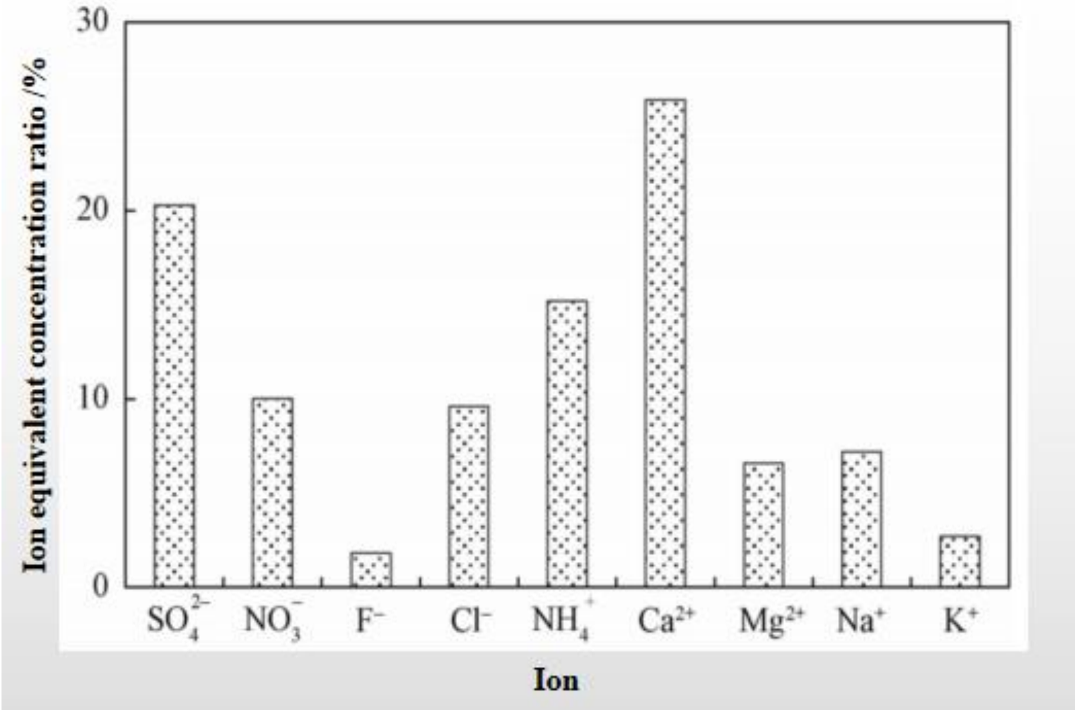

Figure 1.2 – Ion equivalent concentration percentage of precipitation in 2018

In 2018, the major cations in national precipitation were Ca^{2+} and NH_4^+, accounting for 25.9% and 15.2% of the total ionic equivalent, respectively (fig. 1.2). The main anion in precipitation is SO_4^{2-}, accounting for 20.3% of the total ionic equivalent, and NO^{-3} accounts for 10.0% of the total ionic equivalent. The equivalent concentration ratio of NO^{-3} to SO_4^{2-} was 0.49, indicating that acid rain was sulfuric acid, and SO_4^{2-} was still the main acid-causing ion in precipitation [2].

2.2 Distribution of acid rains in China

2.2.1 Regional distribution of acid rains in China

There are obvious geographical differences in precipitation in China, with Qinling and Huaihe River as the boundary, showing more in the south and less in the north, and acid rain in China also presents a similar differential distribution. The average annual PH of precipitation less than 5.6 is distributed in the south of the Yangtze River, and gradually weakens from south to north, and Southwest China has become the most serious acid rain area due to topographic reasons, as shown in fig. 1.3. Acid rain mainly distributes in Sichuan Basin, Guizhou, Hunan, Hubei, Jiangxi, and coastal Fujian and Guangdong provinces south of the Yangtze River. The average annual PH of acid rain in this region is less than 5.0, which is the most seriously polluted area in China. In recent years, the acid rain pollution tends to be serious in the southeast coastal areas of China, and the areas represented by Nanjing, Shanghai, Hangzhou, Fujian and Xiamen have gradually become the main battlefield of acid rain in China, and have started frequent acid precipitation like central and North China. Precipitation of acid rain is rarely observed in North China, which may be due to the low precipitation, low air humidity and low soil acidity in the north. However, it is worth noting that the north such as Houma, Beijing and Tianjin, Dandong, Tumen and other areas are now also acidic precipitation (fig. 3).

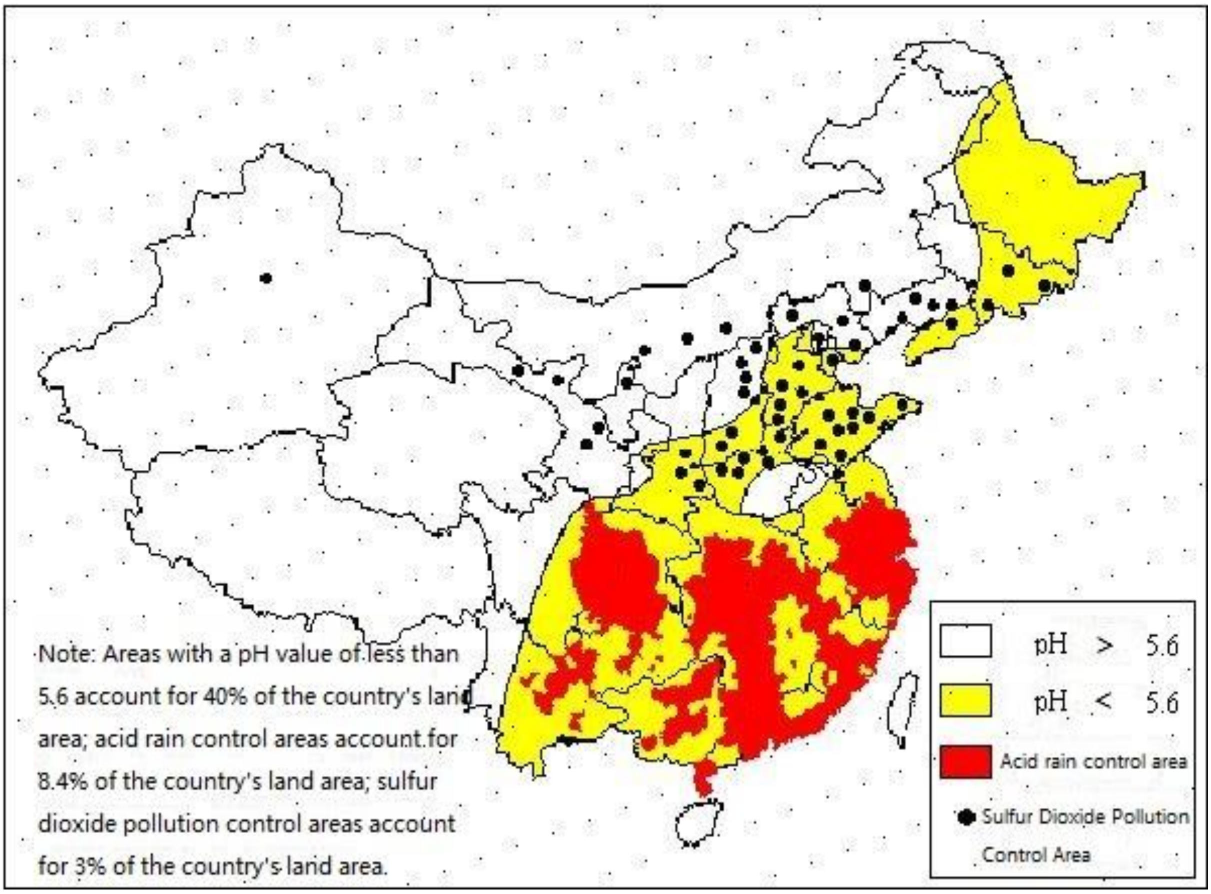

Figure 1.3 – Distribution of acid rains in China

Acid rain is almost a prairie in China, covering more than 30% of the country's land area. The total annual loss due to acid rain is 13 billion yuan. In fact, the emission of sulfur dioxide in northern cities is not less than that in the south, just because the soil in the north is alkaline, the atmosphere is more dusty, and the raindrops are neutralized when they pass through the atmosphere. Whenever the rainfall is prolonged, after the alkaline dust is washed to the ground, the rain will also be acidic. The frequency of acid rain in southern China is high in winter and spring, and relatively low in summer and autumn. This is because there are often quasi-stationary fronts in winter and spring, and the low-altitude front is a stable stratification. The atmospheric pollutants accumulated below the front are often unable to diffuse upward, and the concentration gradually increases. Air pollutants are easily diffused and diluted, thus reducing the acidity of rainwater. The main component of acid rain in Chinais sulfuric acid. The ratio of sulfuric acid and nitric acid in rainwater is very large, 6 to 7 times that of the United States and Germany.

2.2.2 The vertical distribution of acid rain

Acid rain can also form over cities. In the city, the atmospheric composition above varies, the weak acid effect of alkaline in the particles is particularly obvious, the content of matter is small, among which the acid aerosol generated by transformation. On the ground layer, the dust particles increase sharply, the concentration of acid gaseous pollutants increases, but after being elution by rain, it shows different degrees of neutralization. The results of acid rain vertical distribution monitoring in Shanghai, Chongqing and Guangzhou show that the acidity of precipitation in the upper air is higher than that in the near ground.

2.2.3. Seasonal variation of Chinese acid rain

China has more humid air in the south summer, acid rain pH value on the high side. It shows the weak trend in the north, the general development trend is winter and spring acid rain acidity is low, in summer and autumn, acid rain acidity on the high side, presents obvious seasonal acid and change, but seasonal change of acid rain in the south is more prominent.

2.3 Distribution of acid rains in the world

As shown in fig. 1.2, the UK was the first country in the world to accept the baptism of air pollution. Because Great Britain deforested very early on, and relied on coal for fuel. The dangers of soot and sulphur dioxide in large cities and industrial areas emerged as early as the 17th century. In 1661, writer John Ibson wrote in "The Expulsion of Smoke": "A ghastly smoke like hell hangs over London like the volcanoes of Sicily and the Balkan temples (gods of fire and smelting)". After the Industrial Revolution, the consumption of coal soared, and in the second half of the

18th century, the damage gradually became serious. In 1772, the naturalist Gilbart White wrote in the preface to a new edition of "Expel the Smoke", "The fruit trees in the courtyards around London are not. As a result, even the leaves withered. About half of the children who are growing and developing will die before they are 2 years old."

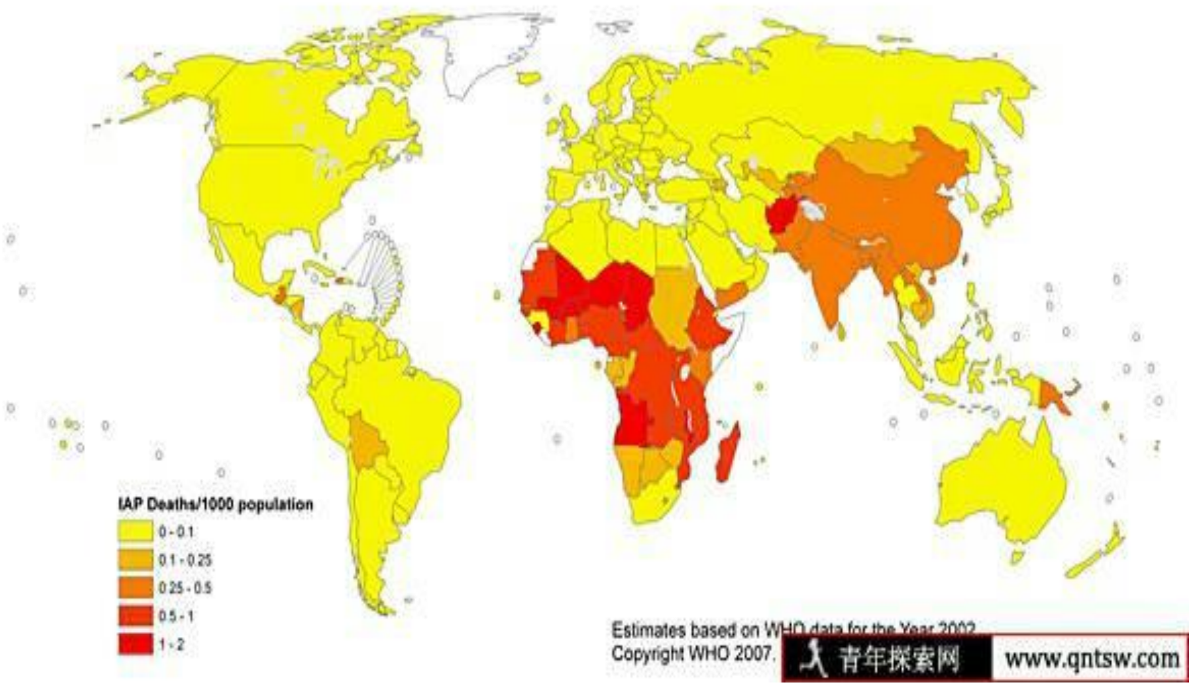

Figure 1.4 – The distribution of acid rains in the world

In 1881, Norwegian scientist Broga pointed out in the report "Pollution Snow" that the cause of Norway's dirty snow was air pollution from the United Kingdom. Thirty years later, in 1911, a large number of fish began to die in the rivers of southern Norway. By the 1980s, there were actually no fish in 1,700 lakes with a total area of 13,000 square kilometers in Norway. The sodium in fish blood is unusually low, which is exactly the typical symptom of acid rain poisoning. Changes in Sweden, which is adjacent to Norway, came later. Around 1940-1950, many unusual changes began to take place in rural southern Sweden. Even without fertilizer, crops can grow well; fishing in rivers or lakes can lead to big fish. It turns out that this is because the nitrate content in the polluted atmosphere is a kind of "nitrogen fertilizer" for crops. "Nitrogen fertilizer" also makes aquatic plants (food for fish) in rivers and lakes proliferate, and the small fish and shrimps poisoned by acid rain into the lake become the food of big fish. Sure enough, the fish disappeared soon after, the scientists said in the paper this is also the result of the effect of acid rain. Scientists also warned in the paper that the harm that acid rain will cause to water quality, soil, forests, and buildings in the future may be a "chemical warfare" for human beings. Unfortunately, they are really right.

The other two acid rain regions in the world are centered on Germany, France, the United Kingdom and other countries, affecting more than half of Europe, the Nordic acid rain region, and the North American acid rain region including the United States and Canada. The total area of these two acid rain areas is about 10 million square kilometers, and the pH value of precipitation is less than 0.5, and some are even less than 0.4. The worst air pollution event in the history of London and the United Kingdom occurred on 4-9 December 1952. The smog incident killed more than 4,000 people, so it was called "killing smog". After the smog dissipated on the 9th,acid rain and acid fog began to run rampant. The pH value of rainwater was as low as 1.4 to 1.9, which was more acidic than lemon juice. After the incident, the public launched a protest movement against the power plant, the main source of London's flue gas. So in 1956, the United Kingdom implemented the "Air Purification Act". In fact, the main goal of this law is to control the visible soot. To quell protests by residents, the factory built tall chimneys to take advantage of high-altitude winds to send pollutants far away. In this way, local pollution has indeed been reduced, but it has caused long-distance transport of pollutants, blaming others, and caused pollution in northern Europe downwind of the UK. The exhaust gas produced by the factory is synthesized into sulfuric acid and nitric acid in the atmosphere. These compounds build up in clouds, and the rain that forms from these clouds tends to fall downwind from pollution sources, and rainwater has high levels of these acids. Acid rain fell there, which later caused an international dispute. Trees absorb acid rain through their roots and leaves. Acid rain deforms roots and prevents branches and shoots from developing, and pines and other evergreen trees lose their needles. In the end, many trees died. Germany and the Scandinavian countries are regions with southwesterly winds, and their forests, rivers and lakes are severely damaged by acid rain [3].

3 FORMATION MECHANISM OF ACID RAIN

It was not until the 18th century, when the caustic soda industry centered in Britain flourished, that air pollution developed into acid rain. In particular, the production of caustic soda as a raw material for glass and soap exploded in the late 18th century. The hydrogen gas emitted during the production process caused acid rain near the plant (hydrogen chloride solution is hydrochloric acid), and all the crops in the fields and the nearby forests died. Later, as the number of coal-burning factories increased, the amount of sulfuric acid in rainwater gradually increased. Acid rain is so serious that the UK has set up the world's first air pollution and public hazard monitoring network. Smith first used the term "acid rain" in his 1872 book "Air and Rain: The Beginnings of Chemical Meteorology". According to the book, One gallon of rain contains two to three reams (one ream is 0.065 grams of acid) in severe cases. So the plants and the tin rotted away quickly, and even the stones and tiles became loose. Now back to the British-made sulfur dioxide gas. Taking the west wind, it crossed the North Sea and first came to Norway in Scandinavia.

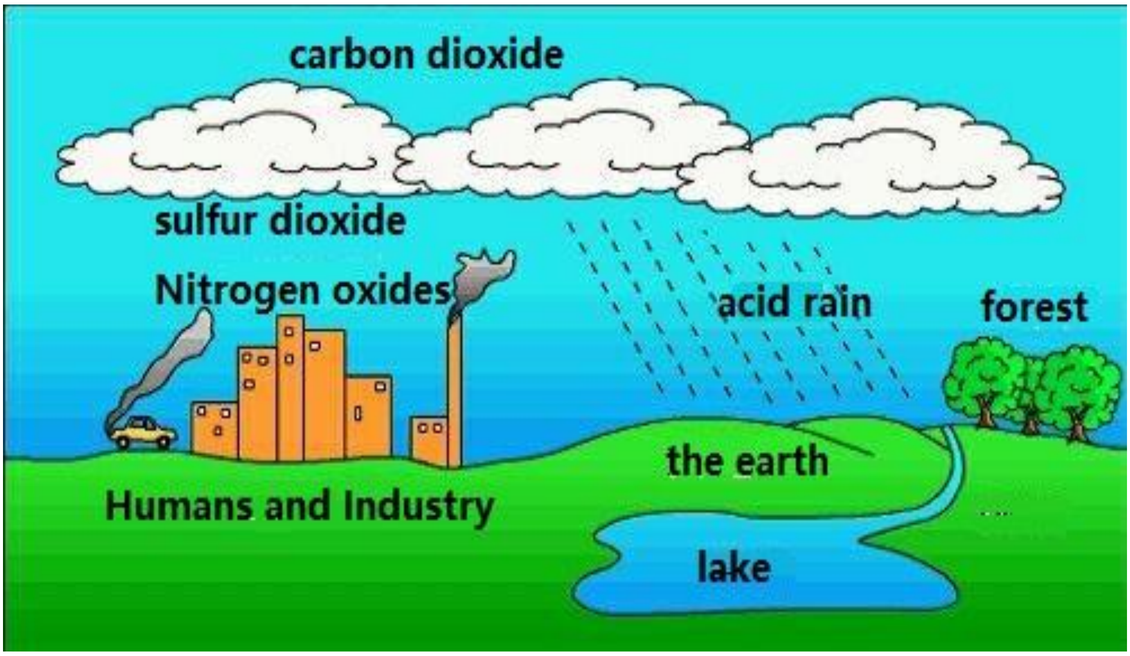

Figure 1.5 – Schematic diagram of the formation process of acid rain

The formation of acid rain is a very complicated atmospheric chemical and physical process. Acid rain contains sulfuric acid and nitric acid and other acidic substances, which are mainly sulfuric acid, generally accounting for about 60% ~ 65%. Nitric acid followed with about 30%, hydrochloric acid about 5%, and organic acids about 2%. Sulfuric acid comes mainly from sulfur dioxide emitted by burning fossil fuels, the biggest sources of which are power plants, steel mills, smelters and small coal stoves in homes.

Acid rain is mainly formed by the reaction of rising atmospheric pollutants NO, SO_2, etc. with moisture in the atmosphere under light or other conditions. There are many other organic pollutants containing phosphorus, sulfur, nitrogen, fluoride, bromide, chloride, etc. Even CO_2 produces acid rain under special circumstances. The reducing substances will be oxidized by ozone, etc., and then combine with water to form acid fog or acid rain. At the same time, ozone depletion will lead to the ozone hole, and ultraviolet rays will take advantage of this and directly kill all life on earth. Oxidizing substances react with reducing substances in the atmosphere to form oxides, and oxides, etc., will directly combine with water to form acid rain (as shown in fig. 1.5) [4].

3.1 Emission of acid gas

Many countries and regions in the world are studying acid rain. After years of observation and experimental analysis, it has been confirmed that SO_2 and NO in the atmosphere are the main substances forming acid rain. According to the United States determined acid rain composition: sulfuric acid accounted for 60%, nitric acid accounted for 32%, hydrochloric acid accounted for 6%, the rest is carbonic acid and a small amount of organic matter. In addition to natural causes such as volcanic eruption, forest fire, earthquake, lightning, decomposition of Marine and land organisms, splashing and evaporation of sea water, the sources of atmospheric SO_2

and NO are mainly man-made causes. The sources of acid gas are summarized in the following aspects:

3.1.1 Natural emission sources

(1) Ocean: Marine fog, which will ensnare some sulfuric acid into the air.

(2) Biological corpse transformation: Some organisms in soil, such as dead animals and plant leaves, can decompose some sulfur compounds under the action of bacteria, and then convert them into sulfur dioxide.

(3) Volcanic eruption: a considerable amount of sulfur dioxide gas emitted.

(4) Earthquake: a large amount of acid gases, such as SO_x and NO_x, will be released through the crust.

(5) Forest fires: Forest fires caused by lightning and dry heat are also a natural source of sulphur oxide emissions, as trees also contain trace amounts of sulphur.

(6) Lightning: high-altitude rain-cloud lightning has strong energy, which can partially combine nitrogen and oxygen in the air to produce carbon monoxide, which is then oxidized into nitrogen dioxide in the troposphere. Nitrogen oxide is the sum of nitric oxide and nitrogen dioxide, which react with water vapor in the air to form nitric acid.

(7) Bacterial decomposition: Even unfertilized soil contains trace amounts of nitrates, which can be broken down into nitric oxide with the help of soil bacteria.

3.1.2 Artificial emission source

With the growth of population, human progress and demand, a large number of fossil fuels such as coal, oil and natural gas are used, and the smoke released after combustion contains a large number of sulfur oxides and nitrogen oxides, especially coal. About 66.7% of the annual SO_2 emissions come from the combustion of coal. For a large coal producing country like China, The situation is even more serious with the long-term dominance of coal-based energy utilization. After complex reactions of sulfur oxides and nitrogen oxides in the atmosphere, sulfuric acid or nitric acid aerosols are formed. When coal, oil and natural gas are burned, high temperature is generated, which makes nitrogen and oxygen in the air combine to produce nitric oxide and then transform into nitrogen dioxide and eventually form nitric acid. In addition, non-ferrous metal smelting will also escape a lot of SO_2 gas.

In the transportation industry, automobile exhaust emissions are also very serious. Inside the engine, the pistons frequently shoot sparks, like lightning in the sky, turning nitrogen into nitrogen dioxide. Different models, the concentration of nitrogen oxides in the exhaust gas is more or less, and the concentration of nitrogen oxides in the exhaust gas of the engine with poor mechanical performance or a long service life is higher. In recent years, the number of all kinds of cars has soared in China, and its exhaust gas contribution to acid rain is increasing year by year, which should not be taken lightly.

In industrial production and civil life, sulfur dioxide from burning coal, nitrogen oxide from burning oil and automobile exhaust, chemical production, especially in the preparation of sulfuric acid and nitric acid, the so-called industrial exhaust contains sulfur dioxide and nitric oxide gas, and some organisms in the soil (fertilizers, etc.) release and decompose the nitric oxide, etc. These gases go through the "rain formation process in the cloud", that is, the water vapor condenses on the condensation nuclei such as sulfate and nitric acid, and the liquid phase oxidation reaction occurs, forming sulfuric acid raindrops and nitric acid raindrops. After the "cloud flushing process", acid rain drops in the process of falling constantly merge adsorption, flushing other acid rain drops and acid gas, forming larger raindrops, and finally landed on the ground, forming acid rain. Because China burns more coal, acid rain is sulfuric acid rain, while countries that burn more oil rain nitric acid rain.

3.2 Oxidation of acid gases in the air

Since the acids in acid rain are mainly sulfuric acid and nitric acid, and the main acidic substances are SO_2 and NO, the oxidation process of SO_2 and NO is mainly discussed here. Their oxidation can be divided into homogeneous oxidation and heterogeneous oxidation according to the reaction system. According to the reaction mechanism, it can be divided into photochemical oxidation, free radical oxidation, catalytic oxidation and strong oxidant oxidation.

3.2.1 Homogeneous oxidation of sulfur dioxide

The absorption spectrum of SO_2includes three absorption bands, which produce singlet state and triplet state, and the homogeneous oxidation reaction usually starts from the triplet state. SO_2reacts directly with $O_2$to generate SO_3 and O, and then H_2O acts to generate H_2SO_4 aerosol. The reaction process is:

$$SO_2 + V \rightarrow SO_2$$

$$SO_2^* + O_2 \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Reaction of SO_2 with oxidative radicals: There are a certain number of oxidative radicals in the atmospheric environment, which are mainly from the intermediate products in the interaction between NO_x and carbon oxides, and also from photochemical pollution products such as aldehydes, nitrites and peroxides. Photolysis of hydrogen oxide. SO_2 collides with oxidative radicals such as OH, CH_3O_2, O_2, H_2O, etc. and oxidizes. The reaction process is as follows:

$$OH + SO_2 \rightarrow HSO_3$$

$$HSO_3 + OH \rightarrow H_2SO_4$$

$$HO_2 + SO_2 \rightarrow OH + SO_3$$

SO_2 can also react with O_3, NO_x, CO, etc. in the atmosphere to form SO_3 such as:

$$SO_2 + O_3 \rightarrow SO_3 + O_2$$

But these reactions can only be in a secondary position compared to free radical reactions. Once SO_2 forms SO, it is very easy to react with H_2O steam to form

H_2SO_4. Therefore, under normal atmospheric conditions, once SO_2 is oxidized, it basically exists in the form of H_2SO_4 aerosol.

3.2.2 Liquid-phase oxidation of sulfur dioxide

When SO_2 in the atmosphere enters into fog, clouds and rainwater, and there are various oxidizing substances (such as O_2, O_3, H_2O_2) in the water droplets, and catalytic substances (such as Mn^{2+}, $2Fe^{+}$, V, etc.) that can promote oxidation. The liquid phase process of SO_2 will occur. There are three main forms of liquid phase oxidation of SO_2:

(1) Non-catalytic reaction of SO_2 and O_2: This reaction process mainly includes the dissolution and dissociation of SO_2 in water, and the ion oxidation of sulfite or sulfite.

(2) Catalytic oxidation of SO_2 and O_2 in Mn^{2+}, Fe^{3+}, etc.:

$$2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4$$

(3) The oxidation reaction of SO_2 with O_2, H_2O_2:

$$SO_2 + O_3 \rightarrow SO_3 + O_2$$

$$SO_2 + HO_2 \rightarrow HSO_2$$

The NH_3 in the atmosphere also has a certain influence on the oxidation of SO_2, because NH_3 can form NH^{4+} in the droplets, which will increase the pH value of the water droplets and accelerate the oxidation of SO_2. The oxidation reaction of SO_2 on the surface of solid particles is also typical.

3.2.3 Solid-phase oxidation of sulfur dioxide

The oxidation reaction of SO_2 on the surface of solid particles is also typical. There are many carbon blacks and metal oxides (such as Fe_2O_3, MnO_2, etc.), which adsorb SO_2 and make it catalytically oxidized to SO_4^{2-}. It has been found that the oxidation rate of SO_2 can be increased by about 30% per hour on the surface of activated carbon, so the oxidation of SO_2 by soot is also very important.

3.2.4 Gas-phase oxidation of nitric oxide

The main components of NO_x in the atmosphere are NO, NO_2, and NO_2 often undergo photolysis in the atmosphere to generate NO, and then generate NO_2 through the action of O_3, H_2O, RO_2, $RCOO_2$, etc.

It can be converted into nitric acid by reacting with OH radicals:

$$OH+NO_2+M \rightarrow HNO_3+M$$

This reaction occurs mainly during the day, and there is another way of producing acid:

$$NO_2 + O_3 \rightarrow NO_3 + O_2$$

$$NO_3+NO_2 \rightarrow N_2O_5$$

$$2O(s) + H_2O \rightarrow 2HNO_2$$

This is mainly a reaction that occurs at night[5].

3.3 Acid precipitation

The addition of acidic substances in the atmospheric environment is a prerequisite for the production of acid rain. However, the formation of acid rain is related to the conditions and formation process of the atmospheric environment. The water vapor in the atmosphere becomes a cloud, and the process of growing into rain is a physical process, which is a change process from a gas phase to a liquid or solid phase. This process can be divided into four stages. The first stage is the supersaturated state of water vapor; the second stage is the generation of cloud particles: it may be fine water droplets or ice crystals. It is the stage of condensation nuclei production; the third stage is when tiny cloud particles or ice crystals condense with water vapor and grow up to become raindrops and snowflakes; the final stage is the growth of raindrops or snowflakes, which is when small raindrops collide, attach and merge with each other. The process of. The first and second stages are the process of cloud formation, and the third and fourth stages are the process of cloud becoming precipitation. Acids can enter the cloud in the first stage, and it can also enter the precipitation during the precipitation process. These two different acidification processes form two distinct types of clear air pollution in wet deposition. The former type, called "rain removal", uses acidic aerosols as condensation nuclei as clouds form. The latter type is called "washout", which is during the rain falling under the cloud. The process of absorbing acidic substances from the atmosphere. This forms acid rain.

3.4 Chinese acid rain characteristics and composition

3.4.1 Characteristics of Chinese acid rain

In recent decades, with the acidification of the earth's atmosphere environment, acid rain pollution has become an international environmental problem. Acid rain in China has its own characteristics compared with acid rain in other parts of the world.

(1) The characteristics of acid rain in China are:

The ion concentration in rainwater is high. The concentration of sulfate (SO_4^{2-}), calcium (Ca^{2+}) and ammonium (NH^{4+}) ions is much higher than that of European and American countries, while the concentration of nitrate (NO_3^-) ions is much lower than that of European and American countries. It is a typical sulfuric acid rain.

Affected by the use of high-sulfur coal in local areas, topography, soil properties and monsoon climate, there are clear boundaries between acid rain and non-acid rain areas. Very low precipitation pH values can be measured in local areas.

(2) Acid rain in Europe is formed by sulfate and nitrate ions. In Western Europe, the contribution of nitrate is more important, but for Europe as a whole, sulfate contributes slightly more to the acidity of rainwater than nitrate ions.

(3) The topography of the United States is generally flatter than that of China. The pH contour changes gradually, and the low value area increases gradually from east to west in the northeast. The pH value in the western arid region with little rainfall is greater than 6. The area with annual pH value lower than 4.5 is similar to

China, but the lowest pH value is higher than China. The contribution of sulfate ion to the acidity of rainwater is less than in China.

(4) In Asia, Japan is the country with the most serious acid rain pollution besides China. The average value of pH in the country is 4.7, and the lowest value is 4.5, which is significantly higher than China. In terms of precipitation acidity and acid rain area, Korea is lighter than Japan, and the annual mean pH of precipitation is greater than 5. The Korean Peninsula is between China and Japan, so the idea that acid rain in Japan comes from China is debatable. Observations show that Malaysia is also a country with severe acid rain in Asia, but lighter than China and Japan [6].

3.4.2 Chemical composition of Chinese acid rain

Acid rain contains a variety of inorganic and organic acids, most of which are sulfuric acid and nitric acid. It can be seen that the formation of acid rain mainly comes from the conversion of SO_2 and NO_x. In the atmosphere, SO_2 and NO_x are oxidized by oxidants, such as O_3 and HO_2, and dissolved in water to form H_2SO_4, HNO_3 and HNO_2, which are the main reasons for the decrease of precipitation pH. In addition, many gaseous or solid substances enter the atmosphere, which also has an impact on the pH of precipitation. Atmospheric particles are catalysts for oxidation such as SO_2. In addition, some alkaline substances in the atmosphere can neutralize the acid in precipitation and buffer the acidity of precipitation, such as lime CaO, $CaCO_3$ in soil, natural and man-made ammonia and other alkaline substances. Therefore, precipitation acidity is the result of acid-base balance.

Through the analysis of rainwater samples, its chemical composition is mainly the following ions:

Cations: H^+, Ca^{2+}, NH_4^+, Na^+, K^+, Mg^{2+}

Anions: SO_4^{2-}, NO_3^-, Cl^- , HCO_3^-

The contribution of these ions to acid rain is not equal. In terms of precipitation chemistry data, the concentrations of Na^+ and Cl^- are close to each other, so it can be considered that these two ions mainly come from the ocean and have no effect on precipitation acidity. SO_4^{2-} dominates the total number of anions. In the total number of cations, H^+, Ca^{2+} and NH_4^+ account for more than 80%, which indicates that the acidity of precipitation is mainly determined by the interaction of these three ions. Generally, there is little difference in the total number of anions in acid rain and non-acid rain areas, and the total number of cations is very different, so the formation of acid rain is not only related to the acid in the water, but also determined by the amount of alkali in the water.

The key ion groups in acid rain in China can be divided into SO_4^{2-}, Ca^{2+}, and NH_4^+, among which SO_4^{2-} is an acid index, mainly from SO_2 discharged from coal, and Ca^{2+} and NH_4^+ are alkali indexes, mainly from natural sources, that is, related to the properties of local soil. Therefore, the regional causes of acid rain distribution in China can be explained to a certain extent.

3.4.3 Forming course of acid rain in China

With the rapid development of iron, steel and electric power industry, acid rain caused by natural fall contains a variety of inorganic acids and organic acids, of which sulfuric acid and nitric acid account for a large proportion. The formation of acid rain in this period is a complicated atmospheric physical and chemical process. Industrial production, burning coal emissions of sulfur monoxide and sulfur dioxide, burning oil and automobile exhaust emissions of nitrogen oxides form the "cloud rain". This includes water gas adsorption in sulfuric acid, nitric acid and other condensation nuclei, liquid phase oxidation reaction, the formation of sulfuric acid raindrops and nitric acid raindrops. In the process of precipitation, other acid rain drops and acid gas continue to merge and absorb, forming larger raindrops, and finally fall on the ground, forming acid rain. The formation of these two kinds of acid rain can be represented by the following two types of chemical reactions:

(1) Formation process of sulfuric acid rain:

Acid rain is mostly caused by the burning of fossil fuels:

Combustion of coal containing sulfur produces sulfur dioxide:

$$S+O_2\text{ (ignition)} = SO_2$$

Sulfur dioxide reacts with water to form sulfite:

$$SO_2+H_2O=H_2SO_3\text{ (sulfite)}$$

Sulfite can be oxidized to sulfuric acid in air:

$$2H_2SO_3+O_2=2H_2SO_4\text{ (sulfuric acid)}$$

Total response equation:

$$S+O_2\text{ (ignition)} = SO_2$$

$$2SO_2+2H_2O+O_2=2H_2S0_4$$

(2) Formation process of nitric acid rain

Nitrogen oxides dissolve in water to form acid: during thunderstorms and lightning, there is often a small amount of nitrogen dioxide in the atmosphere. When lightning occurs, nitrogen and oxygen combine to form nitric oxide:

$$N_2+O_2=\text{discharge}=2NO$$

Nitric oxide is structurally unstable and oxidized into nitrogen dioxide in the air:

$$2NO+O_2=2NO_2$$

Nitrogen dioxide reacts with water to form nitric acid:

$$3NO_2+H_2O=2HNO_3+NO$$

Total reaction equation:

$$4NO+2H_2O+3O_2=4HNO_3$$

$$NO_2\rightarrow HNO$$

$$4NO_2+2H_2O+O_2=4HNO_3$$

In the formula, [O] represents various oxidants. SO_2 and NO in the atmosphere dissolve in water after oxidation to form sulfuric acid, nitric acid and nitrous acid, which is the main reason for the decrease of precipitation pH value.

In addition, there are many gaseous and solid substances in the atmosphere that also affect the pH of precipitation. Calcium oxide in lime, calcium carbonate in soil, natural and human sources of ammonia, and other alkaline substances can neutralize the acid in precipitation, acting as a buffer against acidic precipitation. It can be seen that the key ionic components in acid rain are sulfate ions, calcium ions and ammonia ions. As the target of acid value is sulfate ion, its source is mainly sulfur dioxide emission from combustion. From the difference of acid rain distribution and the cause of formation, sulfur dioxide is mainly man-made at present. It is indicated that the acid rain of China is typical sulfuric acid rain. With the in-depth study of environmental pollution, American scientists found that acid fog formed after the reaction of acid rain and smoke, its acidity is higher, acid fog is 100 times more acidic than acid rain, its more harmful. Acid fog, like acid rain, is originally caused by pollutants from coal-fired power plants and exhaust from cars. Acid fog is formed when pollutants mix with water vapor near the ground. The process is: it first knots on the particle size of small smoke particles, forming droplets, and constantly absorb water from the humid air, so that the unreacted sulfur continues to change into sulfuric acid. When the droplets increase to a certain number, acid fog is formed. Some experts believe that the first two are the main ways to form sulfuric acid smog. However, an expert at the Environmental Research Institute of the US Environmental Protection Agency believes that photochemical oxidation of gas phase is not important for the overall production of sulfur acoustic carbon salts. If gas-phase photochemical reactions were the only way to convert sulfur dioxide to sulfate, the sulfate in winter would seem to be a tenth of that in summer, when there is much less sunlight, but it is actually less than half that. Experts believe that harmful gases discharged into the air, such as sulfur dioxide and ozone, are diffused into the air to react in the liquid phase. There are also many types of primary pollutants in the atmosphere the interaction between the great influence. These materials may be transformed in clouds, raindrops, or after settling. The exact process is unclear. Other experts believe that previous studies of acid rain, which focused more on the reaction of sulfur dioxide in a large amount of water solution rather than on tiny droplets, do not represent the actual situation of the atmosphere. The mechanism by which nitrogen oxides form acid rain is poorly understood. Although nitrogen photochemical smog has been extensively studied in the past, its homogeneous reaction chemistry is almost completely unknown. Some experts believe that part of the reason is that nitrate hinge, a common particle of nitrate, is extremely volatile and easily lost from the filtration medium during the measurement process. To sum up, it can be seen that the formation mechanism of acid rain still needs to be further studied by environmental scientists. According to the above, the acidity of rain comes from sulfur dioxide and nitrogen oxides produced by fuel combustion. But what is dominant varies from place to place. In addition, the acidity and composition of rain also vary significantly with different seasons and regions. For example, acid rain analysis in some areas shows that sulfuric acid accounts for 60% of the total acid, and nitric acid accounts for about 40%. Acid rain in the northeastern United States, 65% sulfuric acid, 30% nitric acid, 5% hydrochloric acid; In addition to sulfuric acid and nitric acid, acid rain in Japan also contains RCHO and other irritants. Japan calls this substance wet air pollution. In China, most of the acid rain is sulfuric acid type. Unpolluted rainwater in the atmosphere is slightly acidic because it is converted into carbonic acid by absorbing and dissolving carbon dioxide in the air as it falls [7].

3.5 Conditions of acid rain formation

Conditions that acid rain forms in China are different, but in the main aspect China is a big coal-burning country that makes China acid rain mainly to sulfuric acid rain. And because of geographical differences, the conditions that affect the formation of acid rain also show different differences.

3.5.1 Fuel

Due to the uneven distribution of fossil resources in China, the energy structure has gradually changed to coal-based, paved with oil and natural gas. 75% of China's resource consumption is coal, and the proportion of high-sulfur coal in coal is large, 84% of which is used for combustion, resulting in a large amount of sulfur dioxide discharged into the atmosphere every year. In addition, China's low utilization rate of coal and backward technology, coal desulfurization and removal rate is low before combustion, which makes fine particles of high-sulfur coal discharged directly into the atmosphere causing pollution, therefore, the proportion of sulfuric acid in the precipitation is high, forming mainly acid rain-sulfuric acid type.

3.5.2 Forest resources

China's existing forest area is about 1.2 million square kilometers, close to 13% of the country's land area, far lower than the world's average forest resource rate of 31.3%. Forests can absorb a large number of carbon dioxide, sulfur dioxide and nitrogen oxides and other acid gases, thus reducing the acidity of precipitation, due to human unreasonable activities, a large number of deforestation resulting in a sharp reduction of large areas of forest. It leads to the formation of acid rain and aggravates the harm of acid rain.

3.5.3 Meteorological conditions

The influence of meteorological conditions on the formation of acid rain is mainly in the chemical and physical aspects. In the chemical aspect, it affects the conversion of preconditions. In terms of physics, it mainly affects the diffusion, transport and sedimentation of acid substances. Sunlight and water vapor can also promote the conversion of sulfur dioxide, forming sulfuric acid in local deposition, and forming acid rain through precipitation. The intensity of sunlight varies with latitude, and the intensity of sunlight in regions with high latitude is relatively weak. For China, the humidity of air decreases gradually from south to north, so under the same conditions. The sulfur dioxide in the southern atmosphere can be converted into sulfuric acid more quickly, which is one of the reasons for the acid rain in the South.

3.5.4 Location

Distribution of acid rain in China has obvious regional characteristics. The general trend is to take the Yangtze River as the boundary, north of the Yangtze River acid rain is generally neutral or alkaline. In the south of the Yangtze River, the region is generally acidic, especially some areas in the south are surrounded by the surrounding low and medium mountains and hills, and the terrain is relatively occluded. In winter, the cold air from the north is difficult to invade due to the effect of the upward purchase. Typhoons entering the south in summer have no great influence on it. The wind speed is small and the frequency of static wind is high. The terrain features that pollutants are not easy to diffuse. Resulting in frequent acid rain. Especially, Chongqing and Chengdu in Sichuan Basin are typical representatives of severe acid rain areas.

3.5.5 Urban planning

The unreasonable urban planning also affects the acidity of precipitation to a certain extent. In the urban development and construction, energy is not included into the overall planning from the perspective of urban sustainable development, and the unreasonable structure and distribution of urban energy make it difficult to implement the subsequent remediation work. The main way to reduce sulfur dioxide pollution is to control the construction scale. The construction of high smoke pipe and the use of atmospheric diffusion self-cleaning capacity can only deal with the surface phenomenon but not the fundamental problem. Therefore, this kind of method can not play a big role in the reduction of sulfur dioxide, and further expand the pollution area, aggravate the regional pollution, can not solve the pollution situation of this effect [8].

3.6 Factors affecting the formation of acid rain

The formation of acid rain is also subject to the restriction and influence of various factors. In the discharge and transformation of acid pollutants, as China is sulfuric acid acid rain, it is mainly polluted by sulfur dioxide, which makes the PH value of acid rain low. What has a great influence on the PH value of acid rain is ammonia in the atmosphere. The change of weather situation and the properties of soil also have great influence on the acid rain.

3.6.1 Ammonia in the atmosphere

Ammonia is the only common gaseous base in the atmosphere. Because of its water solubility, it can react with acid aerosols or acids in rainwater to neutralize and reduce acidity. The main sources of ammonia in the atmosphere are decomposition of organic matter and volatilization of ammonia fertilizer applied in farmland. The volatilization of ammonia in soil increases with the increase of soil PH value. However, the acidity of the soil in the north of China is generally weak, for example, the PH value of the soil in Beijing and Tianjin is above 7~8. The acidity of soil in the southern region is generally acidic, such as Chongqing, Guiyang area is generally 5~6. This is also one of the important reasons for the high level of atmospheric ammonia water in the north and low level in the south. Where the soil is more acidic, the buffering capacity of wind-blown sand and dust is low. These two factors together, at least for the time being, can solve the problem of acid rain in southern China.

3.6.2 Particulate matter in the atmosphere

In addition to acid gases SO_2 and NO_2, there is an important member of atmospheric pollutants - particulate matter. Due to China's special geographical location, the sources of airborne particulate matter are very complex, which mainly consist of coal dust and wind-blown sand dust. In the north, it is mainly wind-blown sand and dust, and in the south, it is estimated to be about one third. The particles have two effects on the formation of acid rain. One is that the catalytic metal contained in the particles promotes the oxidation of SO_2 into acid. The second is to neutralize acid, but if the particles themselves are acidic, they cannot neutralize and will become one of the sources of acid. At present, the concentration level of atmospheric particulate matter is generally very high in China, and the natural factor is one of the factors that cannot be neglected in acid rain research.

The particulates in Beijing are more alkaline, and the buffer capacity is greater than that in southwest China, and acid rain is rarely formed. Therefore, the buffer capacity and pH of particulate matter in the area without acid rain are higher than those in the area without acid rain.

3.6.3 The influence of weather situation

For China, summer winds are typhoons, wind speed is large, static wind rate is low. In winter, due to the influence of the cold air from Siberia, the particles from the north move southward, buffering the accumulation of acid rain in the south and neutralizing part of acid gas, thus reducing the occurrence of acid rain. For strong weather and terrain, it can increase the diffusion of pollution and reduce the concentration of pollutants in the atmosphere, acid rain will weaken, on the contrary, it will increase the degree of acid damage in the region.

3.6.4 Influence of soil properties

The content of alkaline metal ions and pH in soil is one of the important factors affecting the formation of acid rain. The alkaline PH value of the soil in the north is 7~8, and the acidic PH value in the south is 5~6. The contents of metal sodium and calcium in soil decreased from north to south, especially after crossing the Qinhuai River and Qinling Mountains. However, about half of the particulate matter in the air came from the soil, and the ammonia volatilization in the soil in the north was greater than that in the acidic soil in the south. Therefore, the acid rain in the south was also caused by the difference of soil properties in the south to some extent.

4 ACID RAIN CONTROL INDICATORS AND ACID RAIN MONITORING

4.1 Control indicators

4.1.1 Control index of precipitation acidity

Precipitation pH is a measure of the acidity of precipitation. The "natural" pH of rain is generally considered to be 5.6 and used as an indicator of whether it is contaminated by humans. Studies have shown that there is a threshold value for the impact of acid rain on crop and forest ecology. It can be seen from the simulation results of acid rain and acid rain combined with sulfur dioxide pollution on different sensitive tree species in the growth period, even for sensitive tree species, under the condition of acid rain combined with sulfur dioxide pollution, the damage threshold is still rainwater pH≥4.5 and sulfur dioxide concentration 2.14 mg/m^3. Therefore, from the perspective of damage to trees caused by acid rain, it is also appropriate to regard the rain water in the south of the Yangtze River with pH equal to or less than 5.0 as acid precipitation. The area north of the Yangtze River, however, is more sensitive to acid rain because of the alkaline nature of plants and soil. The standard pH for acid rain should be 5.5. Therefore, from the perspective of the impact of acid rain on crops in China, taking the Yangtze River as the boundary, it is more appropriate to set the pH of acid rain below 5.0 in the south of the Yangtze River and 5.5 in the north of the Yangtze River.

4.1.2 Control index of sulfur and nitrogen deposition

Sulfur and nitrogen deposition is an important acid deposition index, which is closely related to human activities. To control sulfur dioxide and nitrogen dioxide emission is to reduce the dry and wet deposition of sulfur and nitrogen. Because the acid settlement in China is sulfuric acid type, the acid settlement in China is controlled mainly to control the sulfur settlement. There are obvious differences in climate, ecology and soil across our vast region, so it is impossible to specify a unified control index of sulfur deposition. Therefore, the concept of critical load value is introduced. The so-called critical load value refers to the maximum amount of acid deposition that an ecosystem can tolerate. If the actual amount of acid deposition exceeds this value, the ecosystem will gradually acidify, change the overall characteristics of the ecosystem, damage the ecosystem, and destroy the original ecosystem [8].

4.2 Acid rain monitoring

In order to predict the occurrence of acid rain and master the law of its change, acid rain must be monitored. However, the monitoring of acid rain is a rather complicated research subject, because: (1) The factors affecting the pH value of rainwater are not only sulfur oxides, nitrogen oxides and their hydrates, but also hydrolyzed acid salts. In addition, the alkaline material in the dust will raise the pH of the rain significantly. However, some of the sulfates produced as a result of neutralization reactions may be physiological acidic salts, such as $(NH_4)_2SO_4$, K_2SO_4 etc. Therefore, measuring the pH value of rainwater alone does not reflect the actual problem. (2) The pH value of the early and late rainfall is very different. For example, outside Qianzao city, due to the influence of alkaline dust, the initial pH value of rainfall is high. In rainy areas, the opposite is true. (3) The sampling method is complicated due to the interference of dust. If the volume sampler (BS) is used, the dust mixed with the rain is also the object of analysis, and the material in the dust is very complex. At the same time, the alkaline dust particles are generally larger, which is more likely to fall into the sampler. However, acidic dust mostly exists in aerosols, which is difficult to capture into the sampler, thus bringing errors. (4) The selection of sampling sites, such as different azimuths and heights of sampling points, will produce large errors. Because the composition of rain is quite complex, and can not only use the acidity meter to determine the pH value, to make an accurate judgment. Thus, adding trouble to the analysis. The actual situation is that there are many monitoring stations, and the concentration of various ions should be measured at the same time, mainly NH_4^+, Ca^{2+}, Mg^{2+}, K^+, SO_4^{2-}, NO_3^-, $C1^-$, HCO_3^- plasma concentration. And then you have to figure out the pH from the ion concentration, which is obviously pretty messy. Therefore, it is an important task for acid rain monitoring workers to study the analysis items of acid rain, which can not only be simple but also reflect the objective reality.

5 IMPACT AND HARM OF ACID RAIN

5.1 Harm of acid rain to human beings

Direct human contact with acid rain, such as walking in acid rain or swimming in acid ponds, does not pose serious health risks. However, people's health is directly at risk when they are exposed to air containing pollutants that cause acid rain, such as sulfur dioxide and nitrogen oxides.

The physical and chemical reactions of sulfur dioxide and nitrogen oxides in the atmosphere produce fine particles of sulfates and nitrates, which can enter the human body through the respiratory system. Numerous scientific studies have shown that the level of these fine particles is directly related to people's heart and lung function, and when the level is high, the rate of sudden heart attacks and asthma patients will be significantly increased. Nitrogen oxides can also react with other substances to form ozone (photochemical smog). Sulfur dioxide and nitrogen oxides are also closely related to severe smog in China in recent years.

The severity of urban air pollution changes the rules of seasonal and diurnal variations, which can be roughly divided into coal type and petroleum type. Coal type is caused by burning coal, so the intensity of pollution is lightest in summer and daytime when the convection is strongest, and heaviest in winter and night when the inversion is strongest and the convection is weakest. The London smog was of this type. The petroleum type is produced by petroleum and petrochemical products and automobile exhaust. Due to the high temperature and strong sunlight are required for the photochemical smog generated by nitrogen oxides and hydrocarbons, the change rule of pollution intensity is just opposite to that of coal type, that is, it occurs most frequently in summer afternoon, and rarely or not at night in winter. Los Angeles photochemical smog falls into this category. In addition, as a result of the increase of urban cloud cover, the sunshine duration and solar radiation in urban areas are reduced. As a result of the increase of soot particles in the city, the transparency of the atmosphere becomes worse, so some people call the city "haze island" or "cloudy island". Soot greatly reduces the ultraviolet part of the sun's rays (by 30 to 50 percent at low solar altitudes), which is also bad for the health of city dwellers. Acid rain can increase the solubility of mercury, lead and other harmful heavy metals, and transfer to water bodies, crops and other plants through the food chain, and eventually endanger human health. Living in an environment containing acid fallout for a long time, acid gas will cause injuries and diseases of human respiratory system. Acid rain contains many carcinogenic factors, which can destroy human skin mucous membranes and lung tissues, induce a variety of diseases and cancers, and reduce children's immune ability. At the same time can cause irritation to the eyes and throat and other parts; On the other hand, acid rain can change various factors around human beings and indirectly affect human health. The sedimentation of acid rain can pollute soil and drinking water resources, and the pollution of drinking water makes human beings face the depletion of the source of life. Some of these toxic metallic acids dissolve into lakes and precipitate in fish, posing a serious threat to humans. According to statistics, acid rain caused thousands of deaths of the elderly and children in some European countries, the United States and Canada in 1990 a year about 200 deaths due to acid rain. In late June 1973, 144 people in Shizuoka and Yamanashi prefectures, Japan, suffered from sore eyes and cough within a 50Km radius. In the year after 1973, about 30,000 people in our Kanto region suffered from the same disease, and on this day the acidity of the local acid rain was 2.85. In 1981, Mosaics, Sweden, found a family of three children with green hair. The reason was that acid rain had acidified drinking water, well water had corroded steel pipes, and washed hair had been stained green by dissolved copper compounds. In Mexico City, a PH of 3.4-4.9 is not uncommon. A survey by the Ministry of Health showed that the death rate from respiratory diseases in Mexico was 93.1 million. In 1989, corrosion was the highest, and more than 100,000 people died each year from public hazards, of which about 30,000 were children [9].

The acidic atmosphere brought by acid rain will seriously affect human respiratory system. In areas seriously polluted by acid, the mortality rate of respiratory system patients increases and the lives of the elderly and children are difficult to protect. Even ordinary people's bodies can suffer great damage. According to the information, acid rain may cause "baldness", sulfur dioxide and nitrogen dioxide can cause respiratory problems, such as asthma, dry cough, headaches and eye, nose and throat allergies; In addition, toxic metals dissolved in water are absorbed by the tissues of fruits, vegetables and crops and animals irrigated with acidified water. They gradually accumulate and enter the human body through the food chain, with serious health implications. For example, mercury accumulated in animal organs and tissues has been linked to brain damage and neurological disorders, and aluminum has been linked to kidney disease. Acid mist invading the lungs to induce pulmonary edema, atherosclerosis, myocardial infarction and other diseases will increase the prevalence; Contaminate food and harm human health. When the acid rain containing cadmium, lead, mercury and other toxic substances pollute water and soil, and enter the food chain, it will pose a threat to human health. Cadmium, lead, mercury and other highly toxic substances can cause a variety of diseases and even death when ingested in excess.

5.2 Acid rain hazards to equipment, facilities and building materials

Acid rain can corrode building materials, metal surfaces and painted surfaces, especially historic buildings and works of art made of rocks such as marble and limestone (Figure 6). Because the composition of the rock is easy to react with sulfuric acid and nitric acid in acid rain, and long-term exposure to the natural environment, the frequency of acid rain leaching is high, easy to be subjected to acid rain corrosion and discoloration. Acid particles can also deposit on buildings and statues, causing erosion. Limestone and marble change into a crushed substance called gypsum when they come into contact with acid. Acid rain will corrode the structure of buildings for a long time, causing the collapse of buildings, corrode buildings (construction materials containing calcium carbonate), power transmission lines, rails, machinery and equipment, leather, paint, ancient buildings, cultural relics and sculptures, etc. Acid rain can also reduce the service life of metals. Acid rain can make non-metallic building materials (concrete, mortar and gray sand brick) surface hardened cement dissolve, appear holes and cracks, resulting in reduced strength and damage to the building. Dirty and black building materials affect the quality of urban appearance and urban landscape, which is known as the "black shell" effect [10].

Figure 1.6 – Erosion of stone statues by acid rain

The railway and aircraft industries will also have to spend more money to repair the damage caused by acid rain. The Canadian Parliament building in Nirvana was reportedly blackened by acid erosion; Ancient buildings and cultural relics in Poland were also damaged. The Lincoln memorial statue near Washington has lost 8 millimeters of marble to acid rain since 1922. The United States estimates that acid rain costs $2.5 million a year. Due to acid rain and acid fog in Chongqing, Sichuan Province, the maintenance cycle of metal parts of the power supply system has been shortened by half in recent years, and the loss of metal parts and line maintenance of mercury lamps along the street alone is more than 100,000 yuan. In recent years, buildings and some metal facilities in Chongqing have been seriously damaged. For example, the service life of Jialing River Bridge, urban public transport vehicles and construction machinery is greatly reduced due to the rapid corrosion of metal materials caused by acid rain and acid fog. New building external decoration can only keep 1-2 years began to change color, fall off. Concrete materials only 3-4 years after the outer mortar erosion peel off, exposing sand. The cement balustrade of the stadium completed in 1956 has been riddled with holes, uneven, and exposed more than 1 cm of stone. Over time, the average cement erosion is 0.4 mm per year. Acid rain poses not only an economic burden but also a danger to the safety of the general public. As an example, the bridge over the Ohio River collapsed in 1967, killing 46 people. The main reason is corrosion by acid rain. In addition, acid rain erosion of statues also causes the destruction of cultural assets, which worries many people. As can be seen from the above, acid rain is very harmful.

5.3 Harm of acid rain to soil and plants

Acid rain can inhibit the decomposition of organic matter in soil and the fixation of nitriding. After the acid rain washes the soil, it will cause the loss of nutrients such as calcium, magnesium and potassium which are combined with the soil particles, making it more difficult for the plants to grow in the barren soil. Secondly, it will hurt the new buds and leaves of plants. In the growing season, the new buds and leaves of most plants cannot withstand the acid rain washing, and eventually the plants will become diseased or even die. By damaging plant cell membranes, inhibiting plant metabolism, and impeding photosynthesis of their green leaves, acid rain reduced Swedish forest productivity by 2%-7% from 1950 to 1965. Acid rain and air pollution are estimated to cause billions of dollars in ecological damage in the United States each year. Similarly, the direct economic losses caused by acid rain pollution in the south of China are up to 4.4 billion yuan per year according to the study of the Seventh and eighth Five-Year Plan [11].

Dead or dry trees are a sign of areas affected by acid rain. Acid rain will leach aluminum from soil, thus causing harm to plants and animals. Acid rain will also cause the loss of soil minerals and nutrients, affecting the growth and development of plants. In high altitude areas, acid rain can exist in the form of fog or cloud, and strip the nutrients in plant leaves, leaves gradually dried up and died, the area of plants for photosynthesis is reduced, they will become more vulnerable and difficult to resist low temperature stress in high altitude areas.

Acid rain can cause soil acidification. The soil in southern Chinawas originally acidic, and then washed by acid rain, which accelerated the acidification process; the soil in northern China is alkaline and has a strong buffer capacity against acid rain. It can accelerate the weathering of primary and secondary minerals containing aluminum in the soil, and release a large amount of aluminum ions to form aluminum compounds that can be absorbed by plants. Long-term and excessive absorption of aluminum by plants can cause poisoning and even death. Acid rain can still accelerate the loss of soil minerals and nutrients; change the soil structure, lead to barren soil, and affect the normal development of plants; acid rain can also induce plant diseases and insect pests to greatly reduce crop yields, especially wheat under the influence of acid rain. 34%. Soybeans and vegetables are also susceptible to acid rain, which reduces protein content and yields. Soil acidification further harms plant roots and foliage. Plants are producers of terrestrial ecosystems, animals are consumers, and microorganisms are decomposers. Plants are harmed, animals and microorganisms are successively affected, disrupting the balance of terrestrial ecosystems. Scientists have tried watering plants with acid water. As long as the pH value of the water is lower than 3, necrotic spots will appear on the surface of leaves such as rice, pine trees, and sunflowers. Under the microscope, the pores and stomata on the surface of the leaves are damaged, which seriously affects photosynthesis. . Moreover, the acid water deprives the plant of calcium, magnesium and other substances, which gradually weakens the plant. The yellowing of plant leaves is due to the lack of magnesium and the difficulty in synthesizing chlorophyll. Conifers, such as pines, are particularly sensitive to acid rain because conifers do not shed their leaves year-round, and the damage from acid rain builds up in the needles over the years. Acid rain can also drastically reduce crop yields. For example, winter wheat yields were reduced by 13.7% under the influence of acid rain at pH 3.5 and 34% at pH 2.5. Soybeans and vegetables are also susceptible to acid rain, which reduces yield and quality (protein content) [12]. In the northernmost part of the European continent near the Arctic Circle, moss and lichens are lost in many areas due to acid rain. At the same time, the sulfuric acid in acid rain makes the soil more infertile, it melts nutrients such as calcium, magnesium, and potassium in the soil and sulfates them. Acidified soil further affects the activity of microorganisms, making the soil lose its neutralizing ability. If the pH of the soil is too low (acidic), most plants cannot continue to grow, and they will die due to strong acid. The chlorophyll content of leaves eroded by acid rain will be reduced, hindering photosynthesis, causing leaf atrophy and deformity.

Acid rain also affects the chemical composition of the soil. The first is the influence on K, Na, Ca and Mg. K, Na, Ca and Mg play a crucial role in plant growth and are indispensable nutrient elements in the process of plant growth. Exchangeable bases in soil require large amounts of cations in the form of K, Na, Cl and Mg, because these cations are important components of the exchange process. The greater the total amount of exchangeable bases, the greater the corresponding base saturation in the soil. Generally, neutral and alkaline soils have high base saturation, for example, 100% in brown soils. However, base saturation in acidic soils is lower. For example, red soils only have 20 to 30 percent base saturation. Sulfur tetroxide and nitrogen trioxide are the main sources of soil acidification. When the soil is dissolved by acid rain, the concentration of sulfur tetroxide and nitrogen trioxide will increase and enter the soil to form ion pairs corresponding to K, Na, Ca and Mg.

These metals increase the positive solubility of the leaching and then release in the soil solution, reducing the base saturation in the soil.

The other is the influence on N, S and P. N, S and P, namely nitrogen, sulfur and phosphorus, play a special role in plant nutrition. N, S and P are three important participants in the synthesis of important organic matter such as protein, amino acid and nucleic acid in plants. Among them, phosphorus is an essential nutrient element in the process of plant growth, and phosphoric acid is almost the way for plants to obtain phosphorus to meet growth. Soil has a very strong affinity for phosphates, whose main form of existence is solid phase. Acid rain affects the content and form of N, S and P in soil, which indirectly affects the normal growth of plants.

Third, the influence on Al. The most abundant element in soil is aluminum. It makes up about 7% of the weight of the lithosphere. Red soil is the most abundant aluminum element in all kinds of soils. Aluminum is a chemical element toxic to life. Bauxite and diaspore are the main forms of solid aluminum in soil. However, the degree of hydrolysis produced by different pH conditions is also different.

Fourth, the impact on rare earth elements. At present, 16 rare earth elements have been known, although they are only in the form of 0.8 to 24.0 mg/kg in the soil, but can have serious effects on the health of the soil growth. The lower the solubility of rare earth elements, the better the growth and development of crops can be obtained. Conversely, the higher the solubility of rare earth elements. The growth and development of plants will be limited. When the acidity of acid rain increases, the leaching amount of rare earth elements in soil will increase, and different forms of rare earth elements will also appear different development changes, thus affecting the growth of vegetation [13].

5.4 Harm to forestry and agricultural development

Acid rain (fog) harm to forestry and agricultural development, mainly in the destruction of trees and crops. Acid rain (fog) damages the surface of broadleaf and coniferous plants, reducing the plant's ability to resist hazards such as drought, disease, pests and cold, and inhibiting growth and regrowth. Soil exposed to acid rain for long periods of time can lose valuable nutrients. Weak acid precipitation can dissolve minerals in the ground soil, such as sulfur and nitrogen, etc. High acidity will inhibit the decomposition of organic matter and the fixation of nitrogen in the soil, leaching calcium, magnesium, potassium and other nutrient elements combined with soil particles, and the soil Ca^{2+}, Mg^{2+} base ions are more sensitive to acid rain than K^{+}, Na^{+}, so that the soil tends to be barren. At the same time, the increase of the concentration of aluminum makes the nutrient transport of trees and crops chaotic, growth retarded or completely stopped, and then destroys the whole forest and farmland ecosystem, hindering the normal development of forestry and agriculture. When acid rain falls on plants, it is even more harmful. Acid rain directly damages the waxy coating on the surface of the leaves, while the roots are deprived of nutrients in the soil and poisoned. Plants wilt due to interference with transpiration and gas exchange. Acid rain has a great impact on the growth of vegetables and fruit trees. For example, acid rain in Shizuoka and Yamanashi prefectures in Japan will make the upper leaves of eggplant, cucumber and other crops dry and reduce the yield. According to Environmental Protection Agency laboratory experiments, when water with a pH of 3 is applied to pineapples and red carrots, their harvests are reduced by 15 percent and 50 percent, respectively. From May to July 1982, several acid rains (pH 3.8–4.6) in Jiangbei County, Ba County and Chongqing City of Sichuan Province killed all crops near water within a few days. Field beans, weeds also occurred withered phenomenon. Green beans and taro are also affected. In one commune in Ba County alone, rice production was reduced by 800,000 jin due to acid rain. Suzhou on May 13, 1980, a pH of 4.7 acid rain, a commune watermelon vine withered, watermelon harvest. Due to the sedimentation of excessive acid in forest soil, the trace elements calcium, magnesium, sodium, aluminum and copper in the soil are reduced, and the content of other calcium substances in the soil is changed, so that the balance of nutrients in the soil is destroyed, and the forest growth is rapidly reduced, or withered and even died. It has been reported that the growth of forests in north-eastern northern Europe has decreased due to acid rain, especially in Sweden, where forest growth decreased by 2-7% between 1950 and 1965. In West Germany, the damage is even more pronounced, with 1,500 hectares of evergreen forests already dead from acid rain and eight hectares of cold pine forests seriously threatened. Half of its harvest is lost to trees. Half of East Germany's forests were polluted by acid rain. French forests were also badly hit [14].

The effect of acid rain on forests is largely caused by the deterioration of the physical and chemical properties of soil. Acid rain releases nutrients such as potassium, sodium, calcium and magnesium from the soil, which are leached away by the rain. Therefore, long-term acid rain will make a large number of nutrient elements in the soil leaching, resulting in a serious shortage of nutrient elements in the soil, thus making the soil barren. In addition, acid rain can release the aluminum in the soil from the stable state, increasing the active aluminum and decreasing the organic complex aluminum. The increase of active aluminum in soil can seriously inhibit the growth of forest trees. Acid rain can inhibit the reproduction of some soil microorganisms and reduce enzyme activity. Azotobacter, bacteria and actinomyces in soil are obviously inhibited by acid rain. Acid rain can also significantly increase forest pests and diseases. In Sichuan, the disease index of Masson pine forest in heavy acid rain area was 2.5 times higher than that in no acid rain area. According to the simulation experiment on 105 woody plants in China, when the pH value of precipitation is less than 3.0, it can cause direct damage to plant leaves, making the leaves turn green and yellow and start to fall off. The longer the leaves are exposed to acid rain, the more serious the damage is. Field investigation showed that in the area with precipitation pH less than 4.5, a large number of yellow leaves appeared in Masson pine forest, Huashan pine forest and fir forest, and the forest was declining in patches. For example, in Fengjie County, Chongqing, where the pH value of precipitation is less than 4.3, The average annual high growth of 20-year Masson pine forest decreased by 50%.

Acid rain harms China's forests mainly in provinces south of the Yangtze River. According to preliminary survey statistics, the Sichuan Basin has the largest forest area affected by acid rain, about 280,000 hectares, accounting for 32% of the woodland area. The affected forest area in Guizhou is about 140,000 hectares. According to some studies, in southwest China alone, 6.3 million cubic meters of timber were lost due to the decline in forest productivity caused by acid rain, with direct economic losses amounting to 3 billion yuan (at 1988 market prices). It is estimated that the direct economic loss caused by acid rain in 11 southern provinces could reach 4.4 billion yuan.

Most experts now believe that the ecological value of a forest far exceeds its economic value. Although the method of calculating the ecological value of forests is still controversial and the calculated figures are not universally accepted by society, it is almost unanimous that the ecological value of forests exceeds its economic value. According to these calculations, the ecological value of a forest is between two and eight times its economic value. If calculated according to this proportion, acid rain is very harmful to forest damage.

5.5 Acid rain harm to water bodies

The effects of acid rain on aquatic environments, such as fish in rivers, lakes, swamps and other flora and fauna in their habitats, are obvious. When acid rain flows into water through soil, it will leach aluminum and other metal elements in soil. The greater the acid rain flow, the more obvious the leaching effect will be, as shown in fig. 1.7.

Figure 1.7 – The harm of acid rain to water

Lakes and rivers are the first victims of acid precipitation, and the changes after acid rain are also the most obvious. Acidification of sensitive water bodies will bring about various adverse biological consequences. The decomposition rate of some organic matter in the water body will decrease, and the composition of the primary producer in the water body will change. The animals and plants in the water can withstand the acidic water and the increased metal elements to a certain extent, while the populations or individuals with weak tolerance will exit the ecosystem with the decrease of pH. In general, young individuals are more sensitive to environmental changes than mature individuals. In water with a pH of 5, most fish eggs do not hatch, and if the pH is lower, adult fish cannot survive. Some acidic lakes, for example, have no fish at all. Even if some species can tolerate an increasingly acidic environment, the prey they prey on cannot, and the loss of any link in the food chain can wreak havoc on the system. Some frogs, for example, can tolerate extreme pH 4 conditions, but the mayflies they prey on cannot, and this can lead to frog extinction. In addition, the species of plankton will be reduced, but the biomass and productivity of plankton will not be reduced due to water acidification, and the biomass of herbivorous and carnivorous microorganisms will be reduced. At the initial stage of lake acidification, the concentration of trace metals in fish will increase. The biggest impacts are reduced economic efficiency, reduced affluence and slower recovery of fishermen of a certain age.

Nitrogen contained in acid rain can pollute ecosystems to some extent. For example, nitrogen pollution reduces fish and shellfish populations in coastal waters. Except for agriculture and sewage treatment, most nitrogen pollutants in coastal water come from atmospheric nitrogen precipitation related to human activities.

On the quality of drinking water, acidification of water bodies may dissolve some toxic substances and harmful metals, such as lead, mercury, cadmium, aluminum and copper, from the soil and water distribution network. The presence of these metals in drinking water can cause a range of diseases in humans.

Lake acidification is the main aspect of acid rain on aquatic ecosystem. The acid rain falls directly into the lake or the river and then flows or falls on the vegetation. The rain washes and forms runoff, which is injected into the river or lake or seeps into the soil and into the groundwater and then flows into the lake. Eventually, the lake acidifies. When the pH value of the lake is between 5.0 and 6.5, the fish eggs are difficult to hatch, the number of fry is reduced, and many kinds of fish and organisms will not survive and disappear. Most fish cannot survive when the pH of lake water is below 5.0; When the PH drops to 4, almost all organisms, such as microbes, die. So the acidification of the lake will reduce the population of aquatic life, and from the point of view of the ecological food chain, the acidification of the lake will gradually lead to the destruction of the entire ecosystem layer by layer.

Coastal waters are equally at risk from acid rain. The nitrogen in acid rain is an important cause of Marine eutrophication, which causes algae to proliferate and quickly reach the point where other Marine plants and animals cannot breathe oxygen and sunlight, thus killing a large number of fish and seriously deteriorating Marine water quality.

In addition, acid rain promotes the dissolution of toxic and harmful heavy metal ions in the Earth's crust. Under normal circumstances, these heavy metals are insoluble and harmless, but in acidic solution reaction, it will dissolve in water, not only toxic to the growth of organisms, after enrichment in the food chain will pose a serious threat to human health. The impact on groundwater is equally severe. Acid rain seep into the ground, may cause groundwater acidification, acidified water aluminum, copper, zinc, cadmium and other toxic and harmful heavy metals content is many times higher than ordinary neutral groundwater, if human drinking such groundwater, these heavy metals accumulation in the human body will be a serious threat to human health.

5.6 Harm of acid rain to ecosystem

Ecological environment mainly includes aquatic environment and terrestrial environment.. The precipitation of acid rain can cause acidification of water quality, which changes the living environment of fish and other aquatic organisms, and changes the circulation of nutrients and other substances. Especially in the process of biological development, a large number of toxic and harmful substances participate in the biological cycle. The precipitation of acid rain also dissolves heavy metals in water bodies and enters the food chain, leading to a decline in the number of species and productivity. Acid rain harms the terrestrial ecosystem mainly in soil and plants. The harm to the soil includes inhibiting the decomposition of organic matter and the fixation of nitrogen, leaching soil calcium, magnesium, potassium and other nutrients, resulting in soil barren; Acid rain also directly damages the new buds and leaves of plants, affects their growth and development, and leads to the degradation of the ecological environment. The harm of acid rain to water body is related to the following factors:

5.6.1 it is related to natural conditions

Lakes with bases of alkaline earth, limestone, and sand can accommodate higher amounts of acid fallout. In areas lacking sulfate parent materials, acid rain is not neutralized by surface materials, thus increasing the acidity of rivers and lakes. Soils and lakes that sit on very thin sheets of ice or thick slabs of granite are most vulnerable to acid deposits.

5.6.2 Related to the species

Many fish do not die directly from acid rain. Generally normal lakes and rivers, the pH value of the water should be slightly higher. But under the influence of acid rain, the pH of the water keeps dropping. At pH levels below 5, fish are seriously threatened. The death of young fish, in particular, is mainly due to the acidity of the water itself. When the pH drops below 4.7, there is no spitting fish. Some sensitive species, such as squid, sturgeon, obbrama, pomfret and Arctic redspot salmon, will be extinct due to a slightly reduced pH (when pH<4); Other fish, invertebrates and plankton also died. As the acidity of the lake increases, the species of aquatic plants in the lake will also change, and the higher plants will be replaced by moss and algae.

5.6.3 It is related to the combined effect of increasing pH value and concentration of toxic metals

As the water becomes more acidic, more metals are dissolved, which is also an important reason. These metals include mercury, aluminum, copper, manganese, praseodymium, zinc and pickaxes. They are all toxic, aluminum being the biggest. The toxicity of aluminum is closely related to the pH of water, and aluminum is most toxic when the pH of water is 5. The toxic metals affect fish reproduction and allow algae to coat the lake floor, preventing the organisms in the water from absorbing the nutrients they need. Experiments in the United States have shown that cicadas can live for a few days in water with a pH of 9, but with a small amount of aluminum, half of them die within two days. The total toxicity of heavy metals is increased in acidified water. As a result, in water with a pH of 5 or below that contains heavy metals, almost all fish will die, leaving only water beetles and a few hard-shelled old carp. Currently internationally, due to acid rain in Europe and North America, and acidification of lakes and rivers. In the United States and Canada, for example, thousands of rivers and lakes have died (fish and aquatic plants cannot grow in them), and much of the rest is at risk. Of Sweden's more than 90,000 lakes, 20,000 have been damaged by acid rain, more than 4,000 of which have reached the point of severe acidification and fish have disappeared. Eighty percent of lakes and rivers in southern Norway were affected, and more than 13,000 square kilometers of lakes were wiped out of fish.

5.7 Accidental acidification hazards

Melting snow and downpours can cause a sudden drop in the pH of soil or water that is not normally acidic, when the acidification is far greater than the water and soil can buffer. Occasional increases in ecosystem acidity can cause short-term toxicity to various components of the system and reduce biodiversity.

5.8 Other hazards of acid rain

Acidic precipitation can not only destroy buildings, pollute the environment, bridges, dams, industrial facilities, water supply networks, underground water storage systems, power stations, telecommunication cables and other facilities and materials. Acidic precipitation can also damage ancient artifacts, historic buildings, sculptures, ornaments and various important facilities. Experiments have shown that the corrosion rate of metals in the atmosphere of urban and industrial areas is 2 to 10 times that of rural areas. Carbon steel, zinc and galvanized iron, copper, nickel and nickel-plated sodium, sand and limestone, etc. all increase their corrosion rate with the increase of SO_2 concentration in the air. On the other hand, some metals such as aluminum and stainless steel are only slightly corroded by acidic precipitation. Many studies have proved that the economic damage of sulfide in the atmosphere is quite serious.

In the village of Silina in Mark County in southern Sweden, there is a family of three children whose hair has changed from blond to green. The reason is that they changed the suction pipe in the well from zinc pipe to copper pipe, and the water with pH less than 5.6 is highly corrosive to copper, resulting in patina. So this family's bathroom and vanity have been dyed patina. This water with copper or zinc ions can also cause unexplained diarrhea in infants and young children. The collective "food poisoning" in kindergartens in Mark County is also the cause (about half of Swedes rely on groundwater as a source of drinking water). In Lankeshire, England, turbid water containing a large amount of rust caused by corrosion of water pipes was released from the tap.

Cause the water pipeline to rupture due to corrosion. Four days before Christmas in 1985, a 1-meter-diameter water pipe broke in Yorkshire, England

Even the spare parts could not be used, leaving 200,000 people in a panic of running out of water.

Shockingly, acid rain has also been observed in Antarctica, and it is relatively strong acid rain. For example, China's Antarctic Great Wall Station observed acid rain eight times in April 1998, and the lowest pH value was only 4.45. The iron houses and towers of the Great Wall Station were rusted and peeled off in layers, and some had to be updated. To slow down corrosion, paint 2-3 times a year [15].

In Europe, there are more than 100,000 buildings, such as churches and churches with ancient stained glass from the Middle Ages. The stained glass is so precious that it was unloaded and evacuated during World War II, and most of them were unharmed. However, like other ancient buildings, it cannot escape the attack of acid rain.

Second, fine dust with acid (dry deposition) enters the room and begins to erode the ancient collections in the library when the relative humidity of the air is high. The paper is oxidized to brown, and the quality of the paper is deteriorated or damaged. The leather covers of the British Library collections from the 1920s and 1930s have also been attacked by sulfuric acid and are discoloring like rust. The same is true for murals. Fortunately, since the mid-to-late 1980s, the control of air pollution in Europe has accelerated, and the speed of all kinds of corrosion and damage has slowed down significantly. The phobia of the corrosion phenomenon of oil painting has also expanded among collectors.

6 ACID RAIN PREVENTION AND CONTROL MEASURES

Acid rain is a restless kind of pollutants. When the atmospheric pollutants that can form acid rain reach a certain height, they will exert their ability to disperse and drift with the air flow across the China. SO_2 produced in the United States can form acid rain in Canada, and Sweden is a victim of acid rain in northern Europe. Pollution from central Europe drifts over Sweden. Japan thinks half of its domestic SO_2 is due to long-distance transmission from China. Acid rain afflicts not only the countries that emit pollutants, but also their neighbours. According to the Memorandum of Intent on Transboundary Air Pollution between the United States and Canada, acid rain is a serious environmental problem that, if allowed to develop and unchecked, may become a problem with enormous economic and social costs. "Acid rain is a striking example of our many environmental problems," Canadian environmental experts stressed in the journal Downwind. "Its effects are international, its causes involve many countries, its consequences extend beyond national borders, and its successful solution requires international cooperative action." The control of acid rain is a very complicated problem. At present, some countries adopt the method of ultra-high chimneys to reduce local air pollution, this method is actually married to people's practice, should not be emulated. The most fundamental way to prevent acid rain harm is to control the emission source, increase the combustion value to reduce the burn up, and remove the acid in the fuel and flue gas. From the source and formation process of acid rain, acid rain can be effectively controlled as long as the sulfur and nitrogen gases in the source area are treated and then discharged into the atmosphere.

After many years of acid damage in European and North American countries, acid rain has officially spread in China. People also realize that acid rain is an international environmental problem that cannot be solved by itself. Corresponding measures must be taken together with relevant countries and even the whole world to control the emission of carbon dioxide in order to reduce regional pollution. To this end, the Convention on the Control of Long-distance Transboundary Air Pollution was adopted at the Geneva Conference in November 1979 after many consultations among countries, and stipulated that States should meet by the end of 1993. Would reduce carbon dioxide by 30 percent from 1980 levels. European countries, along with the United States and Canada, have signed up to the convention, each adhering to its own promises to form oversight and improve regulations to control acid pollution emissions. At present, according to the characteristic of Chinese acid rain and the economic and technical level of China, the effective prevention strategy mainly has the following aspects:

6.1 Improve environmental laws and regulations and strengthen supervision and management

Below are the main suggestions.

Improve laws, regulations and standards. Accelerate the revision of the law on the prevention and control of air pollution, focus on improving the systems of total amount control, pollutant discharge permit, emergency early warning, legal liability, etc., study and increase the content of criminal liability investigation for enterprises and their relevant responsible persons who maliciously discharge pollutants and cause major pollution hazards, and increase the punishment for illegal acts. Establish and improve the environmental public interest litigation system. We will study and draft the environmental tax law, accelerate the revision of the environmental protection law, and promulgate regulations on the prevention and control of motor vehicle pollution and regulations on the administration of pollutant discharge licenses as soon as possible. All regions may, in light of their actual conditions, issue local laws and regulations on the prevention and control of air pollution.

Accelerate the formulation of emission standards for key industries, as well as standards for automobile fuel consumption, oil products and heating metering standards, and improve industrial pollution prevention and control technical policies and cleaner production evaluation index system.

Improve the ability of environmental supervision. We will improve the environmental supervision system under which the state, local and unit governments are responsible, and strengthen supervision over the implementation of environmental laws, regulations and policies by local people's governments. We will strengthen capacity-building in environmental monitoring, information, emergency response and supervision to meet the requirements of standardization.

Build a national air quality monitoring network with unified layout of urban stations, background stations and regional stations, strengthen the quality management of monitoring data, and objectively reflect the status of air quality. We will strengthen the construction of an online monitoring system for key pollution sources and promote the application of environmental satellites. Build a national, provincial and municipal three-level vehicle emission supervision platform. By 2015, all cities at prefecture level and above will have built fine particle monitoring points and national monitoring points directly under the jurisdiction of the state.

Strengthen environmental protection law enforcement. We will promote the innovation of law enforcement mechanisms such as joint law enforcement, regional law enforcement and cross enforcement, clarify the key points, intensify efforts, and severely crack down on environmental violations. Illegal enterprises that illegally discharge, release, investigate and commit crimes shall be shut down according to law. Those suspected of environmental crimes shall be investigated for criminal responsibility according to law. Implement the responsibility for law enforcement. Supervisory organs should investigate the responsibilities of relevant departments and personnel according to law for the absence of supervision, ineffective law enforcement, bending the law for selfish ends and other acts.

Implement environmental information disclosure. The state publishes the list of the 10 cities with the worst air quality and the 10 cities with the best air quality every month. All provinces (autonomous regions and municipalities) shall publish the air quality rankings of cities at or above the inland level within their respective administrative regions. Cities at or above the prefecture level shall timely release air quality monitoring information in the main local media.

Environmental protection departments and enterprises at all levels shall take the initiative to disclose environmental information such as environmental impact assessment of new projects, pollutant discharge of enterprises and operation of pollution control facilities, and accept social supervision. For construction projects involving the interests of the masses, public opinions shall be fully listened to. Establish a compulsory disclosure system for environmental information of enterprises in heavy pollution industries.

6.2 Control and reduce sulfide emissions

China is mainly sulfuric acid rain, mainly control sulfide emission. The simplest, most direct and most effective way to control sulfur emissions is to use low-sulfur coal. Based on the successful experience at home and abroad, measures should be taken to reduce the emission of sulfide.

In accordance with the mining and use of high-sulfur coal, the mining of coal mines with sulfur content greater than 3% shall be strictly prohibited, and coal mines with sulfur content less than 1.5% shall be renovated.

For the use of low sulfur coal or high sulfur coal in China, desulphurization treatment should be done to minimize emissions. According to relevant information, sulfur content in coal is generally between 0.2-0.5%. When the sulfur content of coal is greater than 1.5%, add a washing process, can reduce the sulfur content. After washing raw coal, carbon dioxide emissions can be reduced by 30-50%.

Strict control of emissions, through flue gas desulfurization, briquette sulfur fixation technology to remove sulfur in high-sulfur coal to reduce sulfur oxide emissions.

Flue gas desulphurization is an important technical approach and a post-combustion desulphurization process. However, the installation and operation of desulfurization equipment is expensive, and only a few developed countries, such as the United States, Germany, Japan, etc., use this technology. While China is still in the early stage, with only a few demonstration areas used in large power plants, such as Chongqing Cashu Power Plant, Sichuan Baima Power Plant, Shandong Huangdao Power Plant and Nanjing Xiaguan Power Plant. The sulfur fixing technology of briquette is that the sulfur fixing agent is added to the briquette during processing and no sulfur dioxide is emitted in the combustion process, so as to realize the sulfur fixing, and the sulfur fixing rate can reach about 50%. At present, only domestic briquette uses this technology, while the application of the sulfur fixing technology of industrial briquette is in its initial stage.

6.3 Adjust energy structure and improve combustion technology

Control the emission of acid gas from the source in order to reduce the source of acid rain, change the energy structure, increase the proportion of non polluting or less polluting energy, transform the heating mode, and vigorously develop and utilize clean energy that does not produce acid rain pollution, such as water energy, wind energy, geothermal energy, etc. The use of clean energy can reduce the emission of sulfur dioxide and nitrogen oxide acid gas, which is very beneficial to environmental protection. Using nuclear power plants to generate electricity can also reduce acid rain pollution. Replace gasoline with methanol to reduce NO_x emission. Sulfur dioxide emission sources such as coal-fired power plants can be reduced by gradually using clean energy such as natural gas, reducing the use of coal, changing the mode of heating, using the waste heat of the plant to implement centralized heating and other methods. Smoke purification device shall be installed to ensure normal operation during use. It is forbidden to discharge oil smoke without purification treatment. It is not allowed to burn coal and wood to process food in the open air.

6.4 Expand the green area and use the self-purification of plants to remove sulfur

Self-purification of plants is one of the best control measures for acid rain. Many plants can absorb or accumulate toxic and harmful substances and convert them into non-toxic and harmless substances. According to the effective statistics, the 10,000 square meters of cryptomeria forest can absorb 720kg of sulfur dioxide every year. By taking advantage of the opportunity of returning farmland to forest and grassland on both sides of the Yangtze River and in the "three North" areas in the north of China, many self-purification plants can be planted, such as hawthorn, black locust, spruce, peach, platyclus, etc., for acid absorption. Effectively reduce the adverse effects of acid rain, can also make the environment self recovery and a practical method.

The theory that trees can absorb the excess carbon dioxide emitted by human activities has been put forward for decades. As early as the early 1960s, when people found that the concentration of carbon dioxide in the atmosphere increased, researchers pointed out that trees could absorb excess carbon dioxide from the atmosphere, and proved through experiments that the growth rate of plants growing indoors was 40% higher than the original after absorbing the excess carbon dioxide. In 1995, John F Grace further confirmed this view. He selected an area of 1 square kilometer in the Amazon tropical rain forest and conducted observation and research for two years. It turns out that there is almost no carbon dioxide in the air of this tropical rain forest. He calculated that every square kilometer of tropical rain forest can absorb 100 tons of carbon a year, and the amount of carbon that the entire Amazon tropical rain forest can absorb a year is amazing. During the growth of trees, they will absorb a large amount of carbon dioxide and release a certain amount of carbon dioxide. For example, they will release a certain amount of carbon dioxide when they produce energy through respiration, and when they die or decay. Therefore, to calculate the amount of carbon dioxide absorbed by trees, the difference between these two values must be measured. In fact, through photosynthesis, forests only store part of carbon dioxide as energy for growth in the process of absorbing carbon dioxide. To test Grace's theory, Phillips looked at the 20-year history of plant growth in a small area of the Amazon rainforest. He measured the quality of trees without cutting them down. The results showed that the total mass of trees was increasing. On average, trees absorbed 71 tons of carbon per square kilometer of forest in a year. Later, Ken Phillips expanded the research scope to the entire Amazon basin, with more than 100 research areas. Finally, he calculated that the entire Amazon tropical rain forest would absorb 6million tons of carbon every year. According to this result, Phillips infers that all tropical rain forests in the world can absorb 15% of the carbon dioxide emitted by humans, which will help to curb the trend of global warming. The growth of trees is slowing down. Can the tropical rain forest really absorb so much carbon dioxide? In 2007, American tropical ecologist Ken Phillips pointed out in a report that the growth of trees is slowing down, and even cutting more trees will not change the current situation. Philip selected a total of 500000 trees in the tropical rain forests of Panama and Malaysia.

6.5 Increase administrative legislation and specify strict emission standards

Acid rain prevention and control must have strict atmospheric environment quality standards, through legal means to promote the discharge of pollution sources to implement effective measures to control gas pollutants. In order to curb the worsening trend of acid rain, the Chinese government adopted the resolution on Controlling the Development of Acid Rain at the 19th meeting of the Environment

Committee of The State Council in December 1990. The suggestions on acid rain monitoring, scientific research, sulfur dioxide control project and sulfur dioxide discharge fee collection are put forward. In 1992, The State Council approved the pilot project of collecting industrial discharge fees for sulfur dioxide in some provinces and cities. In our industrial emission standards, the limit of sulfur dioxide emission is specified. It has played a positive role in promoting the control of acid rain. In order to further curb the development of acid rain and sulfur dioxide pollution, the Standing Committee of the National People's Congress passed the newly revised Law on the Prevention and Control of Air Pollution in August 1995. In 1996, the Standing Committee of the People's Congress approved the Ninth Five-Year Plan for National Economic and Social Development and the 2010 Vision Target Outline, as well as the Decision of The State Council on several Issues concerning the Environment, which clearly put forward the key governance of acid rain and sulfur dioxide pollution in the "two controlled areas". Since the Tenth Five-Year Plan, the Standing Committee of the National People's Congress has legislated many times to ensure the control of sulfur dioxide pollution.

On January 4, 2008, the official website of the State Environmental Protection Administration officially announced the requirements of the National 11th Five-Year Plan for the Prevention and Control of Acid Rain and sulfur Dioxide Pollution jointly formulated by the National Development and Reform Commission. By 2010, the total amount of sulfur dioxide emissions in China should be reduced by 10% compared with that in 2005, controlled within 22,944 million tons. This means that sulfur dioxide emissions per unit of power generation will be reduced by 50 percent from 2005 [17].

Strictly control regional SO_2 emissions. That is, according to the regional environmental capacity, limit the total emission of SO_2 in the region. Research on regional SO_2 emission control was carried out to find out the optimal plan of acid deposition control. Acid rain control area SO_2 emission load statistics by industry mainly concentrated in electric power, metallurgy, chemical building materials and other industries. Among many industries, the electric power industry has the largest SO_2 emission load. At the end of 1995, its SO_2 emissions accounted for 35 percent of the total emissions of the 22 countries. At the end of 2000, the China's SO_2 emissions accounted for 50 percent of the country's total emissions, and are expected to account for more than 60 percent by 2012. Therefore, it is necessary to formulate a total SO_2 emission control plan for the electric power industry and prohibit the construction of new coal-fired power plants in the two controlled areas and large and medium-sized cities. Chemical, metallurgy and other industries should focus on the whole process of production control, the implementation of clean production of backward technology.

6.6 Research on desulfurization technology will be accelerated

At present, flue gas desulphurization can be divided into pre-combustion desulphurization, in-combustion desulphurization and post-combustion desulphurization. Due to the limitation of technology and economic development, the desulphurization method after coal combustion is mainly adopted by enterprises in various countries at present. The desulfurization of coal after combustion can be divided into wet, dry and semi-dry flue gas desulfurization. Wet flue gas desulfurization technology is perfect, desulfurization efficiency is high, but easy to corrode equipment, so that investment increases; Dry desulphurization has low efficiency and low popularization value. Semi-dry method has the advantages of both dry method and wet method, and can improve desulfurization efficiency, so it can be popularized and applied vigorously. At the same time, in order to realize acid rain and sulfur dioxide pollution control, the research, development, popularization and application of desulphurization technology should be accelerated, and the construction of relevant demonstration projects should be accelerated. It is necessary to accelerate the introduction, digestion and absorption of advanced treatment technology and equipment mature abroad, and gradually realize the localization of flue gas desulfurization. In the arrangement of projects and funds, we should not only focus on the "two controlled areas", but also pay attention to ecologically fragile areas. In addition, research on desulphurization technology before and during coal combustion should be accelerated to reduce the sulfur content step by step in the coal development process, thus reducing the total amount of acid emissions in the atmosphere.

6.7 Strengthen publicity and raise the national awareness of acid prevention

The media should increase the propaganda of acid prevention and improve the awareness of acid rain prevention. At the same time, to strengthen the control of acid rain pollution, we must strengthen the supervision of environmental management and strengthen the education of environmental awareness, give full play to the education and popularization of relevant knowledge, promote the participation of people, actively carry out the treatment of acid rain areas, restore the local ecology as soon as possible, speed up the development of new energy sources, and fundamentally solve the problem of acid rain.

7 ECONOMIC EFFECTIVENESS OF ENVIRONMENTAL MEASURES

7.1 Economics and environmental protection

Economic effectiveness is a means of measuring the efficacy and purposefulness of a given business activity given by the comparison (ratio) of the value of the obtained effects to the factors invested in order to achieve them [18].

Economics explains how people survive. It concerns the ways in which individuals and groups act to attain what they want in terms of income, subsistence and other goods and services which they feel will provide them with an adequate quality of life. Economics basically addresses the problem of scarcity – how to fulfil people's unlimited needs and aspirations from a scarce resource base in a way which is both equitable and efficient.

Incorporating environmental concerns into economics involves introducing concepts of sustainability into scarcity. It deals with the issue of how to meet people's current needs in a way which is both equitable and efficient and does not diminish the supply or quality of environmental goods and services available for future generations.

If the environmental resource base is conserved it will continue to provide these economic benefits and support human production and consumption in the future. If it is destroyed or environmental quality declines, such goods and services will decrease and human economies will suffer as a result, at global, national and local levels.

Economics is also linked to the environment because economic forces contribute to environmental degradation. While environmental resources support economic production and consumption opportunities, the same economic activities impact back on the environment through using up non-renewable environmental goods and services, by converting environmental resources to other uses and by adding waste and effluent to the environment. A decline in environmental quality and resources impacts on economic activities by diminishing the amount of goods and services available for future production and consumption, and by progressively precluding economic activities. Economic opportunities spiral downwards as the environment becomes more and more degraded.

This downward spiral has implications for both economic efficiency – the sound use and management of scarce resources to generate output, and equity – the access of different groups and individuals to secure livelihoods and economic opportunities. The people who bear the costs of environmental degradation are not necessarily those who are causing degradation, spatially or temporally. For example, many of the indirect or knock-on effects of environmental degradation such as bad health, loss of productive opportunities and ecological disaster are felt by poorer people who lack the resources to cope with these costs, or will be felt by future generations as a result of activities carried out today. Environmental degradation also incurs substantial costs to governments, who bear the overall responsibility for maintaining the basic quality of life in a country [19].

It is clear that production and consumption activities can lead to a downward spiral of environmental degradation, economic costs and loss of productive opportunities. Conversely, environmental conservation can lead to an upward spiral of economic growth and benefits. A major challenge is to ensure that sound environmental management systems are set in place which will enhance current opportunities for production and consumption at the same time as sustaining economic growth in the future.

A range of policy factors, as well as broader socio-economic conditions such as poverty and land pressure, put people in a situation where it makes more economic sense to them to degrade the environment in the course of their day-to-day economic activities than to conserve it. There is often little immediate or tangible economic gain to conserving the environment, and many gains and profits from mining, depleting, polluting or converting it. People are often unwilling − or economically unable − to conserve the environment, because there is no personal benefit to them in doing so.

Economic analysis provides a useful set of tools understanding the forces which lead to environmental degradation. Economic measures can encourage people to conserve the environment by setting in place the conditions which result in their being economically better off by doing so. They aim to make sure that producers and consumers take into account the real value of the environment and the real cost of environmental damage when they make decisions.

Basic tools for the use of economics for environmental planning and management are as follows [20]:

Identifying environmental economic benefits and costs: ensures that the economic impacts of environmental activities, and the environmental impact of economic actvities, are understood and made explicit in both conservation and development planning and management.

Valuing environmental economic benefits and costs: provides important information which can be integrated into both development and conservation planning and management. Making monetary estimates of environmental values means that they can be considered, and given equal weight, alongside other sectors of the economy, benefits and costs.

Analysing the profitability of economic activities in terms of their environmental effects: provides a framework within which to use information about environmental costs and benefits and their values for decision-making. It provides basic measures of whether a policy, programme or activity can be judged desirable in environmental and economic terms.

Highlighting the economic causes of environmental degradation and the need for economic measures for environmental conservation: points to areas and groups where there is a need for the use of economic measures to provide incentives and finance for environmental conservation. It forms the basis of identifying and planning conservation activities.

Setting in place economic incentives for environmental conservation: forms a cross-cutting component of environmental planning and management. Unless people are provided with positive incentives to conserve the environment in the course of their economic activities, and the perverse incentives which encourage environmental degradation are overcome, environmental programmes and projects are unlikely to succeed.

Financing mechanisms for environmental conservation: form an important part of environmental planning and management because they provide the basic funding which enables environmental projects, programmes and activities to be carried out.

Ensuring that economic measures for conservation are appropriate and sustainable: means that they are practically implementable in different social, cultural, institutional and ecological situations.

7.2 Calculation of the financial profit of resource saving

Net financial result due to the implementation of resource-saving measures in company is calculated by the equation:

$$FP = t \cdot (C_f + p_e + p_h) - I_t \qquad (7.1)$$

where:

t is time of implementation of resource saving measures, years;

C_f is the cost of fuel saved, USD/year;

p_e is the payment for emissions of pollutants into the environment, USD/year;

p_h is the payment for damage to public health, USD/year. We accept equal to 0 USD;

I_t is the investment in resource-saving measures, USD.

Cost of fuel saved:

$$C_f = Pr \cdot N_f \qquad (7.2)$$

where:

Pr is the price for fuel (1 m^3 of natural gas - 0.38 USD, 1 ton of coal – 125 USD);

N_f is the amount of fuel saved or the amount of fuel that would need to be burned to obtain energy produced by alternative sources. In fact, N_f is the total amount of fuel used by company (then we suggest that we completely replace it with alternative energy).

Payment for emissions of pollutants into the environment:

$$p_e = (M_1 \cdot r_1) + (M_2 \cdot r_2) + ... + (M_n \cdot r_n) \quad (7.3)$$

where *M* is the amount of pollutant emission, ton:

$$M = q \cdot N_f \quad (7.4)$$

where *q* is specific emission of pollutant:
for coal: SO_2 – 30 kg/t, NO_x – 9 kg/t, CO – 55 kg/t
for natural gas: SO_2 – 0.0037 kg/m^3, NO_x – 0.0031 kg/m^3, CO – 0.0051 kg/m^3.

r is fee rate per ton of pollutant, USD/t (see Table 7.1).

Table 7.1. Fee rate for pollutants [21]

Pollutant	**rate, USD/t**
Nitrogen oxides	75
Ammonia	15
Sulfur dioxide	75
Carbon monoxide	3
Hydrocarbons	5

Investments (e.g., in wind or solar energy) are calculated as follows:

$$I_t = k \cdot N_f \cdot T / 8760 \quad (7.5)$$

where:

k is the specific investment in the production of 1 kWh of energy (for wind turbines k = 500 USD/kWh, for solar panels k = 900 USD/kWh);

T is the heat capacity of the fuel to be replaced (7.5 kW/t for coal and 8.8 kW/m^3 for natural gas).

Calculate the net result from the implementation of resource saving measures in company ABC. The company consumes 1000 ton of coal per year and is going to replace it with wind turbines). The project implementation period is 5 years.

1. Time of implementation: t = 5 years

2. Amount of fuel used (= amount of fuel saved): Nf = 1000 t/year

3. Cost of fuel saved: Cf = Pr · Nf (Eq. 7.2).

The price for coal Pr = 125 USD/t.

Then, Cf = 125 USD/t · 1000 t/year = 125000 USD/year

4. To calculate the payment for emissions of pollutants (Pe), we need to know amount of pollutant emission (M) for each pollutant (see Eq. 7.4):

Pollutant 1. Nitrogen oxides. q1 = 9 kg/t (see specific emission of NOx for coal). Then, M1 = q1 · Nf = 9 kg/t · 1000 t/year = 9000 kg/year = 9 t/year.

Pollutant 2. Sulfur dioxide. q_2 = 30 kg/t (see specific emission of SO_2 for coal). Then, $M_2 = q_2$ · Nf = 30 kg/t · 1000 t/year = 30000 kg/year = 30 t/year.

Pollutant 3. Carbon monoxide. q_3 = 55 kg/t (see specific emission of CO for coal). Then, M3 = q3 · Nf = 55 kg/t · 1000 t/year = 55000 kg/year = 55 t/year.

5. From Table 7.1:

for NOx r_1 = 75 USD/t

for SO_2 r_2 = 75 USD/t

for CO r_3 = 3 USD/t

According to Eq. 7.3:

$p_e = (M_1 \cdot r_1) + (M_2 \cdot r_2) + (M_3 \cdot r_3)$ = (9 t/y·75 USD/t) +(30 t/y·75 USD/t) +(55 t/y ·3USD/t) = 3090 USD/year

6. Specific investments for wind turbines k = 500 USD/kWh, heat capacity for coal T = 7.5 kW/t.

Then investments:

It = k·Nf·T / 8760 = 500 USD/kWh · 1000 t/year · 7.5 kW/t / 8760 h/year = 428 USD

7. Financial result (Eq. 7.1):

FP = t (Cf $+p_e +p_h$) – It = 5 y · (125000 USD/y + 3090 USD/y + 0) – 428 USD = 640000 USD.

Therefore, implementation of resource-saving measures in company (use of wind turbines for energy production) would lead to income 640000 USD during 10 years.

CONCLUSIONS

In a word, acid rain is caused by air pollution, which is a common disaster in the world. All countries should work together and arouse the high vigilance of the world. The most fundamental measure to prevent acid rain is to improve energy utilization technology, develop clean new energy, reduce the emission of acid gases such as sulfur oxides and nitrogen oxides, vigorously carry out coal washing and processing, comprehensively develop coal and sulfur resources, implement the division of production and rational use of high sulfur coal and low sulfur coal, and adopt smoke exhaust and desulfurization technology to recover sulfur dioxide, produce sulfuric acid, develop desulfurized coal.

Vigorously develop clean coal technology and clean fuel coal technology, effectively reduce air pollution, effectively control the formation of acid rain, and ensure that we have a healthy and harmonious ecosystem, relatively stable ecological balance, and a living space for sustainable development, so that our human beings can make great strides towards a brilliant and glorious tomorrow, and further promote the civilization and progress of human society. At the same time, this behavior of damaging the environment is linked with the lack of correct understanding of the environment.

Therefore, strengthening environmental education, improving people's awareness of environmental protection, correctly understanding the environment and environmental problems, and making human behavior and the environment develop harmoniously are the fundamental ways to protect the earth, the cradle of human survival. Let us all establish a strong awareness of environmental protection, start with everything around us, and work together to protect our environment, the earth, and build a better environment for our survival.

I believe that through the joint efforts of all countries and members of society, we will certainly achieve a win-win situation in environmental protection and resource utilization.

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APPENDIX A
Technical task

Ministry of education and science of Ukraine
Vinnytsia National Technical University
Faculty of Construction, Civil and Environmental Engineering

APPROVED
Head of the Department
ECEPT
Prof. V. Petruk
____
27.09. 2022

TECHNICAL TASK

for master thesis

"The mechanism of acid rain formation and measures to reduce its impact on the environment"
specialty 183 – Environmental protection technologies

08-12.МКР.101.01.01 ТЗ

Supervisor: PhD, Dr.
_______________ V. Ishchenko
(signature)
«27.09» 2022

Student: group 2ТЗД-21м
_______________ Jing Wenjing
(signature)
«27.09.» 2022

Vinnytsia VNTU 2022

1. Basis.

The basis for master thesis preparing is the order of VNTU No 203 on "14" 09 2022, and individual task approved by protocol of Department ECEPT No. 3 on "21" 09 2022.

2. Goal.

The goal is to aanalyze the environmental problems of acid rain in China and propose feasible control and elimination measures.

3. Input data.

China's sulfur dioxide emissions: 31.72 million tons per year

4. Research methods

Analysis, mathematical modelling, environmental impact assessment, statistical methods.

5. Stages and deadlines

No	Stages of master thesis	Deadline
1.	Technical task	
2.	Literature review	
3.	Overview of acid rain	
4.	Current situation and distribution of acid rain	
5.	Formation mechanism of acid rain	
6.	Acid rain control indicators and acid rain monitoring	
7.	The influence and harm of acid rain	
8.	Acid rain prevention and control measures	
9	Conclusions, literature list	

6. Area of use

The research results can popularize acid rain environmental problems and provide theoretical basis for relevant environmental protection departments to prevent acid rain problems.

7. Requirements

Main part and illustrative part.

8. Procedures

Public defense «27» 06. 2024
Beginning of writing «27» 06. 2024

Finish due to «27» 06. 2024

Student Wenjing Jing Wenjing

APPENDIX B

PROTOCOL
OF CHECK FOR PLAGIARISM

Title of work:_ The mechanism of acid rain formation and measures to reduce its impact on the environment

Type of work:_master thesis

Department __Ecology, Chemistry and Environmental Protection Technologies

Similarity report by Unicheck

Originality____87,9%__________ Similarity____12,1%____________

Analysis of similarity report (mark the relevant)
1. Similarities found in the work are correctly formatted and may not be considered as plagiarism.
2. Similarities found in the work may not be considered as plagiarism, but their large amount results in doubts about the value of the work and the lack of independence of the author during writing. The work has to be assessed by expert committee of the Department.
3. Similarities found in the work may be considered as plagiarism.

Person responsible for the check ____________ M. Matusiak

Acquainted with the similarity reportgenerated by Unicheck:

Author Wenjing Jing Wenjing

Supervisor ____________ V. Ishchenko

APPENDIX C

ILLUSTRATIVE PART

THE MECHANISM OF ACID RAIN FORMATION AND MEASURES TO REDUCE ITS IMPACT ON THE ENVIRONMENT

Table C.1 – Statistics of precipitation pH value and acid rain frequency from 2003 to 2018

year	PH of annual urban precipitation			Acid rain frequency /%		Acid rain city ratio /%		
	minimum value	maximum value	average value	maximum value	average value	pH<5. 6	4. 5≤pH<5. 0	pH<4. 5
2003	3. 67	8. 05	4. 99	100. 0	21. 5	36. 4	15. 5	6. 2
2004	3. 80	8. 16	4. 87	100. 0	23. 4	40. 9	18. 6	7. 6
2005	4. 02	8. 13	4. 87	100. 0	24. 6	39. 2	15. 5	12. 7
2006	3. 85	8. 58	4. 85	100. 0	25. 6	39. 9	18. 2	10. 3
2007	3. 99	7. 95	4. 92	100. 0	23. 8	39. 5	15. 8	9. 3
2008	4. 04	8. 11	4. 94	100. 0	23. 8	40. 5	16. 8	8. 9
2009	3. 86	7. 97	5. 00	100. 0	22. 0	38. 8	14. 8	7. 2
2010	3. 93	8. 16	4. 96	99. 0	22. 0	36. 1	14. 8	8. 6
2011	4. 19	8. 34	5. 09	100. 0	20. 7	34. 4	15. 1	5. 5
2012	4. 22	7. 94	5. 00	100. 0	22. 0	35. 7	15. 1	5. 5
2013	4. 01	7. 93	5. 18	100. 0	19. 5	30. 9	12. 7	3. 1
2014	4. 19	8. 07	5. 18	100. 0	18. 7	32. 6	15. 1	1. 7
2015	4. 18	7. 81	5. 34	100. 0	15. 6	25. 8	8. 6	1. 0
2016	4. 06	8. 07	5. 40	100. 0	14. 0	22. 0	6. 2	1. 0
2017	4. 51	8. 04	5. 48	100. 0	11. 8	21. 3	6. 5	0. 0
2018	4. 49	8. 05	5. 56	96. 0	11. 7	21. 6	4. 1	0. 3

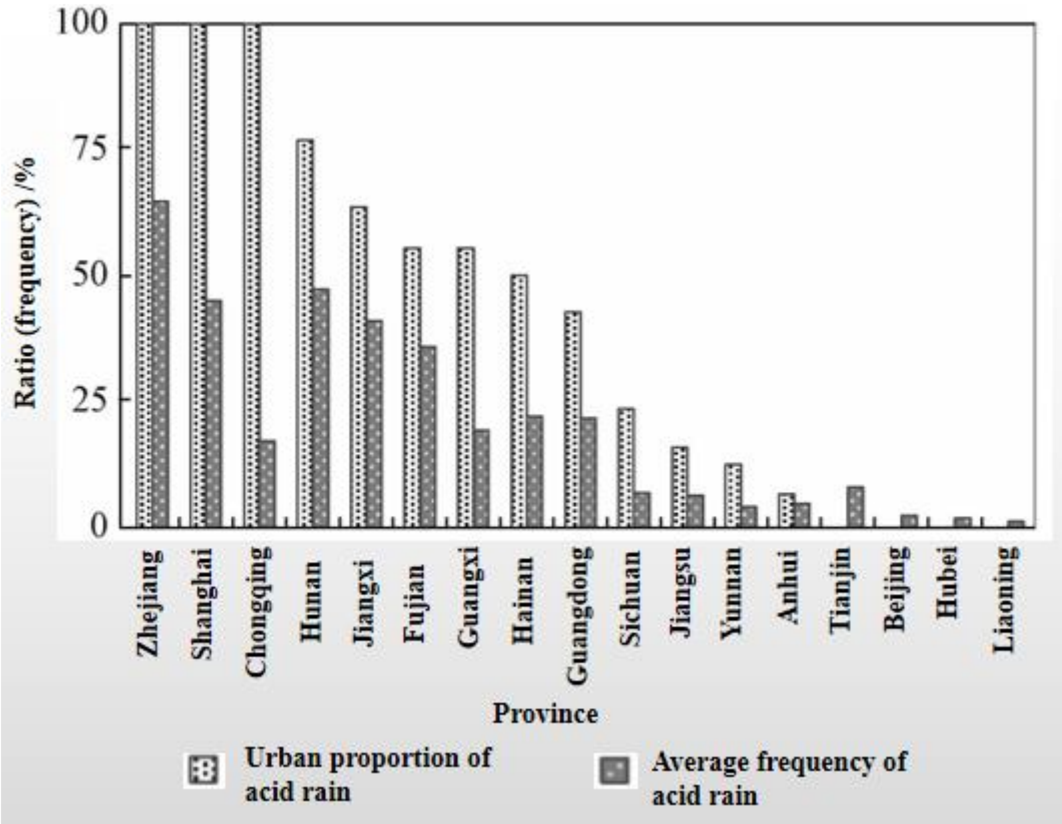

Figure C.2 – Proportion and average acid rain frequency of some provinces in 2018

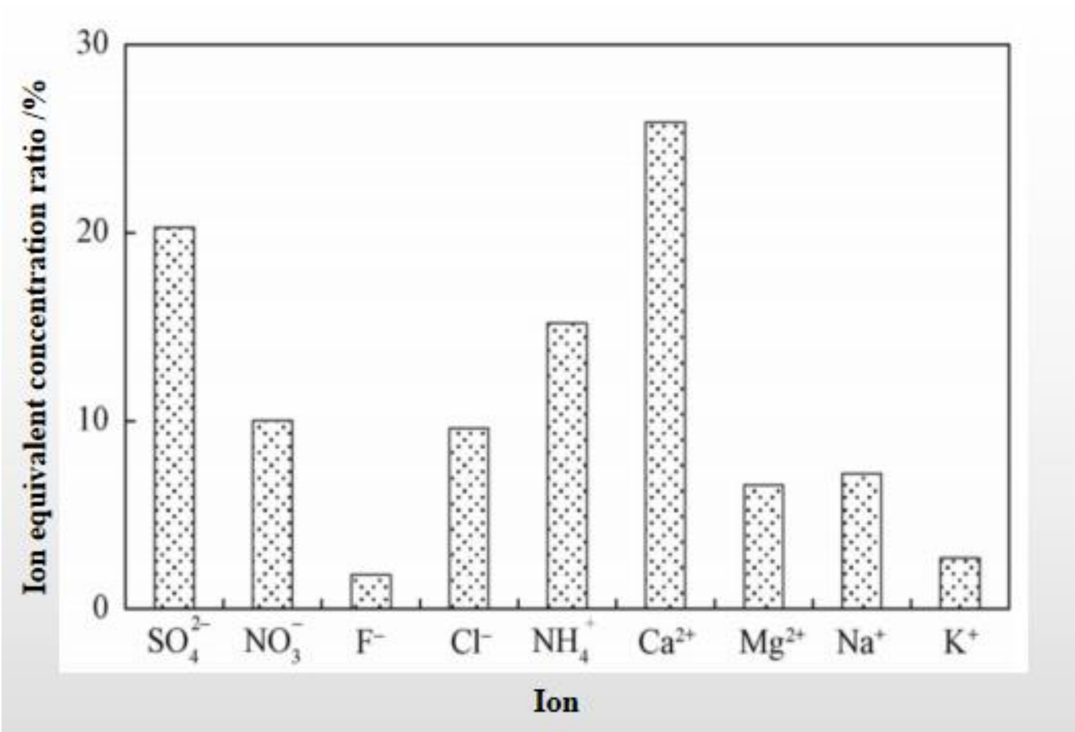

Figure C.3 – Ion equivalent concentration percentage of precipitation in 2018

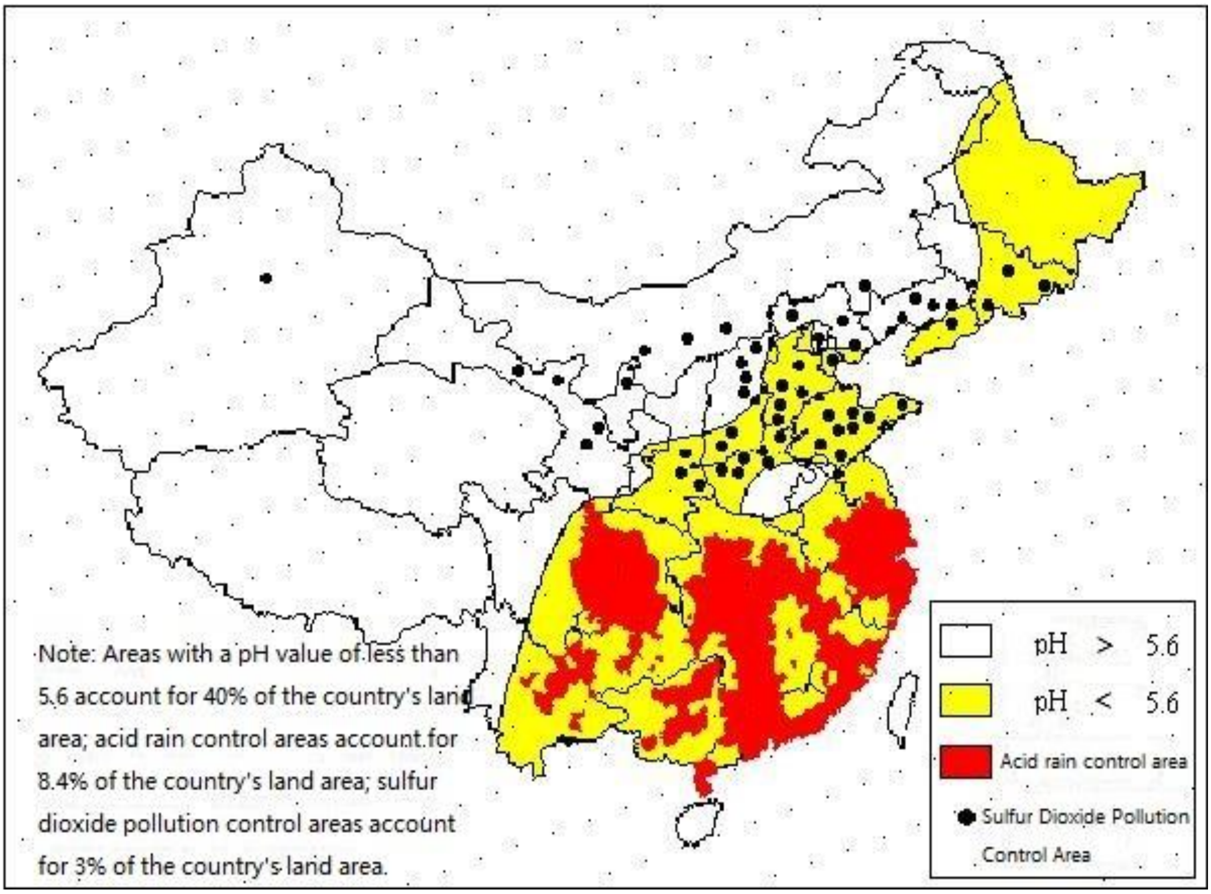

Figure C.4 – Distribution of acid rain in China

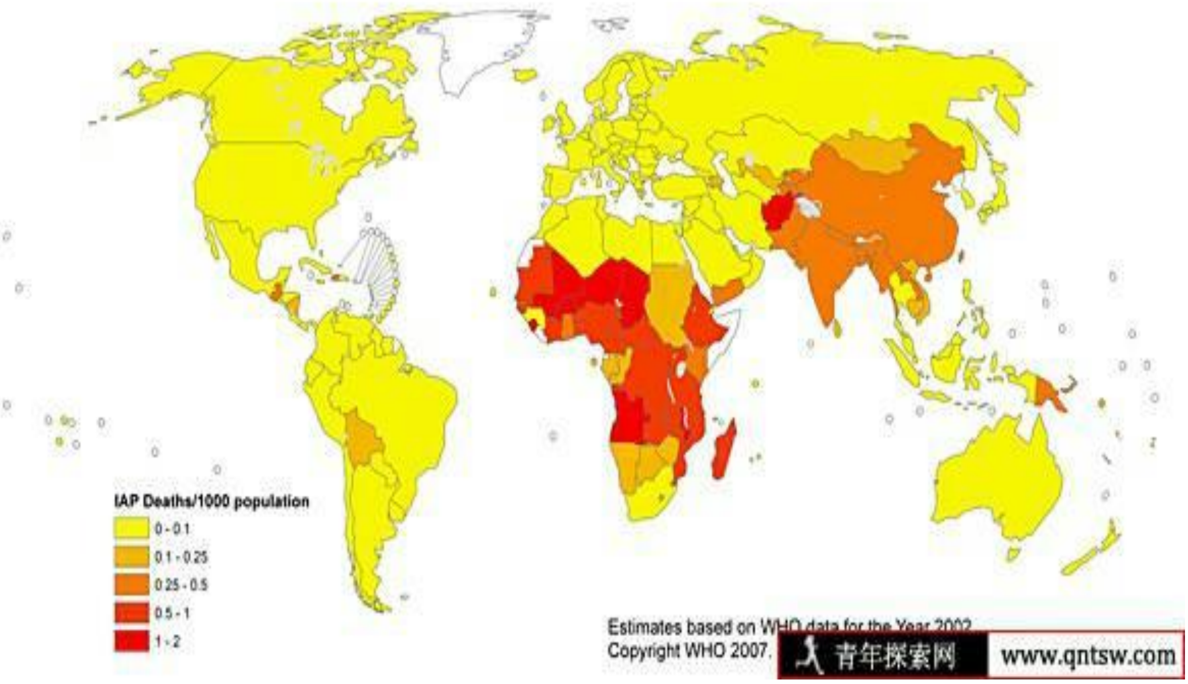

Figure C.5 – The distribution of acid rain in the world