ISSN: 3139-0862

Earth's Natural Balance: An Integrated Study of Resources and Biogeochemical Cycles

Sushma M V, Anoushka Abhilash, Amit T N, G V Abhishek Bhargav, Pavan M, Deekshitha K P

Department of Computer Science and Engineering (Artificial Intelligence and Machine Learning), Malnad College of Engineering, Hassan, Karnataka, India

Sushma M V (Assistant Professor); all other authors are students

Corresponding author Anoushka Abhilash anoushkaabhilash@gmail.com

smv@mcehassan.ac.in, pavanmreddy287@gmail.com, preethamarmy058@gmail.com

Abstract

This paper reviews mineral resources, forest resources and the carbon, nitrogen and sulphur cycles. It considers the uses of these resources, their roles in ecosystems, the main processes through which materials move, and the effects of human activities. Minerals provide raw materials for construction, manufacturing, transport and energy systems. Forests supply timber, fuelwood and other products, while also storing carbon, supporting biodiversity and helping maintain soil and water processes. Research on forest accounting in India shows that timber, carbon storage, fuelwood and non-timber products all contribute to forest value, although some benefits are not fully represented in conventional economic measures [1]. Studies of forest nutrient cycling identify climate, soil properties, vegetation and litter decomposition as important influences [2], [3]. The paper also describes the main reservoirs and transformations in the carbon, nitrogen and sulphur cycles. It discusses how iron redox reactions may interact with these cycles in soils, wetlands and sediments [4]. This is a literature review and does not report new field measurements. The supplied references focus mainly on forests and biogeochemical processes; therefore, the mineral-resources section provides general background rather than a review of a dedicated mineral-resource study.

Index Terms— Mineral resources, forest resources, biogeochemical cycles, carbon cycle, nitrogen cycle, sulphur cycle, nutrient cycling, sustainable management.

INTRODUCTION

Natural resources support both human activities and the functioning of ecosystems. Minerals are used to make buildings, vehicles, machinery, electronic equipment and energy infrastructure. Forests provide timber, fuelwood and a range of other products. They also create habitats, store carbon, influence the movement of water and help maintain soil fertility. Alongside these resources, elements move continually between the atmosphere, water, rocks, soil and living organisms. These movements are known as biogeochemical cycles. The subjects covered in this paper are linked. Mining can remove vegetation, disturb soil and affect nearby water. Clearing forests reduces the amount of carbon held in vegetation and may interrupt the return of nutrients to the soil. Changes in the carbon, nitrogen and sulphur cycles can, in turn, affect soil quality, water bodies, air composition and climate. Considering these connections helps explain why resource use and environmental protection need to be planned together.

The paper reviews the studies supplied on forest-resource accounting in India, nutrient cycling in forest ecosystems and iron-related biogeochemical processes. The supplied papers do not include a dedicated study of mineral deposits or mining. For that reason, the mineral-resources section introduces established environmental-studies concepts and is not presented as a finding from those papers.

MINERAL RESOURCES

A. Meaning and classification

Mineral resources are naturally occurring materials found in the Earth's crust that can be extracted for their physical or chemical properties. Metallic minerals are commonly grouped into ferrous minerals, such as iron ore and manganese, and non-ferrous minerals, such as copper, bauxite, lead and zinc. Non-metallic minerals include limestone, mica, gypsum, clay, salt and phosphorite. Coal, petroleum, natural gas and uranium-bearing ores are also discussed in the context of extractive resources and energy.

B. Uses and importance

Minerals are important raw materials for industry and infrastructure. Iron ore is used to make iron and steel, while bauxite is the main ore used to produce aluminium. Copper is widely used in electrical equipment and wiring. Limestone is an important ingredient in cement, and phosphate minerals are used to manufacture fertilizers. The economic value of a deposit depends on factors such as its size, ore grade, location, available infrastructure and the technology needed to extract and process it.

ISSN: 3139-0862

C. Extraction and environmental effects

The mining method usually depends on how deep the deposit lies. Surface mining is used for deposits near the land surface, whereas underground mining is used to reach deeper deposits. Quarrying is common for stone and other construction materials. These activities can produce waste rock, tailings, dust, noise and wastewater. Clearing vegetation and removing topsoil may damage habitats, divide landscapes and increase erosion. Water draining from some mine sites can carry acidity and dissolved metals. Fuel used in extraction, processing and transport also adds to greenhouse-gas emissions.

D. Sustainable management

Reducing the environmental effects of mining begins with suitable site selection and careful mine planning. Environmental assessment, secure storage of waste and tailings, treatment of affected water, and rehabilitation during and after mining are important measures. Monitoring should continue after a mine closes. Using materials efficiently and recovering metals such as steel, aluminium and copper from discarded products can also reduce demand for newly mined material. This section is general background because the supplied references concentrate on forests and biogeochemical cycling rather than mineral deposits or mining policy.

The impacts of mineral use extend beyond the mine. Processing the ore, smelting, transporting materials, manufacturing products and disposing of them all require energy and may create waste or emissions. Longer-lasting products, repair, reuse and the recovery of metals from discarded equipment can reduce some of these impacts. Recycling is therefore a useful complement to better environmental management at mine sites.

FOREST RESOURCES

A. Forest resources and their value

Forests provide timber, fuelwood, fodder, bamboo, fibres, medicinal plants, honey, resin, gum, lac and many other products that people use. Their value is not limited to goods sold in markets: forests also provide ecological benefits and support the livelihoods of communities living near them. Gundimeda and colleagues examined natural-resource accounting across Indian states. Their work considered timber production, carbon storage, fuelwood and non-timber forest products, and noted that conventional measures of income may fail to capture the full contribution of forests, particularly when households use products that are not formally marketed [1].

B. Ecological functions

Forest ecosystems hold carbon in tree trunks, branches, leaves, roots, dead plant material and soil. Through photosynthesis, plants take in carbon dioxide and use the carbon to build organic matter. Forest cover also reduces the exposure of soil to erosion, affects how rainfall enters and moves across the ground, and provides habitats for many species. Nutrients are returned to the soil as leaves and other plant material fall and decompose. Microorganisms and plants then take part in the release, transformation and reuse of these nutrients.

C. Nutrient cycling in forest ecosystems

In a forest, nutrients move between plants, fallen litter, soil organisms and the surrounding environment. Leaves, twigs and other plant remains collect on the forest floor. Fungi, bacteria, insects and earthworms help break down this material and mix it with the soil. As decomposition proceeds, nutrients are released into forms that plants may absorb through their roots. The speed of this process depends on litter quantity and quality, the tree species present, climate and soil conditions [2].

The forest nutrient-cycling review supplied for this paper identifies climate as one of the factors affecting plant growth and nutrient availability. Temperature and moisture influence the activity of decomposers and other soil microorganisms. Soil characteristics—including parent material, nutrient content and pH—also affect nutrient supply and plant development. Forest type and vegetation influence how much nutrient material is held in living plants and dead plant matter [2].

A review of studies on Pinus and Eucalyptus forests also reports links between local environmental conditions, litter and plant nutrient dynamics, soil fertility and water availability [3]. Taken together, these studies indicate that nutrient cycling differs from one forest ecosystem to another. Management decisions should therefore take account of local vegetation, climate and soil rather than assume that all forests recycle nutrients at the same rate.

Nutrient cycling in a forest involves a repeating series of transfers. Nutrients stored in leaves and wood reach the forest floor when plant material falls. Soil animals and decomposers break this material into smaller parts, and nutrients are released as decomposition continues. Plant roots can then absorb some of the released nutrients. Others may be carried away by water or lost with eroded soil, especially where the ground has little vegetation cover.

MATERIAL CYCLES AND BIOGEOCHEMICAL PROCESSES

A biogeochemical cycle describes how an element moves between living organisms and non-living parts of the environment, including air, water, rocks and soil. Plants and other organisms take up elements; feeding transfers them through food webs; and respiration, decomposition, weathering, chemical reactions, sedimentation and gas exchange move them between environmental reservoirs. These processes help keep essential elements available. However, pollution, land-use change, mining and industrial activity can alter the pathways or rates of movement.

ISSN: 3139-0862

Carbon forms the basis of organic matter and is involved in the transfer of energy through ecosystems. Nitrogen is needed to make proteins and nucleic acids, while sulphur is part of several important biological compounds. Microorganisms carry out many of the chemical transformations involving these elements, particularly in soils and sediments. The availability of oxygen and the redox conditions of an environment influence which reactions can take place.

CARBON CYCLE

A. Major reservoirs and processes

Carbon is stored in several parts of the Earth system. It occurs in the atmosphere mainly as carbon dioxide and methane, and is also present in plants, animals, dead organic matter, soils, oceans, carbonate rocks and fossil fuels. During photosynthesis, plants, algae and some bacteria use carbon dioxide to form organic compounds. Carbon then moves through food webs as organisms consume plants and other organisms. Respiration by plants, animals and microorganisms returns carbon dioxide to the air or water.

After organisms die, decomposers act on their remains. Some of the carbon is released through microbial respiration, while some becomes part of the soil's organic matter. Carbon dioxide is also exchanged between the atmosphere and the oceans. Over much longer periods, burial and sedimentation can store carbon in geological deposits. Burning biomass or fossil fuels releases stored carbon relatively quickly into the atmosphere.

B. Human influence

Human activities have changed the movement of carbon through the environment. Burning coal, oil and gas, producing cement and clearing forests all add carbon dioxide to the atmosphere. Forest degradation can also reduce carbon uptake and release carbon previously stored in plants and soil. Protecting existing forests, restoring damaged land, conserving soil, using energy more efficiently and shifting towards lower-carbon energy sources can help reduce these pressures.

The carbon balance of an ecosystem reflects the difference between the carbon entering it and the carbon leaving it over a period of time. Photosynthesis and the addition of plant residues increase carbon stored in an ecosystem. Respiration, decomposition, fire and conversion of land to other uses release carbon back to the atmosphere. The oceans and geological reservoirs exchange carbon over much longer periods, so short-term changes in living ecosystems should be distinguished from long-term geological storage.

NITROGEN CYCLE

A. Major transformations

Nitrogen is required to form amino acids, proteins, nucleic acids and chlorophyll. Although nitrogen gas (N_2) makes up a large part of the atmosphere, most plants cannot use it directly. Nitrogen fixation changes atmospheric nitrogen into ammonia or other forms that organisms can use. This conversion is carried out by certain microorganisms and can also occur through lightning and industrial fertilizer production. Some nitrogen-fixing bacteria live in close association with plants.

During ammonification, decomposers convert nitrogen in dead organisms and waste into ammonium. Nitrifying microorganisms then convert ammonium first into nitrite and subsequently into nitrate, usually where oxygen is present in the soil. Plants can absorb ammonium or nitrate and use the nitrogen to build organic compounds. Animals obtain nitrogen by eating plants or other organisms. Where oxygen is limited, denitrifying microorganisms can convert nitrate through several intermediate forms and release nitrogen gas back to the atmosphere. Nitrous oxide may also be produced during these reactions.

B. Human influence

Fertilizers, animal manure, sewage and emissions from fuel combustion add reactive nitrogen to the environment. When too much nitrogen enters an ecosystem, it can encourage excessive algal growth, reduce oxygen in water, contaminate groundwater with nitrate, contribute to soil acidification and increase nitrous oxide emissions. Applying fertilizer according to crop needs, handling manure carefully, treating wastewater and maintaining vegetated buffer strips can help limit these losses.

The availability of oxygen and water in soil affects which nitrogen transformations occur. Nitrification is generally favoured in aerated soil, while denitrification can take place in areas where oxygen is scarce. Different parts of the same soil may therefore support different nitrogen processes at the same time. The amount of nitrogen that remains available to plants depends on uptake by vegetation, retention by microorganisms, movement in drainage water and losses to the atmosphere.

SULPHUR CYCLE

A. Major reservoirs and transformations

Sulphur is found in rocks and minerals, organic matter in soil, seawater and living organisms. Plants usually take up sulphur from the soil in the form of sulphate (SO_4^{2-}), which they use to make organic compounds. Animals receive sulphur through their food. Weathering releases sulphur from rocks into soil and water, and decomposition returns sulphur from dead organic matter to the environment.

Microorganisms change sulphur from one chemical form to another, and the reactions depend partly on oxygen availability. In oxygen-rich conditions, reduced sulphur compounds can be converted into sulphate. In oxygen-poor environments, sulphate-reducing microorganisms can produce sulphide, including hydrogen sulphide. Volcanic emissions, sea spray and biological activity also release sulphur-containing

ISSN: 3139-0862

gases. These compounds can be changed in the atmosphere and later returned to land and water through deposition.

B. Human influence

Burning coal and oil that contain sulphur, as well as processing sulphide ores, can release sulphur dioxide. Reactions in the atmosphere may convert it into sulphuric acid and sulphate particles, which contribute to acid deposition. This can affect soils, lakes, vegetation and buildings. Controlling industrial emissions, using lower-sulphur fuels and adopting cleaner energy sources can reduce the release of these pollutants.

The amount of sulphur available to plants depends on several processes, including rock weathering, atmospheric deposition, decomposition of organic matter and microbial reactions. Roots generally absorb sulphur as sulphate. In strongly oxygen-limited conditions, sulphide may build up instead. Changes in drainage, flooding and oxygen supply can therefore affect which sulphur compounds are present and how easily they move through soils and sediments.

INTERACTIONS AMONG IRON, CARBON, NITROGEN AND SULPHUR CYCLES

The 2012 review supplied for this paper considers whether the Fe(III)–Fe(II) redox wheel helps link the biogeochemical cycles of carbon, nitrogen, sulphur and phosphorus in environments where redox conditions change [4]. Iron occurs in forms such as ferric iron [Fe(III)] and ferrous iron [Fe(II)]. The conversion between these forms is affected by oxygen conditions, pH and the activity of microorganisms.

The review describes several possible connections. Microorganisms may oxidize organic matter while reducing iron(III) (hydr)oxides; iron reactions may occur alongside nitrogen oxidation and reduction; and iron can combine with sulphur to form iron-sulphide minerals. Iron (hydr)oxides can also bind dissolved phosphorus. The authors discuss these interactions in changing redox conditions and point out that further research is needed to understand how consistently the cycles are coupled in natural environments [4].

These interactions matter in soils, wetlands and sediments, where oxygen levels can change across small distances or over time. They show why carbon, nitrogen and sulphur cycles are best understood as connected processes rather than as completely separate systems.

Iron-bearing minerals can provide surfaces for chemical reactions and can also act as electron acceptors in waterlogged soils and sediments. When oxygen becomes scarce, some microorganisms use Fe(III) minerals while breaking down organic matter. If oxygen later becomes available, Fe(II) can be oxidized again. Such changes may affect the chemical forms and availability of carbon, nitrogen and sulphur. These are conceptual links discussed in the supplied review; they should not be taken as one fixed sequence that occurs in every environment.

CONSERVATION AND SUSTAINABLE MANAGEMENT

Managing natural resources sustainably requires decisions that consider several environmental effects at once. Mining plans should limit land disturbance, pollution and waste, and include rehabilitation and follow-up monitoring. Forest management should protect native species, maintain soil cover and watershed functions, and support the continued supply of forest products. Involving local communities and recognizing benefits that are not traded in markets can also lead to better decisions.

Nutrient losses can be limited by controlling erosion, retaining vegetation, applying fertilizers carefully, treating wastewater and reducing emissions from industrial activity and fuel use. Monitoring forest cover, soil conditions, water quality and carbon storage over time can help determine whether management measures are protecting ecosystem functions.

CONCLUSION

SYNTHESIS: RESOURCE USE AND ECOSYSTEM FEEDBACKS

Resource

use affects ecosystems through connected flows of matter and energy. Mining can change vegetation cover, soil structure and drainage, with possible effects on forest growth and the movement of nutrients into streams. Forest removal reduces carbon storage and changes the amount of litter returned to the soil. Excess nitrogen and sulphur emissions can also alter water and soil chemistry. These links support an integrated approach that considers mine planning, forest conservation, pollution prevention and material recovery together.

Mineral resources, forests and biogeochemical cycles are connected parts of the environment. Minerals provide materials needed for industry and infrastructure, although extracting them can disturb land, water and habitats. Forests supply products and support livelihoods while storing carbon, providing habitats and helping recycle nutrients. Carbon, nitrogen and sulphur move through biological, chemical and geological processes, and human activities can change the balance of these cycles. The studies reviewed here highlight the economic contribution of forests, the influence of climate and soil on nutrient cycling, and possible links between iron redox reactions and the cycles of carbon, nitrogen and sulphur. Long-term resource management therefore depends on reducing pollution, restoring damaged ecosystems and using scientific evidence when making decisions.

REFERENCES

[1] H. Gundimeda, P. Sukhdev, R. K. Sinha, and S. Sanyal, “Natural resource accounting for Indian

ISSN: 3139-0862

states—Illustrating the case of forest resources," Ecological Economics, vol. 61, pp. 635–649, 2007, doi: 10.1016/j.ecolecon.2006.07.035.

X. SYNTHESIS: RESOURCE USE AND ECOSYSTEM FEEDBACKS

XI. CONCLUSION[4] Y. Li, S. Yu, J. Strong, and H. Wang, "Are the biogeochemical cycles of carbon, nitrogen, sulfur, and phosphorus driven by the 'FeIII–FeIredox wheel' in dynamic redox environments?" Journal of Soils and Sediments, vol. 12, pp. 683–693, 2012, doi: 10.1007/s11368-012-0507-z. (Supplied 2012JSS-YCLI.pdf.)

Source-scope note: The supplied NRAIndia_bk.pdf and forest nutrient-cycling papers support the forest and biogeochemical discussion. The supplied set does not contain a dedicated mineral-resource paper; Section II is general environmental-studies background and should be supplemented with a course textbook or mineral-resource reference if formal source coverage is required.