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Causes, Effects and Management Measures of Acid Rain: A Review

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ABSTRACT

A common environmental problem brought on by the atmospheric deposit of acidic accoutrements is acid rain. This abstract looks into the colourful aspects of acid rain, emphasizing its sources, consequences and strategies used to lessen its dangerous impacts. Anthropogenic emigrations of sulphur dioxide and nitrogen oxides, primarily from the burning of fossil energies and artificial processes, are the main causes of acid rain. Another factor contributing to this complex miracle is natural sources like stormy eruptions. The goods of acid rain span colourful ecosystems, impacting submarine life, soil quality, foliage and mortal health. Acidification of water bodies disrupts ecological balance, causing detriment to submarine organisms and posing a trouble to biodiversity. Also, acid rain's ecological goods are made worse by the release of poisonous essence into the terrain. Enhancing energy effectiveness and promoting indispensable energy sources are two sustainable practices that support a holistic strategy to reduce precursors of acid rain. One naturally being remedy that helps restore acid rain- affected ecosystems is reforestation. Understanding the sources, impacts and measures of acid rain is essential for developing effective programs and practices that promote sustainable cohabitation with our earth as humanity tries to strike a balance between development and environmental preservation.

Key words: Atmospheric pollutants, Environmental impact, Mitigation strategies, Soil acidification, 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, observations in Sweden revealed that nitric oxide and sulphur dioxide emissions cause acid rain (Oden, 1976), which was later detected in North America (Likens and Bormann, 1974). Afterward, numerous environmental consequences of acid rain on aquatic animals and plants were also recognised and it was determined that acidification in fishes was caused by long-range transportation of sulphur pollutants (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 US Congress passed the Acid Deposition Act in 1980, following ten years of ongoing National Acidic Precipitation Assessment Programme (NAPAP) (Fatima *et al*., 2020). This facilitates the observation of dry deposition and acid rain effects on buildings, aquatic environments and monuments. In the mid-1990s, it was clear that acid rain interacts with other environmental issues such as climate change and ozone layer depletion (Sivaramanan, 2015).

Humans have harnessed natural resources to their advantage since the dawn of civilization. To make their lives easier, they have created facilities that make extensive use of the Earth's energy resources. Acid rain is especially harmful to lakes, streams, forests and the plants and

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animals that inhabit these habitats. Rain is one of the most important elements for human and animal survival. Rain provides the water that every life on Earth requires to survive. Rain is inherently acidic, but it is becoming increasingly acidic due to pollution from homes, companies, power plants and automobiles. This issue is referred to as "acid rain". Acid rain has not only occurred in the last twenty to thirty years. This happened nearly 100 years ago. 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 to cause environmental damage and transboundary air pollution. Acid rain is caused by the emissions of SO_2 (from fossil fuel combustion and metal smelters) and NOx (from vehicles, industries and power plants), which precipitate as sulphuric and nitric acid. Acid rain has various negative effects on ecological aspects (it hurts both flora and fauna), biogeochemical cycles and soil quality because of nutrient loss from topsoil to subsurface and below subsoil in the presence of acid rain (Sonwani and Maurya, 2018).

Aside from the aforementioned effects, acid rain has various negative effects on human health, including itching, skin burn, respiratory difficulties (asthma, dry cough and throat irritation), headaches, brain damage and renal problems. Acid rain exposure causes degradation in building materials (historical structures and sculptures all over the world), as well as yellowing and weakening of fabrics. Acid rain is primarily responsible for the corrosion of many metals and constructions. It also causes the loss of carved details and the 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). Acid deposition can be moist or dry. Snow, rain and fog are all examples of wet deposition. When acid compounds are transported into a moist environment, they fall to the ground in the form of snow, fog and rain. This acidic water percolates into the ground, influencing the diversity of animals and plants (Rennenberg and Gessler, 2001).

Acid deposition can also occur by dry deposition in the absence of precipitation. This can account for 20-60% of total acid deposition. This happens when particles and gases adhere to the earth, plants, or other surfaces (Bhardwaj, 2016). In arid climates, acid chemicals may become mixed into dust or smoke and fall to the ground via dry deposition, clinging to the ground, buildings, residences, cars and trees. Rainstorms can wash away dry deposited gases and particles from these surfaces, increasing runoff (Kumar, 2017).

B) Wet deposition

The term "dry deposition" refers to acidic particles and gases. Wind blows these acidic particles and gases towards cars, buildings, homes and trees, causing them to adhere to the material (Baedecker *et al*., 1992). These dried deposited particles and gases can be washed away during rainstorms from other surfaces and trees. When this occurs, rushing water mixes these acids with the acid rain, increasing its acidity (Lower, 1999).

Wet deposition of acids happens when any type of precipitation (rain, snow and so on) takes acids from the atmosphere and transports them to the Earth's surface. This can be caused by the deposition of acids created in raindrops (see to aqueous phase chemistry above) or by precipitation removing acids from clouds or below clouds. Wet removal of gases and aerosols is essential for wet deposition (Bhardwaj, 2016).

Wet deposition includes acidic rain, fog and snow. If acid substances in the air are blown into rainy weather zones, they can fall to the ground as rain, snow, fog, or mist. Acidic water that runs over and through the earth has an impact on a number of plants and animals (Kumar, 2017).

Causes of acid rain

Fig 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).

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).

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

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. Acid rain causes indirect harm to people. Walking in acid rain or swimming in an acid lake is no more risky than walking or swimming in clear water. However, the pollutants that create acid rain, sulphur dioxide (SO_2) and nitrogen oxides (NOx), endanger human health. These gases react in the atmosphere to generate fine sulphate and nitrate particles, which can be carried long distances by winds and breathed deeply into people's lungs. Fine particles can also travel indoors. Many scientific investigations have found a link between high levels of fine particles and increased illness and early death from heart and lung diseases like 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).

Effects on plants

Acid rain damages the plants and the plant cells and hence adversely affects the growth of trees. The various damages

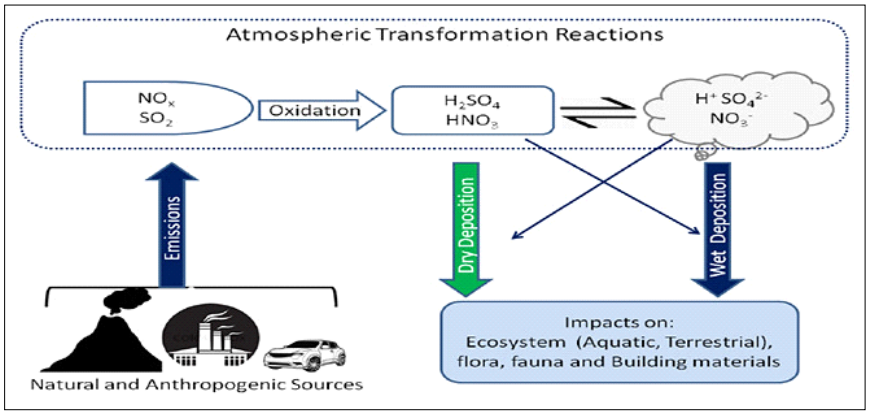


Fig 1: Causes, formation mechanism and environmental impacts of acid rain, (Adapted from Sonawani and Maurya, 2018).

caused by acid rain to the plant cell are membrane damage, chlorophyll destruction and plasmolysis (Bhardwaj, 2016).

Acid rain can destroy other plants in the same manner that it does trees. Although other air pollutants, such as ground-level ozone, might harm food crops, they are rarely badly harmed since farmers routinely add fertiliser to the soil.

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).

Effects on agriculture

Various agricultural crops have been affected by acid rain throughout the world. A research was carried out by Nain Mohit, Hooda (2019) on probability and trend analysis of monthly rainfall in Haryana. Researching a region's rainfall patterns over an extended period of time may be quite beneficial for crop planning and scheduling irrigation. The probability and trend analysis of monthly rainfall at a few chosen rain gauge stations dispersed around the state of Haryana are the subjects of the current study. The state of Haryana's 27 rain gauge stations' monthly rainfall data for the 42-year period (1970-2011) was used to calculate the probabilities of drought, normal and anomalous occurrences. According to analysis, normal months are more likely than abnormal months, while months experiencing drought are more likely than normal months. The Mann-Kendall test and Sen's slope estimator tests have been used to analyse the monotonic trend direction and size of change in rainfall over time. Ballabgarh and Thanesar had a substantial decline in yearly rainfall using the Mann-Kendall test and Sen's slope estimator, whereas Thanesar and Narnaul saw a significant decrease in monsoon rainfall. However, only one district-Sirisa-shows a discernible rise in both yearly and monsoon rainfall. According to probability calculations, Ambala, Hassanpur and Dujana had the greatest percentages of normal, draught and anomalous months, respectively.

A comparative study of drying of Muga Cocoons using Convection and Infra-red Heating Method (Bhagabati and Shakuntala, 2024). The ideal temperature range for Muga cocoon drying was between 50 and 100°C in order to achieve a safe moisture content that would provide high-quality Muga silk. Convection (1 kilowatt) and infrared (650 watts) heating methods are used to dry the Muga cocoon for the same amount of time. To preserve the moisture content at an ideal level, Muga cocoons were first placed in a drying chamber at a high temperature (100±5°C) utilising both convection and infrared heating methods independently. The temperature measurement was taken every 15 minutes using both techniques and it took around 75 minutes to reach a temperature of 100 from room temperature. Temperature, time, moisture content, cocoon weight, shell weight and shell ratio were the variables that were examined. These variables were looked at, assessed and contrasted for the infrared and convection heating techniques. The comparison study's findings showed that, for both convection and infrared heating techniques, the performance of the examined cocoon parameters-temperature, cocoon weight, shell weight, shell ratio and moisture content-is roughly comparable. For both the convection and IR techniques, the moisture content was kept within the ideal range of 6-12%. In terms of energy usage and safety for the same amount of time, the study showed that the infrared heating method performed better than convection heating. A 650-watt infrared heater uses 0.8125 kWh of energy, whereas a 1 kW convection heater uses 1.25 kWh.

Akpan *et al*. (2023) carried a research on identification and validation of pedochemical and fertility indices of soils influencing maize (*Zea mays*) crop production in the rain forest agro-ecology of Nigeria. Since the soil is a vital natural resource for any country, a thorough evaluation of its nature and extent is necessary before it can be improved and used wisely.The soils from each of the 18 LGAs in Cross River State, Nigeria, were collected using a random sample approach and divided into two halves. Local maize was grown in one section of the soil, while its fertility index and pedochemical characteristics were examined in the other. The findings show that the range of organic carbon was 1.40 g/kg3 to 2.84 g/kg3. The range of available phosphorus was 3.31 mg/kg to 29.24 mg/kg. Total nitrogen ranged in amount from 0.11 to 0.24 g/kg3. Moreover, there was a difference in cation exchange capacity (CEC) between 7.01 and 12.01 cmol/kg3. Throughout the agroecology, the soils ranged in acidity from 5.00 to 0.61. Zinc also varied, ranging from 1.93 mg/kg3 to 5.0 mg/kg3, while boron varied from 0.52 mg/kg3 to 2.01 mg/kg3. Additionally, according to the data, 33.33% of the soils had accessible phosphorus ratings of high, medium, or low. It was discovered that the soils' overall nitrogen nutrient fertility ratings were 22.22% medium and 77.78% high. According to the results, the organic carbon content had a medium fertility rating of 26.77% and the organic carbon content had a high fertility rating of 72.23%. In order to provide the research area's maize crop production with 100% assistance, ten (10) principle components (PC) were found.

Effects on animals

Various metabolic activities of animals are affected by acid rain. For example, brown trout is particularly vulnerable to acid rain and it has a significant impact on female sexual behaviour. Acidic water also inhibits their nest-digging behaviour (Kitamura and Ikuta, 2001). Acid rain also has

an impact on the normal functioning of the human body. Acid rain has also caused problems in the immune system; after being exposed to acidity, the number of antibodies in plasma drops significantly (Nagae *et al*., 2001).

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 (Bhardwaj, 2016).

Heavy metals which are leached out from the soil through acid rain, reach nearby lakes and streams and cause water pollution (Ferenbaugh, 1975). 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, 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).

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).

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 (Bhardwaj, 2016).

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

Marble and limestone have long been popular materials for building long-lasting structures and monuments. Marble and limestone are both made of calcium carbonate ($CaCO_3$) and differ solely in their crystalline structures. Limestone, which is more porous than marble and made up of smaller crystals, is more commonly utilised in construction. Marble, with its larger crystals and smaller pores, can achieve a high polish and is hence used for monuments and statues. Despite the fact that they are known to be extremely long-lasting.

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). Sulphur dioxide in acid rain supplies aqueous ions by dissolving calcium carbonates, which are swept away in the flow of water. This phenomena occurs on the surface of a monument or building. Rain containing sulphur and nitric acid causes fading in building paint by accumulating on the coating (Keuken *et al*., 1990),

causing damage to historical buildings. As a result, acid rain has corroded a prominent building in India, such as the Taj Mahal and in New York, the Statue of Liberty (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.

Management measures

Limining

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).

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. In 1980, several northeastern states and the Province of Ontario, Canada, sued the US Environmental Protection Agency for failing to control acid precursor emissions emitted by federal agencies. Under the Acid Precipitation Act of 1980, the United States Congress established the National Acid Precipitation Assessment Programme (NAPAP) and tasked it with conducting a 10-year scientific, technological and economic assessment of acid rain (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. 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.

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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Conflict of interest

The authors do not declare any conflict of Interest.

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