Semester IV

GEO-A-CC-4-10-TH- Soil and Biogeography

-by Srabani Mitra

Topic:Bio-geochemical Cycles:-

The term biogeochemical is derived from **“bio”** meaning **biosphere**, **“geo”** meaning the **geological components** and “**chemical**” meaning the **elements that move through a cycle**. Energy flows directionally through ecosystems, entering as sunlight (or inorganic molecules for chemoautotrophs) and leaving as heat during energy transformation between trophic levels. Rather than flowing through an ecosystem, the matter that makes up organisms is conserved and recycled. The six most common elements associated with organic molecules—carbon, nitrogen, hydrogen, oxygen, phosphorus, and sulfur—take a variety of chemical forms and may exist for long periods in the atmosphere, on land, in water, or beneath Earth’s surface. Geologic processes, such as weathering, erosion, water drainage, and the subduction of the continental plates, all play a role in the cycling of elements on Earth. Because geology and chemistry have major roles in the study of these processes, the recycling of inorganic matter between living organisms and their nonliving environment are called **biogeochemical cycles**. Unlike the one-way flow of energy, matter is recycled within and between ecosystems. Elements, chemical compounds, and other forms of matter are passed from one organism to another and from one part of the biosphere to another through cycles that connect living things to the earth.

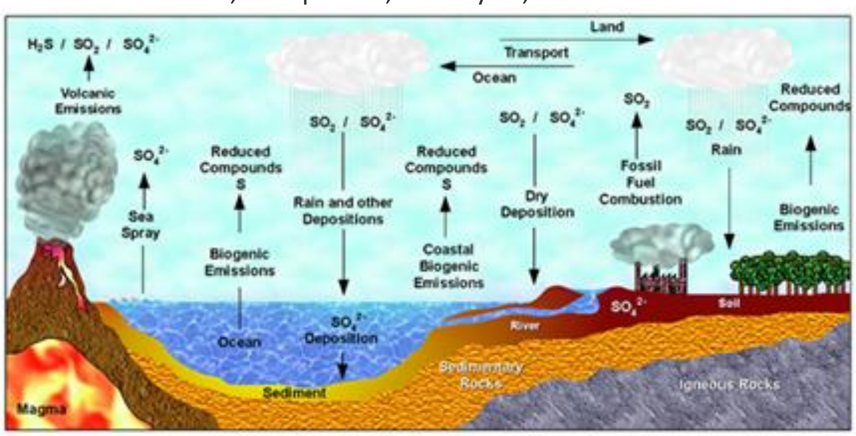
“Biogeochemical cycles mainly refer to the movement of nutrients and other elements between biotic and abiotic factors.”

Types of Biogeochemical Cycles

Biogeochemical cycles are basically divided into two types:

Gaseous cycles – Includes Carbon, Oxygen, Nitrogen, and the Water cycle.

Sedimentary cycles – Includes Sulfur, Phosphorus, Rock cycle, etc.



The Carbon Cycle

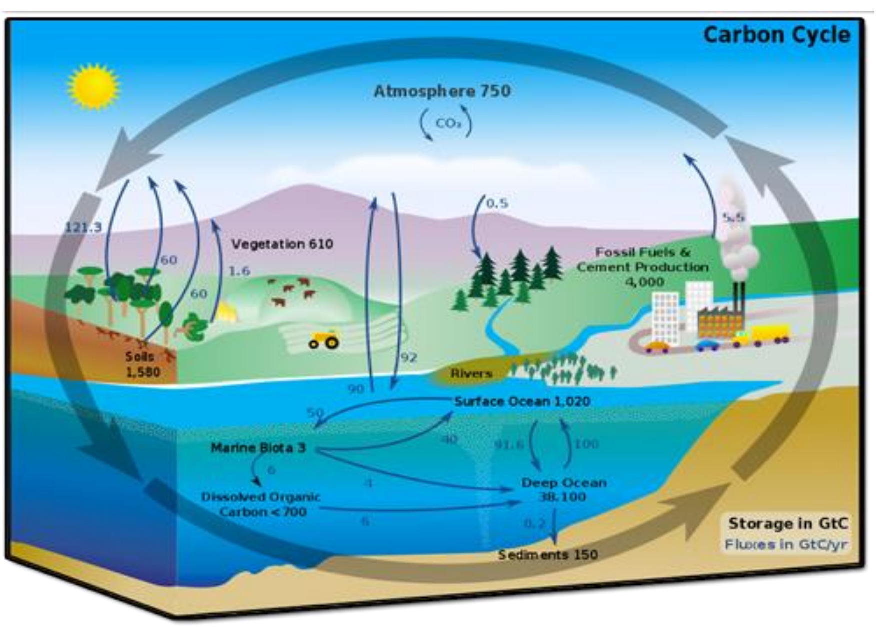
Carbon is the second most abundant element in organisms, by mass. Carbon is present in all organic molecules (and some molecules that are not organic such as CO_2), and its role in the structure of biomolecules is of primary importance. Carbon compounds contain energy, and many of these compounds from dead plants and algae have fossilized over millions of years and are known as fossil fuels. Since the 1800s, the use of fossil fuels has accelerated. Since the beginning of the Industrial

Revolution the demand for Earth's limited fossil fuel supplies has risen, causing the amount of carbon dioxide in our atmosphere to drastically increase. This increase in carbon dioxide is associated with climate change and is a major environmental concern worldwide.
The Earth's atmosphere contains carbon in the form of carbon dioxide (CO^2). There are five major reservoirs of carbon:

- the atmosphere
- the terrestrial biosphere
- oceans
- ocean sediments and
- the earth's interior

Processes of the Carbon Cycle:

Photosynthesis: During photosynthesis, plants and other autotrophs use CO^2 along with water and solar energy, to build organic molecules (carbohydrates), thus storing the carbon for themselves and other organisms.
Cellular Respiration: Both autotrophs and heterotrophs use oxygen to break down carbohydrates during cellular respiration. Consumers obtain energy-rich molecules that contain carbon by eating plants and animals.
Volcanic Eruptions and geothermal vents: carbon from deep within the earth's interior is brought back to the surface during eruptions of steam, gasses and lava.
Decomposition: Carbon is returned to the environment through decomposers and cellular respiration (breathing releases CO_2 back to the atmosphere).
Combustion: When wood or fossil fuels are burned, the chemical reaction releases carbon dioxide back into the atmosphere.
Deposition: Coal, petroleum, and calcium carbonate rock are deposited in sediment and underground. Calcium carbonate deposits are eroded by water to form carbon dioxide. Large amounts of carbon are tied up in wood, only returning to the atmosphere when wood is burned.



The black numbers in the image above indicate how much carbon is stored in various reservoirs, in billions of tons. The dark blue numbers indicate how much carbon moves between reservoirs each year. The **carbon cycle** is most easily studied as two interconnected sub-cycles: one dealing with rapid carbon exchange among living organisms and the other dealing with the long-term cycling of carbon through geologic processes.

Carbon dioxide gas exists in the atmosphere and is dissolved in water. Photosynthesis converts carbon dioxide gas to organic carbon, and respiration cycles the organic carbon back into carbon dioxide gas. Long-term storage of organic carbon occurs when matter from living organisms is buried deep underground and becomes fossilized. Volcanic activity and, more recently, human emissions bring this stored carbon back into the carbon cycle.

The Oxygen Cycle

As we all know, air is a mixture of gases. The air in the atmosphere is composed of different gases, namely nitrogen (78%), oxygen (21%), argon and other trace gases ((1%).According to Earth's history, oxygen gas was first introduced by cyanobacteria through the process of photosynthesis. Earlier, around 4.6 billion years ago, there was no life on planet earth because the atmosphere was devoid of oxygen. Later, there was a gradual increase in the oxygen levels and by the Carboniferous Period- 299 million years ago, oxygen reached the levels that were similar to today's estimates.

Today, oxygen is freely available in the air, and also dissolved in water. It is the second most abundant gas present in the atmosphere and also the most common element of the human body. It plays an essential role in most life forms on Earth and also serves as an essential element in biomolecules like proteins, and nucleic acids.

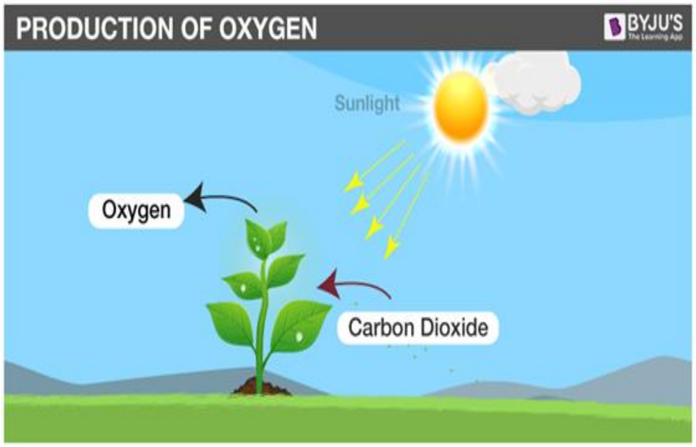
The oxygen cycle is a biological process which helps in maintaining the oxygen level by moving through three main spheres of the earth which are:

- Atmosphere
- Lithosphere
- Biosphere.

Production of Oxygen

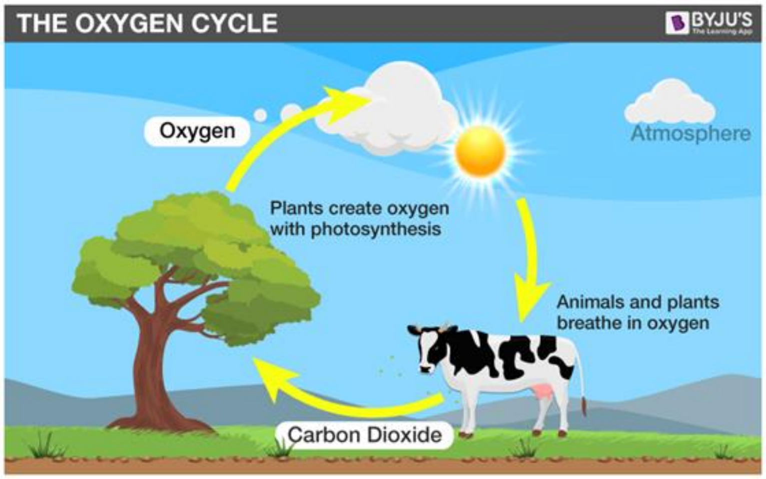
Plants: The leading creators of oxygen are plants by the process of photosynthesis. Photosynthesis is a biological process by which all green plants synthesize their food in the presence of sunlight. During photosynthesis, plants use sunlight, water, carbon dioxide to create energy and oxygen gas is liberated as a by-product of this process.

Sunlight: Sunlight also produces oxygen. Some oxygen gas is produced when the sunlight reacts with water vapor in the atmosphere.



Stages of the Oxygen Cycle

The steps involved in the oxygen cycle are:
Stage-1: All green plants during the process of photosynthesis, release oxygen back into the atmosphere as a by-product.
Stage-2: All aerobic organisms use free oxygen for respiration.
Stage-3: Animals exhale Carbon dioxide back into the atmosphere which is again used by the plants during photosynthesis. Now oxygen is balanced within the atmosphere.



Importance of Oxygen Cycle

As we all know, Oxygen is one of the most essential components of the Earth's atmosphere. It is mainly required for:

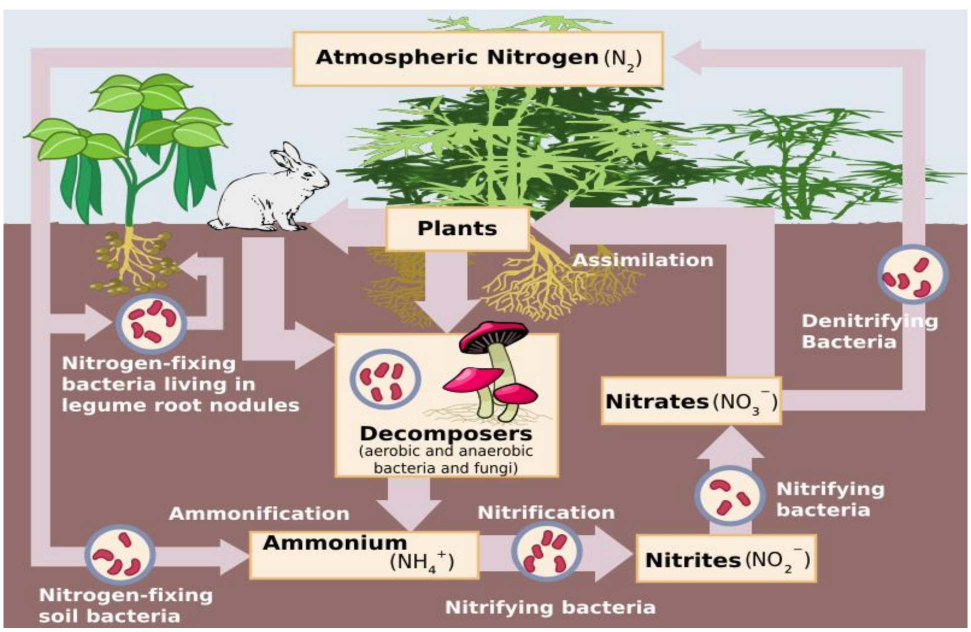
- Breathing
- Combustion
- Supports aquatic life
- Decomposition of organic waste.

Oxygen is an important element required for life. The oxygen cycle is mainly involved in maintaining the level of oxygen in the atmosphere. The entire cycle can be summarized as, the oxygen cycle begins with the process of photosynthesis in the presence of sunlight, releases oxygen back into the atmosphere, which humans and animals breathe in oxygen and breathe out carbon dioxide, and again linking back to the plants.

The Nitrogen Cycle

Getting nitrogen into living organisms is difficult. Plants and phytoplankton are not equipped to incorporate nitrogen from the atmosphere (where it exists as tightly bonded, triple covalent N_2) even though this molecule comprises approximately 78 percent of the atmosphere. Nitrogen enters the living world through free-living and symbiotic bacteria, which incorporate nitrogen into their organic molecules through specialized biochemical processes. Certain species of bacteria are able to perform **nitrogen fixation**, the process of converting nitrogen gas into ammonia (NH_3), which spontaneously becomes ammonium (NH_4^+). Ammonium is converted by bacteria into nitrites (NO_2^-) and then nitrates (NO_3^-). At this point, the nitrogen-containing molecules are used by plants and other producers to make organic molecules such as DNA and proteins. This nitrogen is now available to consumers.

Processes of the Nitrogen Cycle:
Nitrogen fixation is the conversion of nitrogen gas to ammonia; Ammonia can be absorbed by plants from the soil, and used to make proteins, and enter the food web for consumers.
Assimilation: Consumers obtain nitrogen from the plants and animals they eat by digesting the food's proteins and using it to make their own proteins.



Ammonification: Decomposers return the nitrogen from the remains of dead plants and animals back to the soil. Nitrogen is also returned from animal and plant waste by decomposers (dung, urine, leaves and bark).Through ammonification, nitrogen that would be lost, is recycled back into the ecosystem.

Denitrification occurs when anaerobic bacteria (chemoautotrophs) break down nitrates and release nitrogen gas back into the atmosphere.
Nitrification: Bacteria convert ammonia into nitrogen compounds that plants can utilize more easily Autotrophs (plants) are therefore DEPENDENT on nitrogen-fixing bacteria, and all other organisms are DEPENDENT on autotrophs.

Importance of Nitrogen Cycle

1. All organisms need nitrogen, an important nutrient, to make proteins and nucleic acids.
2. Most nitrogen is found in the atmosphere (80%) as N_2, and most living things cannot use it. ALL organisms rely on the actions of bacteria that are able to transform nitrogen gas into a usable form.
3. Nitrogen-fixing bacteria (Cyanobacteria and Rhizobium) play a key role in the nitrogen cycle. They live in the soil and in the roots of some kinds of plants, such as beans, peas, clover, and alfalfa. These bacteria have enzymes that can break the atmospheric N_2 bonds. Nitrogen atoms are then free to bond with hydrogen atoms to form Ammonia (NH^3).

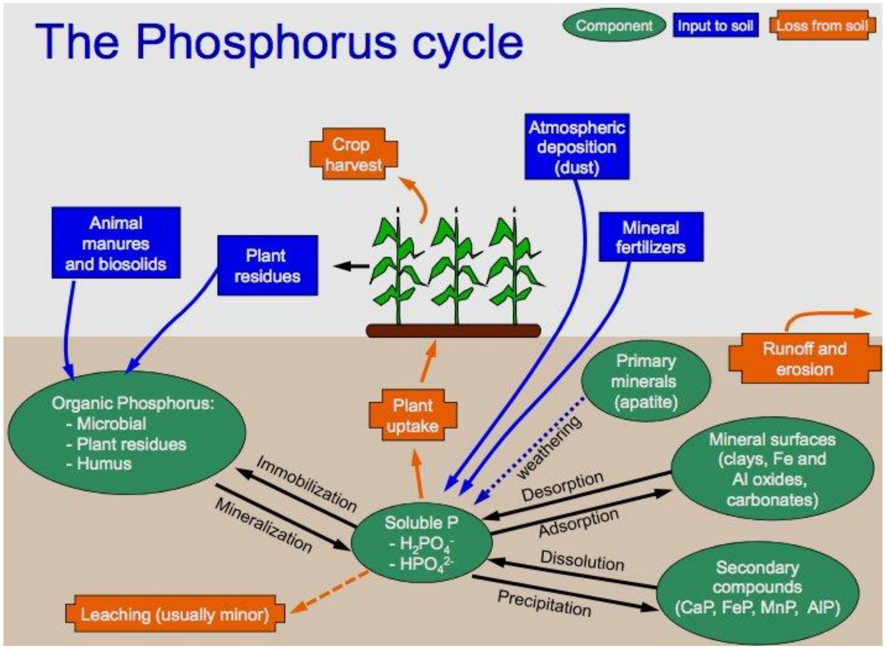
Human activity can alter the nitrogen cycle by two primary means: the combustion of fossil fuels, which releases different nitrogen oxides, and by the use of artificial fertilizers (which contain nitrogen and phosphorus compounds) in agriculture, which are then washed into lakes, streams, and rivers by surface runoff. Atmospheric nitrogen (other than N_2) is associated with several effects on Earth's ecosystems including the production of acid rain (as nitric acid, HNO_3) and greenhouse gas effects (as nitrous oxide, N_2O), potentially causing climate change. A major effect from fertilizer runoff is saltwater and freshwater **eutrophication**, a process whereby nutrient runoff causes the overgrowth of algae, the depletion of oxygen, and death of aquatic fauna.

In marine ecosystems, nitrogen compounds created by bacteria, or through decomposition, collects in ocean floor sediments. It can then be moved to land in geologic time by uplift of Earth's crust and thereby incorporated into terrestrial rock. Although the movement of nitrogen from rock directly into living systems has been traditionally seen as insignificant compared with nitrogen fixed from the atmosphere.

The Phosphorus Cycle

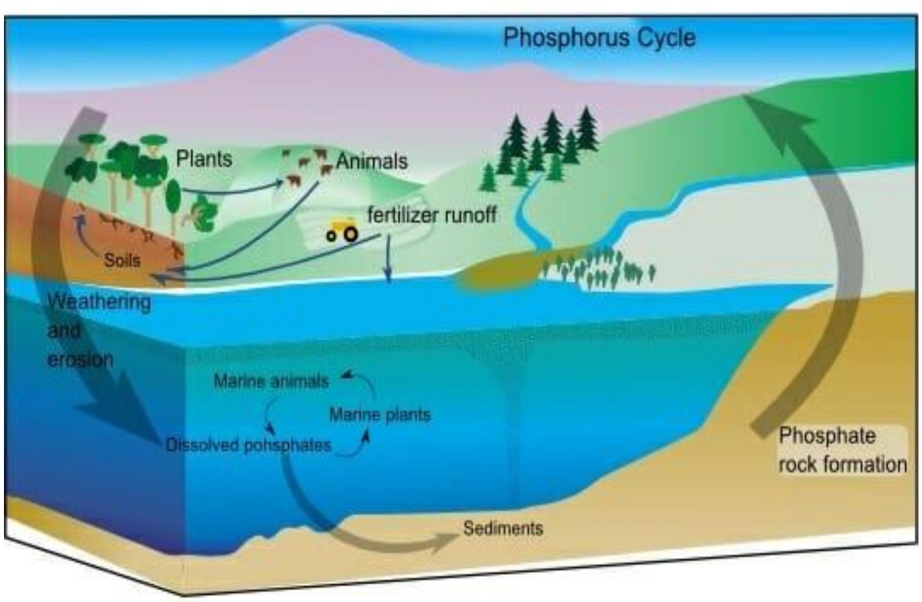
Phosphorus is an essential nutrient for living processes. It is a major component of nucleic acids and phospholipids, and, as calcium phosphate, it makes up the supportive components of our bones. Phosphorus is often the limiting nutrient (necessary for growth) in aquatic, particularly freshwater, ecosystems.

Phosphorus occurs in nature as the phosphate ion (PO_4^{3-}). In addition to phosphate runoff as a result of human activity, natural surface runoff occurs when it is leached from phosphate-containing rock by weathering, thus sending phosphates into rivers, lakes, and the ocean. This rock has its origins in the ocean. Phosphate-containing ocean sediments form primarily from the bodies of ocean organisms and from their excretions. However, volcanic ash, aerosols, and mineral dust may also be significant phosphate sources. This sediment then is moved to land over geologic time by the uplifting of Earth's surface.



Phosphorus is also reciprocally exchanged between phosphate dissolved in the ocean and marine organisms. The movement of phosphate from the ocean to the land and through the soil is extremely slow, with the average phosphate ion having an oceanic residence time between 20,000 and 100,000 years.

In nature, phosphorus exists as the phosphate ion (PO43-). Weathering of rocks and volcanic activity releases phosphate into the soil, water, and air, where it becomes available to terrestrial food webs. Phosphate enters the oceans in surface runoff, groundwater flow, and river flow. Phosphate dissolved in ocean water cycles into marine food webs. Some phosphate from the marine food webs falls to the ocean floor, where it forms sediment.

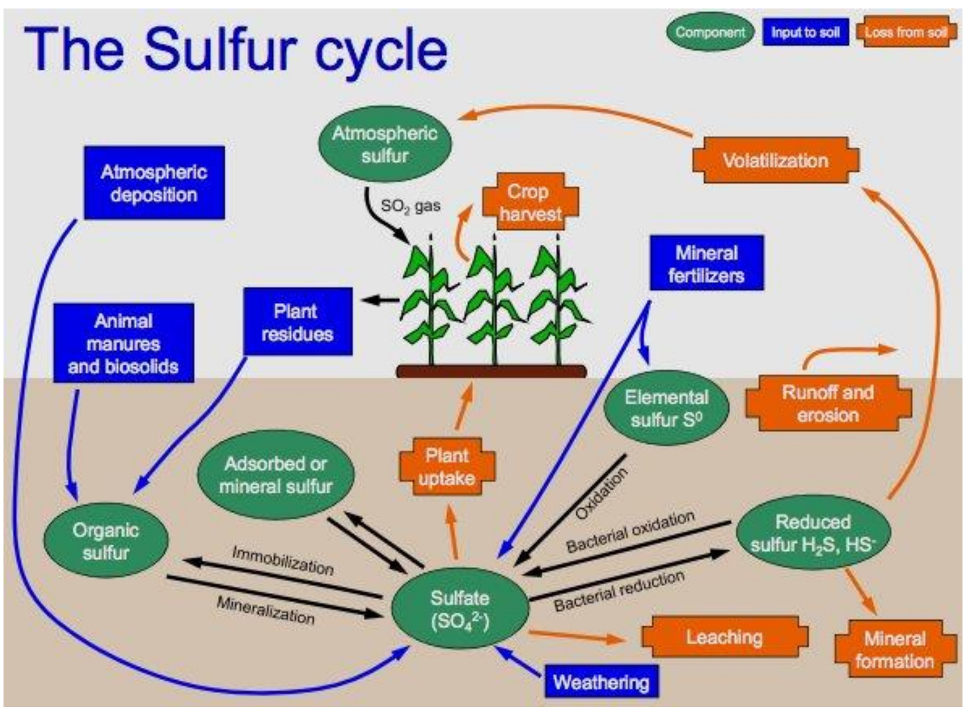


Excess phosphorus and nitrogen that enter these ecosystems from fertilizer runoff and from sewage cause excessive growth of algae. The subsequent death and decay of these organisms depletes dissolved oxygen, which leads to the death of aquatic organisms such as shellfish and fish. This process is responsible for dead zones in lakes and at the mouths of many major rivers and for massive fish kills, which often occur during the summer months. Dead zones occur when phosphorus and nitrogen from fertilizers cause excessive growth of microorganisms, which depletes oxygen and kills fauna. Worldwide, large dead zones are found in coastal areas of high population density.

The Sulfur Cycle

Sulfur is an essential element for the molecules of living things. As part of the amino acid cysteine, it is involved in the formation of proteins. Atmospheric sulfur is found in the form of sulfur dioxide (SO_2), which enters the atmosphere in three ways: first, from the decomposition of organic molecules; second, from volcanic activity and geothermal vents; and, third, from the burning of fossil fuels by humans.

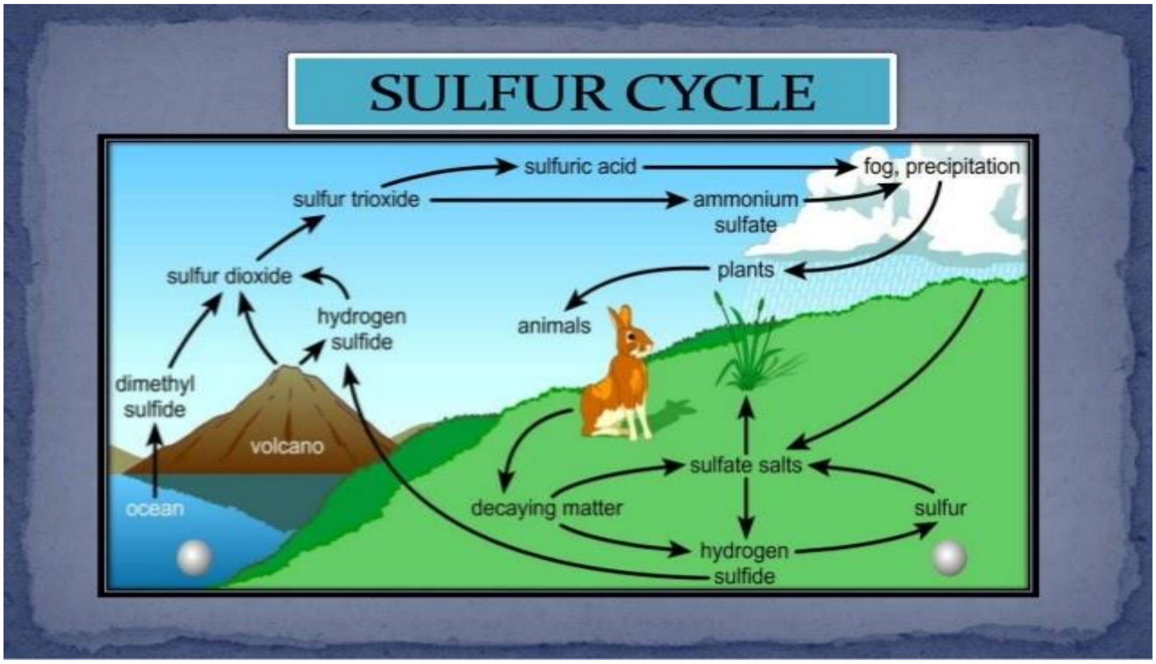
Sulfur dioxide from the atmosphere becomes available to terrestrial and marine ecosystems when it is dissolved in precipitation as weak sulfuric acid or when it falls directly to Earth as fallout. Weathering of rocks also makes sulfates available to terrestrial ecosystems. Decomposition of living organisms returns sulfates to the ocean, soil, and atmosphere.



On land, sulfur is deposited in four major ways: precipitation, direct fallout from the atmosphere, rock weathering, and geothermal vents. Atmospheric sulfur is found in the form of sulfur dioxide (SO_2), and as rain falls through the atmosphere, sulfur is dissolved in the form of weak sulfuric acid (H_2SO_4). Sulfur can also fall directly from the atmosphere in a process called fallout. Also, as sulfur-containing rocks weather, sulfur is released into the soil. These rocks originate from ocean sediments that are moved to land by the geologic uplifting of ocean sediments.

Terrestrial ecosystems can then make use of these soil sulfates (SO_4^{2-}), which enter the food web by being taken up by plant roots. When these plants decompose and die, sulfur is released back into the atmosphere as hydrogen sulfide (H_2S) gas.

Sulfur enters the ocean in runoff from land, from atmospheric fallout, and from underwater geothermal vents. Some ecosystems rely on chemoautotrophs using sulfur as a biological energy source. This sulfur then supports marine ecosystems in the form of sulfates.



Human activities have played a major role in altering the balance of the global sulfur cycle. The burning of large quantities of fossil fuels, especially from coal, releases larger amounts of hydrogen sulfide gas into the atmosphere. As rain falls through this gas, it creates the phenomenon known as acid rain, which damages the natural environment by lowering the pH of lakes, thus killing many of the resident plants and animals. **Acid rain** is corrosive rain caused by rainwater falling to the ground through sulfur dioxide gas, turning it into weak sulfuric acid, which causes damage to aquatic ecosystems. Acid rain also affects the man-made environment through the chemical degradation of buildings. For example, many marble monuments, such as the Lincoln Memorial in Washington, DC, have suffered significant damage from acid rain over the years. These examples show the wide-ranging effects of human activities on our environment and the challenges that remain for our future.