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# A Review on Acid Rain Causes, Effects and Control Strategies

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***ABSTRACT:*** ***Since the 19th century, acid rain has been a significant environmental concern. This article examines the US EPA's 2012 progress report and analyzes the problem from different environmental perspectives. The active implementation of the Clean Air Interstate Rule (CAIR), Acid Rain Program (ARP), and NOx budget training program has resulted in significant reductions in SO2, NOx emissions, and acid deposition (NBP). The US EPA's Cross State Air Pollution Rule and Litigation (CSAPR) has reduced wastewater cross-border flow between the US and Canada since 2011. Between 1980 and 2012, the national composite mean of average SO2 annual mean ambient concentration in the United States decreased by 85 percent. The scientific and regulatory aspects of acid rain contamination are addressed. First, the negative consequences of acid deposition and trans boundary acidification are discussed. Then, for acid rain precursors, components, and depositions in the United States and China, observational efforts and outcomes are detailed. The production of inorganic sulfate and nitrate in the global troposphere as a result of human emissions is then described using a photochemical process. Then, using a step-by-step explanation, an actual regulatory simulation scenario in support of the establishment of the third sulfur emission control region, which includes coastal California, is shown. Finally, the difficulties of replicating acid rain are discussed.***

***KEYWORDS:*** ***Acid Rain, Acidification, Acid Deposition, Effect, Emission.***

## 1. INTRODUCTION

Reduced reproduction of aquatic fish species, plant dieback and stunted growth, accumulation of toxic aluminum and heavy metals in soil and water bodies, biodiversity loss including corals and shellfish, degradation of manmade structures made of marble and stone, and corrosive effects have all been observed around the world as a result of acidification. The impacts of key worldwide environmental issues such as acid rain, acid deposition, ozone layer depletion, and health and environmental consequences of particle matter are decreasing, according to the US EPA's 2012 progress report (2013).

Though there has been a significant reduction in SO2, NOx emission and acid deposition as a result of the active implementation of the Clean Air Interstate Rule (CAIR), Acid Rain Program (ARP), and NOx budget training program (NBP), the current emission levels are insufficient to achieve full recovery of acid-sensitive ecosystems, according to the report. However, between 1980 and 2012, the national composite averages of average SO2 annual mean ambient concentration decreased by 85 percent (see Figure 1&2)[1].

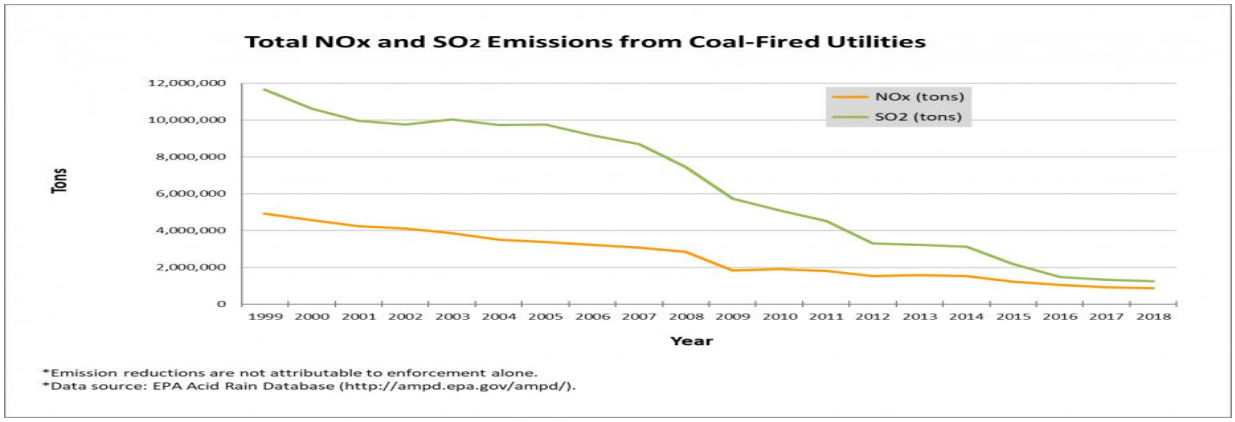


**Figure 1: National SO2 air quality USA**[2].

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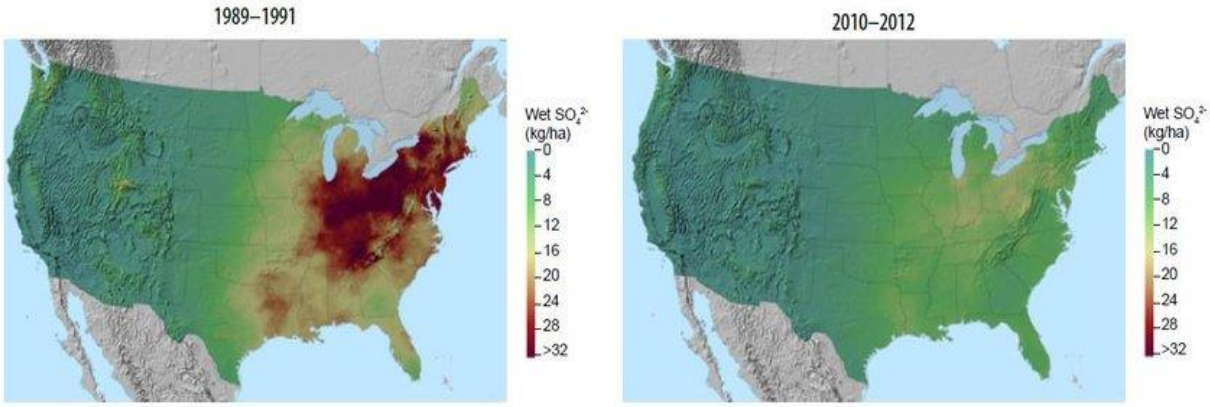


**Figure 2: Three year mean of wet sulphate deposition in USA in different periods**[3]**.**

Acid rain was first seen in Europe in the mid-nineteenth century. In a forest situated downwind of major industrial zones, signs of leaf degradation were discovered. After seeing that acid precipitation destroys the leaves, an English scientist named Robert Angus Smith coined the phrase "acid rain" in 1872. The first effort to minimize acid rain was made in 1936 at the Battersea Power Station in London, UK, however the severity of the problem worsened after 1970. Because increased use of coal fuel has resulted in higher amounts of SO2 in the atmosphere, the United States Congress enacted the Acid Deposition Act in 1980 following a ten-year continuous National Acidic Precipitation Assessment Program (NAPAP). This increased the number of monitoring sites for dry deposition and acid rain's impacts on monuments, fresh water, the terrestrial environment, and structures. Studies on atmospheric processes and possible control programs were funded.

According to NAPAP's initial acid rain assessment study in 1991, approximately 5% of New England's (in the United States) lakes were acidic, and problems such as changes in biochemical patterns in soil, fresh water bodies, and damages to built buildings were identified.

By 1990, the Clean Air Act had been amended by the US Congress. Control measures for SO2 and NOX are included in Title IV of the amendment. This was done in two stages with the goal of reducing overall SO2 emissions by 10 million tons. Phase 1 (which began in 1995) restricted SO2 emissions from 110 of the country's biggest power plants; Phase II (which began in 2000) impacts the majority of the country's remaining power facilities. Between 2000 and 2006, SO2 emissions decreased by 54% (from 211,000 to 96,500 tons). Since 1999, various initiatives have been implemented to decrease NOx emissions from industries and vehicles. By March 2005, the US Environmental Protection Agency (EPA) had established the Clean Air Interstate Rule (CAIR), which lowers pollution from power plant emissions from one state to another .Acid rain is produced by the release of SO2 and NOX into the atmosphere from different sources, which dissolve in atmospheric water and form acids in rainwater. SO2 does not react much with atmospheric chemicals, but it may travel longer distances faster and generates SO3 when it comes into touch with ozone or hydrogen peroxide, which is extremely soluble in water and forms sulphuric acid[4].

Volcanic eruptions, marine spray, planktons, decaying plants, and forest fires all generate sulphur dioxide naturally. Sources of anthropogenic pollution Sulphur dioxide emissions from industrial combustion (point sources), household heating (firewood and coal) (area or non-point sources), and transportation (3.7 percent) account for 69.4 percent, 3.7 percent, and 3.7 percent, respectively (mobile sources). It is also released from the manufacture of sulphuric acid during the production of disinfectants, bleaching agents, and fumigants, as well as from the smelting of metal ore, production of iron and steel, process pure metal (obtaining pure metals of Zn, Ni, and Cu), oil refinery, domestic and industrial boilers, and it is released from the manufacture of sulphuric acid during the production of disinfectants, bleaching agents, and fumigants.

Lightening, bacterial activity, forest fires, and volcanoes generate NOX naturally; cars (43 percent) and fertilizer businesses, utilities plants, and other industrial combustion (32 percent) produce NOX manmadely ('Causes and Effects of Acid Rain,' 2012). Wet deposition, such as acid rain, snow, sleet, and fog, and dry deposition, such as particle matter smaller than PM 2.5, are examples of acid deposition. Acid rain has both chronic and episodic effects. Chronic acidification is a long-term impact caused by years of acid rain; intermittent acidification is caused by severe rain storms; it also occurs in the spring when concentrated nitrate and sulphate in the bottom layer of the snow pack melt. Soil nitrate levels rise as a result of acid rain, resulting in nitrogen saturation. Excess nitrogen causes eutrophication in water bodies, when nitrate ions take more calcium and magnesium from the soil. Because soil aluminum is transformed to aluminum nitrate or sulphate when taken by trees, plants become deficient in aluminum and other minerals. Sulphate and nitrate ions fall as tiny particles without dissolving in water in dry deposition, which accounts for approximately 20-60% of total deposition[5].

## 2. REVIEW OF LITERATURE

Arti verma in her study discloses about the effects of simulated acid rain with pH values of 5.0, 4.0, and 3.0 on three common vegetable plant species, Capsicum annuum, Lycopersicon esculentum, and Solanum melongea of the Solanaceae family, were investigated. The species were grown on agricultural soil in clay pots. With rising acidity, all three species' growth characteristics and fruiting were significantly hampered. The chlorophyll content, on the other hand, was largely unaffected[6].

Louis A. Helfrich in his study focuses on Limestone that may also be used to preserve lakes, ponds, and their watersheds from acidification, provide calcium, and restore their significant ecological, economic, and recreational benefits. Adding limestone to preserve lake and pond water at a near-neutral pH (pH 7) makes aquatic life safe[7].

Paul hunt in his study discuses about the World Bank that has recognized the issue of acid rain in Asia by awarding a $1 million grant. It will contribute to the funding of an international network of scientists who will map the ecological impact of acid rain across Africa. The researchers hope to raise awareness among Asian governments about the harm caused by sulphur and nitrogen oxide emissions from industry, as well as suggest ways to reduce these emissions. For 14 Asian nations, preliminary estimates of sulphur dioxide emissions have already been collected and plotted. Last month, experts from Asia, Europe, and North America gathered in Bangkok to debate the project's future[8].

## 3. DISCUSSION

### *3.1 Effects on surface water:*

Acid rain is toxic to many aquatic organisms because it releases aluminum from the soil into lakes and streams. As the pH goes below 5, 75 percent of lakes and 50 percent of streams in the United States get acidified, according to natural surface effects of deposition. Similarly, 14,000 lakes in eastern Canada were found to be acidic. Acidification is more likely in soft waters with low alkaline metal ions. Acidification causes granite rocks to release more aluminum. Aluminum causes chronic stress, which causes fish to lose weight or shrink in size, making them less efficient in competing for food and habitat. Furthermore, most eggs do not hatch, some adult fish may die, and partially sensitive species like snails and clams cannot tolerate pH levels below 5.5. However, some species, such as frogs, can tolerate lower pH, but their prey species, such as mayflies, cannot, and a decrease in prey population leads to a decrease in frog population. The ecosystem is affected by the food chain's interconnections and interdependencies. Toxic heavy metal ions such as copper, cadmium, nickel, chromium, cobalt, lead, and zinc released into the water body inhibit fish development and growth.

Acidic conditions combined with heavy metal toxicity reduced fish growth and increased stress, making the fish less immune and thus more susceptible to diseases, killing eggs and larval stages, and reducing spawning and reproductive success. Another major cause of episodic acidification is nitrogen dioxide deposition in water bodies; about 10-45 percent of nitrogen dioxide reaching water bodies is airborne, and it is primarily released to the atmosphere by anthropogenic sources. Acidification has an impact on shell-forming mollusks, shell fish, coral reefs, sea grass beds, and aquatic organisms in their juvenile stages. In an acidic environment, the calcareous shell or skeleton of shellfish and corals dissolves. Acid tolerant organisms, such as bacteria and protozoa, thrive in low pH environments. Acid rain is not the only source of acidification; certain swamps, bogs, and marshes have pH levels that are naturally low. Furthermore, acid water runoff from coal mines could reach surface water bodies, resulting in fish kills in Pennsylvania, West Virginia, and Virginia surface waters in the United States and Canada, respectively (see Figure 3)[9].


**Figure 3: a) A signpost in Nova Scotia, Canada proclaims effects of acid rain on salmon fishery b) fish kill due to acidification of river**[9]**.**

*3.2 Effect on Forest:*

Acid precipitation on vegetation reduces photosynthesis and growth, increasing susceptibility to draught and disease. A process known as "dieback" causes browning of leaves and fall off (see Figure 4), as well as other effects such as thinning of annual growth rings and reduction in biomass (due to reduced growth), damage to the fine root system, and root mycorrhiza (due to increased mycorrhizal activity). Asthana and Asthana (2001) found that young seedlings are more susceptible than older plants. Adapted from Verma. The addition of lime to the soil can neutralize the negative ions in the acid, whereas the alkalinity of limestone neutralizes the negative ions in the acid[10].

**Figure 4: a) Branches of trees in Germanys Black forest showed needle lose and yellowed boughs (branch on left) b) Affected trees in the Great Smoky Mountains**[10]**.**

*3.3 Effect on man-made Structure:*

Because nitric acid, sulphuric acid, and sulphuric acid, which are concentrated in dew or rain and deposited on automobile coatings, cause fading, contemporary vehicle manufacturers employ acid resistant top paint, and modern structures use acid resistant exterior wall paints. Metal constructions, such as bronze and alloys, corrode, while acid degrades marble (limestone) buildings.

*3.4 Health Effects:*

Acid rain is caused by a variety of factors. SO2, SO3, and NOx have the potential to harm people's health, especially SO2 and SO3's impact on asthma and emphysema patients, as well as increasing the incidence of asthma and emphysema. Particulate deposition of particles smaller than PM 2.5 may enter the bloodstream via the lungs, causing detrimental consequences like as lung cancer[11].

*3.5 Liming:*

By neutralizing the ions, lime stone is introduced to neutralize the acid in the water body, as well as to promote the release of trapped nutrients from the acidified mud bottoms planktons and plant production improve when essential nutrients such as phosphorus and other limiting elements are liberated. It also lowers the harmful effects of heavy metals, which are usually present in high concentrations in acidified streams. As a result, the aquatic life will be restored to its previous state. Furthermore, calcium in lime aids the development of the calcareous exoskeleton in mollusks. Liming improves primary production and therefore the whole community of the water system, since calcium and phosphorus are important plant nutrients. An increase in rooted plants also improves the quality of breeding and nursery ground, increasing the odds of juvenile forms surviving. Liming was found to enhance the sport fishery in the United States.

Liming, on the other hand, is not advised at all, especially in portable waters, since it causes temporary turbidity and cloudiness, promotes algae blooms, and changes the flavor and mineral content of the water. Liming may be either protective (preventative) or mitigatory; preventive liming is used on vulnerable soft water lakes to improve their buffering capacity against acidification, while mitigatory liming is used to restore acidified lakes and ponds to their original state by neutralizing the acidity. Agricultural lime (CaCO3) is the most commonly used type; Dolomite lime (MgCO3) is an impure substance; Quicklime (CaO) and Hydrated lime (Ca(OH)2) are caustic; when used in large quantities in acidified lakes, they kill fish; and Soda ash (Na2CO3) is also usable but is less preferred due to its high cost. In liming applications, other variables to consider include water hardness, existing pH, alkalinity, chemistry, and acidity of bottom mud, temperature and water quality, density and kind of aquatic plants, intended pH, type, type of limestone (purity and particle size), quantity, and flushing rate. Limestone is applied via boat or barge (flushing lime at high pressure), by snow mobile tractor or spreader on ice covered lakes (lime dissolved on surface ice and then reaches the waters), shore land tractor, feeder stream application, and by air (plane or helicopter) for large areas[2].

*3.6 Reduced Acid Rain:*

Fuel switching or scrubbing may be used to accomplish this. Limiting the use of sulphur-containing fuels like coal or switching to low-sulphur coal or oil, switching to alternative energy sources like gas boilers instead of coal or oil boilers, nuclear power generation, and using renewable energy sources like wind, air, wave, and geothermal energy are all examples of fuel switching. Solar batteries, fuel cells, natural gas, and electric cars may all be used. Reduce carpooling by using public transportation, maintain vehicles for low NOx emissions,

and clean industrial boilers such as stacks and exhaust pipes, according to the EPA's energy star program. Use energy-efficient boilers and filters or scrubbers to capture sulphur and nitrogen oxides in industrial effluents and automobiles, as well as determining the proper stack height. In Europe and North America, smelters and thermal electric generating facilities had typical stack heights of 150-300 meters in the 1970s, but subsequently 400-meter super stacks were built, which reduced local pollution by releasing pollutants beyond the boundary layer.

Scrubbing can take the form of electrostatic precipitators, in which positively charged sulphur particles are attracted to a negatively charged plate, or chemical means, such as wet scrubbing (injecting water or a chemical solution like flue gas desulphurization (FGS), which removes SO2 at a rate of 80-95 percent), or dry scrubbers (lime injection multi stage burning (LIMB) or fracking. To decrease NOx, techniques such as the selective catalytic reduction process (SCR), which reduces NOx by up to 80% by injecting reactive chemicals such as ammonia, which interacts with NOx and converts it to N2 and O2, altering the air-to-fuel ratio, and modifying the combustion temperature are used. Catalytic converters, such as three-way catalytic converters (conversion of NOx into N2 and O2, conversion of CO into CO2), are used in vehicle NOx reduction. Hydrocarbon conversion to CO2 and water). The EPA's acid rain program established a limit on the amount of SO2 released by power plants in Title IV of the 1990 clean air act amendments, as well as steps to decrease NOx emissions. Continuous emission monitors (CEMs) were also employed in the program to track the sulphur content of the fuel, the quantity of fuel consumed, and the rate of SO2 emission.

During the years 1985 to 1987, each plant was granted a number of "allowances" based on yearly SO2 emissions. The program also promoted the use of renewable energy and energy saving. Solar, wind, and geothermal facilities are also eligible for tax breaks. The Title V acid rain permit scheme required plant or industrial owners to apply to the relevant government for legal authorization. Phase I of the acid rain program ran from 1995 to 2000, and phase II began in 2009. A similar initiative, the Regional Acidification Information and Simulation Programme, is being implemented in Asia, where the danger is growing in emerging nations as their energy demands rise. From 2003 to 2008, the NOx Budget Trading Program (NBP) was a cap-and-trade program in which industries in the eastern United States were required to reduce NOx emissions during the summer season. In 1991, the United States and Canada signed a bilateral air quality agreement to minimize the impacts of trans-boundary acid deposition, and an integrated atmospheric deposition network (IADN) was created to gather and manage data on the subject. Similarly, the US EPA has been enforcing the Cross State Air Pollution Rule and Litigation (CSAPR) since 2011, which significantly reduces emissions that cross state lines[5].

## 4. CONCLUSION

Since the 19th century, acid rain has been one of the world's main environmental issues. Coal combustion is the primary source of SO2, as well as car emissions and NOx emissions from different fossil fuel-based power plants. By interacting with atmospheric water vapour, SO2 and NOx create sulphuric and nitric acid, respectively, and precipitate as wet deposition such as rain, snow, sleet, and fog, as well as dry deposition such as dangerous PM 2.5 particles. Acid rain causes yellowing and leaf fall in forest trees, fish mortality in acidified rivers and lakes, and the loss of calcareous shell-forming species (mollusks). It also causes increased nitrification in soil microorganisms, which leads to eutrophication in water bodies and changes in biodiversity. Coral reefs are also harmed by acid rain. It results in the leaching of metal ions, particularly harmful Aluminum and heavy metals like chromium, cadmium, and nickel, which has a negative impact on the soil microflora and aquatic biota.

Acid rain corrodes metal buildings and fades paintwork, causing marble, stone monuments, and architecture to degrade. Liming is a process that is used to neutralize acidity in soil and water. Reduced sulphur content in fuels, scrubbers such as flue gas desulphurization (FGS),

lime injection multi stage burning (LIMB), or fluidized bed combustion (FBC or circulation dry scrubber) are all used to decrease SO2 and NOx emissions. To decrease NOx, techniques such as the selective catalytic reduction process (SCR), in which reactive chemicals such as ammonia are injected and react with NOx to convert it to N2 and O2, as well as altering the air-to-fuel ratio and the combustion temperature, are used. NOx is removed from automobiles using three-way catalytic converters. By 1990, the Clean Air Act had been amended by the US Congress. Title IV of the amendment consists of SO2 and NOx control measures that will be implemented in two stages. A regional acidification information and simulation effort is being carried out throughout Asia. From 2003 to 2008, the NOx Budget Trading Program (NBP) was in place. For trans-boundary acid deposition, the United States and Canada signed a bilateral air quality agreement in 1991, an integrated atmospheric deposition network (IADN) was created, and the US EPA adopted a cross-state air pollution rule and lawsuit (CSAPR) in 2011.

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