

# ***Impact and Composition of Acid Rain in East Asia Regions***

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**Abstract:** Owing to severe effects on ecosystems, acid rain has transformed into a pressing global environmental issue. This paper provides an in-depth discussion of the acid rain problem in East Asia, analyzes the causes and effects of acid rain from various aspects and proposes strategies to mitigate the serious threat it poses to the environment and human life. The results of the study show that the acid rain problem in the region is extremely harmful, mainly due to factors such as rapid economic and population growth and complex geographic features. The impacts of acid rain are far-reaching, negatively affecting ecosystems, agricultural production, building structures and human well-being. Despite the positive changes in some acid rain-related environmental policies, the overall situation is still severe. To tackle this issue, various strategies are put forward, including measures for reducing pollutant emissions, promoting the transition to clean energy sources and strengthening ecological protection. The long-term effects of acid rain are far-reaching, not only destabilizing ecosystems and posing risks to human health, but also altering the chemical composition of soils, destroying the habitat of aquatic organisms, and disturbing the balance of greenhouse gases. Because of these threats, further research on acid rain is urgent.

**Keywords:** Acid rain, inorganic ions, East Asia, environmental policies.

## **1. Introduction**

Acid rain has become a global environmental issue due to its multiple serious impacts on ecosystems. It may cause water and soil acidification, also forest degradation and eutrophication. Acid rain could also affect infrastructure and human health. Nearly a decade after widespread acid deposition was detected in Europe and North America in the early 1980s, it has become a major problem in East Asia. The Acid Deposition Monitoring Network in East Asia (EANET) in January 2001 began regular deposition monitoring activities to understand the state of acidic deposition problems[1].

Since the early 2000s, the global maximum of both sulfur and nitrogen deposition has been found in East Asia, 36% and 29% respectively, including eastern China and South Korea[2]. East Asia experienced rapid growth of economy and populations, which may cause extensive combustion of fossil fuels, agriculture and biomass burning as anthropogenic sources, and also natural sources like sea sources and crust sources. This range of induced phenomena has led to significant increases in emissions of sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>). These pollutants produced in East Asia affect the air quality and climate of neighboring countries or distant countries located in the downwind zone [2]. Long-term sulfur (S) and nitrogen (N) depositions can reduce biological diversity, decrease human health, alter soil chemistry and influence greenhouse gas balance[3].

Some studies have focused on spatial and seasonal variations of wet deposition of S and N in parts of East Asia. For instance, research focused on the ionic composition of wet deposition. It not only illustrated the temporal variation pattern of wet deposition but also estimated the contributions of various potential sources to wet depositions. The study revealed that anthropogenic sources have been the predominant factors influencing the wet deposition fluxes of sulfuric acid, nitrate, and ammonium. Specifically, the combustion of fossil fuels emerged as the primary contributor to the presence of sulfuric acid, nitrate, and ammonium in wet deposition. Additionally, biomass burning was identified as a significant contributor to sulfuric acid and nitrate deposition, whereas the agricultural sector played a notable role in contributing to ammonium deposition[3].

From 2011 to 2016, a distinct study carried out in Sichuan province had multiple objectives. Firstly, it sought to determine the inter-annual and seasonal fluctuations in the main inorganic ions and the pH value within rainwater. Secondly, the study aimed to discover the spatiotemporal patterns of the soluble ions and the pH value in rainwater. And thirdly, it intended to quantitatively find out the sources of soluble ions in rainwater. According to the study, sulfuric acid, nitrate, calcium ions, and ammonium were the predominant soluble inorganic ions present in rainwater[4].

Another study had the main objectives of monitoring the acidity of wet depositions, determining the fluxes of S and N wet deposition, and in the previous study, estimating the contributions of potential sources of wet depositions. The study found that, with the exception of ammonium, the concentrations of all ions were lower during the wet season. However, this wet season accounted for approximately 90% of the annual wet deposition fluxes of sulfuric acid, nitrate and ammonium[5, 6].

The long-term hazards of acid rain are extensive, including the destruction of biodiversity, threats to human health, changes in soil chemical properties, and impacts on the greenhouse gas balance. Studying this research could promote agricultural development, protect cultural heritage, create better public health, and most importantly ecological protection. Clarifying the specific impacts of acid rain on soil, water bodies, and forest ecosystems provides a scientific basis for formulating targeted ecological protection strategies. Although some studies have focused on the spatial and temporal variations of sulfur and nitrogen wet deposition in parts of East Asia, further in-depth research is still needed. To conduct this study, research is first needed. The literature will be gathered and the main data will be identified. Then, compositions and impacts of acid rain will be analyzed and suggestions for reducing acid rain will be given.

## 2. Composition and impact analysis of acid rain

The primary anions in acid rain are  $\text{SO}_4^{2-}$  and  $\text{NO}_3^-$  while the main cations are  $\text{NH}_4^+$  and  $\text{Ca}^{2+}$  [4-6]. Fossil fuel combustion ( $\text{SO}_2$  and  $\text{NO}_x$  emissions) and agricultural activities ( $\text{NH}_3$  emissions) are the main causes of acid rain formation, while dust storms ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ) and marine aerosols ( $\text{Na}^+$ ,  $\text{Cl}^-$ ) also play a role[4]. Acid rain has serious impacts on multiple aspects, the most important of which is the severe damage to ecosystems. Firstly, acid rain impacts the acidification of soil[7]. Increased rainfall containing inorganic ions reduces the pH of soil and water bodies, which leads to the loss of nutrients in the soil and reduced soil fertility. It interferes with microbial activity by inhibiting soil microbial activity, which affects the decomposition of organic matter and nutrient cycling in the soil, thereby altering the ecological structure and function of the soil. In some areas severely affected by acid rain, the soil gradually becomes infertile, affecting the growth and development of plants.

Secondly, acid rain also leads to acidification of water bodies, which may leach metal ions (e.g., aluminum) into the water, harming aquatic organisms, and then decreasing the pH value of surface water and groundwater, affecting the living environment of aquatic organisms[4, 5]. Aquatic organisms such as fish and amphibians are sensitive to changes in acidity and alkalinity, therefore acid rain may lead to a decline in their reproductive capacity, an increase in mortality, and even

extinction. Waterbody acidification also promotes the release of heavy metals from bottom sediments, increasing the content of heavy metals in the water and exerting toxic effects on aquatic organisms.

Thirdly, increased nitrogen deposition may cause eutrophication, which increases nitrogen levels in water bodies, triggering algal overgrowth and disrupting aquatic ecosystems[4]. Eutrophication is a water pollution phenomenon. It occurs due to the excessive inflow of nutrients such as nitrogen and phosphorus into water bodies like lakes and rivers, leading to a rapid increase in plankton such as algae, a decrease in dissolved oxygen in the water, and deterioration of water quality. The elevated nutrient levels trigger the rapid growth of algae and other aquatic plants. This over-growth, often visible as algal blooms, can have several detrimental effects. Firstly, as the algae die and decompose, bacteria use up oxygen in the decomposition process. This causes a marked decrease in the dissolved oxygen content of the water, bringing about hypoxic or anoxic conditions. Such low-oxygen environments can be lethal to fish, shellfish, and other aerobic organisms, resulting in fish kills and a decline in biodiversity. Moreover, some algal species produce toxins that are harmful to humans, animals, and other aquatic life, and these toxins can accumulate in the food chain, posing risks to higher-level consumers. Additionally, eutrophication impacts both aquatic life and human activities that depend on clean water resources.

Fourthly, excessive sulfur and nitrogen deposition causes tree withering and reduced forest productivity[5]. Acid rain damages the leaves of plants, affecting their photosynthesis and respiration. Prolonged exposure to acid rain slows down the growth rate of plants, reduces their resistance to diseases and pests, and may even cause withering and death. Acid rain also affects the absorption of nutrients by plants, resulting in plant malnutrition. In forest ecosystems, acid rain may cause the massive death of trees, disrupting the ecological balance of the forest.

Acid rain also impacts agriculture, for some reasons above, like the leaching of nutrients and the acidification of soil. It also directly damages crop leaves, reduces photosynthetic efficiency and impairs nutrient uptake due to soil acidification[4]. Acidic droplets can corrode the waxy cuticle layer on the leaf surface, making the leaves more vulnerable to diseases, pests, and environmental stress[8]. In Sichuan, where acid rain is prevalent in some areas, crops such as rice, wheat, and vegetables may experience leaf yellowing, necrosis, and reduced photosynthetic capacity.

Since photosynthesis is essential for plant growth and energy production, a decrease in photosynthetic efficiency can lead to reduced crop yields. The acidic environment in the soil can make it difficult for roots to absorb necessary nutrients, even if they are present in the soil. This can lead to nutrient deficiencies in plants, resulting in poor growth, fewer fruits or grains, and ultimately, lower crop yields. Some studies have shown that areas with high-intensity acid rain may experience significant losses in agricultural production.

In addition, acid rain has effects on buildings and infrastructure. Acid rain may shorten the lifespan of structures and bridges, as it accelerates the corrosion of metals, stone, and concrete[9]. Acid rain contains sulfuric and nitric acids that react with materials such as limestone, marble, and mortar, which are calcium-based. The acidic components in the rain can dissolve calcium carbonate in limestone, converting it into calcium sulfate. This chemical reaction weakens the structure of the stone, leading to surface erosion, pitting, and the loss of fine details in architectural features. Over time, the structural integrity of the building may be compromised, especially in older buildings where the stone has been exposed to acid rain for extended periods. Many ancient cultural relics and historic sites have experienced surface peeling, discoloration, and other phenomena due to long-term erosion by acid rain, seriously affecting their historical and cultural value.

Acid rain can also corrode metal components in buildings and infrastructure. Iron, steel, and copper are commonly used in construction, and they are susceptible to acid-induced corrosion. In an acidic environment, metals react with the acids in the rainwater to form metal salts, which not only affects the appearance of metal structures but also reduces their strength. In Sichuan's industrial areas, where

acid rain levels may be higher due to pollution, metal structures such as bridges, railings, and roofing materials may experience accelerated corrosion, increasing the need for maintenance and replacement. Metal power lines and communication towers are also vulnerable to acid rain corrosion. The corrosion of these structures can lead to electrical failures and communication disruptions.

Acid rain may impact human health, with risks of respiratory diseases. Fine particulate matter (e.g., sulfates, nitrates) formed by acid rain can penetrate deep into the lungs, causing asthma, bronchitis, and other respiratory illnesses[10]. These ions in acid rain can dissolve in water droplets and form acidic aerosols. In Sichuan, where acid rain is a concern, people are exposed to these aerosols when they breathe. The acidic particles can irritate the respiratory tract, leading to coughing, wheezing, and shortness of breath. Long-term exposure to acidic aerosols has been linked to an increased risk of developing respiratory diseases such as asthma, bronchitis, and emphysema.

Acidic aerosols can also weaken the immune system in the respiratory tract. The lining of the respiratory tract is designed to protect the body from harmful substances, but exposure to acid rain can damage this protective barrier. This makes individuals more susceptible to respiratory infections, such as pneumonia and influenza. In Sichuan's polluted areas, the combination of acid rain and other pollutants may further compromise the immune system, leading to more frequent and severe respiratory infections. Acid rain also pollutes water sources, and people may face potential health risks when drinking contaminated water. In China, policies like the "12th Five-Year Plan" reduced  $\text{SO}_2$  and  $\text{NO}_x$  emissions, leading to higher acid rain pH. However, the proportion of  $\text{NO}_3^-$  increased, shifting acid rain from "sulfuric acid-dominated" to a "mixed type" [4]. The spatial distribution of acid rain is more severe in industrial regions (e.g., southeastern Sichuan), while alkaline dust neutralization results in higher pH levels in western China[4, 5].

### 3. Suggestions for reducing acid rain

To reduce emissions, policies could strengthen controls on industrial and vehicular pollution, and promote clean energy [4]. Industries are major sources of sulfur dioxide and nitrogen oxides, which are precursors of acid rain. They should adopt advanced technologies to reduce these emissions. For example, power plants can install flue-gas desulfurization and denitration equipment to remove  $\text{SO}_2$  and  $\text{NO}_x$  from their exhaust gases. The implementation of stricter environmental regulations and emission standards is also crucial. By imposing higher penalties for non-compliance, industries will be incentivized to invest in cleaner production technologies. With the increasing number of vehicles, vehicle emissions have also become a significant contributor to acid rain. Promoting the use of public transportation, such as subways, buses, and light rail systems, can reduce the number of private vehicles on the road. Encouraging the use of electric vehicles and hybrid vehicles can also effectively reduce  $\text{NO}_x$  emissions. Additionally, implementing vehicle emission inspection programs and stricter emission standards for vehicles can help control the amount of pollutants released into the atmosphere.

Quantify critical S and N loads for ecosystems to develop targeted protection strategies [5]. Improving energy efficiency in all sectors, including industry, agriculture, and households, can reduce the demand for fossil fuels and thus lower the emissions of acid-rain-causing pollutants. Industries can adopt energy-saving technologies and equipment, such as energy-efficient motors and boilers. Households can also contribute by using energy-efficient appliances and improving insulation in buildings. Shifting from fossil fuels to renewable energy sources, such as solar, wind, hydro, and geothermal energy, is a long-term solution to reduce acid rain. Sichuan has rich renewable energy resources, especially hydropower, so expanding the development and utilization of these renewable energy sources can significantly reduce the reliance on coal and oil, which are major sources of  $\text{SO}_2$  and  $\text{NO}_x$  emissions.

For the conservation of soil and water adding lime or other alkaline substances to acidic soils can help neutralize the soil pH. This can improve soil fertility and enhance the ability of plants to resist

the negative effects of acid rain. Additionally, promoting sustainable agricultural practices can help maintain soil health, such as crop rotation and the use of organic fertilizers. For trees and wetlands which play important roles in mitigating the effects of acid rain, reforestation can help absorb pollutants from the atmosphere and reduce the impact of acid rain on the ecosystem. Restoring and protecting wetlands can also help filter pollutants from water, improving water quality and reducing the acidity of surface waters[4, 5].

Importantly, it is needed to monitor the state of environment and raise public awareness. Establishing a comprehensive and accurate monitoring system for acid rain is essential. More monitoring stations should be set up to continuously measure the pH value and chemical composition of rainwater. This data can be used to understand the spatial and temporal distribution of acid rain, evaluate the effectiveness of control measures, and provide a scientific basis for further decision-making. Raising public awareness about acid rain is crucial for promoting collective action. Through public education campaigns, the public can be informed about the causes, impacts, and prevention methods of acid rain. Schools, communities, and media can play important roles in spreading this information. Encouraging the public to participate in environmental protection activities, such as reducing energy consumption and waste, can also contribute to the reduction of acid rain.

#### 4. Conclusion

Acid rain is a menacing global environmental concern, which exerts a heavy burden on ecosystems through multiple detrimental effects. This study focuses on the acid rain issue in East Asia, with in-depth research. Acid rain poses great hazards in East Asia, especially due to its population growth, economic development, and terrain. Acid rain affects ecosystems, agriculture, buildings, and human health. Although some environmental policies have improved some acid rain indicators, the situation remains severe. Some suggestions for addressing acid rain are put forward from aspects such as emission reduction, energy transformation, and ecological protection. Acid rain's long-term consequences are far-reaching. It undermines biodiversity, endangers human health, modifies soil chemistry, and affects the greenhouse gas balance. Given these threats, researching acid rain is an immediate necessity. Some of the data on the impacts and composites of acid rain is taken from Sichuan Province in China and the Jiuzhaigou National Nature Reserve, which means for the acid rain research in East Asia as a whole, the sample coverage is limited. East Asia has a large geographical area with diverse geographical environments and economic development levels, so the research is insufficient to reflect the complex characteristics of acid rain across the region. Although the causes, impacts, and other measures of acid rain are analyzed, there is relatively little research on the interactions between acid rain and other environmental problems, such as global warming and atmospheric particulate pollution. In the actual environment, multiple environmental issues interact with each other, so when these environmental issues are not taken into account, it may lead to an incomplete understanding of the acid rain problem. In the future, it is necessary to expand the research scope to cover more regions in East Asia with different geographical environments and economic development levels. It is also crucial to deeply explore the interaction mechanisms between acid rain and other environmental factors, which could provide a scientific basis for formulating more effective environmental protection policies. If possible, it is beneficial to utilize advanced technical means to strengthen the dynamic monitoring of acid rain, improving the accuracy and frequency of monitoring. The acid rain prediction model based on monitoring data could be improved, so as to provide early warnings of acid rain disasters and enable timely responses.

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