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Chemistry and Ecological Effects of Acid Rain

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ABSTRACT: Acid rain, or acid deposition, is any form of precipitation with acidic components, high levels of sulfuric and nitric acid that fall to the ground from the atmosphere in wet or dry forms. This can also occur as rain, snow, fog, hail or even dust that is acidic or tiny bits of dry material that settle to earth. Normal rain is slightly acidic, with a pH of 5.6, while acid rain generally has a pH between 4.2 and 4.4. Acidification of rain-water is identified as one of the most serious environmental problems of transboundary nature. Acid rain is mainly a mixture of sulphuric and nitric acids depending upon the relative quantities of oxides of sulphur and nitrogen emissions. Due to the interaction of these acids with other constituents of the atmosphere, protons are released causing increase in the soil acidity. Lowering of soil pH mobilizes and leaches away nutrient cations and increases availability of toxic heavy metals. Such changes in the soil chemical characteristics reduce the soil fertility which ultimately causes the negative impact on growth and productivity of forest trees and crop plants. Acidification of water bodies causes large scale negative impact on aquatic organisms including fishes. Acidification has some indirect effects on human health also. Acid rain affects each and every components of ecosystem. Acid rain also damages man-made materials and structures. By reducing the emission of the precursors of acid rain and to some extent by liming, the problem of acidification of terrestrial and aquatic ecosystem has been reduced during last two decades.

Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are emitted into the atmosphere and transported by wind and air currents. The SO_2 and NO_x react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground. While a small portion of the SO_2 and NO_x that cause acid rain is from natural sources such as volcanoes, most of it comes from the burning of fossil fuels.

KEYWORDS: acid rain, pollution, CO_2 , NO_x , carbonic acid, nitric acid, sulphuric acid, heavy metals, soil chemicals

The major sources of SO_2 and NO_x in the atmosphere are:

- Burning of fossil fuels to generate electricity. Two thirds of SO_2 and one fourth of NO_x in the atmosphere come from electric power generators.
- Vehicles and heavy equipment.
- Manufacturing, oil refineries and other industries.

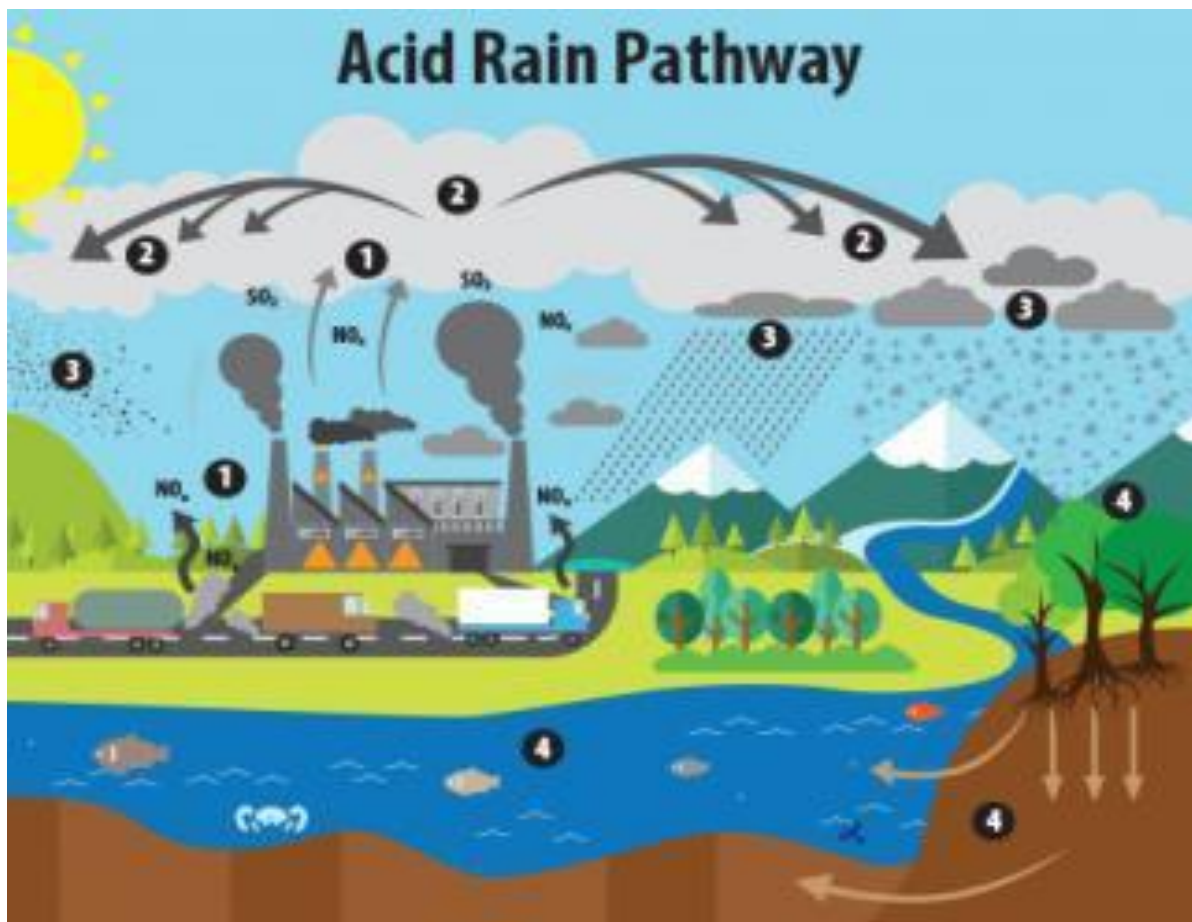
I. INTRODUCTION

Winds can blow SO_2 and NO_x over long distances and across borders making acid rain a problem for everyone and not just those who live close to these sources.

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This image illustrates the pathway for acid rain in our environment:

- (1) Emissions of SO_2 and NO_x are released into the air, where
- (2) The pollutants are transformed into acid particles that may be transported long distances.
- (3) These acid particles then fall to the earth as wet and dry deposition (dust, rain, snow, etc.) and
- (4) May cause harmful effects on soil, forests, streams, and lakes.

The term "acid rain" was coined in 1872 by Robert Angus Smith.[1] "Acid rain" is however a term referring to a mixture of deposited material from the atmosphere containing higher than normal amounts of nitric and sulfuric acids.[2] Any form of precipitation which is acidic in nature is called acid rain. The major human sources do come from the industry, transportation, and a variety of power plants. Strictly speaking these industrial amounts of nitrogen, sulfur oxides and general pollutants from the air cause a drastic increase of the acidity of the precipitation and do also harm plants, humans, and infrastructure.[3] The precursors, or chemical forerunners, of acid rain formation result from both natural sources, such as volcanoes and decaying vegetation, and man-made sources, primarily emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) resulting from fossil fuel combustion. SO_2 and NO_x come from electric power generation that relies on burning fossil fuels, like coal. 17th century by John Evelyn, who remarked upon the poor condition of the Arundel marbles.[4] Since the Industrial Revolution, emissions of sulfur dioxide and nitrogen oxides into the atmosphere have increased. In 1852, Robert Angus Smith was the first to show the relationship between acid rain and atmospheric pollution in Manchester, England. Canadian Harold Harvey was among the first to research a "dead" lake. Public awareness of acid rain in the U.S increased in the 1970s after The New York Times published

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reports from the Hubbard Brook Experimental Forest in New Hampshire of the myriad deleterious environmental effects shown to result from it. Acid rain occurs when these gases react in the atmosphere with water, oxygen, and other chemicals to form various acidic compounds.[5] Burning of fossil fuels in industries and transport sector, industrialization and urbanization have led to increase in concentrations of gaseous and particulate pollutants in the atmosphere leading to air pollution. Industrial acid rain is a substantial problem in China and Russia and areas downwind from them. These areas all burn sulfur-containing coal to generate heat and electricity. The problem of acid rain has not only increased with population and industrial growth, but has become more widespread. The use of tall smokestacks to reduce local pollution has contributed to the spread of acid rain by releasing gases into regional atmospheric circulation. [6] Fact is that air pollution affects both humans and the nature. Most obvious are the so-called direct effects on human health. Results of recent research show that small particles in the air caused more than 350,000 premature deaths within the countries of the European Union. Furthermore it has to be taken into consideration that there are also other air pollutants as well as indirect effects on nature and humans.[7] Those indirect effects include effects such as toxic groundwater and corrosion of materials. Many people use so-called blinds and/or marquees, also called Markisen in German, in order to protect for instance their terrace or patio from polluted air particles. Due to drastic air pollution and the worsening of the general air quality, the climate does also get affected. If the climate gets warmer it affects a human's health. A number of researchers fear that a warmer climate in the course of a general climate change may cause more extreme weather conditions. Strictly speaking this would also lead to more injuries and deaths being caused by hurricanes, flooding as well as to property damage. Another effect resulting from a warmer climate is the spread of a variety of insect transmitted diseases such as malaria and bilharzias.[8]

II. Chemistry Of Acid Rain $\text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g}) = \text{H}_2\text{CO}_3(\text{aq})$ Carbonic acid ionizes in water to form low concentrations of carbonate and hydronium ions.



Carbonic acid is a weak acid. It brings down the pH of the rainwater to 6.0-5.2. With pH levels ranging between 6.0-5.2, rainwater is acidic, but still not dangerous. This is a reversible reaction. Sometimes, the pH level can even become as low as 2. This phenomenon of acidic rainwater precipitation, is called acid rain. [9]

Rain, snow, sleet, freezing rain, hail, fog and dew are other forms of precipitation. Acid rain is a mild combination of mainly sulfuric and nitric acid. Sulfurous acid and nitrous acid are less stable and are present only in very low amounts. Sulfuric acid and nitric acid are the main acids present in acid rain. The problem occurs when rainwater combines with gaseous oxides of sulfur, nitrogen, and phosphoric and hydrochloric acid mists. The latter two and sulfur are released into the atmosphere from automobile exhausts, industries and electric power plants Sulfuric acid is formed as follows:

1. Sulfur released into the atmosphere combines with atmospheric oxygen to form sulfur dioxide (SO_2)
2. Sulfur dioxide reacts with atmospheric water to form sulfurous acid - $\text{SO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) = \text{H}_2\text{SO}_3(\text{aq})$ [10]
3. Sulfurous acid is also present in acid rain.
4. Sulfur dioxide gradually oxidizes to form sulfur trioxide (SO_3) - $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) = 2\text{SO}_3(\text{g})$
5. Sulfur trioxide reacts with water to form Sulfuric acid (H_2SO_4) - $\text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) = \text{H}_2\text{SO}_4(\text{aq})$ Nitrogen forms a major part of atmospheric composition.[11]

These chemicals bring down the acid rain pH level to 5.6-3.5. Nitrogen dioxide (NO_2) is formed as follows: 1. Nitrogen combines with atmospheric oxygen to form nitrogen dioxide (NO_2). 2. Nitrogen dioxide reacts with water to form nitrous acid (HNO_2) and nitric acid (HNO_3) - $2\text{NO}_2(\text{l}) + \text{H}_2\text{O}(\text{l}) = \text{HNO}_2(\text{aq}) + \text{HNO}_3(\text{aq})$. [12]

II. OBSERVATIONS

Types of Deposition

Wet Deposition- 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

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water flows over and through the ground, it affects a variety of plants and animals. The strength of the effects depends on several factors, including how acidic the water is; the chemistry and buffering capacity of the soils involved; and the types of fish, trees, and other living things that rely on the water. The process of wet deposition of acidic compounds. In particular, acidic deposition has adverse effects on vegetation. This is mainly due to soil acidification and the uptake of substances, which disturb the pH levels within plant cells that may lead to the evolution of reactive radicals . [13]

Dry Deposition- 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. This runoff water makes the resulting mixture more acidic. About half of the acidity in the atmosphere falls back to earth through dry deposition. The incremental effects of wet and dry deposition on carbonate stone erosion due to hydrogen ion, SO_2 and NO_x were quantified . 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. The results suggested that approximately 30% of erosion by dissolution could be attributed to the wet deposition of hydrogen ion and the dry deposition of SO_2 and HNO_3 . [14]

Adverse effects of acid rain

Following are the various adverse effects of acid rain on living organisms and infrastructure.

Buildings and Monuments: Acid rain causes severe damage to buildings and marble statues. Acid rain reacts with the calcium carbonate (CaCO_3) to form soluble calcium hydrogen carbonate or calcium bicarbonate, Calcium bicarbonate is a powdery substance, which is easily washed away with water or more specifically, rainwater. This is the way acid rain has partly eroded many world-famous monuments and buildings like the Taj Mahal in India, St. Paul's Cathedral in London, and the Statue of Liberty in New York. High buildings made of concrete in urban areas have damaged due to exposure to cloud water with high acidity for a long time . Acid precipitations with pH level ranging between 3.0 and 5.0 have affected the cement and concrete . [15]

Delhi Red fort and Jama Masjid are also showing signs of damage from sulphur pollution . Acid rain can destroy stained glass windows in churches, bridges made of steel, and railway tracks. It corrodes metal, ruins the paint color, weakens leather and forms a crust on glass surfaces.



Trees and Plants: Other plants can also be damaged by acid rain, but the effect on food crops is minimized by the application of lime and fertilizers to replace lost nutrients. In cultivated areas, limestone may also be added to increase the ability of the soil to keep the pH stable, but this tactic is largely unusable in the case of wilderness lands. When calcium is leached from the needles of red spruce, these trees become less cold tolerant and exhibit winter injury and even death. Acid rain washes away important minerals from leaves and soil. Acid rain also blocks the small pores on the leaves' surface, through which they take in carbon dioxide. With improper functioning of leaves, the growth of trees gets retarded. This results in a loss of leaves, stunted growth and damaged bark. Such trees are more prone to attacks by fungi and insects. This can even result in the death of trees. Soil contains many harmful minerals such as mercury and aluminum. These elements can't be absorbed by plants and trees and are thus harmless. Upon contact with acid rain, these chemicals undergo chemical reactions with the acids. Soil chemistry can be dramatically changed when base cations, such as calcium and magnesium, are leached by acid rain thereby affecting sensitive species, such as sugar maple (*Acer saccharum*). [16] As a result, compounds of aluminum, lead and mercury are formed. Plants and trees can easily absorb these compounds. Such elements, which are extremely harmful to living forms, ultimately affect the entire food chain. These chemicals not only harm the flora, but also the animals that feed on them. Soil biology and chemistry can be seriously damaged by acid rain. Some microbes are unable to tolerate changes to low pH and are killed. The enzymes of these microbes are denatured (changed in shape so they no longer function) by the acid. The hydronium ions of acid rain also mobilize toxins such as aluminium, and leach away essential nutrients and minerals such as magnesium. [17]

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Water Bodies: Harmful substances like aluminum, lead and mercury, are washed away from the soil to neighboring water resources by the acid rain, thus resulting in water pollution. These chemicals and their acids do not allow the flora and fauna to grow and reproduce. This also results in depletion of oxygen levels in water, thereby making it difficult for fish to respire. They die due to suffocation and poisoning caused by the presence of these chemicals. Birds that feed on fish that are affected by these harmful chemicals, accumulate these elements in their systems. These chemicals are then passed on to animals that feed on such birds. In this manner, chemicals get introduced to each trophic level of the food chain. In each trophic level, the concentration of chemicals gets multiplied. This phenomenon is known as biomagnification.[18]

Human Health: Acid rain looks, feels, and tastes just like clean rain. The harm to people from acid rain is not direct. The acid in the rainwater is too dilute to have direct adverse effects. However, the particulates responsible for acid rain (sulfur dioxide and nitrogen oxides) do have an adverse effect. Increased amounts of fine particulate matter in the air do contribute to heart and lung problems including asthma and bronchitis. 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 (SO₂) and nitrogen oxides (NO_x)—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. Acids are very small and fine particles. They are normally in a liquid state. When they are present in the atmosphere, they easily enter the lungs while breathing. Research has proven that these particles can even lead to cancer. SO₂ causes more adverse impact to human health in gas and aerosol forms. Concentrations above 1.6 ppm breathing becomes detectable more difficult and eye irritation increases SO₂ is much more toxic and damaging when combined with aerosols, and mists, and suspended smoke, because these mixture of chemicals form finer suspensions that penetrate the lungs further than the gas alone. In Tokyo the polluted drizzle droplets were resulted into eye and skin irritation.[19]

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. Based on health concerns, SO₂ and NO_x have historically been regulated under the Clean Air Act, including the Acid Rain Program. Decreases in NO_x emissions are also expected to have a beneficial impact on human health by reducing the nitrogen oxides available to react with volatile organic compounds and form ozone. Ozone impacts on human health include a number of morbidity and mortality risks associated with lung inflammation, including asthma and emphysema. Acid rain is harmful to human health.[20]

Table-1: Effects of Acid Rain on Water Ecosystems

As water becomes more acidic and its pH approaches	Effects of acid rain on water ecosystems
5.0	Major changes in the make-up of the plankton community occur. Less desirable species of mosses and plankton may begin to invade. The progressive loss of some fish populations is likely.
6.0	Crustaceans, insects and some plankton species begin to disappear

Table 2: Preferred pH tolerance for some freshwater organisms

Organisms	pH tolerance
Fish	
Flathead minnow	6.5
Pumpkinseed sunfish	5.5 to 6.5
Smallmouth bass	6.0 to 6.5
Brown trout	5.5 to 6.5
Rainbow trout	6.0 to 5.5

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Brook trout	5.5 to 6.5
Yellow perch	5.5 to 6.5
Frog & toad embryos	
American toads	5.0 to 6.5
Bullfrog	5.0 to 6.5
Woodfrog	4.5 to 6.5
Others	
Clam (some species)	6.5
Cray fish	6.0 to 6.5
Snail	6.5
Spotted salamander embryo	5.5 to 6.5

As water becomes more acidic and its pH approaches Effects of acid rain on water ecosystems. Major changes in the make-up of the plankton community occur. Less desirable species of mosses and plankton may begin to invade. The progressive loss of some fish populations is likely. Less than pH 5.0 The water is largely devoid of fish. The bottom is covered with undecayed material. The near shore areas may be dominated by mosses. Terrestrial animals, dependent on aquatic ecosystems, are affected. Waterfowl, for example, depend on aquatic organisms for nourishment and nutrients. As these food sources are reduced or eliminated, the sustainability quality of habitat declines and the reproductive success of birds is affected. Crustaceans, insects and some plankton species begin to disappear.[21]

Acid rain is potent enough to destroy life on Earth. It damages anything it comes in contact with. It ruins forests, water bodies, soil, infrastructure, and the health of living beings. It's high time we take all possible measures to control it. There is a solution to every problem, and acid rain is no exception. Take a look at the various measures we can take. Human beings should reduce the use of fossil fuels. This would lessen the emission of nitrogen and sulfur in the environment. Public transportation, car pools and walking can reduce nitrogen, sulfur and lead emissions into the atmosphere. Sulfur and nitrogen are mostly released into the atmosphere from the burning of fossil fuels (e.g. Coal). Switching over to alternative forms of energy such as geothermal, water, wind, and solar power would help to a great extent. All the above measures are simple steps that can easily be adopted on an individual level. Acid rain has become an international issue because of its serious and definite danger to life on earth. Many international treaties have been signed i.e. the Sulfur Emissions Reduction Protocol and the Convention on Long-Range Transboundary Air Pollution. Installing Flue Gas Desulfurization e.g. wet scrubber in coal-burning power plants to remove sulfur-containing gases - is one of the steps taken by the USA, and is followed by a number of developed and developing countries[22]

Acid rain can be neutralized by reaction with calcium (Ca) and magnesium (Mg) compounds in soil. Limestone (CaCO₃). A substance common in soil, neutralizes acids when H⁺ ions replace calcium-producing Ca²⁺ ions. Deep soils rich in metallic compounds have a greater capacity to neutralize acid rain than shallow soil or soil composed of non-metals do. If the acid rain is not neutralized, the acid percolates into the ground or flows into lakes and streams. Changes in the pH of water have damaging effects on aquatic life, including micro organisms, plants and animals living in the lakes. All aquatic organisms have pH tolerance of range they live within see Table-2. They can soon die in water outside their tolerance. Some organisms appear to be more tolerant of acidic environments than others, and some adult organisms may be more tolerant than their eggs and embryos[23]

Forms of Acid Deposition

Wet form of Deposition

Wet deposition is what we most commonly think of as *acid rain*. The sulfuric and nitric acids formed in the atmosphere fall to the ground mixed with rain, snow, fog, or hail.

Dry form of Deposition

Acidic particles and gases can also deposit from the atmosphere in the absence of moisture as *dry deposition*. The acidic particles and gases may deposit to surfaces (water bodies, vegetation, buildings) quickly or may react during

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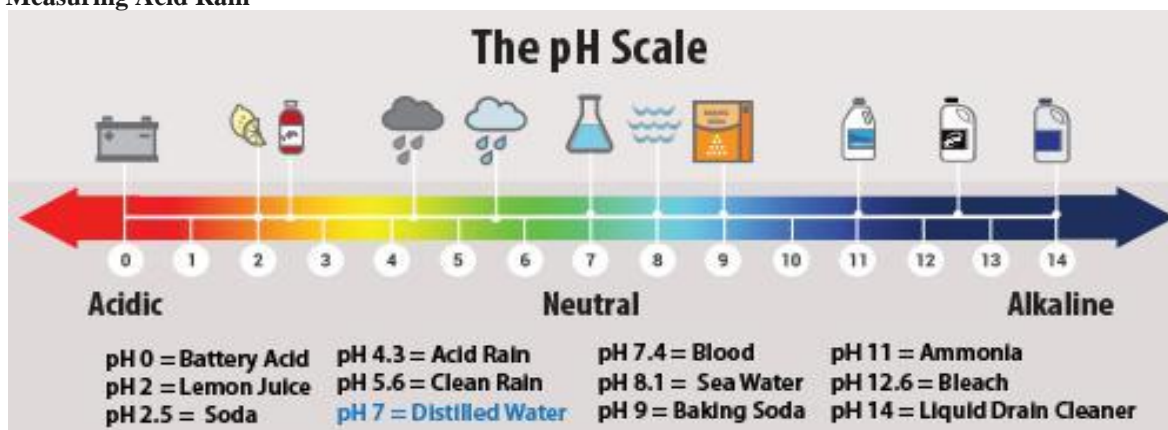
atmospheric transport to form larger particles that can be harmful to human health. When the accumulated acids are washed off a surface by the next rain, this acidic water flows over and through the ground, and can harm plants and wildlife, such as insects and fish.[24]

The amount of acidity in the atmosphere that deposits to earth through dry deposition depends on the amount of rainfall an area receives. For example, in desert areas the ratio of dry to wet deposition is higher than an area that receives several inches of rain each year.

Acid rain can be neutralized by reaction with calcium (Ca) and magnesium (Mg) compounds in soil. Limestone (CaCO₃). A substance common in soil, neutralizes acids when H⁺ ions replace calcium-producing Ca²⁺ ions. Deep soils rich in metallic compounds have a greater capacity to neutralize acid rain than shallow soil or soil composed of non-metals do. If the acid rain is not neutralized, the acid percolates into the ground or flows into lakes and streams. Changes in the pH of water have damaging effects on aquatic life, including micro organisms, plants and animals living in the lakes. All aquatic organisms have pH tolerance of range they live within in table. They can soon die in water outside their tolerance. Some organisms appear to be more tolerant of acidic environments than others, and some adult organisms may be more tolerant than their eggs and embryos[25]

The ecological effects of acid rain are most clearly seen in the aquatic, or water, environments, such as streams, lakes, and marshes. Acid rain flows into streams, lakes, and marshes after falling on forests, fields, buildings, and roads. Acid rain also falls directly on aquatic habitats. Acid rain affects each and every components of ecosystem. Acid rain also damages man-made materials and structures. Acid rain is one of the most serious environmental problems emerged due to air pollution Sulphur dioxide (SO₂) and oxides of nitrogen and ozone to some extent are the primary causes of acid rain. These pollutants originate from human activities such as combustion of burnable waste, fossil fuels in thermal power plants and automobiles. These constituents interact with reactants present in the atmosphere and result into acid deposition. Due to the interaction of these acids with other constituents of the atmosphere, protons are released causing increase in the soil acidity, lowering of soil pH mobilizes and leaches away nutrient cations and increases availability of toxic heavy metals. As acid rain flows through soils in a watershed, aluminum is released from soils into the lakes and streams located in that watershed. So, as pH in a lake or stream decreases, aluminum levels increase. Both low pH and increased aluminum levels are directly toxic to fish. In addition, low pH and increased aluminum levels cause chronic stress that may not kill individual fish, but leads to lower body weight and smaller size and makes fish less able to compete for food and habitat. Acid rain causes a cascade of effects that harm or kill individual fish, reduce fish population numbers, completely eliminate fish species from a water body, and decrease biodiversity. These mobilized contaminants are dissolved in soil and water make their way to groundwater that is drunk by humans and contaminate the food (Fish, meat, and vegetables) eaten by humans. These heavy metals get accumulated in the body and resulted into various health problems like dry coughs, asthma, headache, eye, nose and throat irritations.[26]

Measuring Acid Rain



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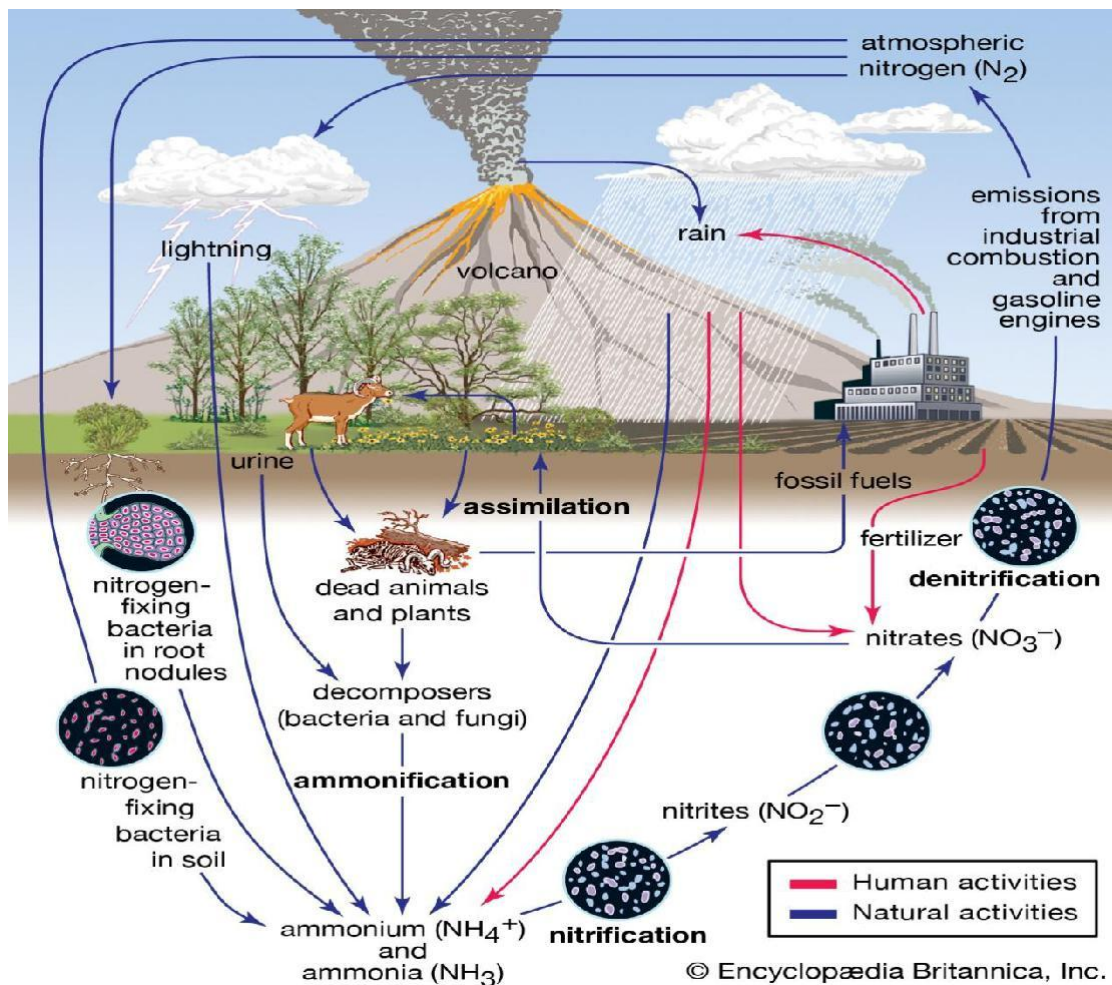
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Acidity and alkalinity are measured using a pH scale for which 7.0 is neutral. The lower a substance's pH (less than 7), the more acidic it is; the higher a substance's pH (greater than 7), the more alkaline it is. Normal rain has a pH of about 5.6; it is slightly acidic because carbon dioxide (CO₂) dissolves into it forming weak carbonic acid. Acid rain usually has a pH between 4.2 and 4.4.

Policymakers, research scientists, ecologists, and modelers rely on the National Atmospheric Deposition Program's (NADP) National Trends Network (NTN) for measurements of wet deposition. The NADP/NTN collects acid rain at more than 250 monitoring sites throughout the US, Canada, Alaska, Hawaii and the US Virgin Islands. Unlike wet deposition, dry deposition is difficult and expensive to measure. Dry deposition estimates for nitrogen and sulfur pollutants are provided by the Clean Air Status and Trends Network (CASTNET). Air concentrations are measured by CASTNET at more than 90 locations. When acid deposition is washed into lakes and streams, it can cause some to turn acidic. The Long-Term Monitoring (LTM) Network measures and monitors surface water chemistry at over 280 sites to provide valuable information on aquatic ecosystem health and how water bodies respond to changes in acid-causing emissions and acid deposition.[27]

III. RESULTS



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An ecosystem is a community of plants, animals and other organisms along with their environment including the air, water and soil. Everything in an ecosystem is connected. If something harms one part of an ecosystem – one species of plant or animal, the soil or the water – it can have an impact on everything else. The ecological effects of acid rain are most clearly seen in aquatic environments, such as streams, lakes, and marshes where it can be harmful to fish and other wildlife. As it flows through the soil, acidic rain water can leach aluminum from soil clay particles and then flow into streams and lakes. The more acid that is introduced to the ecosystem, the more aluminum is released.

Some types of plants and animals are able to tolerate acidic waters and moderate amounts of aluminum. Others, however, are acid-sensitive and will be lost as the pH declines. Generally, the young of most species are more sensitive to environmental conditions than adults. At pH 5, most fish eggs cannot hatch. At lower pH levels, some adult fish die. Some acidic lakes have no fish. Even if a species of fish or animal can tolerate moderately acidic water, the animals or plants it eats might not. For example, frogs have a critical pH around 4, but the mayflies they eat are more sensitive and may not survive pH below 5.5.[28]

Dead or dying trees are a common sight in areas effected by acid rain. Acid rain leaches aluminum from the soil. That aluminum may be harmful to plants as well as animals. Acid rain also removes minerals and nutrients from the soil that trees need to grow.

At high elevations, acidic fog and clouds might strip nutrients from trees' foliage, leaving them with brown or dead leaves and needles. The trees are then less able to absorb sunlight, which makes them weak and less able to withstand freezing temperatures.

Many forests, streams, and lakes that experience acid rain don't suffer effects because the soil in those areas can **buffer** the acid rain by neutralizing the acidity in the rainwater flowing through it. This capacity depends on the thickness and composition of the soil and the type of bedrock underneath it. In areas such as mountainous parts of the Northeast United States, the soil is thin and lacks the ability to adequately neutralize the acid in the rain water. As a result, these areas are particularly vulnerable and the acid and aluminum can accumulate in the soil, streams, or lakes.

Melting snow and heavy rain downpours can result in what is known as episodic acidification. Lakes that do not normally have a high level of acidity may temporarily experience effects of acid rain when the melting snow or downpour brings greater amounts of acidic deposition and the soil can't buffer it. This short duration of higher acidity (i.e., lower pH) can result in a short-term stress on the ecosystem where a variety of organisms or species may be injured or killed.

It's not just the acidity of acid rain that can cause problems. Acid rain also contains nitrogen, and this can have an impact on some ecosystems. For example, nitrogen pollution in our coastal waters is partially responsible for declining fish and shellfish populations in some areas. In addition to agriculture and wastewater, much of the nitrogen produced by human activity that reaches coastal waters comes from the atmosphere.[29]

Not all acidic deposition is *wet*. Sometimes dust particles can become acidic as well, and this is called **dry deposition**. When acid rain and dry acidic particles fall to earth, the nitric and sulfuric acid that make the particles acidic can land on statues, buildings, and other manmade structures, and damage their surfaces. The acidic particles corrode metal and cause paint and stone to deteriorate more quickly. They also dirty the surfaces of buildings and other structures such as monuments.

IV. CONCLUSION

The consequences of this damage can be costly:

- damaged materials that need to be repaired or replaced,
- increased maintenance costs, and
- loss of detail on stone and metal statues, monuments and tombstones.

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In the atmosphere, SO₂ and NO_x gases can be transformed into sulfate and nitrate particles, while some NO_x can also react with other pollutants to form ozone. These particles and ozone make the air hazy and difficult to see through. This affects our enjoyment of national parks that we visit for the scenic view such as Shenandoah and the Great Smoky Mountains.

Walking in acid rain, or even swimming in a lake affected by acid rain, is no more dangerous to humans than walking in normal rain or swimming in non-acidic lakes. However, when the pollutants that cause acid rain —SO₂ and NO_x, as well as sulfate and nitrate particles— are in the air, they can be harmful to humans.

SO₂ and NO_x react in the atmosphere to form fine sulfate and nitrate particles that people can inhale into their lungs. Many scientific studies have shown a relationship between these particles and effects on heart function, such as heart attacks resulting in death for people with increased heart disease risk, and effects on lung function, such as breathing difficulties for people with asthma.[30]

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