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A REVIEW ON ACID RAIN IT'S CAUSES, EFFECTS AND MANAGEMENT MEASURES

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Abstract: A common environmental problem brought on by the atmospheric deposition of acidic materials is acid rain. This abstract looks into the various aspects of acid rain, emphasizing its sources, consequences, and strategies used to lessen its harmful impacts. Anthropogenic emissions of sulfur dioxide and nitrogen oxides, primarily from the burning of fossil fuels and industrial processes, are the main causes of acid rain. Another factor contributing to this complex phenomenon is natural sources like volcanic eruptions. The effects of acid rain span various ecosystems, impacting aquatic life, soil quality, vegetation, and human health. Acidification of water bodies disrupts ecological balance, causing harm to aquatic organisms and posing a threat to biodiversity. Additionally, acid rain's ecological effects are made worse by the release of toxic metals into the environment. International coordination is vital, recognizing the cross-border transfer of contaminants. Enhancing energy efficiency and promoting alternative energy sources are two sustainable practices that support a holistic strategy to reduce precursors of acid rain. One naturally occurring remedy that helps restore acid rain-affected ecosystems is reforestation. It is crucial to conduct ongoing studies, raise awareness, and modify mitigation techniques in response to acid rain's changing characteristics. Understanding the sources, impacts, and measures of acid rain is essential for developing effective policies and practices that promote sustainable cohabitation with our planet as humanity tries to strike a balance between development and environmental preservation.

Keywords: Atmospheric pollutants, Environmental impact, Mitigation strategies, Soil acidification and Water Quality

HISTORY OF ACID RAIN

In the mid-19th century, acid rain was first observed in Europe. In 1845, Ducros was the first scientist who recognized acid rain (Ducros 1845). In 1853, acidic rain was found (Likens et al., 1972). In 1852, the term Acid rain was developed by an English chemist Robert Angus Smith (Smith 1852) who noticed leaves that were damaged by the acid rain (Sivaramanan 2015). His studies linked industrial emissions with the source of acid rain and also contained the early monitoring of harmful environmental effects (Smith 1872).

Until the 20th century, smith's work was mostly forgotten when the studies began to interrelate the atmospheric sulfate and other chemicals constituent's deposition with the air pollution near the metal smelter in Canada (Gorham 1961). In the 1960s and early 1970s in Sweden, observations exposed that nitric oxide and sulfur dioxide emission cause acid rain (Oden 1976), later on, it was also observed in North America (Likens and Bormann 1974). Afterward, various environmental effects of acid rain on aquatic animals and plants were also recognized and it was identified that acidification in fishes was due to long-range transportation of pollutants of sulfur (Overrein et al., 1980). Acid rain was first reported in North America, Europe, and later on in Asia (Zhao and Sun 1986).

In 1936, the first step was taken in London to control acid rain. However, the harshness of the problem increased after 1970 due to increased concentration of sulfur dioxide in the atmosphere which resulted from increased use of coal fuel. The acid deposition act in 1980 was passed by the US Congress after ten years of continuous National Acidic Precipitation Assessment Program (NAPAP) (Fatima et al., 2020). This increases the observation of dry deposition and acid rain effects on buildings, aquatic ecosystems, and monuments. In the mid-1990s it was obvious that acid rain also interacts with climate warming and ozone layer depletion which are other environmental problems (Sivaramanan 2015).

INTRODUCTION

Since the beginning of civilization, human beings have used various natural resources for their benefit. To make their life easier, they have produced facilities that use many of the Earth's energy resources. Acid rain is particularly damaging to lakes, streams forests, and the plants and animals that live in these ecosystems. Rain is one of the most essential ingredients for human and animal life. The water provided by rain allows all life on Earth to survive. Although rain is naturally acidic, it is being increasingly acidified by pollution from homes, factories, power stations, and cars. The term used to describe this problem is "acid rain". Acid rain hasn't just occurred in the last twenty to thirty years. This was over 100 years ago. For years ever since most of the world has been industrialized, the effects of pollution have plagued nations alike (Kumar 2017).

Industrialization, urbanization, and the burning of fossil fuels ease the number of pollutants that lead to air pollution. Acid rain is one of the utmost serious problems of the environment (Grennfelt et al., 2019) that arose due to air pollution. Any kind of precipitation that has an acidic nature is called acid rain (Likens and Butler 2018). Acid rain has a pH of less than 5.6.

Acid rain is also known for its role in environmental damage and transboundary air pollution. Acid rain is a result of the emission of SO_2 (fossil fuel combustion and metal smelter) and NOx (released from vehicular sources, industrial and power plants) forming sulphuric and nitric acid in precipitation. Acid rain has several adverse effects on ecological aspects (it harms flora and fauna both), biogeochemical cycles, and soil quality due to nutrient leaching from topsoil to subsoil and below subsoil in the presence of acid rain (Sonwani and Maurya 2018).

Apart from the above mentioned, acid rain also has several adverse impacts on human health such as itching, skin burn, respiratory problems (asthma, dry cough, and irritation in throat), headache, brain damage, and kidney problems. Degradation in building materials (historical monuments and sculptures all over the world), yellowing, and weakening of fabrics are also results of acid rain exposure. Acid rain is the main reason for the corrosion of several metals and structures made from it. It is also responsible for the loss of carved details and corrosion of copper, zinc, etc (Sonwani et al.,2020).

Chemistry of acid rain formation (Source: Wondyfraw 2014**)**

The major components of acid rain are sulfur dioxide/sulfur trioxide, carbon dioxide, and nitrogen dioxide dissolved in rainwater. These components are deposited as dry and wet depositions. When these pollutants are dissolved in water during rain they form various acids. The chemical reactions of these pollutants are discussed as follows:

- $CO_2+H_2O \rightarrow H_2CO_3$ (carbonic acid)
- $SO_2+H_2O \rightarrow H_2SO_3$ (sulfurous acid)
- $NO_2+H_2O \rightarrow HNO_2$ (nitrous acid) $+HNO_3$ (nitric acid)

Types of acid deposition

A) Dry deposition

Acid rain is also called acid deposition **(**Galloway and Whelpdale 1980). This deposition of acids may be dry or wet. Snow, rain, and fog are wet deposition. When air takes the acid chemicals into such an area that has wet weather then acid on the ground falls in the form of snow, fog, and rain. This acidic water flows through the ground and affects the diversity of animals and plants **(**Rennenberg and Gessler 2001).
Acid deposition also occurs via dry deposition in the absence of precipitation. This can be responsible for as much as 20 to 60% of total acid deposition. This occurs when particles and gases stick to the ground, plants, or other surfaces (Bhardwaj 2016).

In areas where the weather is dry, the acid chemicals may become incorporated into dust or smoke and fall to the ground through dry deposition, sticking to the ground, buildings, homes, cars, and trees. Dry deposited gases and particles can be washed from these surfaces by rainstorms, leading to increased runoff (Kumar 2017).

B) Wet deposition

Acidic particles and gases are called dry deposition. Towards cars, buildings, homes, and trees, these acidic particles and gases are blown by wind which results in the sticking of these chemicals with the material (Baedecker et al.,1992). Through the rainstorms, from the other surfaces and trees, these dry deposited particles and gases can be washed out. When this occurs, then running water mixes these acids with the acid rain and makes it more acidic (Lower (1999).

Wet deposition of acids occurs when any form of precipitation (rain, snow, and so on.) removes acids from the atmosphere and delivers them to the Earth's surface. This can result from the deposition of acids produced in the raindrops (see aqueous phase chemistry above) or by the precipitation removing the acids either in clouds or below clouds. Wet removal of both gases and aerosols is of importance for wet deposition (Bhardwaj 2016).

Wet deposition refers to acidic rain, fog, and snow. If the acid chemicals in the air are blown into areas where the weather is wet, the acids can fall to the ground in the form of rain, snow, fog, or mist. As this acidic water flows over and through the ground, it affects a variety of plants and animals (Kumar 2017).

Causes of Acid rain

Figure 1 shows the cause and mechanism of the acid rain formation. Both natural and anthropogenic causes are responsible for the formation of acid rain in the atmosphere. However, the combustion of fossil fuel releases sulfur dioxide (SO_2) and nitrogen oxides (NOx) which are significantly responsible for the formation of acid rain in the atmosphere (Sonwani and Maurya 2018).

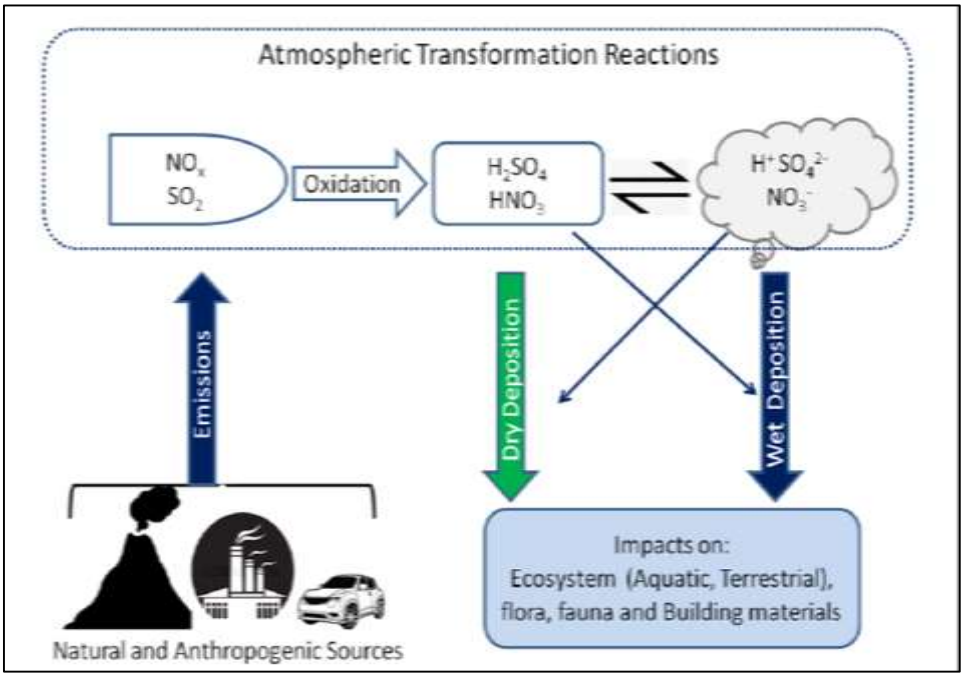


Fig.1 Causes, formation mechanism, and environmental impacts of acid rain,(Adapted from Sonawani and Maurya, 2018)

1. Natural sources

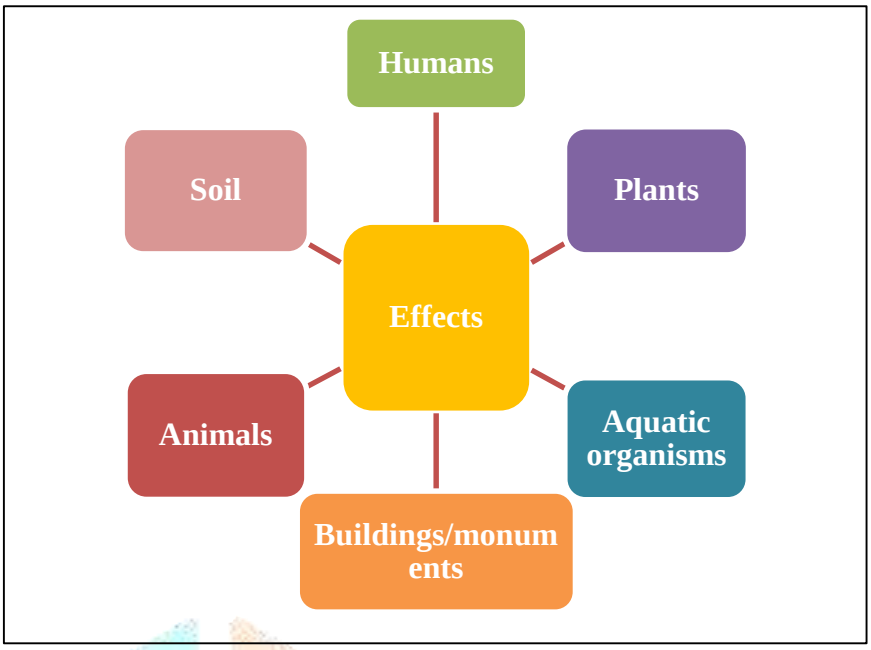
Volcanic eruption is one of the main sources for the acid rain formation. Volcanoes release a large amount of gases responsible for the formation of acid rain and other forms of precipitation (fog and snow) affecting the environment adversely. Forest fire, degrading vegetation, and biological activities also release significant quantities of gasses producing acid rain. Dimethyl sulfide (C_2H_6S) is a major biological contributor to sulfur-containing elements in the atmosphere. Anaerobic biological reactions in the soil/water and photochemical destructions are important sources for the formation of atmospheric oxide of nitrogen in the atmosphere. Lightening activity produces nitric oxide (N_2O) which reacts with the water to form nitric acid which is an important constituent of acid rain (Sonwani et al., 2020).

2. Anthropogenic sources

Several industries, (chemical, petrochemicals, pulp, and paper) oil refineries, thermal power Plants and emissions from motor vehicles are the important sources that release precursor gasses such as oxides of sulfur and oxide of nitrogen responsible for the formation of acid rain (Saxena and Sonwani 2019).

The coal combustion used in electricity generating plants is one of the biggest contributors to the production of gasses responsible for acid rain. In urban areas, gaseous emissions from industries and motor vehicles are the major sources of acid rain formation. Such gases react with the water, oxygen, and other atmospheric chemicals to form several compounds such as sulphuric acid and nitric acid which result in the formation of acid rain. Under the influence of meteorological parameters (such as wind speed, wind directions, temperature, relative humidity, and mixing height) these atmospheric gasses transport at a larger distance and participate in the atmospheric transformation reactions responsible for acid rain. (Sonwani et al., 2020)

Effects of acid rain



1. **Effects on Human Beings:**

Acid rain is very dangerous to human beings. It may lead to skin burning, skin blisters, and graying of hair. Acid rain also affects the human nervous system, respiratory system, etc. This also irritates the eyes (Bhardwaj 2016).

According to Kumar 2017 Acid rain looks, feels, and tastes just like clean rain. The harm to people from acid rain is not direct. Walking in acid rain, or even swimming in an acid lake, is no more dangerous than walking or swimming in clean water. However, the pollutants that cause acid rain sulfur dioxide (SO_2), and nitrogen oxides (NOx) do damage human health. These gases interact in the atmosphere to form fine sulfate and nitrate particles that can be transported long distances by winds and inhaled deep into people's lungs. Fine particles can also penetrate indoors. Many scientific studies have identified a relationship between elevated levels of fine particles and increased illness and premature death from heart and lung disorders, such as asthma and bronchitis. Acid rain is very harmful to health.

Sharma 2018 stated that drinking water contaminated by heavy metals like aluminum, mercury, and lead is very fatal for human beings. Acids are liquid and are very small and fine particles. If present in the air, they become harmful to the lungs. They can even lead to cancer if present in the air. If contaminated (mercury) flora or fauna is eaten as seafood, they are hazardous to health. The appearance and taste of acid rain are just like clean water. It exerts indirect effects on human health.

Acid rain causes the leaching of toxins from the soil, these toxins include Al, Mn, Fe, Pb, and Hg which dissolve in the soil and reach the groundwater, human drink this water **(**Thornton and Plant 1980) due to which various heavy metals accumulated in their bodies and result in headache, cough, throat and nose irritation. These toxins are also absorbed by animals and plants, when humans ingest these toxins then kidney problems and damage to the brain occur. These toxins also lead to heart diseases as well as lung diseases such as bronchitis and asthma. It is very hazardous to swim in an acid lake or to walk in acid rain. Wind transports nitrate and sulfate particles present in the atmosphere which are inhaled during breathing and lead to cancer **(**Lynn and Reist 1976). In Tokyo, skin and eye irritation have also been observed due to polluted droplets **(**Okita 1983).

2. **Effects on plants:**

Acid rain damages the plants and the plant cells and hence adversely affects the growth of trees. The various damages caused by acid rain to the plant cell are membrane damage, chlorophyll destruction, and plasmolysis (Bhardwaj 2016).

Acid rain can harm other plants in the same way it harms trees. Although damaged by other air pollutants such as ground-level ozone, food crops are not usually seriously affected because farmers frequently add fertilizers to the soil (Kumar 2017).

Acid rain blocks the stomata on the surface of the leaf are clogged by acid rain. Gaseous exchange through stomata is hindered. When the proper gaseous exchange is affected, it will cause a malfunction in the development of plants.

Flora becomes vulnerable to pathogens. It causes heavy damage to plants and trees culminating in death. When the ecosystem and food chain are affected survival of interdependent animals and plants becomes difficult and due to lack of food they die. All living organisms are interdependent (Sharma 2018).

3. **Effects on Animals:**

Various metabolic activities of animals are affected by acid rain. For example, brown trout is very sensitive to acid rain, and in females; its sexual behavior is extremely affected by it. The nest-digging behavior in them is also inhibited by the acidity of water (Kitamura and Ikuta 2001). Due to acid rain, the normal function of the human body is also getting affected. Some troubles have also been seen in the immune system due to acid rain, after exposure to acidity, the level of antibodies decreases considerably in plasma (Nagae et al., 2001).

4. **Effects on Aquatic organisms:**

The effect of acid rain on aquatic life is quite serious. Acidification of lakes affects aquatic animals and plants. Green algae, bacteria, etc which are essential to aquatic systems, will be killed due to acidity. The fish population is also reduced due to acid rain(Bhardwaj2016).

Heavy metals which are leached out from the soil through acid rain, reach nearby lakes and streams and cause water pollution (Ferenbaugh1975). These acids lower the pH of water bodies, due to which the reproduction of plants and animals is also affected. These acids do not allow fish to breathe due to which accumulation of heavy metals occurs in the body and results in the death of fish (Watt et al., 1983). When the birds eat these poisoned fishes then chemicals also enter into their system and when other animals eat these birds then these heavy metals are introduced into these animals. In the food chain, chemicals are introduced at each trophic level in this way and chemical concentration also increases at each level (Parks 2007).

Many other aquatic animals such as amphibians are also affected by low pH and Mollusks below 5 pH vanished from the Ontario Lakes (Findlay and Kasian1986), this indicates that mollusks are more vulnerable to acidity. There are several species discovered which are tolerant of high acidity. *Lobella* species and Sphagnum species were dominant in Swedish Lakes which were tolerant to acidity (Grahn 1977).

Aquatic ecosystem has a wide range of abiotic and biotic components (autotrophs and heterotrophs). Acid rain lowers the acidity of the water bodies as water has a lower acid buffering capacity than soil, thus acid rain changes the chemistry of the lake. Thus, acid rain increases the acidity of water bodies such as lakes and streams due to the low buffering capacity of water and surrounding soil. Acid rain also releases aluminum from soil to the lakes and streams which is highly toxic to aquatic life including producers (algae, mosses, and phytoplankton) and consumers. Phytoplankton is an important source of food for filter-feeding crustaceans and rotifers. Many of them are very sensitive to low pH levels and thus disappear from water bodies after acid rain (Sonwani 2020).

5. **Effects on soil:**

Soil is slightly alkaline. Because of acid rain, the alkalinity of the soil will reduce and the soil becomes acidic which in turn reduces the fertility of the soil. Hence world's food production will drastically be affected (Bhardwaj 2016).

According to Sharma 2018**,** Soil contains many detrimental heavy minerals like aluminum and mercury. These heavy metals cannot be taken by plants and trees and are thus harmless. When they come in contact with acid rain, undergo chemical reactions with the acids. As a result compounds of lead, aluminum, and mercury are produced. Plants and trees can easily absorb these compounds such elements which are extremely harmful to living forms ultimately affecting the entire food chain.

These chemicals not only harm the flora, but also the animals that feed on them. Acid rain damages the chemistry of the soil and changes the soil quality (Koptsik et al., 2001). Some harmless minerals such as aluminum and mercury are present in the soil which plants cannot absorb when they react with the acids, then they become easily available to plants for absorption and change the soil biology and chemistry as well as cause harmful effects (Likens et al.,1996). They also harm the animals that feed on these plants. Acid rain denatures the enzymes of microbes in the soil and kills them due to their intolerance at low pH (Rodhe et al., 2002).

6. **Effects on Buildings/monuments:**

Marble, limestone, slate, cement, etc. are the ingredients of buildings and monuments. Acid rain causes extensive damage to these materials by pitting. The pitting materials get weakened mechanically as the soluble sulfates are leached out by rainwater (Bhardwaj2016).

$$CaCO_3 + H_2SO_4 \longrightarrow CaSO_4 + CO_2 + H_2O$$

Marble and limestone have long been preferred materials for constructing durable buildings and monuments. Marble and limestone both consist of calcium carbonate ($CaCO_3$) and differ only in their crystalline structure. Limestone consists of smaller crystals and is more porous than marble; it is used more extensively in buildings. Marble, with its larger crystals and smaller pores, can attain a high polish and is thus preferred for monuments and statues. Although these are recognized as highly durable (Kumar 2017).

According to Sharma 2018 Lotus Temple and Tajmahal in India, the Leshan Giant Stute in Mount Emei (China), St. Paul's, the Cathedral in London, and the Statue of Liberty in New York are getting destroyed by acid rain. Acid rain doesn't affect the area where there is pollution but it is the transboundary pollutant that travels across boundaries and causes damage in other countries. The USA, China, Japan, etc are high emitters, and India, Developing countries, and Canada are high recipients. It has been estimated that a thunderstorm transports atmospheric pollutants more than a thousand kilometers away from the point of their origin within 2-4 days.

Marble and limestone make monuments and buildings consisting of calcium carbonates which are worn by acid rain (Schuster et al., 1994). In acid rain, Sulphur dioxide provides aqueous ions by the dissolution of calcium carbonates which are washed out in the flow of water. At the monument or building surface, this phenomenon occurs. Sulfur and nitric acid in rain cause fading in the paint of buildings by depositing on the coating (Keuken et al., 1990) and damaging the historical buildings. Therefore, a very famous building in India like the Taj Mahal and in New York Statue of Liberty has been eroded by acid rain (Okochi et al., 2000).

Acid rain and climate change

Acid rain has an association with the climate. The emission of sulfur dioxide, nitrogen dioxide, and carbon dioxide causes acid rain. Carbon dioxide is a primary gas that also leads to the greenhouse effect. Human activities produce these chemicals of acid rain which reach the atmosphere, when their concentration becomes high then the temperature of the atmosphere increases and results in climate warming. This warming occurs at a global level. In this way, Acid rain gases are also responsible for climate change (Martin 1989).

Management measures:

1. **Liming:**

The damage to lakes and other water bodies can be eliminated by adding lime. Many chemicals such as caustic soda, sodium carbonate, slacked lime, and limestone are most popular for raising the pH of acidified water (Khemani et al., 1985).

Liming eliminates some of the symptoms of acidification; it is expensive and not a real cure. Liming is a process that is used to neutralize the acid by adding limestone into the lakes, water, and soils and reducing the lethal effects of heavy metals. This method can be applied to a specific area. Liming also allows the survival of the native population of fish in ponds. The addition of lime reduces the damage to the water bodies. The pH of acidic water is raised by the addition of slacked lime, Caustic soda, limestone, and sodium carbonate (Khemani et al., 1985). In water bodies, liming enhances the water quality and also increases the productivity of plants and animals. It also restores various species. Liming is an exclusive process but is no real remedy. This process should be periodically repeated to keep effectiveness (Singh and Agrawal, 2007).

2. **Policy Intervention**:

In the 1970s and 1980s, the effects of acid rain on natural resources and ecosystems became an issue of considerable public concern in both northwestern Europe and the northeastern United States. Several northeastern States and the Province of Ontario, Canada, sued the US Environment Protection Agency in 1980 to take action to control acid precursor emissions emanating from states in the government. U.S. Congress formed the National Acid Precipitation Assessment Programme (NAPAP) and mandated NAPAP to conduct a 10-year scientific, technological, and economic study of the acid rain issue under the Acid Precipitation Act of 1980 (**Source:** Kumar 2017).

The purpose of the study was to inform public policy by providing information on:

1. Specific regions and resources affected by acidic deposition.
2. How and where acid precursor emissions are transformed and distributed?
3. Whether the effects are extensive and require mitigation?
4. What emission control technologies and mitigation options are

In Europe and the United States, during the 1970s and 1980s, acid rain effects on various natural resources were a serious issue. In 1980, the Environment Protection Agency in the state of Canada took action to control the emission of chemicals that cause acid rain (Evans et al., 2001). In 1990, Legislation to control acid rain effects and control programs for acid rain was also introduced (Stoddard et al., 2003). The major aim of this program was to reduce the emission of Sulphur dioxide and nitrogen oxide to achieve health benefits for the environment and the public.

3) Reduce the emission of pollutants:

Acid rain can be controlled by reducing the emission of pollutants such as Sulphur dioxide and nitrogen oxide which causes acid rain **(**Fatima et al., 2020).

CONCLUSION

To sum up, acid rain is a complicated environmental problem with wide-ranging effects that result from both natural and man-made sources. Sulfur dioxide and nitrogen oxide emissions from industrial operations and fossil fuel burning, as well as emissions from natural sources such as volcanic eruptions, are the main causes of acid rain. As a result of the chemical interactions these pollutants undergo in the atmosphere, acidic chemicals are formed that can fall as acid rain. Acid rain has many different and significant effects on soil, water bodies, ecosystems, and even human health. Reducing sulfur dioxide and nitrogen oxide emissions by using cleaner technologies, better industrial processes, and stronger environmental legislation is one important step. The transboundary character of acid rain necessitates international cooperation since contaminants can spread widely and impact areas distant from their sources. Additionally, encouraging sustainable practices can help minimize the generation of precursors to acid rain and lessen dependency on fossil fuels. Examples of these practices include increasing energy efficiency and employing alternative energy sources. While monitoring and study are essential for comprehending the changing nature of acid rain and improving mitigation techniques, reforestation activities can aid in the restoration of damaged ecosystems. We can reduce the effects of acid rain and protect the health of our ecosystem for future generations by embracing sustainable practices, putting in place sensible legislation, and encouraging international cooperation.

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