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1 Overviews

1.1 Introduction

Humans have developed an exceptional ability to adapt to a wide range of atmospheric, terrestrial, aquatic, and climatic conditions encountered on Earth. From early emergence in primordial environments to the establishment of complex societies, humanity has progressively expanded its ecological niche and exerted a profound influence on planetary systems. Unlike other species, this transformation has occurred with unprecedented speed and magnitude, driven by advanced cognitive abilities, technological innovation, and organized social structures. While these capacities have enabled remarkable progress, they have simultaneously produced large-scale environmental modifications that increasingly threaten the stability of life-support systems essential for human survival.

The central challenge confronting modern societies lies in reconciling continued technological and economic development with the preservation of the environmental systems upon which life depends. Environmental compartments such as the atmosphere, hydrosphere, and lithosphere are highly interconnected, and disturbances within one component can propagate through others, generating complex and often unforeseen consequences. For example, although the total volume of the global ocean cannot be significantly reduced, its chemical integrity can be severely compromised by pollution, affecting marine ecosystems, biogeochemical cycles, and climate regulation. Environmental degradation is a major driver of social, economic, and health-related problems. Chemistry, as a holistic scientific discipline, plays a critical role in identifying pollutants, understanding their behavior, and proposing solutions. This knowledge is not confined to scientific communities but is equally essential for decision-makers and policymakers who must evaluate competing claims, interpret uncertain data, and anticipate the long-term consequences of environmental stress. However, the inherent complexity of environmental processes often generates uncertainty, which can foster public mistrust and the rejection of scientifically robust findings, particularly when they conflict with political or ideological beliefs.

In this discussion, the environment is defined specifically as the physicochemical systems of the atmosphere, hydrosphere, and lithosphere that sustain life. Cultural, aesthetic, and social dimensions of the environment, while important, fall outside the scope of this analysis. Ecological interactions are addressed only insofar as they intersect with physicochemical processes, while acknowledging that living organisms have played a decisive role in shaping Earth's system, most notably through the biological production of atmospheric oxygen via photosynthesis.

1.2 Importance of Environmental Chemistry

Nearly all phenomena occurring in the natural world can be interpreted through the framework of environmental chemistry. Countless chemical reactions take place continuously within the atmosphere, oceans, rivers, soils, and living organisms, many of which occur autogenically without direct human intervention. Human activities introduce additional compounds, energy fluxes, and disturbances into these systems, often at rates that exceed natural buffering capacities. Consequently, addressing environmental challenges requires more than the identification of substances released into the environment; it necessitates an understanding of the fundamental laws governing their transformation, transport, interaction, accumulation, and persistence.

Earth functions as a closed system with respect to matter, where energy enters primarily through solar radiation and exits as heat, while most material elements are continuously recycled. Elements such as carbon, nitrogen, sulfur, and phosphorus circulate through interconnected atmospheric, aquatic, terrestrial, and biological reservoirs. Environmental chemistry investigates these biogeochemical cycles, focusing on the sources, pathways, transformations, and ultimate fate of chemical species, whether naturally occurring or anthropogenic.

The discipline is inherently interdisciplinary, integrating concepts and methods from chemistry, biology, toxicology, hydrology, meteorology, geology, and public health. It encompasses the monitoring of pollutants such as sulfur dioxide, nitrogen oxides, hydrocarbons, heavy metals, and persistent organic pollutants, as well as the evaluation of their environmental and health risks through exposure assessment, comparative toxicology, and ecotoxicological studies.

Contemporary environmental chemistry increasingly emphasizes preventive and solution-oriented approaches. Green chemistry seeks to minimize environmental harm by designing safer chemicals, improving energy efficiency, and replacing toxic or non-renewable materials with sustainable alternatives. These efforts have contributed to significant achievements, including the phase-out of ozone-depleting chlorofluorocarbons, the development of cleaner fuels, improved waste treatment technologies, and innovations in renewable energy systems such as solar cells, advanced batteries, and hydrogen fuel technologies. By integrating scientific understanding with technological innovation, environmental chemistry provides a foundation for reducing environmental risk while supporting sustainable development.

1.3 Definition and Components of the Environment

The concept of the environment is multifaceted and encompasses the physical, chemical, and biological factors and their interactions that sustain life on Earth. While the term may include social and built environments, it is most commonly associated with the natural environment, which comprises living organisms and the abiotic conditions that support them. Institutional definitions, such as those proposed by European and American environmental agencies, consistently emphasize air, water, land, and their complex interconnections as determinants of human and ecological well-being. Environmental components are traditionally classified into abiotic and biotic factors, each playing a critical role in ecosystem structure and function.

1.3.1 Abiotic Components

Abiotic factors are the non-living elements of the environment that strongly influence an organism's survival, distribution, and productivity. These factors are generally divided into physical and chemical components. Physical variables include temperature, water availability, light, and soil properties. Temperature varies widely across the planet, from polar extremes to desert and geothermal environments, and species exhibit differing degrees of tolerance. Eurythermal species tolerate broad temperature ranges, whereas stenothermal species survive only within narrow limits.

Water availability is a fundamental determinant of life. Freshwater influences plant productivity, animal survival, and ecosystem distribution, while water quality parameters such as salinity and chemical composition further constrain biological communities. Light provides the primary energy source for photosynthesis and regulates biological rhythms, while soil characteristics such as texture, pH, nutrient content, and water-holding capacity determine vegetation patterns and indirectly influence animal populations.

Organisms respond to variation in abiotic conditions through several adaptive strategies. Regulation involves maintaining internal stability through physiological or behavioral mechanisms, as seen in birds and mammals. Conformation occurs when internal conditions vary in response to external environments, a common strategy among plants and many aquatic organisms. Migration allows temporary relocation to favorable habitats, while dormancy enables survival during adverse periods through reduced metabolic activity.

1.3.2 Chemical Variables

Chemical components of the environment include essential inorganic substances such as water, oxygen, carbon, nitrogen, sulfur, phosphates, and metal ions, which are indispensable for biological processes. Organic compounds, including carbohydrates, proteins, and lipids, form the structural and energetic basis of living organisms and mediate interactions between biotic and abiotic systems.

1.3.3 Biotic Components

Biotic components consist of all living organisms within an ecosystem. Autotrophs, such as terrestrial plants and aquatic phytoplankton, synthesize organic matter from inorganic sources and constitute the foundation of food webs. Heterotrophs consume organic matter produced by others and occupy successive trophic levels, including herbivores, carnivores, and top predators. Decomposers play a crucial role by breaking down dead organic material and recycling nutrients through mineralization, thereby sustaining ecosystem productivity.

1.4 Human Interactions with the Environment

Human interactions with the environment have evolved throughout history, from small-scale subsistence activities to large-scale industrial transformations. Environmental conditions have influenced settlement patterns, cultural practices, and economic activities, while human actions have reshaped landscapes through agriculture, urbanization, and resource extraction.

Industrialization marked a critical turning point by greatly amplifying the scale and intensity of environmental impacts. Mechanized forestry, chemical-based agriculture, mining, and industrial production increased resource extraction and waste generation. Human–environment interactions are therefore primarily characterized by the use of natural resources and the production of wastes and pollutants, with both beneficial and detrimental consequences for human societies.