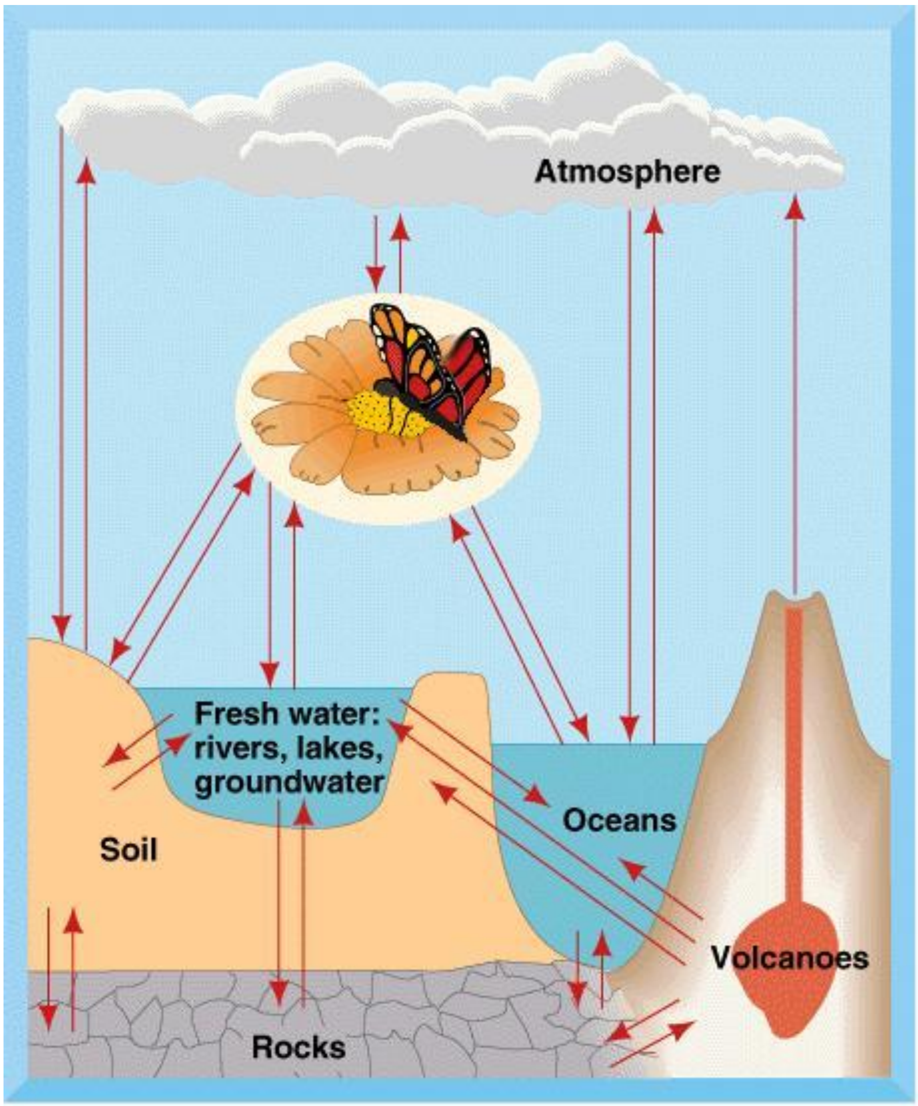
Biogeochemical cycles

Biogeochemical cycles are pathways for the transport and transformation of matter within four categorical areas that make up planet Earth (biosphere, hydrosphere, lithosphere, and the atmosphere).



Generalized biogeochemical cycle. The major parts of the biosphere are connected by the flow of chemical elements and compounds. In many of these cycles, the biota plays an important role. Matter from the Earth's interior is released by volcanoes. The atmosphere exchanges some compounds and elements rapidly with the biota and oceans. Exchanges of materials between rocks, soils, and the oceans are generally slower by comparison.

Biogeochemical cycles are components of the broader cycle that govern the functioning of planet Earth. The Earth is a system open to electromagnetic radiation from the sun and outer space, but is a virtually closed system with regard to matter. This means that the planet has minimal flux of matter, other than meteorite collisions and minor amounts of intergalactic particle trapping (or loss) by the upper atmosphere. Therefore, matter that Earth contained from the time of its birth is transformed and circulated geographically. This is in line with the law of conservation of matter which states that matter cannot be created nor destroyed but can be transformed including the transformation between matter and energy

The transfer of matter involves biological, geological and chemical processes; hence the name biogeochemical cycles derives. Biogeochemical cycles may also be referred to as cycles of nature because they link together all organisms and abiotic features on earth (Figure 1). Matter is continually recycled among living and abiotic elements on earth. Biogeochemical cycles facilitate the transfer of matter from one form to another and from one location to another on planet earth. Additionally, biogeochemical cycles are sometimes called nutrient cycles, because they involve the transfer of compounds that provide nutritional support to living organisms.

Pathways of biogeochemical cycles

Parts that comprise planet earth have been categorized into four spheres (regions). One is the sphere which has life and it is called the biosphere (it is the region occupied by living organisms such as plants, animals, fungi) and the other three spheres are largely devoid of life, they include; lithosphere (region occupied bysoil, land and the earth crust), atmosphere (air and space) and hydrosphere (areas covered by water such as rivers, lakes and oceans). However, where the biosphere overlaps the lithosphere, atmosphere or hydrosphere, there is a zone occupied by living organisms.

Categories and examples of biogeochemical cycles

Biogeochemical cycles differ in their pathways, and on this basis the biogeochemical cycles have been categorized into two:

- **Sedimentary cycles:** these cycles involve the transportation of matter through the ground to water; that is to say from the lithosphere to the hydrosphere. Common examples of cycles under the sedimentary category are:
- **Phosphorus cycle**: Phosphorus is commonly found in water, soil and sediments. Phosphorus cannot be found in air in the gaseous state. This is because phosphorus is usually a liquid at standard temperatures and pressures. Phosphorus is mainly cycled trough water, soil and sediments. However, very small particles in the atmosphere may contain phosphorus or its compounds. Phosphorus moves slowly from deposits on land and in sediments, to living organisms, and much more slowly back into the soil and water sediment. The phosphorus cycle is the slowest one of the sedimentary cycles.
- **Sulphur cycle:** Sulphur in its natural form is a solid, and restricted to the sedimentary cycle in this form. It is transported by physical processes like wind, erosion by water, and geological events like volcanic eruptions. However, in its compounds such as sulphur dioxide, sulphuric acid, salts of sulphate or organic sulphur, sulphur can be moved from the ocean to the atmosphere, to land and then to the ocean through rainfall and rivers.
- **Gaseous cycles:** these involve the transportation of matter through the atmosphere. Common example of gaseous cycles are:
- **Carbon cycle:** Carbon is one of the most important elements that sustain life on earth. Carbon dioxideand methane gases (compounds of carbon) in the earth's atmosphere has a substantial effect on earth's heat balance. It absorbs infrared radiation and hence may contribute to global warming and climate change.
- **Nitrogen cycle:** Nitrogen gas is the most abundant element in the atmosphere and all the nitrogen found in terrestrial ecosystems originate from the atmosphere. The nitrogen cycle is by far the most important nutrient cycle for plant life.
- **Oxygen cycle:** The oxygen cycle describes the movement of oxygen within and between its three main reservoirs: the atmosphere, the biosphere, and the lithosphere. The main driving factor of the oxygen cycle is photosynthesis and because of this, oxygen and carbon cycles are usually linked and the two cycles are collectively called oxygen-carbon cycle.
- **Hydrological cycle**: This is some times called the water cycle. Water is the most important chemical of life for all living organisms on earth. Water in the atmosphere is usually in form of vapor but condenses to liquid water and can solidify when temperatures are $0^{o}C$ to form ice. Ninety three percent of water on earth is in solid state mainly comprising the ice caps and glaciers of Polar Regions.

Nature of elements transported in biogeochemical cycles

When living organisms die and decay, their body structures disintegrate and may be reduced to constituentmolecules. Depending on the region where disintegration of the organisms occurred, the component molecular elements then join the biogeochemical cycle. Elements transported in the biogeochemical cycles have been categorized as:

1. Micro elements – these are elements required by living organisms in smaller amounts. Examples of such elements include boron used mainly by green plants, copper used by some enzymes and molybdenum used by nitrogen-fixing bacteria.
2. Macro elements – these are elements required by living organisms in larger amounts. Examples of such elements include carbon, hydrogen, oxygen, nitrogen, phosphorous, sulfur.

Macro elements are the commonly cited examples of elements that constitute major biogeochemical cycles. The molecules may be further reduced to ionized or hydrated ions in aqueous solutions or to ions in the atmosphere.. These molecules or ions are then cycled and metabolized by new organisms, and the organism may pass them on through excreta or death/decay to be cycled again. Therefore, the whole process becomes a cycle.

The importance of biogeochemical cycles

Biogeochemical cycles serve a variety of functions at ecosystem level and in ensuring survival of various organisms including humans. Below are some of the importances of biogeochemical cycles.

- Biogeochemical cycles enable the transformation of matter from one form to another. This transformation enables the utilization of matter in a form specific to particular organisms. For example humans utilize water in liquid form. Through the hydrological cycle, water vapour is condensed to liquid and ice converted to liquid water. Nitrogen, despite its abundance in the atmosphere it's often the most limiting nutrient for plant growth. This problem occurs because most plants can only take up nitrogen in two solid forms: ammonium ion (NH_4^{+}) and the ion nitrate (NO_3^{-}). Therefore, biogeochemical cycles enable the provision of elements to organisms in utilizable forms.
- Biogeochemical cycles enable the transfer of molecules from one locality to another. Some elements such as nitrogen a re highly concentrated in the atmosphere, but some of the atmospheric nitrogen is transferred to soil through the nitrogen cycle (which is a biogeochemical cycle).

- Biogeochemical cycles facilitate the storage of elements. Elements carried through the biogeochemical cycles are stored in their natural reservoirs, and are released to organisms in small consumable amounts. For example through the nitrogen cycle and with the help of the nitrogen fixing bacteria, green plants are able to utilize nitrogen in bits though it is abundant in the atmosphere.

- Biogeochemical cycles assists in functioning of ecosystems. An ecosystem is a system that properly functions in a state of equilibrium, and when ever any imbalances occur, the ecosystem through the biogeochemical cycles restores to the equilibrium state; this may take a few days or many years. The adjustment is such that the disturbing factor is eliminated.

- Biogeochemical cycles link living organisms with living organisms, living organisms with the non living organisms and nonliving organisms with non living organism. This is because all organisms depend on one another and most especially, the biotic (living component) and a biotic component of the ecosystem are linked by flow on nutrients engineered by the biogeochemical cycles.

- Biogeochemical cycles regulate the flow of substances. Since the biogeochemical cycles pass through different spheres, the flow of elements is regulated because each sphere has a particular medium and the rate at which elements flow is determined by the viscosity and density of the medium. Therefore elements in the biogeochemical cycles flow at differing rates with in the cycle and this regulates the flow of the elements in those cycles.

Lifespan and rate of biogeochemical cycles

Lifespan of biogeochemical cycles is described in terms of the time a particular element or molecule of a substance being carried in the biogeochemical cycle takes to make one complete cycle. Each Biogeochemical cycle has its life span, ranging from several days to millions of years. For example a water droplet of average size may stay in the atmosphere for about ten days before precipitation, and carbon atoms may reside in the earth crust for the age of the Earth.

The speed of the cycles depends on the medium in which the molecule being cycled is and the surrounding conditions. For this reason, climatic conditions have a significant impact on the biogeochemical cycles (discussed in the next sections)

Cycles that involve molecules or ions in a gaseous state are generally shorter than cycles that involve solid or liquid state transfer. Because of the slow rate at which molecules move through the lithosphere, the attainment of some elements of nutritional value by some living organisms in the hydrosphere, and counteract this deficiency, movement from terrestrial biosphere to the ocean (via stream flow) is usually compensated by movement either through the atmosphere (such as with nitrogen and carbon) or by weathering (such as with phosphorous or calcium). Therefore increased or decreased transport by stream flow severely disrupts the cycles of nutrients that lack a gaseous phase.

Reservoirs, exchange pools, and resident time of elements in the biogeochemical cycles

Each of the elements has its biogeochemical cycle and each cycle with a unique pathway characterized by reservoirs, exchange pools and resident times.

A reservoir is a place or region or location where a biogeochemical element is in its highest concentration. Elements being cycled are held and stored for some time in reservoirs, for example coal or fossil fuels are reservoirs for carbon. Some elements have several reservoirs while others have one.

When chemicals are held for only short periods of time, they are being held in **exchange pools** . Examples of exchange pools include plants and animals, which temporarily use elements in their systems and release them back into the air or surrounding medium. Generally, reservoirs are abiotic (nonliving) factors while exchange pools are biotic (living) factors. Carbon is held for a relatively short time in plants and animals when compared to fossil fuel deposits. The amount of time that a chemical is held in one place is called its**resident time .**

The term **Influx** is commonly used in describing biogeochemical cycles to refer to the difference between the amount of elements entering a reservoir and the amount leaving the reservoir.

Human activities and their influence on biogeochemical cycles and climate change

Life on earth is inextricably linked to climate through a variety of interacting cycles and feedback loops. In recent years there has been a growing awareness of the extent to which human activities, such asdeforestation and fossil fuel burning, have directly or indirectly modified the biogeochemical and physical processes involved in determining the earth's climate. These changes in atmospheric processes can disturb a variety of {C}ecosystem services that humans depend upon. In addition to helping to maintain relative climate stability ecosystem services protect living organisms on earth from the sun's harmful ultraviolet rays, mediate runoff and evapotranspiration and regulate nutrient cycling.

Humans clearly disrupt many, if not all biogeochemical cycles and in the process threaten many ecosystems. In resent years human activities have directly or indirectly affected the biogeochemical cycles that determine climatic conditions of earth. It is imperative to mention that, managing and understanding environmental problems caused by climate change would require an understanding of the biogeochemical cycles. Biogeochemical cycles always involve equilibrium states: a balance in the cycling of the element between spheres. However, overall balance may involve elements distributed on a global scale and that is why a disruption in one cycle causes a disruption in all other cycles. Below is a summary of how human activities have contributed to disruption of biogeochemical cycles. For impacts on specific cycles, the reader should refer to the sites where these cycles are presented.

Use of phosphorus fertilizers: Human influences on the phosphorus cycle come mainly from the introduction and use of commercial synthetic fertilizers. Use of fertilizers mainly has affected the phosphorus and nitrogen cycles. Plants may not be able to utilize all of the phosphate fertilizer applied; as a consequence, much of it is lost from the land through the water run-off. The phosphate in the water is eventually precipitated as sediments at the bottom of the water body. In certain lakes and ponds this may be redissolved and recycled as a problem nutrient. Animal wastes or manure may also be applied to land as fertilizer. If misapplied on frozen ground during the winter, much of the fertilizer may be lost when ice melts and forms runoff. In certain areas very large feed lots of animals, may result in excessive run-off of phosphate and nitrate into streams. Other human sources of phosphate are in the out flows from municipal sewage treatment plants. Without an expensive tertiary treatment, the phosphate in sewage is not removed during various treatment operations. Again an extra amount of phosphate enters the water.

Mining of Fossil fuels: Humans have interfered with the carbon cycle where fossil fuels have been mined from the earth crust. Had fossils not been discovered prior to industrial revolution, they could have remained there until now. Carbon dioxide is number one green house gas contributing to global warming and climate change. Additionally, clearing of vegetation that serve as carbon sinks has increased the concentration of carbondioxide in the atmosphere.

Production of Sulphur dioxide: Human impact on the sulfur cycle is primarily in the production ofsulfur dioxide (SO_2) from industry (e.g. burning coal) and the internal combustion engine. Sulfur dioxide can precipitate onto surfaces where it can be oxidized to sulphate in the soil (it is also toxic to some plants), reduced to sulphide in the atmosphere, or oxidized to sulphate in the atmosphere as sulphiric acid (a principal component of acid rain). Sulphur compounds play a big role in the climate system because they are important for the formation of clouds.

Additionally, a lot of sulphur is brought into the air by volcanic eruptions. A strong eruption can emit particles up to the stratosphere hence leading to cooling down of the planet.

Cultivation of legumes and use of nitrogen fertilizers:

As a result of extensive cultivation of legumes, creation of chemical fertilizers, and pollution emitted by vehicles and industrial plants, human beings have more than doubled the annual transfer of nitrogen into biologically available forms. Humans have significantly contributed to the transfer of nitrogen gases from Earth to the atmosphere, and from the land to aquatic systems through four main processes:

- The application of nitrogen fertilizers to crops has caused increased rates of denitrification and leaching of nitrate into groundwater. The additional nitrogen entering the groundwater system eventually flows into streams, rivers, lakes, and estuaries. In these systems, the added nitrogen can lead to eutrophication.
- Increased deposition of nitrogen from atmospheric sources because of fossil fuel combustion and forest burning. Both of these processes release a variety of solid forms of nitrogen through combustion.
- Livestock ranching. Livestock release a large amounts of ammonia into the environment from their wastes. This nitrogen enters the soil system and then the hydrologic system through leaching, groundwater flow, and runoff.
- Sewage waste and septic tank leaching.

Water as a "driver" of biogeochemical cycles

The water cycle is powered from solar energy, more than 85% of the global evaporation occurs from the oceans, reducing their temperature by cooling by evaporation. Without the cooling effect of evaporation the greenhouse effect would lead to a much higher surface temperature of about 67^{0} C and a warmer planet.

While the water cycle is itself a biogeochemical cycle, flow of water over and beneath the Earth is a key component of the cycling of other biogeochemical cycles. Runoff is responsible for almost all of the transport of eroded sediment and phosphorus from land to water bodies. The salinity of the oceans is derived from erosion and transport of dissolved salts from the land. Eutrophication of lakes is primarily due to phosphorus, applied in excess to agricultural fields in fertilizers, and then transported overland and down rivers. Both runoff and groundwater flow play significant roles in transporting nitrogen from the land to water bodies. Runoff also plays a part in the carbon cycle, through the transport of eroded rock and soil.

There are many other biogeochemical cycles that are currently being studied for the first time as climate change and human impacts are drastically changing the speed, intensity, and balance of these relatively unknown cycles. These newly studied biogeochemical cycles include the mercury cycle and the human caused cycle of atrazine.

The climatic conditions determine the speed and the life span of the biogeochemical cycles. Scientists are still investigating the pathways that the biogeochemical cycles take and how human activity has affected these cycles. There are still many questions that are unanswered

However, it has been argued that absence of humans on earth will not guarantee the stability of biogeochemical cycles. The reason advanced is that life has existed for about 3.5 billion years, and a complete breakdown has not occurred since oxygen became available about 1.5 billion years ago. Change is a part of natural biogeochemical cycles resulting in periods of abundant biota and periods of scarce biota (both on terrestrial and aquatic ecosystems).

Image

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Further reading

- Environmental Science by Daniel Bodkin and Edward Keller, John Wiley and Sons; 5th edition, 2004ISBN: 0471658723.
- Introduction to Biogeochemical Cycles by Jason Neff, Colorado State University
- The Blue Planet: An Introduction to Earth System Science by Brian J. Skinner, Stephen C. Porter and Daniel B. Botkin, John Wiley and Sons, 1999, ISBN: 0471161144.
- The Physical Environment: an Introduction to Physical Geography by Michael E Ritter, Pearson Prentice Hall, 2008 ISBN: 0131753045.
- Biogeochemical Cycles in Globalization and Sustainable Development by Vladimir F. Krapivin and Costas Varotsos, Springer, 2008 ISBN: 3540754393.
- Global carbon and climate change by Kirill Ya. Kondratyev, Vladimir F. Krapivin, Costas A. Varotsos and Costas Varotsos, Springer, 2003 ISBN: 3540008098.

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