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Chapter 5
Topic – Biogeochemical cycles

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Biogeochemical cycles

"Biogeochemical cycles mainly refer to the movement of nutrients and other elements between biotic and abiotic factors."
The term biogeochemical is derived from **"bio"** meaning **biosphere**, **"geo"** meaning the **geological components** and "**chemical**" meaning the **elements that move through a cycle**.

The matter on Earth is conserved and present in the form of atoms. Since matter can neither be created nor destroyed, it is recycled in the earth's system in various forms.

The earth obtains energy from the sun which is radiated back as heat, rest all other elements are present in a closed system. The major elements include:

- Carbon
- Hydrogen
- Nitrogen
- Oxygen
- Phosphorus
- Sulphur

These elements are recycled through the biotic and abiotic components of the ecosystem. The atmosphere, hydrosphere and lithosphere are the abiotic components of the ecosystem.

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 Sulphur, Phosphorus, Rock cycle, etc.

Water Cycle

The water cycle, also known as the hydrologic cycle or the hydrological cycle, describes the continuous movement of water on, above and below the surface of the Earth.

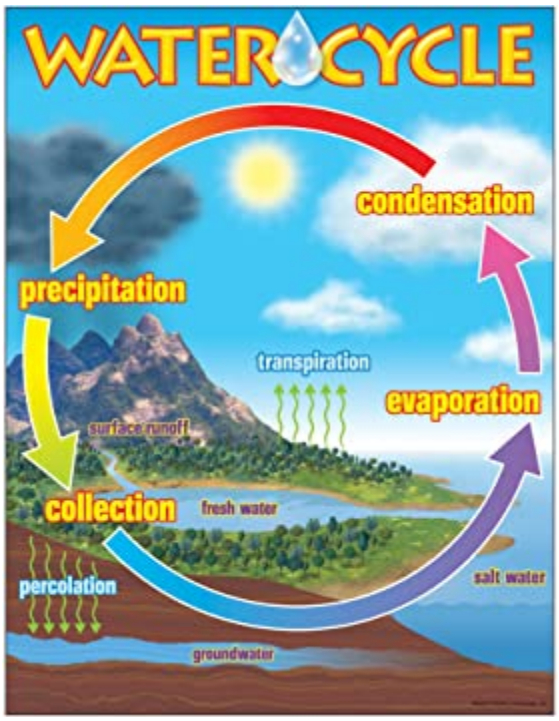
The water from the different water bodies evaporates, cools, condenses and falls back to the earth as rain.

During this process, water changes its state from one phase to another, but the total number of water particles remains the same. In other words, if it were possible to collect and boil 100 gms of water, it will still retain a mass of 100 gms as steam. Likewise, if 100 gms of steam is collected and condensed, the resultant water would still weight 100 gms.

Water changes its state through a variety of processes from evaporation, melting and freezing, to sublimation, condensation, and deposition. All these changes require the application of energy.

Stages of Water Cycle

There are many processes involved in the movement of water. Listed below are different stages of the water cycle.



1. Evaporation

The sun is the ultimate source of energy, and it powers most of the evaporation that occurs on earth. Evaporation generally happens when water molecules at the surface of water bodies become excited and rise into the air. These molecules with the highest kinetic energy accumulate into water vapour clouds. Evaporation usually takes place below the boiling point of water. Another process called evapotranspiration occurs when evaporation occurs through the leaves of plants. This process contributes to a large percentage of water in the atmosphere.

2. Sublimation

Sublimation occurs when snow or ice changes directly into water vapour without becoming water. It usually occurs as a result of dry winds and low humidity. Sublimation can be observed on mountain peaks, where the air pressure is quite low. The low air pressure helps to sublimate the snow into water vapour as less energy is utilised in the process. Another example of sublimation is the phase where fog bellows from dry ice. On earth, the primary source of sublimation is from the ice sheets covering the poles of the earth.

3. Condensation

The water vapour that accumulated in the atmosphere eventually cools down due to the low temperatures found at high altitudes. These vapours become tiny droplets of water and ice, eventually coming together to form clouds.

4. Precipitation

Above 0 degrees centigrade, the vapours will condense into water droplets. However, it cannot condense without dust or other impurities. Hence, water vapours attach itself on to the particle's surface. When enough droplets merge, it falls out of the clouds and on to the ground below. This process is called precipitation (or rainfall). In particularly cold weather or extremely low air pressure, the water droplets freeze and fall as snow or hail.

5. Infiltration

Rainwater gets absorbed into the ground through the process of infiltration. The level of absorption varies based on the material the water has seeped into. For instance, rocks will retain comparatively less water than soil. Groundwater can either follows streams or rivers. But sometimes, it might just sink deeper, forming aquifers.

6. Runoff

If the water from rainfall does not form aquifers, it follows gravity, often flowing down the sides of mountains and hills; eventually forming rivers. This process is called runoff. In colder regions, icecaps form when the amount of snowfall is faster than the rate of evaporation or sublimation. The biggest icecaps on earth are found at the poles.

All the steps mentioned above occur cyclically with neither a fixed beginning nor an end.

Implications of Water Cycle

- The water cycle has a tremendous impact on the climate. For instance, the greenhouse effect will cause a rise in temperature. Without the evaporative cooling effect of the water cycle, the temperature on earth would rise drastically.
- The water cycle is also an integral part of other biogeochemical cycles.
- Water cycle affects all life processes on earth.
- The water cycle is also known the clean the air. For instance, during the process of precipitation, water vapours have to attach themselves on to particles of dust. In polluted cities, the raindrops, apart from picking up dust, also pick up water-soluble gas and pollutants as they fall from the clouds. Raindrops are also known to pick up biological agents such as bacteria and industrial soot particles and smoke.

Carbon Cycle

It is one of the biogeochemical cycles in which carbon is exchanged among the biosphere, geosphere, hydrosphere, atmosphere and pedosphere(The **pedosphere** is the outermost layer of the Earth that is composed of soil and subject to soil formation processes).

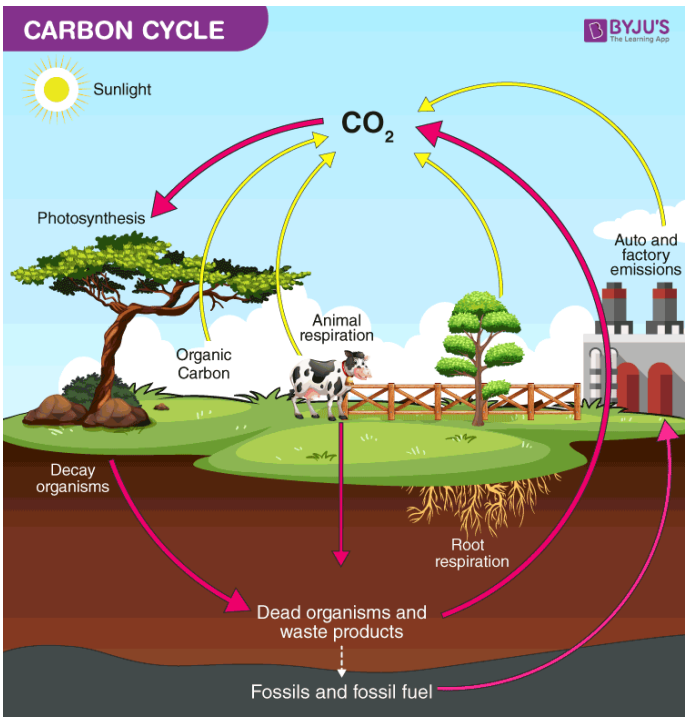
Carbon cycle is the process where carbon compounds are interchanged among the biosphere, geosphere, pedosphere, hydrosphere, and atmosphere of the earth.

Carbon Cycle Steps

Following are the major steps involved in the process of the carbon cycle:

1. Carbon present in the atmosphere is absorbed by plants for photosynthesis.

2. These plants are then consumed by animals and carbon gets bioaccumulated into their bodies.
3. These animals and plants eventually die, and upon decomposing, carbon is released back into the atmosphere.
4. Some of the carbon that is not released back into the atmosphere eventually become fossil fuels.
5. These fossil fuels are then used for man-made activities, which pumps more carbon back into the atmosphere.



CO2 makes up only 0.04% of the earths atomosphere.

Nitrogen cycle consists of the following steps:

(1) Nitrogen fixation, (2) Nitrogen assimilation,

(3) Ammonification,

(4) Nitrification,

(5) Denitrification, and

(6) Sedimentation.

1. Nitrogen fixation:

Conversion of free nitrogen of atmosphere into the biologically acceptable form or nitrogenous compounds is referred to as nitrogen fixation.

This process is of two types:

(a) Physicochemical or non-biological nitrogen fixation

(b) Biological nitrogen fixation.

In physicochemical process of nitrogen fixation, atmospheric nitrogen combines with oxygen (as ozone) during lightning or electrical discharges in the clouds and produces different nitrogen oxides:

$$N_2 + 2\,(O) \xrightarrow[Discharge]{Electric} 2NO$$

$$2NO + 2\,(O) \longrightarrow 2NO_2$$

$$2NO_2 + (O) \longrightarrow N_2O_5$$

The nitrogen oxides get dissolved in rain water and on reaching earth surface they react with mineral compounds to form nitrates and other nitrogenous compounds:

$$N_2O_5 + H_2O \longrightarrow 2HNO_3$$

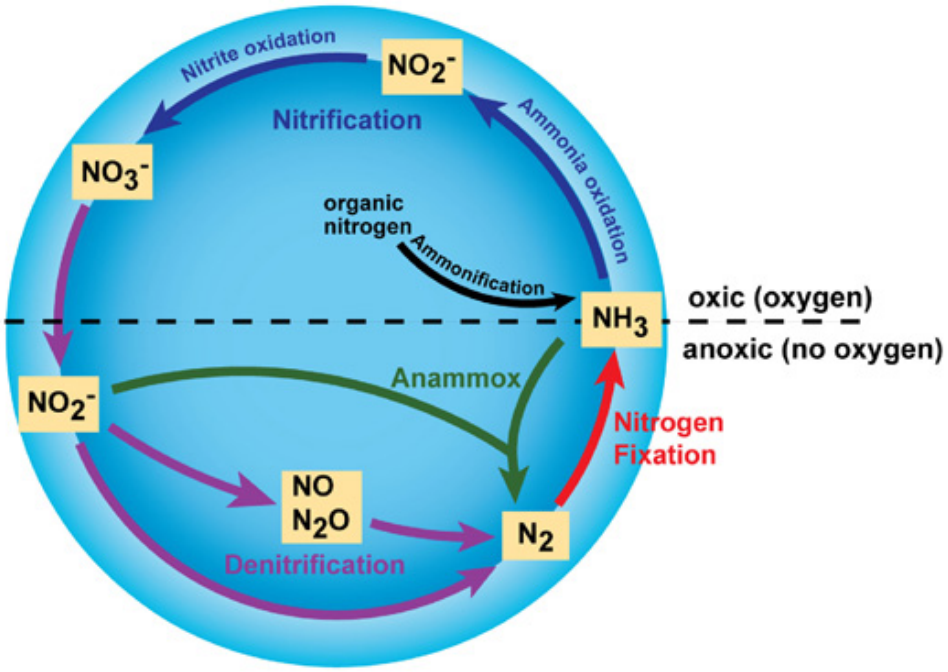
$$2HNO_3 + CaCO_3 \longrightarrow Ca(NO_3)_2 + CO_2 + H_2O$$

Biological nitrogen fixation is carried out by certain prokaryotes. Some blue-green algae fix significant amounts of nitrogen in the oceans, lakes and soils. Symbiotic bacteria (Rhizobium) inhabiting the root nodules of legumes and also the species of alder, buck brush and a number of other non-leguminous genera and symbiotic blue-green algae (species of Nostoc Anabaena, etc.) found in free state or in the thalli of Anthoceros, Salvenia, Azolla, coralloid roots of Cycas fix atmospheric nitrogen. The relation is mutualistic because the microbes use energy from the plants to fix nitrogen that is made available to the host plants and other plants of the community.

Certain free living nitrogen fixing bacteria, such as Azotobacter, Clostridium Beijermckia. Derxia. Rhodospirillium also fix free nitrogen of atmosphere in the soil. Frankia an actmomycetous fungus found in the roots of Alnus, Percia, Casuarina, etc. also fixes nitrogen. Nitrogen fixing organisms combine the gaseous nitrogen of atmosphere with hydrogen obtained from respiratory pathway to form ammonia which then reacts with organic acids to form aminoacids. Biological nitrogen fixation is the major source of fixed nitrogen upto 140—700 mg/m^2/year as against 35 mg/m^2/year by electrical discharge and photochemical fixation.

2. Nitrogen assimilation:

Inorganic nitrogen in the form of nitrates, nitrites and ammonia is absorbed by the green plants and converted into nitrogenous organic compounds. Nitrates are first converted into ammonia which combines with organic acids to form amino acids. Amino acids are used in the synthesis of proteins, enzymes, chlorophylls, nucleic acids, etc. Animals derive their nitrogen requirement from the plant proteins. Plant proteins are not directly utilized by the animals. They are first broken down into amino acids during digestion and then the amino acids are absorbed and manipulated into animal proteins, nucleic acids, etc.



3. Ammonification:

The dead organic remains of plants and animals and excreta of animals are acted upon by a number of microorganisms especially actinomycetes and bacilli (Bacillus ramosus, B. vulgaris, B. mesenterilus). These organisms utilize organic compounds in their metabolism and release ammonia.

4. Nitrification:

Certain bacteria, such as Nitrosomonas, Nitrococcus, Nitrosogloea and Nitrospira in oceans and soils convert ammonia into nitrites and then nitrites into nitrates. These bacteria primarily use the energy of dead organic matter in their metabolism.

$2NH_4^+ + 20_2 \rightarrow NO_2^- + 2H_2O$ + energy

Conversion of nitrites to nitrates is brought about by several microbes like Penicillium species, Nitrobacter, Nitrocystis etc. Nitrocystis oceanus is the common marine autotroph which performs nitrification for obtaining energy.

$2NO\text{-}2 + O2 \rightarrow 2NO_3^- + \text{energy}$

Some nitrates are also made available through weathering of nitrate containing rocks.

5. Denitrification:

Ammonia and nitrates are converted into free nitrogen by certain microbes. This process is referred to as de-nitrification. Thiobacillus denitrificans, Micrococcus de-nitrificans, Pseudomonas aeruginosa are the common examples of denitrifying bacteria.

$2NO\text{-}_3 \rightarrow 2NO\text{-}_2 \rightarrow 2NO \rightarrow N_2O \rightarrow N_2$

6. Sedimentation:

Nitrates of the soil are washed down to the sea or leached deep into the earth along with percolating water. Nitrates thus lost from the soil surface are locked up in the rocks. This is sedimentation of nitrogen. Nitrogen of rock is released only when the rocks are exposed and weathered.

Thus a large part of nitrogen is fixed up and stored in plants, animals, and microbes. Nitrogen leaves the living system in the same amount it is taken in from the atmosphere and the input and outflow of nitrogen are balanced in the ecosystem.

3. Sedimentary Cycles:

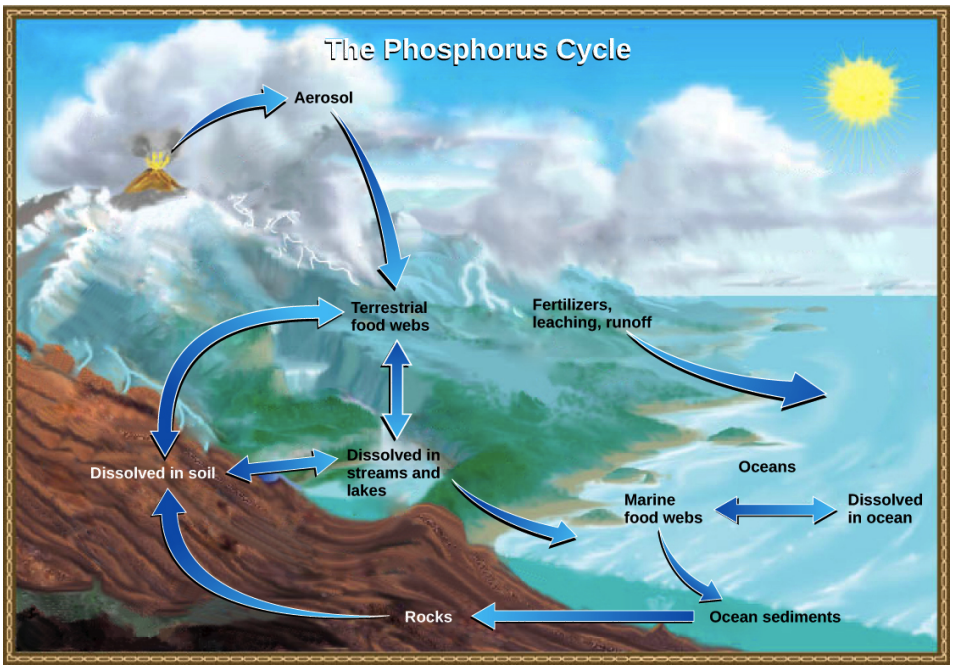
Phosphorus cycle

The phosphorus cycle is slow compared to other biogeochemical cycles such as the water, carbon, and nitrogen cycles.

In nature, phosphorus is found mostly in the form of phosphate Phosphate compounds are found in sedimentary rocks, and as the rocks weather—wear down over long time periods—the phosphorus they contain slowly leaches into surface water and soils. Volcanic ash, aerosols, and mineral dust can also be significant phosphate sources, though phosphorus has no real gas phase, unlike other elements such as carbon, nitrogen, and sulfur.

Phosphate compounds in the soil can be taken up by plants and, from there, transferred to animals that eat the plants. When plants and animals excrete wastes or die, phosphates may be taken up by detritivores or returned to the soil. Phosphorus-containing compounds may also be carried in surface runoff to rivers, lakes, and oceans, where they are taken up by aquatic organisms.

When phosphorus-containing compounds from the bodies or wastes of marine organisms sink to the floor of the ocean, they form new sedimentary layers. Over long periods of time, phosphorus-containing sedimentary rock may be moved from the ocean to the land by a geological process called uplift. However, this process is very slow, and the average phosphate ion has an oceanic residence time—time in the ocean—of 20,000 to 100,000 years.



This illustration shows the phosphorus cycle. Phosphorus enters the atmosphere from volcanic aerosols. As this aerosol precipitates to earth, it enters terrestrial food webs. Some of the phosphorus from terrestrial food webs dissolves in streams and lakes, and the remainder enters the soil. Another source of phosphorus is fertilizers. Phosphorus enters the ocean via leaching and runoff, where it becomes dissolved in ocean water or enters marine food webs. Some phosphorus falls to the ocean floor where it becomes sediment. If uplifting occurs, this sediment can return to land.

Image credit: *Biogeochemical cycles: Figure 5* by OpenStax College, Concepts of Biology, CC BY 4.0; modification of work by John M. Evans and Howard Perlman, USGS

Phosphorus Cycle Steps

The phosphorus cycle is a slow process, which involves five key steps, as shown in the diagram below and described as follows:

Weathering

Since the main source of phosphorus is found in rocks, the first step of the phosphorus cycle involves the extraction of phosphorus from the rocks by weathering. Weather events, such as rain and other sources of erosion, result in phosphorus being washed into the soil.

Absorption by Plants and Animals

Once in the soil, plants, fungi, and microorganisms are able to absorb phosphorus and grow. In addition, phosphorus can also be washed into the local water systems. Plants can also directly absorb phosphorus from the water and grow. In addition to plants, animals also obtain phosphorus from drinking water and eating plants.

Return to the Environment via Decomposition

When plants and animals die, decomposition results in the return of phosphorus back to the environment via the water or soil. Plants and animals in these environments can then use this phosphorus, and step 2 of the cycle is repeated.

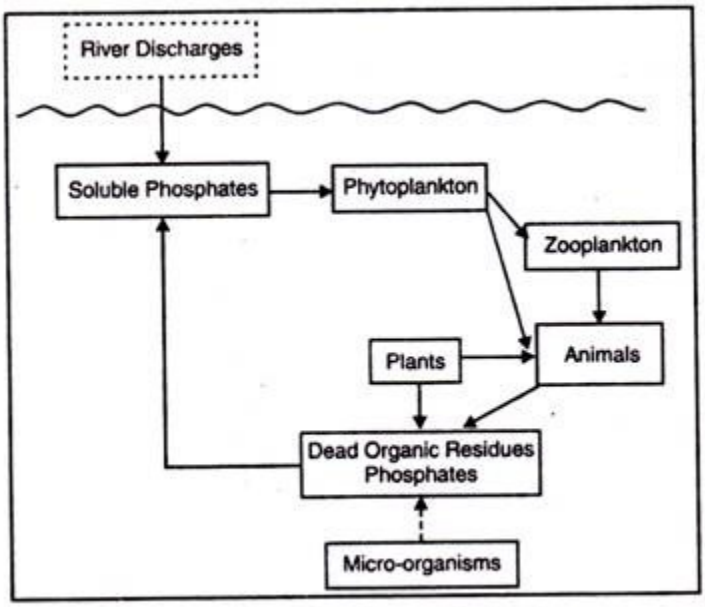


Fig. 5.11. The Phosphorus cycle in water.

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4. https://byjus.com/