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Environmental and Ecological Concepts

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Dedication

This work is dedicated to two great men:

Sheikh Diab Abu Naib Badi

According to an oral narration, about a century after the death of Sheikh Ajeeb Al-Manjilak in 1612, Sheikh Diab Abu Naib Badi, around the year 1708, ordered that Grey-leaved saucer berry (*Cordia sinensis*) timber be brought from the Dinder region—now part of the Dinder National Park—to renovate the roof of the Sheikh’s mausoleum.

The camels that were supposed to carry the timber were frightened by the roaring of lions and fled away. With no other option, the man entrusted with the task loaded the timber onto elephants instead. He drove the elephants along the right bank of the Dinder River until they reached the Blue Nile. From there, they continued along the eastern bank of the Blue Nile and then along the eastern bank of the Nile, eventually arriving at the village.

After the timber had been unloaded, Sheikh Diab ordered that the elephants be returned to their natural habitat. What a remarkable example of environmental awareness and respect for wildlife, especially for that time.

An anonymous sheikh

A sheikh from the Butana region, known for his sense of nature conservation, strictly prohibited cutting green trees or their branches, allowing only the use of dead trees and dry wood as fuel and part of housing material. When a man violated this rule “around 1904”, the sheikh imprisoned him for one year in a detention house. Afterwards, he sent a letter to the Commissioner of Khartoum North, requesting the man’s imprisonment for an additional six months for discourteous of his ordinance and so it was. As further punishment, the sheikh ordered the offender to walk the entire 100km on foot.

Introduction

Environmental and ecological sciences provide the analytical basis for understanding interactions between human societies and natural systems. They are integral to advancing sustainable development, which aims to satisfy present needs and the right of future generations to access vital resources. Modern-day pressures, industrial expansion, urbanization, and intensive agriculture have intensified pollution, accelerated ecosystem decline, and driven unsustainable resource use. These trends are related to negligence of environmental considerations within development strategies and policy frameworks. As global environmental concerns grow, sustainability has become a central priority for international institutions, financial bodies, and developmental partners. Ensuring ecological integrity now directly influences food and water security, public health, and long-term economic resilience. In response, many nations are formulating coordinated plans to conserve ecosystems, rehabilitate damaged landscapes, and promote responsible resource management, often in collaboration with national, regional and global organizations. Scientific research formulates evidence-driven solutions, supporting biodiversity conservation, efficient resource use, and the adoption of sustainable practices. Yet societal engagement remains equally vital; enduring environmental progress requires enlightened communities committed to and supports fully responsible environmental actions. This book examines the evolving relationship between humanity and the natural world, presenting essential environmental concepts to support policymakers, practitioners, and students. It emphasizes the growing interconnection between environmental challenges and political, economic, and social decision-making at all levels. It also incorporates emerging concepts, such as green economy, environmental governance, climate neutrality, and environmental justice, that increasingly frame global environmental discourse. Additionally, it explores future-oriented topics, including human expansion into deep-sea and extraterrestrial environments, and the associated physiological, ecological, and contamination risks.

Concepts

Abiotic factors refer to the non-living physical and chemical components of an ecosystem that significantly influence the structure, function, and dynamics of the biological communities within it. These factors include, but are not limited to, air (atmospheric gases), water (hydrosphere), soil (lithosphere), sunlight (solar radiation), temperature, pH, salinity, and nutrient availability. Abiotic factors are critical determinants of ecosystem health and productivity. They not only support the base of the food chain (primary producers) but also shape the broader ecological interactions and biogeochemical cycles that sustain life on Earth.

Acid rain refers to any form of precipitation—rain, snow, fog, or dew—with a pH lower than 5.6, indicating increased acidity. This acidic precipitation significantly alters the natural pH of water bodies and soils, often reaching levels harmful to both aquatic and terrestrial organisms, as well as human health.

Acid rain forms when gaseous oxides of sulfur (SO_2), nitrogen (NO_x), and carbon (mainly CO_2) are released into the atmosphere, primarily through anthropogenic activities such as the combustion of fossil fuels (coal, oil, and gas), industrial emissions, and vehicle exhaust. Although some natural sources like volcanic eruptions also emit these gases, human activities remain the dominant contributor.

Once in the atmosphere, these gases undergo chemical reactions with water vapor (H_2O), oxygen (O_2), and other atmospheric compounds, leading to the formation of sulfuric acid (H_2SO_4) and nitric acid (HNO_3). These reactions are catalyzed by sunlight (UV radiation) and elevated temperature, accelerating the formation of acidic compounds that are then deposited as precipitation. Acid rains has impact on aquatic ecosystems, forests and vegetation, on soil chemistry, wildlife and herbivores, cultural heritage and infrastructure.

1. When acid rain enters rivers, lakes, or wetlands, it lowers the pH of water bodies, adversely affecting aquatic life. Many species, especially fish and invertebrates, have narrow pH tolerance ranges and may experience stress, reproductive failure, or

death in acidic conditions.

2. Acid rain damages foliage by leaching nutrients such as calcium and magnesium from the leaves and soil. It also causes physical deterioration of leaf surfaces, leading to premature leaf drop and reduced photosynthetic capacity. The leaching of essential minerals also weakens trees, making them more susceptible to disease and harsh weather.

3. Soil Chemistry: Acid deposition increases soil acidity, disrupting microbial communities and nutrient cycles. It dissolves beneficial nutrients (e.g., calcium, potassium) and mobilizes toxic metals such as aluminum, which impair root water uptake and further hinder plant growth.

4. A reduction in calcium content in grasses and leaves due to acid saturation can impact herbivorous animals, such as deer and cattle. Additionally, birds may lay eggs with thinner shells, making them more vulnerable to predation and environmental damage.

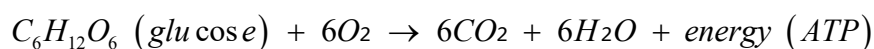
5. Cultural Heritage and Infrastructure: Acid rain accelerates the weathering of buildings, monuments, and archaeological structures, particularly those made from limestone (calcium carbonate), marble, and gypsum. The acidic components react with minerals in these materials, leading to erosion, pitting, and structural degradation.

Activated carbon refers to a highly porous form of carbon with exceptional adsorptive properties, used extensively in water and air purification systems. It consists of granules or powders with a vast surface area, capable of adsorbing a wide range of organic contaminants, impurities, and some low-molecular-weight heavy metals.

By trapping pollutants on its surface through physical adsorption and chemical interactions, activated carbon functions as an effective filtration medium, improving water quality and making it suitable for domestic, industrial, and environmental use.

Aeration is the process of introducing air into water to increase its oxygen content through physical mixing or dissolution. This process facilitates the oxidation of certain dissolved metals (e.g., iron and manganese), promotes the release of dissolved gases (such as carbon dioxide and hydrogen sulfide), and aids in the volatilization of some organic compounds. In aquaculture, aeration significantly enhances water quality and supports higher metabolic activity and growth rates in fish, thereby improving overall system productivity.

Aerobic respiration is a metabolic process in which cells utilize oxygen to convert glucose into usable energy in the form of adenosine triphosphate (ATP). This process occurs in most eukaryotic organisms and is essential for sustaining vital cellular functions. The end products of aerobic respiration are carbon dioxide (CO₂), water (H₂O), and energy (ATP), which is used to drive various biological processes. The overall chemical equation for aerobic respiration is:



This reaction primarily takes place in the mitochondria and consists of three main stages: glycolysis, the citric acid cycle (Krebs cycle), and oxidative phosphorylation.

Aerosols are suspensions of fine solid particles or liquid droplets in a gas, typically in the atmosphere. Common examples include dust, mist, smoke, and fumes. Aerosols can originate from natural sources—such as volcanic eruptions, sea spray, and biological emissions—or from anthropogenic activities, including industrial processes, combustion of fossil fuels, and agricultural practices. They play a significant role in atmospheric chemistry, climate regulation, and public health.

Aestivation is a physiological adaptation employed by certain animals to survive prolonged periods of high temperatures and arid conditions, particularly in tropical and subtropical regions. This state of dormancy is characterized by significantly reduced metabolic activity, decreased physiological functions, and prolonged inactivity during hot and dry seasons.

Species known to aestivate include certain terrestrial snails, lungfish, amphibians such as frogs, some bees, and the rock squirrel. During aestivation, these organisms minimize water loss, avoid cellular damage caused by thermal stress, and conserve energy by relying on internal energy reserves. This strategy enhances survival by allowing the organism to maintain homeostasis until environmental conditions become favorable again.

Air quality standards are regulatory limits established to define the maximum allowable concentrations of specific air pollutants in the atmosphere, aimed at protecting human health, ecosystems, agricultural productivity, and materials. These standards are based on scientific evidence regarding the health and environmental impacts of air pollution and are enforced by national and international agencies.

Key pollutants regulated under air quality standards include ground-level ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and lead (Pb). For example, exposure to nitrogen dioxide (NO_2) is recommended not to exceed a concentration of $80\mu g/m^3$ averaged over a 24-hour period, to minimize the risk of respiratory and cardiovascular harm, particularly in vulnerable populations.

These standards serve as benchmarks for environmental monitoring and policy implementation to ensure sustainable air quality and public safety.

Algae are diverse, primarily aquatic, photosynthetic organisms that contain chlorophyll and other pigments enabling them to convert sunlight into chemical energy. They can exist as free-floating (planktonic) forms or be attached to substrates such as rocks, sediments, or aquatic vegetation. Algae thrive in water bodies that receive adequate sunlight and contain sufficient nutrients.

The group “algae” encompasses a wide range of organisms, from microscopic unicellular species like *Chlorella* and diatoms, to large multicellular forms such as giant kelp. In marine environments, the largest and most complex algae are commonly referred to as seaweeds, while in freshwater systems, filamentous green algae like *Spirogyra* are commonly found.

Phytoplankton, a type of microscopic algae, plays a crucial role in maintaining the ecological balance of aquatic ecosystems. Through photosynthesis, phytoplankton absorb carbon dioxide and release oxygen, contributing significantly to global oxygen production. Additionally, they form the base of the aquatic food web, serving as a primary food source for many fish and invertebrate species.

However, excessive algal growth—often due to nutrient enrichment (eutrophication)—can degrade water quality. Dense algal blooms can alter the taste and odor of drinking water and may react with disinfectants like chlorine to form harmful byproducts. Moreover, algal overgrowth can reduce sunlight penetration and oxygen levels in the water, negatively impacting submerged aquatic vegetation and fish populations.

Allopatric describes populations or closely related species of plants or animals that are geographically isolated from one another by an extrinsic physical barrier, such as a mountain range, body of water, or desert. This spatial separation prevents gene flow between the groups, resulting in no overlap in their natural ranges. Classical examples include Darwin’s finches and the gazelle populations in the Dahlak Archipelago of Eritrea and those found along the Eritrean coast.

Alluvium refers to unconsolidated sediment composed of a mixture of clay, silt, sand, gravel, and varying amounts of organic matter, which is transported and deposited by running water. These deposits typically accumulate in riverbeds, floodplains, alluvial fans, and occasionally along beaches. Alluvial soils are geologically young and are continuously replenished by fluvial processes, making them dynamically rich in nutrients.

Chemically, alluvial soils are often fertile due to their high content of essential minerals such as potassium, phosphate, copper, zinc, and lime. They typically exhibit a slightly alkaline pH range (approximately 7.5 to 8.0), which enhances nutrient availability

and supports microbial activity, both critical factors for healthy plant growth. Because of these characteristics, alluvium forms some of the most agriculturally productive soils, particularly in river valleys and delta regions.

Ambient temperature refers to the temperature of the surrounding air, environment, or medium in a specific location. It is influenced primarily by the prevailing climatic and meteorological conditions. Ambient temperature plays a critical role in various applications and can be regulated or controlled within enclosed spaces—such as buildings, laboratories, storage facilities, or food display units—to achieve desired thermal conditions. Adjusting ambient temperature is essential to meet requirements related to human health and comfort, optimize production processes, preserve stored materials, and ensure accuracy in experimental settings.

Anaerobic respiration is a metabolic process in which certain bacteria and other microorganisms generate energy in the absence of molecular oxygen (O_2), utilizing alternative electron acceptors such as nitrate (NO_3^-), sulfate (SO_4^{2-}), or carbon dioxide (CO_2). This process is essential in various biogeochemical cycles, including the nitrogen cycle, where specific microbial communities facilitate the oxidation of ammonium (NH_4^+) and the reduction of nitrates. In water treatment systems, anaerobic bacteria play a critical role during filtration by colonizing specific anaerobic zones within filters. These microorganisms degrade organic matter and contribute to the production of biogas—primarily composed of methane (CH_4) and carbon dioxide—through anaerobic digestion, offering both waste reduction and energy recovery benefits.

Animal migration is a seasonal, often long-distance movement of species from one habitat or ecoregion to another, typically driven by changes in food availability, breeding needs, or environmental conditions. Migratory species span various taxa, including arthropods (e.g., grasshoppers), fish (e.g., eels), amphibians, marine turtles, birds, and mammals. For example, Atlantic salmon migrate from freshwater rivers—where they hatch—to the ocean, and return to their natal rivers upon reaching reproductive maturity to spawn.

Animal sanctuary is a secure and regulated facility established to provide permanent care and refuge for wild animals that cannot be reintroduced into their native habitats due to injury, captivity, habitat loss, or other limiting factors. These sanctuaries are designed to minimize anthropological stressors and environmental hazards, while simulating key aspects of the animals' natural ecosystems to support species-appropriate behaviors. Animals housed in sanctuaries receive continuous veterinary oversight, species-specific nutrition, and behavioral enrichment programs, all aimed at maintaining optimal physical health and psychological welfare.

Aquaponic is an integrated, sustainable system combining aquaculture and hydroponics. Nutrient-rich water from fish or other aquatic animals, containing ammonia and other nitrogenous compounds, is converted by nitrify bacteria into nitrates, which supply essential nutrients to hydroponically grown plants. The plants absorb these nutrients, purifying the water for recirculation to the aquaculture unit. Aquaponic systems are commonly categorized as media-based beds, floating rafts, or nutrient film technique, with media-based systems exhibiting higher nitrogen utilization due to increased surface area for microbial activity. This closed-loop approach enhances water efficiency, supports high-density food production, and minimizes reliance on synthetic fertilizers, promoting sustainable urban and semi urban agriculture.

Aquifer is a subsurface geological formation consisting of permeable materials such as rock, sand, or gravel, capable of storing and transmitting significant quantities of groundwater. These formations function as natural reservoirs, supplying water through natural discharge points like springs, as well as through human-engineered systems such as wells and artesian boreholes. Excessive or unregulated groundwater extraction from aquifers can result in a decline in water table levels, reduction in water quality, land subsidence, and disruption of connected surface water systems, posing long-term environmental and geotechnical risks.

Arctic region refers to the polar region located at the northernmost part of the Earth, encompassing the Arctic Ocean, surrounding seas, and adjacent terrestrial areas. This region includes portions of Canada, Greenland, Iceland, Norway, Sweden,

Finland, Russia, and the United States (Alaska). The Arctic landscape is characterized by seasonally variable snow and sea ice cover, with extreme winter temperatures typically ranging from -29°C to -54°C .

Despite its harsh climatic conditions, the Arctic supports over 21,000 known species. These include cold-adapted organisms such as lichens, mosses, fungi, grasses, herbaceous plants, dwarf shrubs, various invertebrates, and numerous vertebrate species. Notable Arctic fauna include Arctic foxes, musk oxen, walruses, polar bears, and a wide range of fish and migratory bird species, all of which have evolved unique adaptations to survive in this extreme environment (Figure 1).



Figure 1:

Artesian water refers to groundwater that is confined under pressure within a permeable aquifer, bounded above and below by layers of impermeable rock or clay. When a well taps into this confined aquifer, the internal hydrostatic pressure may be sufficient to force the water to rise naturally toward or above the land surface, resulting in a flowing artesian well or spring.

In some cases, artesian water may be extracted through mechanical pumping, especially when the natural pressure is insufficient for surface discharge. A system of aquifers, particularly unconfined or water table aquifers, occurs when the upper surface of groundwater (the water table) is in equilibrium with atmospheric pressure. Recharge of both confined and unconfined aquifers typically occurs through the natural percolation of precipitation and surface water, driven by gravitational forces (Figure 2).

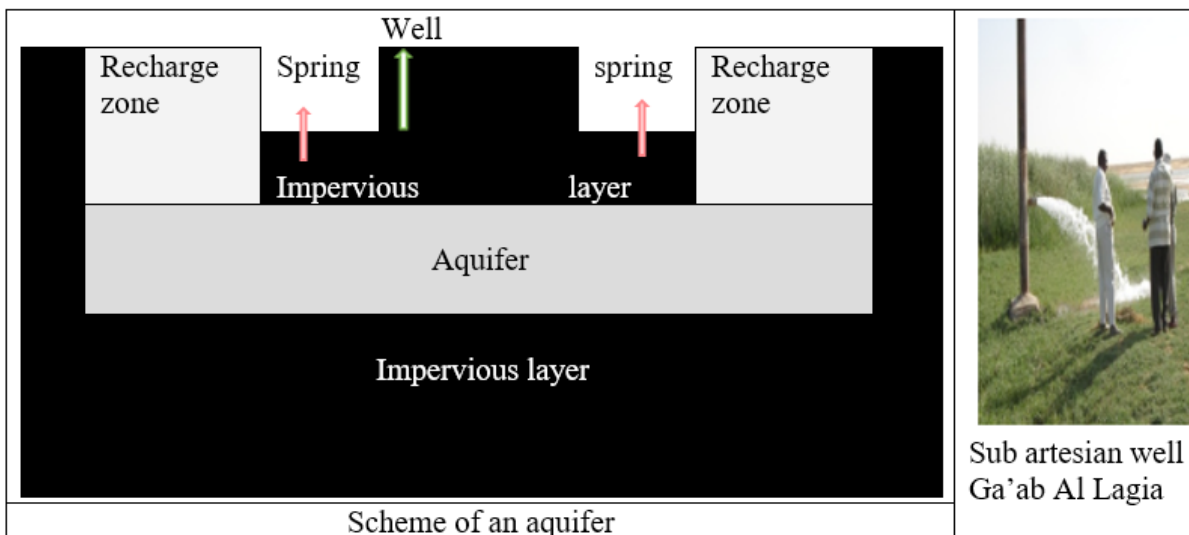


Figure 2:

Artisanal mining: Artisanal mining is a subsistence activity practiced by a person or a group of peoples. Simple tools are used to extract gold, gemstones, cobalt, tin, tungsten etc. from the earth. These miners do not have licenses to carry out extraction, which results in destructive impacts on the environment. They use mercury and cyanides in extraction of gold from the ore. This leads to intoxication of workers and contamination of the nearby water bodies.

Atmosphere is the gaseous envelope surrounding Earth, held in place by the planet's gravitational field. It is stratified into five distinct layers, each characterized by differences in thickness, temperature, density, chemical composition, and dynamic behavior. These layers are:

1. Troposphere is the lowest and densest layer of the atmosphere, containing approximately 75% of the atmospheric gases, including significant amounts of water vapor and aerosols. It extends from the Earth's surface up to about 18–20 km near the equator and approximately 6 km near the poles. This layer is where most weather phenomena occur, and air density decreases with altitude, causing the air to become progressively thinner.
2. Stratosphere is located above the troposphere; the stratosphere contains about 19% of atmospheric gases and very low concentrations of water vapor. Unlike the troposphere, temperature increases with altitude due to the absorption of ultraviolet radiation by the ozone layer, which releases heat during ozone formation.
3. Mesosphere is the coldest atmosphere layer. It exhibits decreasing temperatures and gas density with altitude. Extending roughly from 50 km to 85km above the surface, this layer is where most meteoroids burn up upon entry, preventing them from reaching the Earth's surface.
4. Thermosphere gas density continues to decline with altitude. The thermosphere absorbs high-energy ultraviolet and X-ray radiation from the Sun, causing temperatures to rise significantly with height. A sublayer within the thermosphere, known as the ionosphere, contains ionized particles that reflect and modify radio waves, facilitating long-distance communication.
5. Exosphere releases gradually escape into space from its outermost layer gas molecules. The exosphere is characterized by extremely low densities of helium and hydrogen atoms, along with higher relative concentrations of nitrogen, oxygen, and carbon dioxide. During intense solar storms, the absorption of shortwave solar radiation can raise temperatures in this layer to approximately 1700°C (Table 1).

Table 1:

Space				
Km	Layer	°C	Gas	%
700-10000	Exosphere	0-1700	Dry	
80-700	Thermosphere	120-2000	Nitrogen	78
			Oxygen	20.9
			Argon	0.9
			Carbon dioxide	0.04
			Neon + Helium + Krypton + Methane	0.001
50-80	mesosphere	90-143	Wet	
12-50	Stratosphere	15-51	Water vapor	0-3
0-12	Troposphere	17-5	Composition of troposphere.	
Thickness of layers, not drawn to scale.				

Atoll is a ring-shaped coral reef island that partially or completely encircles a central lagoon, typically formed from the subsidence of a volcanic island surrounded by coral growth. Over time, as the volcanic island erodes and sinks, the coral continues to grow upward, maintaining the circular structure and enclosing the lagoon.

Sanganab Atoll, located in the Red Sea off the coast of Sudan, is the only known atoll in this region. It was designated a Marine Protected Area in 1990 due to its rich biodiversity and ecological significance. In 2016, it was recognized as a UNESCO International Heritage site (Figure 3).

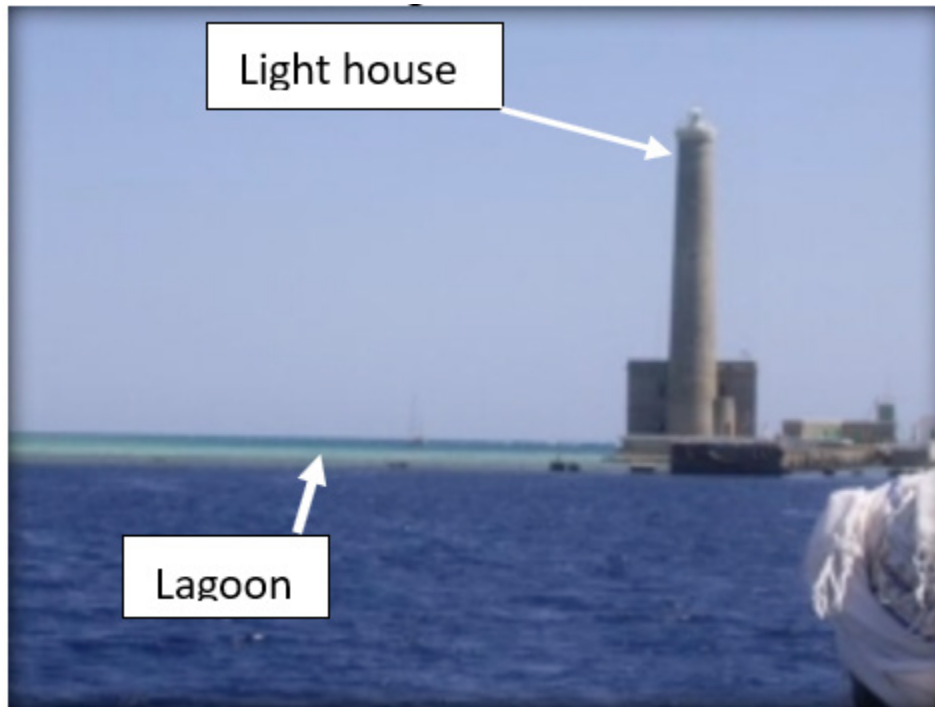


Figure 3: Sanganab atoll east of Port Sudan, Red Sea.

Backwater refers to a section of a river, stream, or other flowing waterbody where the current is significantly reduced or stagnant. This hydrological phenomenon often occurs when water is diverted from the main flow due to natural or anthropogenic alterations in the river's morphology or flow dynamics. It is typically formed in: areas where flow is obstructed or diverted, such as:

1. **Sides of peninsulas** or islands, where the main current bypasses and creates a calm pool.
2. **Floodplains** and **oxbow lakes**, remnants of meandering rivers cut off from the main channel.
3. **Human-made structures**, such as dams, weirs, culverts, or embankments, can alter hydrodynamics and lead to artificial backwaters.
4. **Vegetative blockage**, especially from aquatic macrophytes, fallen trees, or accumulated detritus, can obstruct flow and generate stagnant zones.

The reduction in current velocity promotes sedimentation, leading to fine silt and organic matter accumulation, which influences the ecological character of the backwater.

Backwaters serve as unique ecological niches and are often characterized by:

1. **Low flow and high nutrient retention**, supporting the growth of aquatic vegetation and providing cover and food for aquatic organisms.
2. **Thermal stability**, which can be beneficial for certain ectothermic (cold-blooded) organisms.
3. **Oxygen gradients**, where stratification can occur due to low turbulence, especially in deeper or shaded backwaters.
4. **4.Fish breeding and nursery habitats**: Species like tilapia and catfish utilize backwaters for spawning due to the calm environment and abundant plant cover. Eels and other species with benthic or ambush-feeding behavior prefer these areas because of low disturbance and ample hiding spots.
5. **Amphibians and aquatic invertebrates**, such as dragonfly larvae, thrives therein.
6. **Human Uses and Management Implication** included recreational activities, angling, bird watching, flood mitigation and water quality management.

Ballast water refers to fresh, brackish, or saltwater that is taken into the ballast tanks of ships to provide stability during voyages. Its primary function is to compensate for changes in cargo load, fuel consumption, and ocean conditions by maintaining a ship's balance and hydrodynamic performance. When cargo is unloaded, ballast water is taken on to maintain draft and stability. Conversely, ballast water is discharged when cargo is loaded. This process poses significant ecological risks, due to the translocation of aquatic organisms, including bacteria, algae, plankton, invertebrates, and larvae of larger species. These organisms can survive and become invasive species when discharged into non-native environments. Invasive species may outcompete native biota, disrupt local ecosystems, alter food webs, introduce novel pathogens, and cause economic damage to aquaculture.

To mitigate these risks, the International Maritime Organization, Convention, which came into force in 2017¹; requires ships to: Exchange ballast water at sea (at least 200 nautical miles from coast and in water at least 200 meters deep), or Treat ballast water using approved systems that may involve filtration, ultraviolet radiation, chemical disinfection, or deoxygenation, thereby reducing or eliminating viable organisms.

Barrier reef is a type of coral reef system that typically formed parallel to a continental shelf or island shoreline, but is separated from the coast by a lagoon, a relatively deep, calm body of water. Growth requires warm temperatures (generally 23–29°C), high light availability, low nutrient concentrations, and stable salinity. Barrier reefs are among the largest and most complex biogenic structures on Earth and are primarily composed of calcium carbonate (CaCO_3), secreted by colonies of scleractinian (stony) corals and other reef-building organisms such as coralline algae.

The formation process spans thousands to millions of years, beginning with fringing reefs that grow directly adjacent to a coast. As geological subsidence or sea-level rise occurs, the reef maintains upward growth, while the coastline recedes, eventually leading to the formation of a lagoon between the reef and the shore, thus forming a barrier reef.

Barrier reefs play a critical ecological role and provide numerous ecosystem services, including:

1. **Coastal protection**: The reef structure acts as a natural barrier, dissipating wave energy from storms, hurricanes, and high tides. This reduces coastal erosion, infrastructure damage, and saltwater intrusion into coastal freshwater systems.
2. **Biodiversity hotspots**: Barrier reefs support highly diverse ecosystems, hosting thousands of marine species making them important centers of marine biodiversity.
3. **Carbon cycling**: Coral reefs play a role in biogeochemical cycling, especially the carbon cycle, through calcium carbonate deposition and organic productivity.

4. Economic and Societal Importance:

- a) They provide breeding and nursery grounds for many commercially important fish species, supporting subsistence and commercial fishing industries.
- b) Marine organisms from reef ecosystems have been sources of biologically active compounds including anti-cancer, anti-inflammatory, and antibacterial agents.
- c) Barrier reefs, are tourist destinations. Activities like scuba diving, snorkeling, and eco-tourism generate revenue and create employment opportunities.

Despite their importance, barrier reefs are highly vulnerable to environmental stressors such as:

coral bleaching (caused by rising sea temperatures), ocean acidification (which impairs calcification), pollution (from land runoff and plastic waste), overfishing, and physical destruction (from coastal development and unsustainable tourism) (Figure 4).



Figure 4: *Coptodon zillii* in courtship in a backwater at Gimai, Lake Nubia.

Bay is a coastal water body partially enclosed by land, with a wide opening that connects it to a sea or ocean. Bays are typically formed through geological processes such as the tectonic movement of Earth's lithospheric plates, erosion, and sea-level changes.

Historically, bays have been favorable locations for human settlement due to their rich marine resources, availability of food, natural protection from harsh sea conditions, and the economic opportunities provided by ports and maritime trade.

Depoe Bay in the United States is considered the smallest bay in the world, while the Bay of Bengal is the largest, occupying a vast area in the northeastern Indian Ocean.

Dungnab Bay is located along the Sudanese coast of the Red Sea, is ecologically and economically significant. Dungnab Bay, in particular, is known for its involvement in sustainable marine activities, including the cultivation of pearl oyster.

Bioaccumulation refers to the process by which the concentration of a substance increases within an organism over time to levels higher than those found in its surrounding environment. This occurs through direct absorption from the environment or indirectly through trophic transfer within the food chain. Substances such as heavy metals and persistent industrial compounds are often resistant to metabolic breakdown and are not readily excreted, resulting in their accumulation within biological tissues. The analysis of tissues from organisms such as fish or birds can serve as a bioindicator of environmental contamination by these toxicants.

Biocides are products used to control harmful living organisms that pose a threat to human health, crops, animals, or the environment, or that can damage human activities. These organisms include pests (such as insects, rats, or mice) and

microorganisms (such as bacteria, viruses, and molds). Biocidal products include: (a) Insecticides, (b) Insect repellents, (c) Disinfectants, (d) Preservatives for materials like wood, plastics, and fibers and (e) Anti-fouling paints used to protect ship hulls.

Biodegradable refers to any organic material capable of being broken down and assimilated by microorganisms such as bacteria and fungi. Through the process of biodegradation, these organisms convert the organic matter into simpler substances, primarily carbon dioxide (CO_2), water (H_2O), and inorganic minerals, under aerobic or anaerobic conditions.

Biodiversity is the diversity of life on earth from genes, species and ecosystem such as grasslands, estuaries and lakes. Its ecosystem services protect water resources; soils formation and protection; provide food, medicinal and pharmaceutical resources; scientific, research, education, cultural recreation and tourism values.

Biodiversity is measured by a variety of indices to describe its status (stable, flourishing or degrading) or species in a habitat.

Biodiversity is important to life as each species have a specific function to play in the ecosystem and its disappearance leads to ecosystem imbalance. Biodiversity is threatened by pollution, over grazing, over hunting over exploitation of resources among other reasons. Therefore, contribution towards nature recovery, enhancing existing habitats in which species can thrive and adapt to climate change is vital (Figure 5).

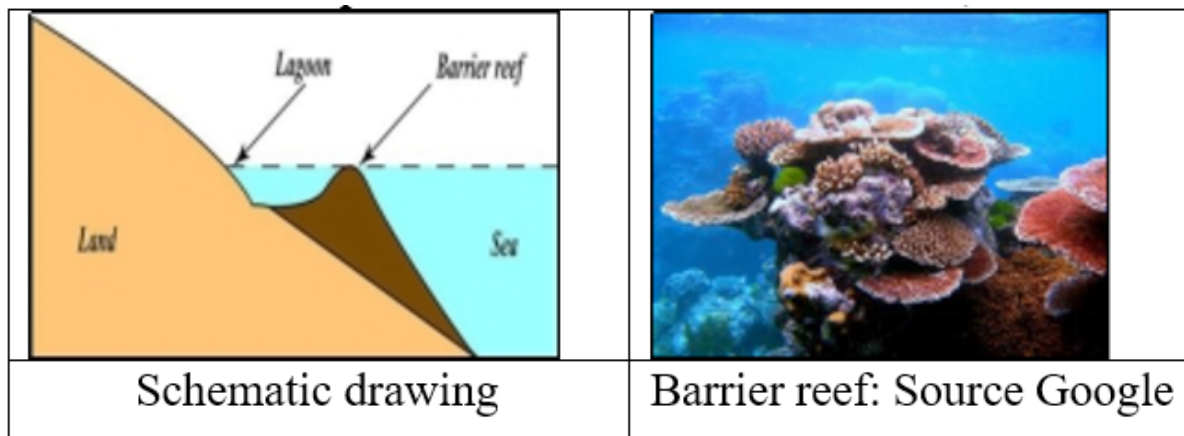


Figure 5:

Bioflicks technology (BFT) is a sustainable aquaculture approach that utilizes microbial biotechnology to enhance feed utilization and water quality. It promotes the formation of microbial aggregates (bioflicks) that convert organic waste, such as uneaten feed and excreta, into protein-rich biomass serving as supplementary nutrition for fish and crustaceans. By adding carbon sources, heterotrophic bacteria efficiently assimilate nitrogenous compounds, minimizing ammonia accumulation and improving water quality. BFT systems require minimal water exchange (<5% monthly), reducing environmental impact and resource use. This technology supports higher stocking densities, improves growth performance, strengthens immunity, and lowers disease incidence through natural microbial interactions and balanced nutrition.

Biogas is a renewable biofuel generated through the anaerobic digestion of organic matter—such as animal manure, sewage sludge, agricultural residues, and food waste—within oxygen-free, sealed reactors known as anaerobic digesters.

The primary component of biogas is methane (CH_4), typically comprising 50–75% of the gas mixture. Other constituents include carbon dioxide (CO_2), hydrogen sulfide (H_2S), water vapor, and trace amounts of siloxanes and other impurities.

Prior to utilization, biogas typically undergoes a purification or upgrading process to remove contaminants and adjust its composition to meet the quality standards of natural gas. This involves: desulfurization to remove H_2S , drying to eliminate

moisture and CO₂ to increase methane concentration.

The methane in purified biogas can be combusted or oxidized with oxygen to release energy in the form of heat. This energy can be used for: cooking and heating, electricity generation, fuel for vehicles (when compressed as biomethane).

Biogas is a sustainable environmentally friendly energy source as it:

1. Reduces greenhouse gas emissions by capturing methane that would otherwise be released from decomposing organic waste,
2. Supports waste management and nutrient recycling.
3. Provides a low-carbon alternative to fossil fuels without contributing significantly to air or water pollution.

Biogeography is the scientific study of the geographical distribution of biodiversity, including species, populations, communities, and ecosystems, and the environmental and historical factors that influence these patterns.

Biogeographical patterns are shaped by geographic gradients such as latitude, altitude, isolation (e.g., islands), and ecosystem type. As a result, the composition and abundance of living organisms often vary systematically across different regions of the Earth.

Biogeography is an interdisciplinary field that integrates concepts and data from multiple sciences, including:

1. Biology to understand species traits and adaptations.
2. Ecology to examine interactions within and between species and their environments.
3. Climatology to analyze the influence of temperature, precipitation, and climate regimes.
4. Geology and Paleontology to provide insights into continental drift, plate tectonics, and fossil records.
5. Taxonomy to classify and identifying species and their relationships.

Biogeographers use ecological and physiological constraints, such as temperature tolerance, water availability, and reproductive strategies, to explain the distribution and dispersal of species across various habitats.

Additionally, biogeography investigates the interactions between individuals, populations, and communities, as well as their relationships with abiotic factors (e.g., climate, topography, soil) and with human activities, such as habitat modification, species introduction, and climate change.

Biological control refers to the deliberate use of natural enemies such as predators, parasitoids, and pathogens, to suppress populations of invasive weeds, insect pests, and disease vectors. These biocontrol agents offer an environmentally sustainable alternative to chemical pesticides and often provide long-term population management of target species.

Natural enemies of weeds play a crucial role in limiting their spread and density. Several organisms have been successfully employed for weed control:

1. The fungus *Alternaria solani* is used to manage the aquatic weed *Salvinia* species.
2. Water hyacinth (*Eichhornia crassipes*) is targeted by weevils such as *Neochetina bruchi*, *N. eichhorniae*, and the moth *Sameodes albiguttalis*.

3. The planthopper *Megaelus scutellaris* is effective in controlling other invasive aquatic weeds.
4. The grass carp (*Ctenopharyngodon idella*) is widely introduced to consume freshwater aquatic vegetation.
5. Pathogens such as viruses, bacteria, and fungi are commonly used to control insect pests:
6. Viruses like *Nucleopolyhedrovirus* (NPV) and *Nucleopolyhedrosis* viruses are major natural regulators of moth populations.
7. Granuloviruses are effective against the larvae of various lepidopteran species.
8. Bacterial agents, such as *Bacillus thuringiensis* (Bt) and *B. sphaericus*, are widely used against caterpillars of butterflies and moths, as well as beetles.
9. At least 14 species of entomopathogenic fungi have been reported to infect aphids. *Beauveria bassiana* and *Lecanicillium* spp. are commonly used against aphids, thrips and weevils.
10. Numerous natural predators and parasitic insects contribute to pest control: Important predators of pests like whiteflies, mites, and thrips include species of *Encarsia*, *Eretmocerus*, and *Prospaltella*, along with various lady beetles, ground beetles, rove beetles, flower bugs, true bugs, and lacewings.
11. Parasitic wasps, such as *Aphidius colemani*, lay their eggs inside pest insects (e.g., aphids), effectively reducing pest populations in both greenhouse and outdoor setting.
12. Biocontrol agents are also employed to control vectors of human disease: The mosquitofish (*Gambusia affinis*) is an effective predator of mosquito larvae. In aquatic systems affected by schistosomiasis, the river prawn and the cichlid fish *Trematocranus placodon* help reduce disease transmission by feeding on infected snails, the intermediate hosts of the schistosome parasite.
13. Effective biological control requires active human management, which includes: Conservation and augmentation of existing natural enemies. Introduction and establishment of beneficial species through structured release programs. Ongoing monitoring and impact assessment to ensure ecological balance.
14. It is critical to assess the non-target effects of introduced biocontrol agents. In some cases, introduced species may adversely affect native or non-target organisms. Therefore, rigorous ecological risk assessments must precede any large-scale introduction to ensure that the benefits of biocontrol outweigh potential unintended consequences.

Biome: A biome is a large-scale ecological unit defined by its distinct climate, geography, and the specific plant and animal communities that are adapted to those environmental conditions. Biomes are primarily characterized by factors such as temperature range, soil type, availability of water, and light intensity. Organisms within a biome exhibit physiological, behavioral, and structural adaptations that enable them to survive and reproduce under those conditions. Biomes can span across multiple continents or several countries, depending on Africa, or the River Nile, biome, which traverses multiple countries in northeastern Africa. Biomes can encompass a range of ecosystems or habitats, including: Deserts, Freshwater systems, Marine and brackish water environments. Forests (tropical, temperate, boreal), Grasslands (savannas, prairies) and Tundra.

Examples of Biomes and Their Biodiversity:

1. Desert Biome – Sahara Desert. The Sahara Desert is one of the largest hot desert biomes, characterized by extreme aridity, high temperatures during the day, and low nighttime temperatures. Its flora includes drought-resistant species such as cacti, desert grasses, aromatic herbs, umbrella thorn acacia (*Acacia tortilis*), and the date palm (*Phoenix dactylifera*). The fauna is

adapted to scarce water and extreme temperatures, it includes scorpions, rattlesnakes, Fennec foxes (*Vulpes zerda*), and camels.

2. **Freshwater Biome – Nile River.** The Nile biome represents a freshwater ecosystem rich in biodiversity and essential for agriculture, transportation, and human settlement. Its flora includes phytoplankton, algae, water lilies (*Nymphaea* spp.), and reeds (*Phragmites* spp.). The fauna supports species such as freshwater crabs, various fish species, Nile crocodiles (*Crocodylus niloticus*), aquatic birds, and hippopotamuses (*Hippopotamus amphibius*).

3. **Marine Biomes** cover approximately 70% of Earth's surface and are the most biodiverse aquatic systems. Its flora area dominated by phytoplankton, macroalgae (seaweeds), seagrasses, and mangroves in coastal areas. Its flora exhibits high diversity, including protozoa and zooplankton, sponges, worms, crustaceans, mollusks, echinoderms, cartilaginous and bony fishes, sea turtles, marine birds, seals, dolphins, and whales.

Biomes function as critical ecological frameworks supporting biodiversity, nutrient cycling, and ecosystem services essential to life on Earth. Understanding their composition and interdependence is fundamental to ecological research and conservation efforts.

Bioregenerative life support refers to a life support system that utilizes biological processes—primarily involving plants, algae, and microorganisms—to regenerate essential resources for sustaining human life in closed environments such as spacecraft, space stations, or sea bed habitats. These systems aim to recycle air by converting carbon dioxide into oxygen via photosynthesis, purify water through biological filtration and transpiration, and produce food through controlled ecological agriculture. Unlike physico-chemical systems that rely on consumable supplies and hardware-based filtration, bioregenerative systems are designed for long-duration missions, offering sustainability, self-repair, and integration with ecological cycles. They play a critical role in future deep space exploration, enabling autonomy from earth resupply.

Bioproducts refer to materials, chemicals, and forms of energy that are derived from biological resources. These include natural polymers such as cellulose and lignin, as well as energy-rich compound like oils, fats, and waxes. Bioproducts encompass a wide range of biological materials including seeds, fruits, edible fungi, various plant and animal products, honey, milk, and dairy derivatives.

Bioproducts are renewable and sustainable, biodegradable or environmentally friendly (many types), reduce pollution and greenhouse gas emissions, lower dependence on non-renewable fossil resources and support a circular bioeconomy. Industries that utilize bioproducts are diverse and include sectors such as:

1. Biofuels such as ethanol, biodiesel for cars, buses, and generators; reduces dependence on fossil fuels.
2. Bioplastics including polylactic acid (PLA), polyhydroxyalkanoates (PHA) used in packaging, disposable cutlery, bottles, medical devices.
3. Biogas is mainly methane produced from animal manure or food waste used for cooking, electricity generation, and heating.
4. Biofertilizers species such as Rhizobium, Azotobacter and Mycorrhiza improves soil fertility and promote plant growth.
5. Biopesticides from *Bacillus thuringiensis* (Bt), and Neem-based pesticides etc., controls insect pests and plant diseases with almost no environmental impact.
6. Biopharmaceuticals including insulin, vaccines, monoclonal antibodies which are in use to treat diseases such as diabetes, infections, and cancer.
7. Industrial enzymes such as Amylase, Protease, Cellulase are used in detergents, food processing, textiles, paper, and biofuel production.

8. Biopolymers like Cellulose, Chitosan, etc. are used in biodegradable films, wound dressings, food packaging, and water treatment.
9. Single-Cell protein including yeast protein, spirulina are protein-rich food supplements and also used in aquaculture and dairy animal feed.
10. Fermented products preserve food in form of yogurt, cheese and vinegar, improving nutrition, and enhancing palatability and flavor.
11. Natural products industry based on gums, adhesives, natural dyes, and organic fertilizers.
12. Timber and wood products used in construction, furniture and paper production.

These industries demonstrate the sustainable use of renewable biological resources through traditional and modern technologies, with applications in agriculture, healthcare, energy production, food processing, manufacturing, and environmental management.

Biosphere: The biosphere comprises biota and their habitats and biomes, and abiotic factors that supply biota with nutrients and energy. The life in the biosphere span from the oceanic trenches to the tops of mountains. The biosphere is virtually an open system with regard to energy (solar energy and photosynthesis) and a closed one with regard to matter. The biosphere biota is well adapted with lithosphere, cryosphere, hydrosphere and atmosphere elements.

Biosphere reserves are designated areas that serve as sites for interdisciplinary research and experimentation aimed at understanding, managing, and conserving biodiversity, while promoting sustainable development. These reserves emphasize the complex interactions between human societies and natural ecosystems.

A typical biosphere reserve comprises three interrelated zones:

1. Core area is strictly protected region that contributes to the conservation of landscapes, ecosystems, species, and genetic diversity.
2. Buffer zone is surrounds or adjoins the core area, where activities compatible with conservation objectives (e.g., environmental education, ecotourism, and sustainable resource management) are permitted.
3. Transition area is the outermost part, where sustainable economic and human development is encouraged in harmony with nature.

Biosphere reserves contribute significantly to the conservation of ecological and cultural diversity, support research and monitoring, and enhance the socio-economic well-being of local communities. Conservation efforts can be strengthened through initiatives such as afforestation, water resource protection, habitat and species conservation, the promotion of environmentally responsible practices among local populations, and the deployment of well-trained and adequately equipped conservation personnel.

Use of biosphere renewable supplies of timber, fiber, food, fish and other goods must be under restrict measures. Pollution, intentional burnings, poaching, deforestation and mining must be strictly forbidden. In Sudan there is one Biosphere, Jebel Al Dayer Biosphere in North Kordofan (Figure 6).

Biotic components refer to all living organisms within an ecosystem, including viruses, bacteria, fungi, plants, and animals. These organisms play integral roles in ecological processes and are essential for the functioning of food chains and food webs.

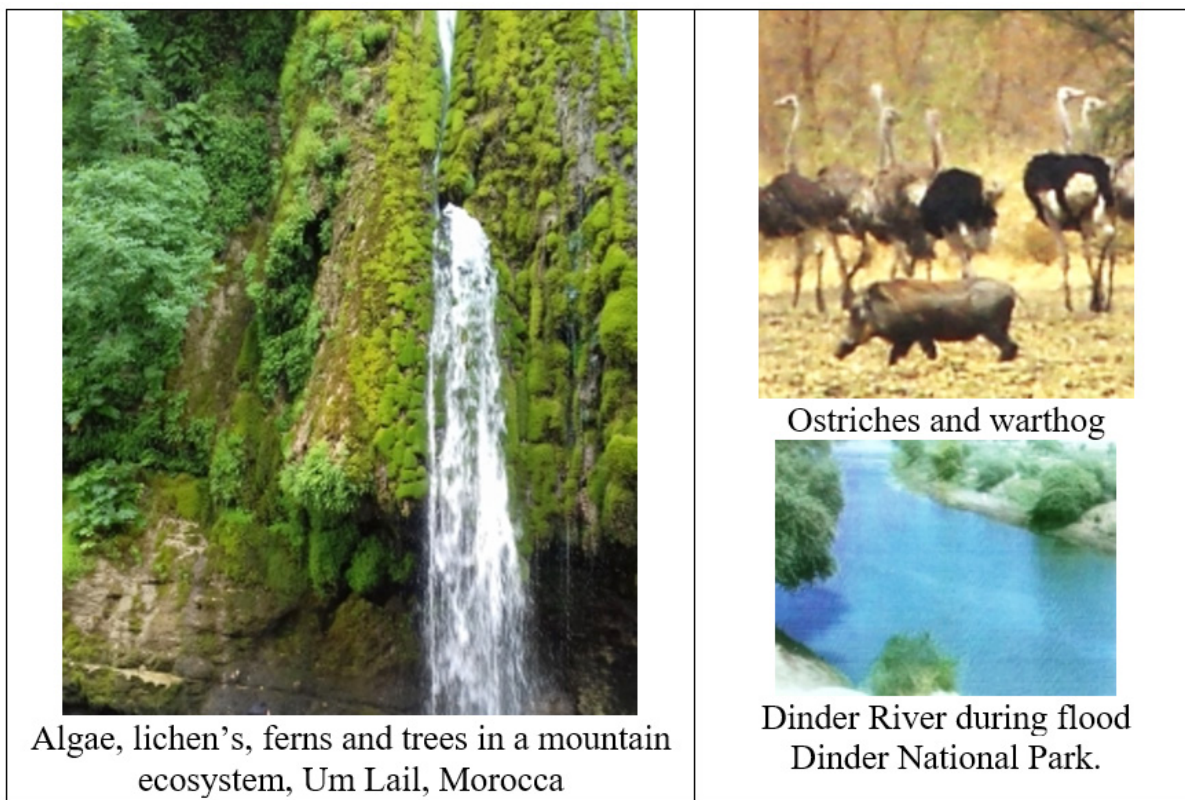


Figure 6:

Biota can be functionally categorized into three major groups:

1. Producers are autotrophic organisms such as algae and green plants that synthesize organic compounds through photosynthesis.
2. Consumers are heterotrophic organisms, primarily animals, that rely on other organisms for nutrition.
3. Decomposers are organisms, including many bacteria and fungi, that break down dead organic matter, recycling nutrients back into the ecosystem.

Based on their ecological interactions, biotic organisms can also be classified as:

- a) Competitors are species that vie for the same resources within a habitat.
- b) Commensals are organisms that benefit from others without affecting them.
- c) Predators are organisms that hunt and consume other organisms.
- d) Parasites are organisms that live on or within a host, deriving nutrients at the host's expense.

In terms of habitat, biota can be further classified according to the ecosystem they inhabit, such as desert biota, aquatic biota, forest biota, and so on.

Blackwater refers to wastewater that originates primarily from toilets and contains human excreta, including feces, urine, water, and toilet paper. Due to the presence of organic matter and potential pathogenic microorganisms, blackwater poses significant health and environmental risks and requires specialized treatment before disposal or reuse.

In an industrial context, the term blackwater can also describe wastewater generated during coal processing and purification. In this case, the water becomes dark-colored due to the presence of fine coal particles and suspended solids.

Typically, blackwater especially from domestic sources—is not recycled directly, given its high pathogen load and contamination level. However, with advanced treatment technologies, it can be processed for safe reuse in non-potable applications.

Botanical gardens are scientifically managed area of land where a diverse collection of plant species—native, endemic, and exotic—are cultivated, documented, and displayed for purposes of conservation, research, education, and public engagement. Each plant specimen is typically labeled with its common name, English name, scientific (binomial) name, and geographic distribution.

Botanical gardens play a vital role in ex situ conservation, preserving plant biodiversity outside of their natural habitats. They serve as living repositories for rare, threatened, and economically or medicinally important plant species.

In addition to their conservation role, botanical gardens provide valuable resources for scientific research, taxonomy, and horticultural studies. They are also accessible to the general public, offering recreational and educational opportunities that promote environmental awareness and appreciation of plant diversity.

Brackish water is water with a salinity level ranging between 0.5‰ and 30‰ (parts per thousand), placing it between freshwater and seawater in terms of salt concentration. It occurs naturally in estuarine environments, where freshwater from rivers or streams mixes with seawater.

In addition to natural occurrences, brackish water may also be found in fossil aquifers with residual salinity or may be artificially created for specific aquaculture purposes, such as in freshwater prawn farming ponds, where controlled salinity levels are maintained to support optimal growth conditions.

Borrow pits are excavated land areas created to extract fill materials such as soil, sand, or gravel for use in construction and infrastructure development. These depressions often retain water, either from precipitation, surface runoff, or intentional rainwater harvesting. In some regions, abandoned borrow pits are intentionally or passively filled with water from adjacent lands and repurposed as artificial ponds.

Borrow pits can have significant ecological and socio-economic impacts. When left unmanaged, they may pose physical hazards, such as drowning risks for children and animals. Stagnant water in borrow pits can also serve as ideal breeding habitats for disease vectors like mosquitoes, potentially increasing the risk of vector-borne diseases (e.g., malaria, dengue). Furthermore, while the water in these pits may be unsuitable for direct human consumption, it may still be used by domestic livestock and wildlife.

In Sudan, over 2,500 borrow pits have been excavated in regions such as Darfur, Kassala, and Kordofan. Additionally, numerous natural depressions, locally known as “fula,” “id,” or “idad,” are traditionally utilized for rainwater harvesting, serving as important seasonal water sources in arid and semi-arid environments.

Carbon footprint refers to the total amount of greenhouse gases, primarily carbon dioxide (CO₂), that are emitted directly or indirectly by human activities. It is usually measured in units of carbon dioxide equivalents (CO₂e) to account for the impact of other greenhouse gases such as methane (CH₄) and nitrous oxide (N₂O). Common sources of carbon footprint include transportation, electricity usage, industrial processes, and food production. Reducing one’s carbon footprint is essential for mitigating climate change and promoting environmental sustainability.

Carnivores’ plants most carnivorous plants live in nitrogen poor soil. It has different strategies to capture its preys mostly arthropods, but large plants occasionally capture amphibians, reptiles, birds and rodents. They still generate all of their energy

from photosynthesis.

There are around 650 species of carnivorous plant. Some carnivorous plants e.g., *Drosera* sp., produce a sticky substance from the spines of the leaf to make the prey stuck before being completely surrounded by the spines and captured. After digestion the leaf retain its original shape.

In some plants e. g. *Nepenthes* sp., the leaf is modified to a pitcher-like with lid and filled with acidic secretion. When the lid is open, preys will be attracted and if slipped to the inside, the lid will be closed. The pitch may reach 1.5m in length, big enough to capture large preys. The leaf blade of *Dionaea* sp., is made up of two valves each with three sensitive hairs, and the leaf margin is surrounded by sharp spines. When an insect touches a hair, the valves closed capturing the insect inside. The prey will be consumed by a carnivorous insect leaving its feces in the pitch and the plant in turn feeds on these feces.

Most carnivorous plants secrete digestive enzymes, some rely on bacteria to decompose the prey and some uses both methods (Figure 7).

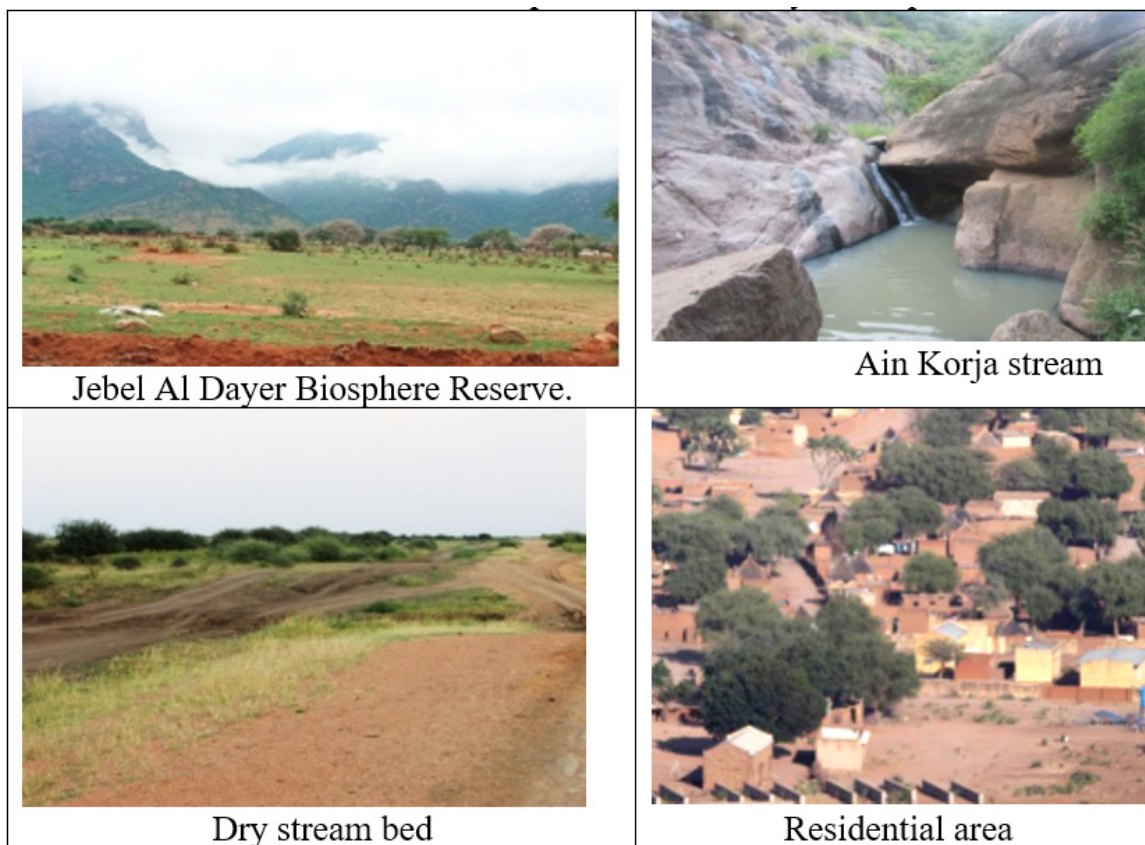
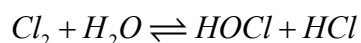


Figure 7: With permission from Mr. Mohamed Adam, Natural History Museum, University of Kordofan.

Chlorination is a water disinfection process involving the addition of chlorine or chlorine-based compounds, such as sodium hypochlorite, to eliminate pathogenic microorganisms. This method is widely employed to control and prevent the transmission of waterborne diseases, including cholera, dysentery, and typhoid fever. Upon dissolution in water, chlorine undergoes a hydrolysis reaction, forming an equilibrium mixture of hypochlorous acid (HOCl) and hydrochloric acid (HCl):



Hypochlorous acid, the primary disinfecting agent, is highly effective against a broad spectrum of viruses and bacteria.

Chlorofluorocarbons (CFCs) are non-toxic, liquefied chemical compounds commonly used as refrigerants in refrigeration and air conditioning systems. Despite their industrial utility, CFCs have significant environmental impacts. In the stratosphere, they contribute to ozone layer depletion by releasing chlorine atoms upon photodissociation, which catalytically destroy ozone (O₃) molecules. Additionally, CFCs are potent greenhouse gases that absorb infrared radiation, trapping heat in the Earth's atmosphere and thereby contributing to global warming.

Circadian rhythm disruption refers to a disturbance in the body's natural 24-hour biological cycle, which regulates physiological processes such as sleep-wake patterns, hormone secretion, body temperature, and metabolism. These rhythms are primarily synchronized by external environmental cues—most notably the light-dark cycle. Disruption occurs when these cues are altered or absent, as in shift work, jet lag, or spaceflight, where the absence of a regular day-night cycle leads to desynchronization between internal clocks and the external environment. Prolonged circadian disruption can impair cognitive performance, weaken the immune system, disturb metabolic processes, and increase the risk of chronic diseases. In space missions, artificial lighting schedules and timed routines are critical countermeasures to maintain circadian alignment.

Circular economy (CE) is an economic model that aims to decouple economic growth from resource consumption and environmental degradation. By promoting principles such as waste minimization, resource efficiency, product life extension, and closed-loop systems, the Circular Economy presents transformative environmental implications across multiple domains. The circular economy plays role in:

1. Reducing the demand for virgin raw materials by encouraging the reuse, remanufacturing, and recycling of products and components. This leads to a lower environmental footprint associated with mining, deforestation, and water extraction, thus preserving natural ecosystems.
2. Significantly lowers landfill use and reduces emissions of pollutants into air, water, and soil. This contributes to improved environmental quality and reduced risks to public health and biodiversity.
3. Increasing material efficiency and product circularity to reduce greenhouse gas emissions associated with production, transportation, and waste management. This aligns the CE with climate mitigation goals under the Paris Agreement.
4. Reducing environmental pressures and lower pollution levels, the CE supports ecosystem regeneration and resilience. It also helps maintain ecological balance by promoting sustainable production-consumption patterns.
5. Fostering innovation in sustainable materials and product design, leading to longer-lasting, repairable, and recyclable goods. Eco-design principles reduce environmental harm throughout the product lifecycle.

Despite these positive implications, implementing the circular economy requires overcoming challenges such as technological limitations, market barriers, and policy gaps. Nevertheless, its potential to promote environmental sustainability makes it a key strategy for transitioning toward a low-carbon, resource-efficient global economy. Some electronics companies implement programs to recycle old devices as part of their circular economy strategies. Some electronics companies implement programs to recycle old devices as part of their circular economy strategies.

Clean air and water acts are legislative frameworks that regulate the emission of pollutants into the environment, specifically targeting air and water pollution. These acts establish permissible limits for contaminants, enforce pollution control measures, and promote environmental and public health by ensuring cleaner air and water resources.

Clean Production refers to an industrial manufacturing approach aimed at minimizing environmental impact through the reduction of pollution and waste generation. This method emphasizes efficient use of raw materials, water, and energy,

alongside the reuse and recycling of waste products. Modern industries increasingly adopt clean production strategies to reduce their environmental responsibilities while enhancing economic efficiency and profitability. The concept gained international recognition during the Rio Earth Summit.

Climate refers to the long-term average of atmospheric conditions, including temperature, precipitation, and wind patterns, in a specific region over an extended period, typically spanning decades. It represents the integrated state and interactions among the Earth's major systems: the hydrosphere (water bodies), cryosphere (frozen components), and lithosphere (Earth's solid surface). Climate systems are typically classified based on quantitative measurements of temperature and precipitation.

Climate change refers to significant and persistent alterations in the average weather patterns of the Earth over decades or longer. These changes may involve increases or decreases in temperature and shifts in precipitation patterns, leading to warmer, wetter, or drier conditions. While climate variability can occur due to natural processes, since the Industrial Revolution in the 1800s, human activities—particularly the combustion of fossil fuels such as coal, oil, and natural gas—have become the primary drivers of climate change. These activities release greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), chlorofluorocarbons (CFCs), and water vapor, which trap heat in the atmosphere through the greenhouse effect, leading to global warming and associated climatic shifts.

Climate neutrality “carbon neutrality” refers to achieving a state in which the amount of greenhouse gas emissions produced by human activities is balanced by the amount removed from the atmosphere or offset through recognized mechanisms, such as reforestation or carbon capture technologies. It is a key strategic goal in global efforts to combat climate change, particularly under the Paris Agreement, which calls for net-zero emissions by the middle of the century. Achieving climate neutrality requires transformative changes in energy systems, transportation, industry, agriculture, and consumption patterns — including reducing emissions at the source, improving resource efficiency, adopting renewable energy sources, and implementing circular economy practices.

Climate neutrality prioritizes reducing greenhouse gas emissions before using carbon offsets. Governments, businesses, and international organizations are adopting time-bound strategies to achieve net-zero emissions while integrating climate justice principles, ensuring equitable transitions, safeguarding vulnerable communities, and promoting sustainable development through effective mitigation and responsible offsetting measures.

Climate neutrality represents both an environmental authoritative and an economic opportunity. It contributes to reducing climate-related damages, stimulating innovation, and creating new green jobs. However, it requires strong political commitment, adequate financing, and broad international cooperation. The European Commission announced a plan to reach climate neutrality by 2050 as part of the “Green Deal.”

Climate resilience refers to the capacity of social, economic, and environmental systems to anticipate, prepare for, respond to, and recover from the adverse impacts of climate change. This includes the ability to minimize damage, adapt to changing climate conditions, and transform systems when necessary to maintain functionality and well-being. Climate resilience involves proactive strategies in urban planning, infrastructure, agriculture, water management, and public health to reduce vulnerability and enhance adaptive capacity.

Closed ecological life support system (CELSS) is an integrated, self-sustaining system designed to support human life in space or other isolated environments by recycling essential resources—primarily air, water, and food. CELSS typically incorporates biological components such as plants, algae, or microbes to perform critical life-support functions: producing oxygen through photosynthesis, removing carbon dioxide, purifying water, and regenerating nutrients. Unlike open systems that rely on external resupply, CELSS aims for near-complete closure, minimizing waste and resource loss. Such systems are essential

for long-duration space missions (e.g., to Mars or lunar bases), where resupply from Earth is limited or impractical. Research on CELSS also contributes to sustainable technologies on Earth, particularly in closed-loop agricultural and waste management systems.

Community forests are forested areas where local communities actively participate in their afforestation, conservation, and sustainable management, often in collaboration with governmental and non-governmental organizations. These forests may be located on public, private (leased), communal, or state-owned lands. Community forests provide both ecological services (such as carbon sequestration, biodiversity conservation, and water regulation) and perceptible goods (like fuelwood, timber, and non-timber forest products), from which the local population derives direct social and economic benefits.

Composting is an aerobic biological process in which microorganisms (aerobic bacteria and fungi), decompose organic matter such as plant residues, food waste, and animal manure—into a stable, nutrient-rich humus-like material known as compost. The process is typically conducted in controlled environments, such as compost bins or piles, located away from residential areas to manage odors and pests. To optimize aeration and microbial activity, the composting material is periodically turned or mechanically agitated. The final product serves as an organic fertilizer and soil amendment, enhancing the soil's physical structure, chemical composition, and biological activity, thereby supporting sustainable agriculture and reducing waste.

Contaminant is any harmful physical, chemical, or biological substance that is introduced into the environment, including air, water, soil, or food, in concentrations that can negatively affect ecosystems, human health, or biodiversity. Contaminants may originate from natural processes or anthropogenic activities. For example, oil spills in coastal waters release toxic compounds that can poison marine life and impair the physiological functions of wildlife, such as covering bird feathers and hindering their ability to fly (Figure 8).

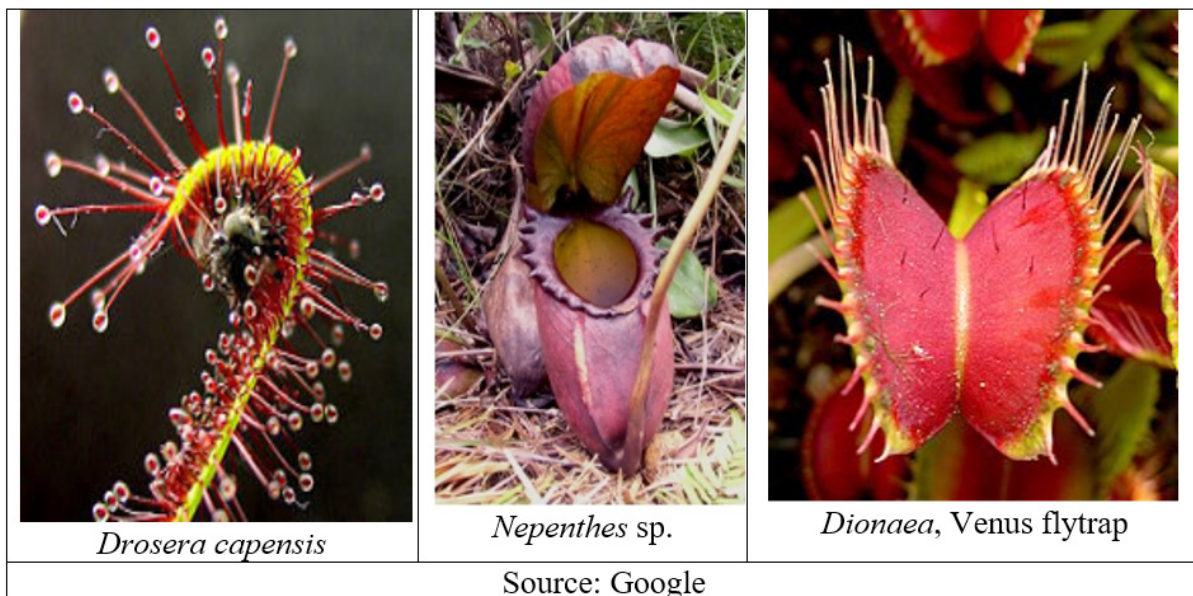


Figure 8:

Conservation refers to the active management and protection of biological diversity and ecosystems to sustain ecological balance and natural processes. This practice is typically undertaken by governmental bodies, non-governmental organizations (NGOs), and environmental conservation professionals.

Consumers are heterotrophic organisms that obtain energy by consuming other organisms, and they are classified based on their feeding behavior into:

- a) Herbivores (e.g., domesticated livestock and certain fish species) derive their energy exclusively from primary producers such as plants and algae.
- b) Carnivores (e.g., wild animals, some domestic pets, and predatory fish) feed primarily on other consumers, typically herbivores.
- c) Omnivores, including humans, consume both primary producers and other consumers, utilizing a mixed diet for energy.

Some plant species are carnivores deriving some or most of their nutrient from arthropods and sometimes from small birds and mammals. *Nepenthes* spp. are examples of carnivore's plants.

Continental shelf is the submerged, gently sloping portion of the continental margin that extends from the shoreline to a depth of approximately 100 to 200 meters, where it transitions into the steeper continental slope. This relatively flat and shallow marine zone is characterized by high concentrations of nutrients, primarily due to terrestrial runoff and upwelling processes, which support high biological productivity and dense marine ecosystems. Continental shelves account for approximately 90% of the world's fishery resources and are also significant reservoirs of hydrocarbons, including oil and natural gas. Additionally, the shallow benthic habitats of the continental shelf serve as critical spawning and nursery grounds for numerous fish species and as stopover or breeding sites for many migratory bird species.

Coral bleaching occurs when coral polyps expel the symbiotic zooxanthellae algae residing within their tissues, resulting in a loss of pigmentation and the corals appearing stark white. This phenomenon is primarily triggered by elevated sea surface temperatures, but other environmental stressors such as changes in light intensity, nutrient imbalances, and pollution can also contribute. Prolonged or severe bleaching events can lead to coral mortality, as the symbiotic algae provide essential nutrients through photosynthesis. The accumulation of greenhouse gases in the atmosphere contributes to global warming, leading to rising ocean temperatures and altered storm patterns, both of which significantly increase the frequency and severity of coral bleaching events.

Cumulative effects refer to the combined impact of past, present, and anticipated future human activities—both direct and indirect—as well as natural processes on the environment. These effects are often the result of multiple stressors acting over time and space, and may not be apparent when assessing individual actions in isolation. Major contributors include energy infrastructure development, land use changes, and the exploitation of marine resources. Assessing and predicting cumulative effects require comprehensive environmental baseline data to understand trends and interactions among stressors. Human-induced cumulative impacts are a significant driver of global warming and climate change, as they intensify environmental degradation through synergistic and compounding processes.

Decarbonization refers to the process of reducing or eliminating carbon dioxide (CO₂) emissions resulting from human activities, particularly those related to the combustion of fossil fuels in sectors such as energy, transportation, and industry. It involves a transition to low-carbon or carbon-free energy sources—such as renewable energy (e.g., solar, wind, hydro), energy efficiency measures, electrification, carbon capture and storage (CCS), and sustainable practices. Decarbonization is a critical component of climate change mitigation strategies aimed at achieving net-zero emissions and limiting global temperature rise.

Decomposers: Decomposers clean the environment by feeding on dead biota, feces and rotten garbage thus aiding in the recycling of nutrients. Decomposers secrete substances that break down the chemical composition of organic matter, create new compounds and recycle matter.

Decomposing is performed by an array of living organisms such as bacteria, fungi, flies, ants, termites, cockroaches, termites, earthworms, millipedes, snails and slugs play only a small role compared with other decomposers. Termites possess symbiotic bacteria and protozoa, and in their absence, they cannot assimilate wood. Decomposers get their energy from organic wastes and dead organisms and release heat into the ecosystem (Figure 9).

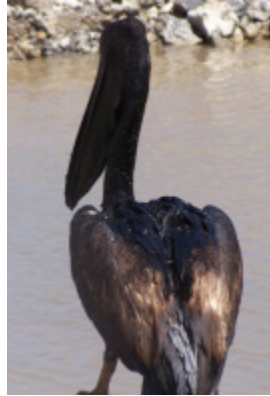


Figure 9: A White Pelican *Pelecanus erythrorhynchos* contaminated with oil spills from Bashayer Marine Oil Terminal (source: Engineer Abdelhameed Elsayed Adeel).

Deforestation refers to the large-scale removal of forest cover, primarily driven by logging for commercial purposes, agricultural expansion, livestock grazing, urban development, and mining activities. This process leads to a significant reduction in forested land, particularly in regions such as Southeast Asia and the Amazon Basin in Latin America.

Tree removal disrupts soil structure, making it more prone to erosion. It also contributes to elevated atmospheric levels of carbon dioxide (CO₂), either through the burning or decomposition of biomass, or due to the decreased carbon absorption capacity resulting from reduced photosynthesis. These changes exacerbate the greenhouse effect and contribute to global climate change.

Desalination is the removal of minerals from saline water to provide fresh water for drinking and irrigation. It is also used in soil reclamation.

Desertification is the gradual degradation of land in arid, semi-arid, and dry sub-humid areas, leading to a significant decline in its productivity and eventual transformation into desert-like conditions. It is driven by a combination of unsustainable land use practices—such as overgrazing, deforestation, and poor agricultural methods—as well as natural factors, including prolonged droughts and climate variability.

Desert encroachment refers to the gradual expansion of arid, desert-like conditions into previously non-desert regions, often as a result of climatic changes and anthropogenic activities. In Sudan, this phenomenon has led to the abandonment of several villages located along the second bend of the Nile River due to advancing sand dunes. Additionally, desertification has affected parts of northern Kordofan and Darfur, contributing to land degradation and displacement of local populations (Figure 10).

Disinfectant a chemical agent or physical method used to eliminate or deactivate pathogenic microorganisms in water, air, or on surfaces, thereby reducing the risk of infection and disease transmission.

Dissolved oxygen is the amount of oxygen that is dissolved in water, which is essential for the survival of aquatic organisms. Adequate levels of dissolved oxygen also help prevent the release of foul odors resulting from the decomposition of organic pollutants.

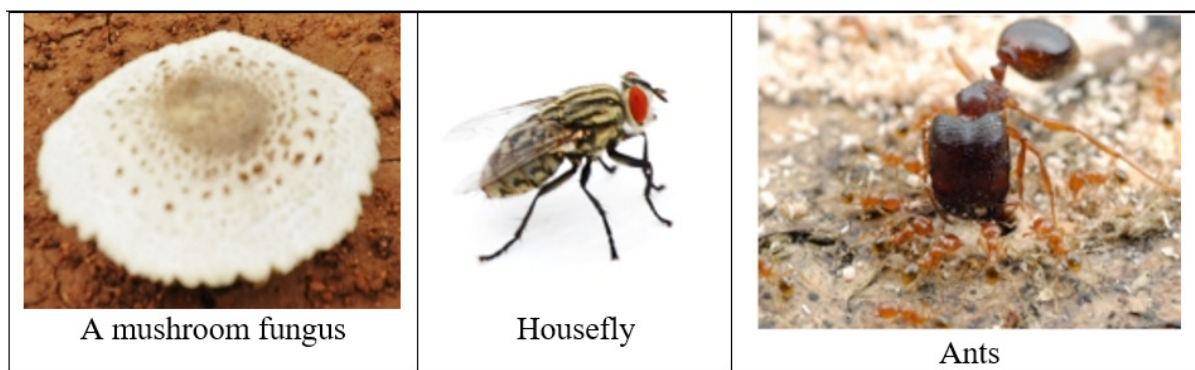


Figure 10:

Dispersion of pollutants in the environment is influenced by the mode and frequency of release, which may be instantaneous (single event), intermittent (sporadic), or continuous.

In the case of air pollutants, dispersion is largely governed by wind speed and atmospheric conditions, whereas for waterborne pollutants, water currents, turbulence, and flow rate are the primary dispersal mechanisms. The extent and pattern of dispersion affect the pollutant's concentration and environmental impact.

Diversity varies by discipline. In ecology, it refers to the variety and variability of living organisms and their interactions within ecosystems, often measured in terms of species richness and evenness. In, diversity encompasses variations among human populations, including differences in ethnicity, gender, physical abilities, skills, cultural practices, and belief systems.

Domestic water source is a supply of treated surface water used for residential purposes, including potable water for drinking and other domestic activities such as cooking, cleaning, and irrigation in both households and commercial enterprises.

Drain water is the water removed from the surface or subsurface of the soil due to excessive irrigation, precipitation, seepage, or flooding. This water is typically collected through drainage systems to prevent waterlogging and maintain soil health.

Drought is a climatic phenomenon characterized by a prolonged period of below-average precipitation, leading to a significant reduction in water availability. It can occur in any geographic region and may persist for weeks, months, or even years. Droughts exert profound impacts on public health, agricultural productivity, economic stability, and ecological systems. These effects are particularly severe in vulnerable regions such as parts of Africa and Asia. Extended drought conditions can lead to critical shortages in water and food supplies, potentially resulting in famine, population displacement, and increased rates of both internal and cross-border migration.

Earth summit, formally known as the United Nations Conference on Environment and Development (UNCED), was held in Rio de Janeiro from June 3 to 14, 1992. This landmark conference aimed to foster international cooperation toward sustainable economic development that minimizes environmental degradation and conserves natural resources. It emphasized the need for a paradigm shift in human attitudes, recognizing that poverty and the unsustainable exploitation of resources significantly contribute to environmental decline.

As a result, both national and international policies began to prioritize the reduction of pollutant emissions, the transition to renewable energy sources, improved water resource management, and increased investment in public transportation systems. The Summit reaffirmed the right of all nations to pursue both environmental safety and socio-economic development.

Eco-friendly materials are substances derived primarily from natural, renewable, or sustainably managed sources that have minimal adverse impact on the environment throughout their life cycle. A wide range of environmentally friendly products can be manufactured using such materials. Examples include textiles made from natural fibers like cotton, wool, and leather; footwear and accessories produced from jute and leather; the cultivation and use of medicinal and aromatic plants; the development of renewable energy sources; the production of organic or “green” food; and the extraction of natural rubber. These materials contribute to reducing environmental degradation by being biodegradable, recyclable, and generally less energy-intensive in their production and disposal processes.

Ecology is a branch of biology that focuses on the study of interactions between living organisms and their physical and biological environments. It examines these relationships across multiple levels of biological organization, including the individual, population, community, ecosystem, and biosphere. Ecological studies emphasize factors such as species biomass, abundance, distribution, and the flow of energy and matter through food chains, food webs, and ecological pyramids. Furthermore, ecology investigates intra- and interspecific interactions such as competition, predation, commensalism, and parasitism. The principles of ecology are fundamental to the conservation and sustainable management of natural resources, as well as understanding the dynamics of human–environment interactions.

Eco-design (Ecological design) is an interdisciplinary approach that integrates knowledge from fields such as fine arts, architecture, interior design, and engineering to develop products, services, and systems that are environmentally sustainable and promote human well-being. The goal of eco-design is to create durable, multifunctional products that utilize renewable energy sources (e.g., solar cookers, electric vehicles) and are recyclable, easy to disassemble, repair, or repurpose, while minimizing environmental impact throughout their life cycle. In the context of urban planning, eco-design seeks to create aesthetically pleasing, ecologically harmonious, and comfortable spaces that enhance both environmental quality and human experience.

Eco-efficiency is a management-oriented concept aimed at facilitating the transition from unsustainable development toward a sustainable and resilient form of growth. It emphasizes minimize environmental degradation while simultaneously maximizing resource-use efficiency.

As a strategy for sustainable production and consumption, eco-efficiency involves reducing the generation and use of environmentally harmful goods, services, and materials. It promotes greater reliance on renewable energy sources, the manufacture of durable products, and improvements in the recyclability and end-of-life management of materials. The ultimate objective is to decouple economic growth from environmental impact through innovation, cleaner production methods, and life-cycle thinking.

Ecological connectivity refers to the unimpeded movement of species and the flow of natural processes that sustain life on Earth. It can also describe continuous ecosystems that are linked through ecological corridors. Connectivity is generally categorized into two types: structural connectivity, which identifies physical continuity between ecosystems, and functional connectivity, which confirms the actual movement of species or ecological processes.

Ecological engineering is an applied scientific discipline that integrates ecological principles with engineering practices to design, construct, or restore ecosystems in a manner that meets both human and environmental goals. It seeks to develop systems that are sustainable, resilient, and aligned with natural processes.

In ecosystem restoration, ecological engineering involves modeling both biotic (living) and abiotic (non-living) components of the target ecosystem to replicate its structure and function. Controlled disturbances may be introduced to test system responses, followed by monitoring and implementation of adaptive management and protection strategies.

Ecological engineers also contribute to improving technologies and systems for waste treatment (solid and liquid), pollution control (air and water), and overall enhancement of environmental quality. Their work supports sustainable development by creating self-regulating ecosystems capable of providing essential services while reducing anthropogenic impacts.

Ecological footprint is a quantitative measure used to assess the human demand on Earth's biologically productive natural resources required to produce goods and services that sustain lifestyles and economic activities. This metric reflects the environmental, economic, and social pressures exerted on ecosystems at national, regional, and global scales. These demands result in adverse impacts on croplands, grazing lands, fisheries, and forest ecosystem. Assessing ecological footprints is essential for understanding the extent of resource exploitation relative to the planet's capacity for regeneration. It provides a critical basis for evaluating sustainability and guiding strategies aimed at responsible resource management and long-term ecological balance. A population exceeds its ecological capacity when its ecological footprint surpasses the available biocapacity.

Ecological succession refers to the gradual, long-term process by which biological communities and their associated habitats become established in a new or disturbed environment. This process continues until a stable, self-sustaining climax community is formed.

Key abiotic and biotic factors influencing succession include water availability, temperature, humidity, light, climate conditions, soil composition, topography, interspecies competition, and species migration.

Primary succession occurs in areas previously devoid of life, such as newly exposed geological surfaces, volcanic islands, or locations with emerging groundwater springs (e.g., Ga'ab Alsawani west of Dongola).

Secondary succession follows significant disturbances (e.g., wildfires, landslides, volcanic eruptions) and involves the re-establishment of biotic communities in previously inhabited areas.

Ecoregion is a geographically and ecologically defined area that encompasses distinct assemblages of species, natural communities, and environmental conditions. Ecoregions are characterized by specific patterns of climate, soil, geology, and topography, leading to biodiversity that is relatively unique compared to surrounding regions.

The boundaries of ecoregions are typically gradual rather than sharply defined, and they may contain habitats that deviate from the dominant biome classification. Ecoregions are broadly classified into three categories:

- a) Terrestrial ecoregions comprising land-based ecosystems characterized by soil and rock substrates.
- b) Freshwater ecoregions: Defined by distinct freshwater communities, such as rivers, lakes, and wetlands.
- c) Marine ecoregions: Encompassing oceanic areas with relatively uniform biotic communities that are ecologically distinct from adjacent marine systems.

Ecosystems is a functional unit consisting of a dynamic community of living organisms (biotic components) interacting with their physical environment (abiotic components), such as air, water, soil, and climate. These interactions form complex networks that support life through processes like energy flow, nutrient cycling, and ecological succession.

Ecosystems can be found in a wide variety of environments, ranging from terrestrial systems such as mountains, meadows, deserts, and forests, to aquatic systems including rivers, lakes, oceans, and even microhabitats like small water pools. The diversity of ecosystems spans extreme environments — from deep-sea trenches and hypersaline brine pools on the ocean floor

(e.g., Atlantis II Deep in the Red Sea), to polar ice caps and snow-covered peaks (e.g., the Himalayas).

In some interdisciplinary perspectives, elements of archaeology and cultural heritage are considered as integral parts of certain ecosystems, particularly when examining human–environment interactions over time.

The sustainability of ecosystems relies on continuous and regulated interactions among organisms and between biotic and abiotic components. Key processes include energy transfer through food webs, decomposition, nutrient recycling, symbiosis, competition, and population regulation — all contributing to ecological balance.

In some interdisciplinary perspectives, elements of archaeology and cultural heritage are considered as integral parts of certain ecosystems, particularly when examining human–environment interactions over time.

The sustainability of ecosystems relies on continuous and regulated interactions among organisms and between biotic and abiotic components. Key processes include energy transfer through food webs, decomposition, nutrient recycling, symbiosis, competition, and population regulation — all contributing to ecological balance.

However, ecosystems are increasingly threatened by anthropogenic activities, including pollution, greenhouse gas emissions, deforestation, desertification, overexploitation of natural resources, and climate change. Additionally, unsustainable practices in agriculture, livestock management, and industrial production contribute to ecosystem degradation.

In response to these challenges, there is an urgent need to adopt eco-efficiency strategies practices that enhance productivity while minimizing environmental impact —to ensure long-term ecological health and sustainability (Figure 11).



Figure 11: Merotic pyramids in Albjrawia were buried by creeping sand.

Ecosystem-based approaches are strategies that utilize biodiversity and ecosystem services as part of a broader adaptation plan to help people cope with the adverse impacts of climate change. This concept encompasses a wide range of ecosystem management activities aimed at enhancing resilience and reducing the vulnerability of both people and the environment to climate change and disasters. It refers to a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable manner.

Ecotoxicity refers to the potential of a biological, physical, or chemical substance—whether naturally occurring or anthropogenic—to cause harmful effects on living organisms (biota) and non-living (abiotic) components within ecosystems. The severity of toxic effects can range from mild to acute and may manifest at the cellular level (cytotoxicity) or target specific organs such as the liver (hepatotoxicity) or kidneys in exposed animals. Exposure can occur through single or repeated dermal or oral contact. Ultimately, ecotoxic substances can disrupt ecological balance by damaging or eliminating key components of ecosystems.

Education for sustainability aims to equip individuals of all ages with the knowledge, skills, values, attitudes, and behaviors necessary to build more equitable, environmentally aware, and resilient communities. It supports the development of sustainable

practices that meet present needs without compromising the ability of future generations to meet their own, through integrated economic, social, and environmental planning. This form of education raises awareness about critical global issues, such as biodiversity loss and the impacts of climate change on ecosystems.

Effluent refers to treated or untreated wastewater discharged into natural surface water bodies such as rivers, lakes, or oceans. It may contain a wide range of pollutants, including organic matter, suspended solids, nutrients, heavy metals, and dissolved chemicals, depending on its source and level of treatment.

Electrical conductivity (EC) is a measure of water's ability to conduct an electric current, which is influenced primarily by the concentration of dissolved ions and temperature. Elevated conductivity levels—typically above $1000\mu\text{S}/\text{cm}$ —can indicate poor water quality and may render aquatic environments unsuitable for certain species of aquatic invertebrates and fish due to osmotic stress or toxic ion concentrations.

Emissions refer to the release of gaseous substances into the atmosphere, including but not limited to carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), and hydrofluorocarbons (HFCs). These gases are primarily produced through anthropogenic activities, with industrial processes representing a significant source.

Environment is defined as the totality of all biotic (living) and abiotic (non-living) components surrounding organisms, along with the interactions among them, which collectively influence life on Earth or within a specific geographic region. It encompasses microorganisms such as viruses, bacteria, and fungi, as well as plants, animals, and humans.

Environmental archaeology is the interdisciplinary study of past environments in relation to archaeological sites. It utilizes comparative and reference collections to analyze biological and ecological remains, aiming to reconstruct historical ecosystems, understand how ancient populations utilized natural resources, and assess their environmental impacts.

Environmental auditing involves the systematic monitoring, evaluation, and reporting of the environmental risks associated with development or production projects. This process assesses the effects on biota and ecosystems and recommends mitigation strategies. It also supports the ongoing revision and enforcement of relevant environmental legislation and regulations.

Environmental disasters encompass both natural and anthropogenic events that cause significant disruption or degradation to ecosystems. Natural disasters include volcanic eruptions, earthquakes, storms, floods, and droughts, while anthropogenic disasters may result from pollution, armed conflict, or warfare. These events typically cause widespread ecological damage, with recovery often requiring extended periods. Many countries have established disaster management agencies responsible for planning, response, and recovery based on pre-defined risk scenarios.

Environmental emergency response refers to coordinated actions taken to address sudden events that pose serious threats to ecosystems and biological life. The response framework typically includes four phases: preparedness, response, mitigation, and recovery. These efforts involve both governmental agencies and community volunteers working collaboratively to manage the impacts of disasters such as earthquakes, floods, and coastal oil spills, with the goal of restoring environmental conditions to their original or functional state.

Environmental goods are broadly classified into two categories:

1. **Non-Marketable Environmental Goods:** These goods cannot be directly assigned a monetary value and are not traded in conventional markets. They include ecosystem services such as shade provided by trees, the presence of wildlife, the process of photosynthetic carbon dioxide conversion into carbohydrates, clean air and water, aesthetic value of landscapes, and public natural resources such as parks, lakes, rivers, streams, mountains, forests, and beaches. These contribute significantly to

environmental quality and human well-being but are difficult to quantify financially.

2. **Marketable Environmental Goods:** These are tangible goods derived from natural ecosystems that can be quantified and traded in economic markets. Examples include timber, fodder, non-timber forest products, and other consumable natural resources.

Environmental governance refers to the set of mechanisms, institutions, and processes through which the relationship between humans and the environment is regulated, with the goal of managing natural resources sustainably and ensuring a balance between economic development and the preservation of ecosystems.

It involves the participation of multiple stakeholders, including governments, international organizations, civil society, the private sector, and local communities, in environmental decision-making and policy implementation. Environmental governance is grounded in principles of transparency, accountability, participation, and the rule of law.

This concept represents an evolution in environmental thinking, moving beyond a narrow focus on environmental legislation to include institutional frameworks and multi-level governance — encompassing local, national, and global levels — to address transboundary challenges such as climate change, marine pollution, and biodiversity loss.

Effective environmental governance requires cross-sectoral coordination, access to accurate environmental data, law enforcement capacity, and mechanisms for holding actors accountable. Conversely, weak environmental governance often leads to the worsening of environmental problems, inequitable resource exploitation, and a lack of environmental justice.

Environmental Impact Assessment is a systematic study conducted prior to the initiation of development projects that are expected to have significant environmental consequences, such as oil exploration, road construction, and dam building. The assessment evaluates potential short-term and long-term physical, chemical, biological, and socio-economic impacts on the environment. The primary objectives of EIA are to:

1. Predict and assess potential adverse environmental impacts.
2. Recommend mitigation strategies to minimize negative effects.
3. Enhance decision-making through informed planning.

In several countries, stakeholder participation—especially involving local communities—is legally mandated. In Sudan, for example, the Higher Council for Environment and Natural Resources requires an EIA to be completed and publicly discussed as a prerequisite for project approval to ensure environmental sustainability.

Environmental justice (EJ) refers to the equitable distribution of environmental benefits and burdens across all segments of society, regardless of race, ethnicity, income, or geographic location. It encompasses the right of all individuals and communities to live in a healthy environment and to have equal access to environmental resources and decision-making processes.

1. Principles of environmental justice is stranded in principles of equity, inclusion, and non-discrimination. It asserts that no group of people should disproportionately bear the negative consequences of environmental degradation, such as pollution, exposure to hazardous waste, or the impacts of climate change.

2. Research has shown that marginalized and low-income communities often suffer from greater exposure to environmental risks, such as air and water pollution, proximity to landfills or industrial sites, and lack of green spaces. These disparities are

frequently linked to historical patterns of discrimination, weak regulatory enforcement, and exclusion from policymaking.

3. Environmental justice also involves fair and meaningful participation in environmental decision-making. This includes access to information, transparency in governance, and inclusive mechanisms that allow affected communities to voice concerns and influence outcomes.

4. As a subfield, environmental justice extends to climate justice, which addresses the unequal distribution of climate change impacts and responsibilities. Vulnerable populations—particularly in the Global South—often face the worst effects of a crisis they contributed to the least.

5. Promoting environmental justice requires targeted policies, regulatory reforms, and inclusive governance frameworks that address environmental disparities. It also calls for the integration of social equity into environmental and sustainability planning.

In sum, environmental justice is a critical dimension of sustainable development, linking human rights, environmental protection, and social equity to ensure that no one is left behind in the transition to a greener and more resilient future. Environmental movements in the U.S. advocate for the closure of polluting factories near low-income residential areas.

Environmental law encompasses a set of legal frameworks, policies, and regulations that govern human interactions with the natural environment. These laws aim to:

1. Prevent pollution of air, soil, and water.
2. Combat deforestation and illegal exploitation of wildlife.
3. Regulate industrial and other anthropogenic activities that may degrade the environment.

Effective environmental legislation requires a comprehensive understanding of ecological systems and the impacts of various activities on environmental health.

Environmental physiology is the study of how organisms respond to and adapt physiologically to environmental challenges. These environmental factors include temperature extremes, humidity, altitude, radiation, pollution, and other external stressors. The field integrates concepts from biology, ecology, medicine, and physical sciences to understand the mechanisms that maintain homeostasis and survival in varying environmental conditions. Key areas of research in environmental physiology include:

1. How organisms maintain body thermoregulation: in cold or hot environments.
2. The effects of hypoxia (low oxygen availability) at high altitudes on respiration, circulation, and metabolism.
3. Short-term and long-term physiological changes acclimatization and adaptations to environmental stressors.
4. How the body manages water and electrolyte balance under different environmental conditions.
5. Physiological responses to pollutants and toxins in the environment.
6. How environmental factors influence physical performance and fatigue.

Understanding environmental physiology is essential in fields like aerospace medicine, sports science, climate change biology, and occupational health, where organisms must function under extreme or changing environmental conditions.

Environmental regulation implies the role of abiotic factors in regulating species distribution, physiological functions, reproductive cycles, and ecosystem processes such as:

1. The temperature affects metabolic rates and enzyme activity in organisms.
2. The soil chemical composition and its pH level influence root development, nutrient uptake, and microbial activity.
3. Water availability controls plant transpiration, nutrient mobility, and organismal hydration.

Environmental remediation refers to the process of removing, treating, or containing contaminants in soil, water, or air to restore environmental quality. It involves:

1. Identification and assessment of hazardous materials or toxic spills.
2. Implementation of technologies to clean, neutralize, or isolate pollutants.
3. Ensuring long-term safety and prevention of further contamination.

Remediation is a critical component in the management of environmental hazards, particularly in industrial or accident-prone areas.

Environmental risk refers to the probability and potential consequences of undesirable events that may negatively impact the environment or human health. Such risks often arise due to deficiencies in the systems for waste collection, transportation, treatment, and disposal, leading to the uncontrolled release of pollutants into the environment. These pollutants pose serious threats to ecosystems and human populations. Environmental risk assessment is a systematic process used to:

- a) Quantify the likelihood of adverse ecological and health effects resulting from the exposure of organisms, including humans, to environmental contaminants.
- b) Identify and estimate threshold contaminant concentrations that should not be exceeded to avoid harmful effects.
- c) Classify risks in a qualitative or semi-quantitative manner—typically ranging from safe, low hazard, moderate hazard, to high hazard.

ERA supports decision-making in environmental management, regulatory compliance, and pollution control.

Environmental security pertains to the protection of ecological systems essential for sustaining life, including clean air, safe drinking water, and secure food supplies. It emphasizes the need to make human activities environmentally sustainable.

Key areas of focus include:

1. Impacts of economic development, human conflict, and civil unrest on the environment.
2. Transboundary environmental issues and global challenges such as climate change and biodiversity loss.
3. The capacity of individuals, communities, and nations to collaborate on solving environmental problems, including pollution, resource overexploitation, and ecosystem degradation.

Environmental security seeks to integrate ecological protection into national and global security agendas, recognizing the critical link between environmental health and societal stability.

Environmental services encompass a range of activities and systems designed to protect natural ecosystems and public health by:

1. Removing toxic substances and preventing chemical spills or the spread of contaminants in air, soil, and water.
2. Treating sewage, managing solid and hazardous waste, and maintaining effective sanitation systems to mitigate pollution.
3. Preventing depletion of natural resources, minimizing damage to landscapes, and supporting the conservation of biodiversity.
4. These services are fundamental for maintaining ecological integrity, supporting human health, and ensuring the sustainability of natural resource use.

Environmental sustainability refers to the responsible interaction between humans and natural systems—such as ecosystems, species, and resources—in a manner that ensures their availability and health for future generations. It highlights:

- a) Practices that minimize environmental degradation and reduce anthropogenic pressures on ecosystems.
- b) Long-term conservation of biodiversity, ecosystem functions, and natural habitats.
- c) Enhancement of human well-being without compromising the resilience and integrity of ecological systems.

Sustainable environmental practices aim to balance socio-economic development with ecological stewardship, ensuring that current needs are met without compromising the ability of future generations to meet their own.

Ethnobotany is the interdisciplinary scientific study of traditional knowledge and cultural practices related to the classification, domestication, cultivation, and utilization of wild and cultivated plants. These uses encompass: nutrition, medicine, dyes, ritualistic practices, and construction and shelter.

Ethnobotanical research integrates fields such as anthropology, botany, mycology, chemistry, ethnography, archaeology, folklore studies, religious traditions, and pharmacology. It plays a critical role in understanding human–plant relationships, evaluating the anthropogenic impacts on plant biodiversity, and informing plant conservation strategies.

Ethnozoology is the scientific study of traditional and indigenous knowledge systems regarding the classification, domestication, and use of animals. Animal resources are utilized for: food,

medicine, dyes, transport, and ritual and symbolic purposes.

Ethnozoological investigations combine insights from ecology, anthropology, history, and economics, providing essential information for assessing human impacts on animal populations and ecosystems. These studies support the development of culturally informed and sustainable biodiversity conservation practices.

Evaporation ponds are engineered, shallow basins designed for the disposal and natural drying of sewage sludge and other liquid waste through solar-driven evaporation. These ponds utilize ambient environmental conditions—such as temperature, wind, and solar radiation—for moisture removal.

When integrated with eco-design principles, evaporation ponds can serve as effective, low-energy treatment systems. In certain applications, they are also used for the extraction of valuable minerals from brine or wastewater, contributing to resource recovery in environmental engineering.

Erosion refers to the physical removal and displacement of the uppermost layer of soil (topsoil) by wind or water, particularly in the absence of protective vegetation cover. It results in:

1. Decreased soil fertility due to loss of organic matter, nutrients, and moisture-holding capacity.
2. Reduced agricultural productivity and land degradation.

Erosion is often accelerated by unsustainable human activities such as overgrazing, artisanal mining, and extraction of soil and sand for construction.

Effective soil conservation and land management strategies are essential to mitigate erosion and maintain ecosystem services.

Estuary: An estuary is a semi-enclosed coastal body of water where freshwater—often from rivers or streams and not always continuously present—mixes with saltwater from the sea or ocean. Most estuaries were formed during the Holocene epoch, approximately 10,000 to 12,000 years ago, following the last glacial retreat.

The ecological zones within estuaries vary: sandy areas near the marine interface are typically dominated by salt-tolerant grasses, while areas closer to freshwater sources often support tree species such as mangroves or riparian vegetation. The dynamic mixing of freshwater and seawater, along with the deposition of mud, minerals, and organic matter, results in highly nutrient-rich environments.

Estuaries are among the most productive ecosystems on Earth, with annual biological productivity ranging from 12.5 to 25 metric tons per hectare. They provide critical habitat for a wide variety of species and support important ecological functions such as nutrient cycling and nursery grounds for marine life. Approximately 66% of the global human population resides in or near estuarine and coastal regions, highlighting their ecological and socio-economic importance (Figure 12).

Eutrophication is the process by which a waterbody, either wholly or in part, becomes progressively enriched with nutrients, particularly nitrates and phosphates. This nutrient enrichment stimulates excessive growth of algae, as well as floating and emergent aquatic plants. The resulting algal blooms can significantly disrupt aquatic ecosystem functions and services. As these blooms decompose, they deplete dissolved oxygen levels in the water (a condition known as hypoxia), which can lead to the death of sensitive organisms such as seagrasses and fish, and cause widespread degradation of aquatic habitats.

Epifaunal organisms include species such as sponges, barnacles, tunicates, oysters, and sea stars. These animals live attached to submerged substrates, such as aquatic vegetation, benthic organisms, or hard surfaces on the beds of rivers, lakes, seas, and oceans. Epifauna play a crucial ecological role in coastal and shallow reef ecosystems, serving as an essential trophic link between benthic and pelagic systems by acting as a food source for higher trophic level predators.

Epigenetic changes in space refer to alterations in gene expression that occur without changes in the DNA sequence, induced by environmental conditions unique to spaceflight, such as microgravity, radiation, isolation, and altered circadian rhythms. These changes are mediated by mechanisms such as DNA methylation, histone modification, and non-coding RNA activity, which regulate how genes are turned on or off in response to external stimuli. In space, epigenetic modifications can affect a wide range of biological functions, including immune response, metabolism, bone density, muscle function, and cognitive performance. Understanding these changes is essential for assessing long-term health risks during extended missions and for developing targeted countermeasures to maintain astronaut health.

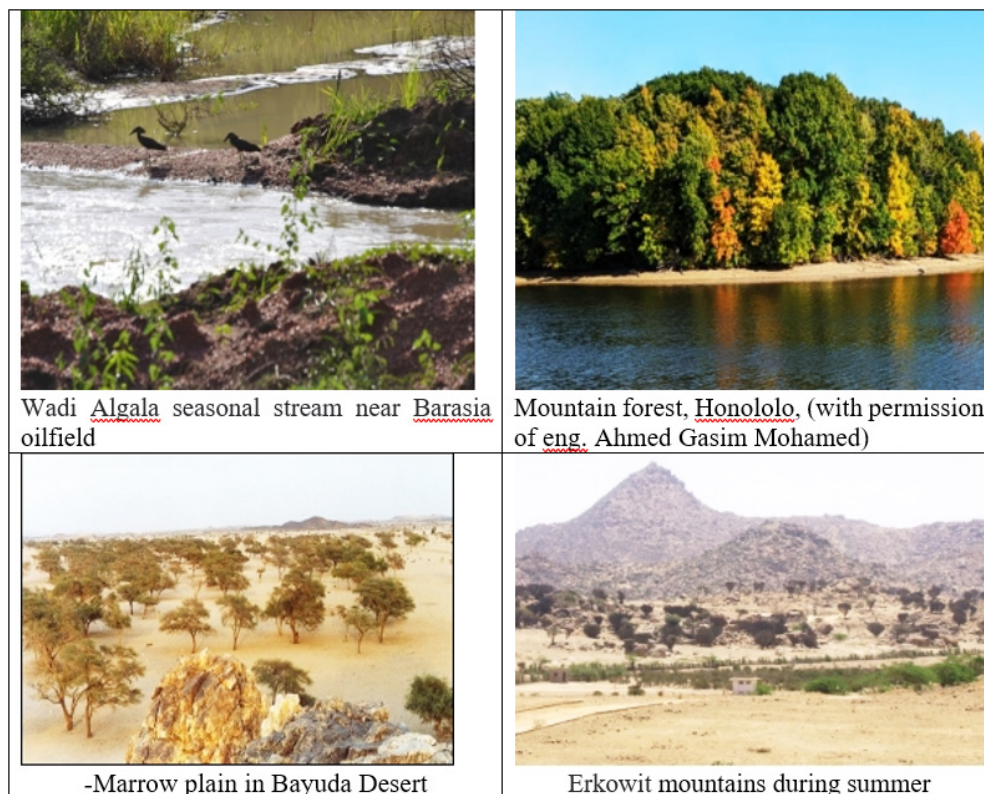


Figure 12:

Exclusive economic zone (EEZ) is a maritime area extending up to 200 nautical miles from the baseline of a coastal state, within which the state possesses exclusive sovereign rights for the exploration, exploitation, conservation, and management of both living (biotic) and non-living (abiotic) natural resources. This includes the use of marine energy sources such as ocean currents and wind.

Exposure pathway refers to the route by which a contaminant travels from its source to a receptor, potentially posing a risk to human health or the environment. In humans, primary exposure routes include inhalation, ingestion, dermal absorption, and injection. In environmental contexts, exposure occurs through mechanisms such as waste disposal, seepage into soils or groundwater, and atmospheric or aquatic emissions.

Extinct: A taxon is considered extinct when there are no surviving individuals of that species or subspecies anywhere on Earth. Notable examples include the horned freshwater crocodile, non-avian dinosaurs, the flightless dodo (endemic to Mauritius), the woolly mammoth, and the Baiji (Yangtze River white dolphin). Environmental physiology

Extraterrestrial contamination refers to the unintended transfer of biological or chemical substances between Earth and extraterrestrial environments, such as other planets, moons, or celestial bodies. This can occur in two forms:

1. Earth-originating microorganisms or organic material are introduced to other celestial bodies, potentially affecting their native ecosystems or scientific investigations.
2. Extraterrestrial material is brought back to earth, possibly posing biological or chemical risks.

Preventing extraterrestrial contamination is crucial in planetary protection protocols to preserve the integrity of space exploration and Astro-biological studies.

Ex-Situ conservation refers to the preservation of living organisms outside their natural habitats, in controlled environments that simulate their native ecological conditions. This approach includes facilities such as botanical gardens, zoological parks, vivaria, aquaria, gene banks, seed banks, and research laboratories. Through ex-situ conservation, species are safeguarded from threats such as poaching, habitat destruction, and natural predation, and are provided with necessary veterinary or horticultural care to support their survival and potential future reintroduction into the wild (Figure 13).

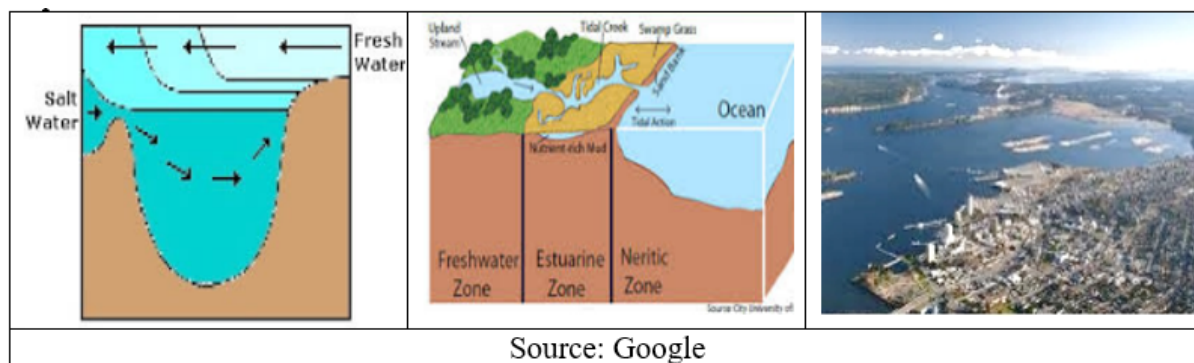


Figure 13

Fauna: All living native or introduced animal species in an ecosystem. Some fauna provides us with food, clothing, wealth and medicines. Some are harmful or vector of diseases. The fauna of a particular area can be documented in a publication e.g., Birds of Al Ga'ab depression.

Fertilizers are substances, either natural or synthetic, that contain essential chemical compounds which enhance soil fertility and support plant growth.

Natural fertilizers include organic materials such as animal manure and guano (bird or bat excreta). Treated human waste is also utilized as manure in some agricultural systems. Additionally, organic waste from slaughterhouses, discarded fish (by-catch), rejected processing materials, household organic matter, and other biodegradable green waste are decomposed through microbial activity to produce compost or organic fertilizer.

Leaf litter that undergoes decomposition forms mulch, which significantly improves soil structure and increases its water retention capacity.

Synthetic (inorganic) fertilizers primarily consist of nitrogen (as nitrates), phosphorus (as phosphate). Secondary nutrients such as calcium and magnesium may also be included depending on crop and soil requirements.

Fertilizers are available in various formulations, including powders, granules (pellets), and liquid forms, allowing for application based on agronomic practices and crop needs.

Biological nitrogen fixation is a crucial natural process facilitated by nitrogen-fixing bacteria such as Cyanobacteria, Anabaena, and Azotobacter, particularly in association with leguminous plants. This process relies on the enzyme urease, which catalyzes the conversion of urea into ammonium ions (NH_4^+) and bicarbonate ions (HCO_3^-), making nitrogen available in a form accessible to plants (Figure 14).

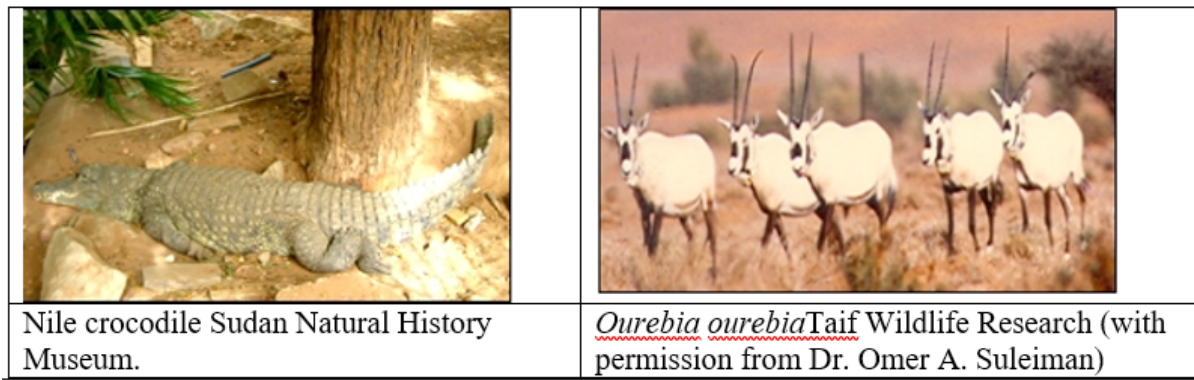


Figure 14:

Filtration is a physical process used to remove fine solid particles and pathogenic microorganisms from a liquid or gaseous medium by passing it through a porous material. This material, known as the filter medium, permits the passage of the fluid while retaining suspended solids and contaminants. In drinking water treatment facilities, slow sand filters, consisting of layers of fine gravel and sand, are commonly employed for the purification of potable water.

Floodplain refers to the flat or gently sloping land adjacent to a river, stream, or other major waterbody that becomes temporarily inundated during periods of high discharge or flooding. The extent of a floodplain is determined by the magnitude of the flood event. After floodwaters recede, sediments such as clay, silt, sand, and gravel are deposited, enriching the soil and significantly enhancing its fertility.

Flora encompasses all plant species—both native and introduced—present within a particular ecosystem. These plants play essential roles by providing food, fiber, shelter, raw materials, medicinal compounds, and aromatic substances. The composition and diversity of flora in a specific region can be systematically recorded and studied through scientific surveys, such as “The Trees of Erkowit.”

Food Chain refers to the linear sequence of energy transfer and nutrient flow among organisms within an ecosystem, starting from primary producers, moving through primary and secondary consumers, and ending with decomposers.

Primary producers, such as terrestrial and aquatic plants, including phytoplankton and algae, utilize carbon dioxide and water to synthesize carbohydrates through the process of photosynthesis, driven by solar energy. These autotrophs form the base of the food chain.

Primary consumers (herbivores) feed directly on the producers. In terrestrial ecosystems, examples include grazing animals like dairy cattle, while in aquatic ecosystems, herbivorous fish such as tilapia serve this role.

Secondary consumers (carnivores or omnivores) feed on the primary consumers. Examples include humans, large predatory mammals (e.g., big cats), and predatory fish like the Nile perch. Humans may also function as tertiary consumers when they consume top-level predators such as the Nile perch.

When organisms die or excrete waste, their organic matter is broken down by decomposers—mainly bacteria and fungi—into inorganic mineral elements, which are then recycled into the ecosystem.

This chain of feeding relationships ensures a unidirectional flow of energy from producers to consumers and ultimately to decomposers, maintaining ecosystem balance and nutrient cycling (Table 2).

Table 2:

Input	Level	Biota		Output
CO ₂ + Water + Photons	Decomposers	→ Bacteria		CO ₂ → + Water + Energy →
	Tertiary consumers		Birds of prey, man feeding on carnivore fishes	
	Secondary consumers	→ Birds of prey, carnivores, man		
	Primary consumers	Seed eating fauna, herbivores, man	Zooplankton, herbivores fish	
	└┐ Primary producers	Plants	→ Phytoplankton algae and hydrophytes	Energy
Medium		Terrestrial	Aquatic	

Fossil: A fossil is the geologically preserved remains, impression, or trace of a once-living organism. Fossilization typically occurs when the organism's body is rapidly buried by sediments, such as sand. Over time, minerals—commonly silica—gradually infiltrate the cavities and tissues of the organism. This mineralization process leads to the hardening and preservation of the remains within sedimentary rock layers (Figure 15).



Figure 15:

Fossil fuels are energy-rich hydrocarbon-based substances such as coal, petroleum (crude oil), and natural gas, formed from the ancient remains of dead plants and animals (biota) that were buried under sediment and subjected to intense heat and pressure over millions of years. Their chemical composition is influenced by the natural carbon cycle.

These fuels are combusted to produce heat and electricity, power vehicles, and support industrial processes. However, their extraction and burning release pollutants and greenhouse gases, significantly contributing to air pollution and climate change.

Fringing reef is a type of coral reef that forms along coastlines or around islands, extending directly from the shore into the sea. It typically consists of three zones: Back reef (nearest to land), Reef crest (the highest point, often exposed at low tide) and Fore reef (sloping seaward into deeper water).

If a volcanic island subsides below sea level and the fringing reef continues to grow upward, it may develop into an atoll. Fringing reefs serve important ecological functions, such as protecting coastlines from storm-induced erosion and providing critical habitats for ecosystems like seagrass beds, mangroves, and saltmarshes. They support high biodiversity, including sponges, mollusks (e.g., oysters, clams), crustaceans (e.g., crabs), echinoderms (e.g., sea stars, sea urchins), and numerous fish species.

Fungi refers to the fungal biodiversity present within an ecosystem. Fungi perform vital ecological roles, including decomposition of organic matter, which recycles nutrients back into the soil. Some fungi are edible, while others are toxic or medicinally valuable. Their presence is essential for maintaining ecological balance.

Game reserve is a protected area designated for the conservation of wildlife, where animals can roam freely and exploit natural resources such as food, water, and shelter. These reserves often include programs for habitat rehabilitation when ecosystems are disturbed.

Game reserves also provide socio-economic benefits by offering employment opportunities to local communities, often requiring minimal formal education. In some reserves, regulated fishing and sport hunting of specific species are allowed during designated seasons, under strict quotas to ensure sustainability.

Geographical Information System (GIS) is a computer-based framework used to capture, store, manage, analyze, interpret, and visualize spatial and geographic data. GIS enables the integration of multiple layers of information to support decision-making in urban planning, environmental monitoring, disaster management, and resource management.

Geothermal heat refers to the thermal energy stored within the Earth's interior. This energy is harnessed by geothermal power plants to generate electricity and provide heating and cooling. As a stable and renewable energy source, geothermal heat offers a low-carbon alternative to fossil fuels. However, the extraction and utilization of geothermal energy may release naturally occurring gases such as carbon dioxide (CO₂) and hydrogen sulfide (H₂S), which are considered environmental pollutants. Despite this, geothermal systems remain an economically viable and sustainable option for building climate control.

Geopark is a designated protected area that contains geologically significant features and landscapes. These areas are established to promote the study of Earth's history, including geological processes, past and present climate change, and biodiversity. Geoparks also serve as centers for sustainable development through eco-tourism, environmental education, and the conservation of natural and cultural heritage.

Global Positioning System is a satellite-based navigation system that provides geospatial positioning information to users anywhere on Earth. By receiving signals from a network of satellites, GPS devices can determine accurate data on location (latitude and longitude), altitude, and precise time, enabling applications in navigation, mapping, and timing synchronization.

Global Warming refers to the long-term increase in Earth's average surface temperature, primarily driven by the accumulation of greenhouse gases (GHGs) in the atmosphere. These gases, including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), are released through the combustion of fossil fuels in industrial processes, power generation, and transportation. GHGs trap infrared radiation, reducing the emission of heat back into space, thereby enhancing the greenhouse effect and contributing to climate change.

Green finance refers to financial activities and investments that support sustainable environmental outcomes. It includes the mobilization of capital for projects that contribute to climate change mitigation and adaptation, biodiversity conservation, pollution reduction, and sustainable resource use. Green finance encompasses a range of financial instruments such as green bonds, green loans, sustainability-linked investments, and environmental risk assessment mechanisms. It plays a critical role in accelerating the transition to a low-carbon, climate-resilient, and environmentally sustainable economy.

Greenhouse gases are atmospheric constituents that absorb and emit infrared radiation, thereby contributing to the greenhouse effect. During the night, the Earth's surface cools and emits heat in the form of infrared radiation. This radiation is partially absorbed and re-emitted by greenhouse gases, such as water vapor (H₂O), carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride (SF₆). Human activities—such as

the burning of fossil fuels, deforestation, agricultural practices (especially livestock farming), and the use of fluorinated gases in refrigeration and air conditioning—have significantly increased the concentrations of these gases in the atmosphere, enhancing the natural greenhouse effect and contributing to global climate change.

Greywater is a category of wastewater generated from domestic, commercial, and some industrial activities, excluding toilet discharge. It typically originates from showers, bathtubs, sinks, washing machines, and dishwashers. Greywater may contain organic matter, food particles, grease, hair, soap residues, and potentially pathogenic microorganisms such as *Salmonella* and *Campylobacter*. It constitutes approximately 30–50% of total wastewater volume. When properly treated, greywater can be reused for non-potable applications such as landscape irrigation and toilet flushing, reducing overall freshwater consumption by up to 40%. However, it is not suitable for drinking or for irrigating edible plants consumed raw.

Halophytes are plants that have evolved to grow and thrive in environments with high salinity, such as salt marshes, coastal regions, and saline soils. These plants possess specialized physiological, biochemical, and structural adaptations that allow them to tolerate, exclude, or compartmentalize excess salts. Common adaptations include salt excretion glands, succulent tissues for water storage, selective ion transport, and osmotic adjustment using compatible solutes. Halophytes are important in ecological restoration, saline agriculture, and phytoremediation of salt-affected lands. *Avicennia marina*, *Suaeda* spp., *Tamarix* spp., are common Red Sea halophytes.

Hazardous substances and wastes are materials that pose significant risks to human health or the environment due to their physical, chemical, or biological properties. These may include flammable or explosive chemicals, corrosive substances that damage living tissues, and compounds that are carcinogenic or mutagenic. In some cases, biological agents such as pathogenic microorganisms or vectors of disease are also classified as hazardous. Hazardous wastes include items like heavy metals (e.g., mercury, lead), spent batteries containing toxic liquids, and damaged electronic equipment (e.g., televisions) that may contain high-voltage components or hazardous materials. Many countries maintain regulatory lists of hazardous substances and prescribe specific guidelines for their safe handling, storage, transport, and disposal.

Hibernation is a physiological adaptation employed by certain animals to conserve energy during periods of low food availability, typically in cold winter months. During hibernation, animals significantly reduce their metabolic rate and lower their body temperature to minimize energy expenditure while protecting tissues from cold-induced damage. This state of dormancy is observed in various mammals, including bats, hedgehogs, ground squirrels, mouse lemurs, monotremes, and marsupials. Although rare, some bird species—such as the Common Poorwill (*Phalaenoptilus nuttallii*)—are also known to undergo hibernation.

Hotspots are biogeographic regions characterized by exceptionally high levels of species richness and endemism, which are under significant threat from human activities. A region is typically classified as a hotspot if it contains at least 1,500 species of endemic vascular plants and has lost more than 70% of its original natural vegetation. Currently, 36 biodiversity hotspots have been identified globally, 10 of which are considered critically threatened. These include terrestrial hotspots such as the Eastern Himalayas and the Cape Floristic Region, as well as marine hotspots like the New Zealand Archipelago. Together, these regions harbor approximately 60% of the world's plant, amphibian, reptile, bird, and mammal species, while collectively occupying only about 15.7% of the Earth's terrestrial surface.

Hurricane is a powerful tropical cyclone that forms over warm ocean waters in regions of low atmospheric pressure, typically within tropical and subtropical latitudes. It is characterized by a rapidly rotating system of thunderstorms with sustained wind speeds ranging from 60 km/h to over 250 km/h. Hurricanes are associated with intense rainfall, storm surges, and high winds, which can cause widespread structural damage, flooding, and displacement of populations. The impact of a hurricane may render affected areas uninhabitable for extended periods due to destruction of infrastructure and disruption of essential services.

Hydrology is the scientific discipline concerned with the distribution, movement, and properties of water on and beneath the Earth's surface, as well as in the atmosphere. It encompasses the study of the hydrologic cycle, water resources, drainage basin management, and the effects of anthropogenic activities on water availability and quality.

Hydrophytes are plants that have adapted to grow in aquatic environments. Depending on their growth habit, they may be categorized as emergent (e.g., *Phragmites karka*), submerged (e.g., *Potamogeton pectinatus*), or floating species (e.g., *Pistia stratiotes* and *Pontederia crassipes*). These morphological adaptations allow them to survive and reproduce in water-saturated conditions.

Hydrosphere encompasses all forms of water present on Earth, including surface water (e.g., rivers, lakes, and oceans), groundwater (e.g., aquifers and wells), atmospheric water vapor, clouds, glaciers, and polar ice caps. It includes both freshwater and saline water systems. Approximately 71% of the Earth's surface is covered by water, with freshwater representing only about 3% of the total volume.

Hyper gravity refers to a condition in which the gravitational force acting on a body exceeds that of Earth's normal gravity (1 g). This occurs naturally during rapid acceleration events such as rocket launch or atmospheric re-entry. Exposure to hypergravity affects physiological and cellular functions in both humans and other organisms. Common effects include increased cardiovascular strain, fluid redistribution, musculoskeletal loading, and altered vestibular function. In experimental research, hyper gravity is used to study biological adaptation, simulate launch conditions, and investigate the limits of human performance and tolerance under elevated gravitational stress.

Hypoxia is a physiological condition characterized by an insufficient supply of oxygen to the tissues and organs of the body to maintain normal cellular metabolism and function. It can result from a variety of causes, including reduced atmospheric oxygen pressure (as in high altitudes or space environments), impaired respiratory or circulatory function, or obstruction of oxygen transport at the cellular level. There are several types of hypoxias, such as hypoxic hypoxia (low oxygen in the air), anemic hypoxia (insufficient hemoglobin), circulatory hypoxia (poor blood flow), and histotoxic hypoxia (cells unable to utilize oxygen). Symptoms can range from mild cognitive impairment and fatigue to severe organ dysfunction or death. In aerospace and space medicine, hypoxia is a critical concern, particularly in unpressurized cabins, suit malfunctions, or during extravehicular activities.

Impervious surface is an impervious surface is a land cover type—such as concrete, asphalt, or compacted soil—that significantly reduces water infiltration into the ground. As a result, it increases surface runoff, which can carry sediments and a variety of pollutants (e.g., oils, heavy metals, nutrients) into nearby water bodies, thereby degrading water quality and aquatic habitats.

Infauna are benthic organisms that inhabit the sediments of aquatic environments such as riverbeds, lake bottoms, and the ocean floor. They primarily feed on suspended plankton and organic detritus. Representative taxa include clams, snails, polychaete worms, flatworms, and small crustaceans. Infaunal species play a crucial ecological role in sediment bioturbation, nutrient recycling, and serve as a food source for higher trophic levels, including fish and larger crustaceans.

Intact areas are regions with minimal physical disturbance from human activities, such as fragmentation where physical integrity is largely preserved (despite the presence of invasive alien species or pollution) and natural ecosystem functions continue to operate fully.

Invasive (exotic, alien) species are organisms—plants, animals, or microorganisms—that are introduced, either intentionally or accidentally, into ecosystems outside their native range. These introductions often disrupt local biodiversity and ecological balance, potentially causing significant environmental and economic harm.

Intentional introductions may be for agricultural, aquacultural, or biological control purposes. In Sudan, examples include the water hyacinth *Pontederia* (= *Eichhornia*) *crassipes* introduced into Southern Sudan, *Prosopis chilensis* for afforestation or land reclamation, and fish species such as *Gambusia affinis*, introduced for mosquito larvae control, and *Gibelion catla* and *Oreochromis urolepis* to improve aquaculture productivity.

Accidental introductions occur without human planning, often through trade, livestock movement, or transport. For example, the invasive plant *Acanthospermum hispidum* is believed to have entered Sudan via transboundary grazing cattle from West African countries led by nomadic groups such as the Ampararrow. Another example is the introduction of the Indian crow (*Corvus splendens*), brought to Port Sudan about a century ago, which has since become a dominant bird species along the Sudanese coast.

These alien species often outcompete native species, degrade habitats, and lead to substantial ecological disruptions and economic losses in agriculture, fisheries, and public health (Figure 16).

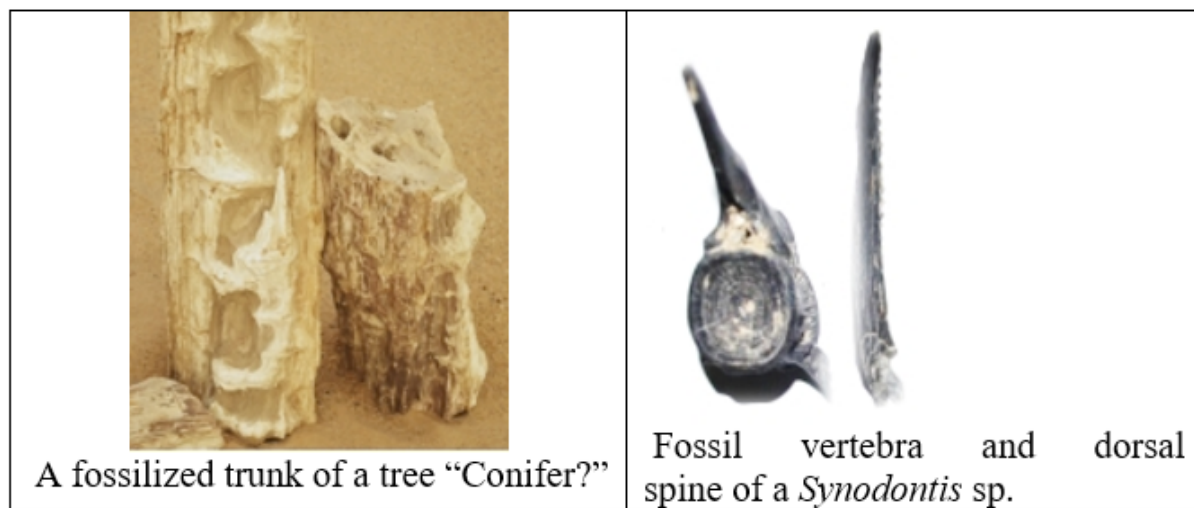


Figure 16:

Injection well is a specially engineered and drilled structure designed to introduce fluids—such as treated wastewater, saline water, or water mixed with chemicals—into deep underground geological formations. These formations typically consist of porous rocks such as sandstone or limestone, which allow the injected fluids to percolate and undergo natural filtration. The purpose of injection wells may vary, including waste disposal, groundwater recharge, or enhanced oil recovery. In some cases, the injected water can later be recovered as naturally filtered water from nearby extraction wells.

In-situ conservation refers to the protection and maintenance of biological diversity within the natural habitats of species. It involves conserving ecosystems and natural habitats, along with the maintenance and recovery of viable populations of species in their original environments. For example, whales conserved in marine ecosystems, and elephants or lions in forested areas.

In Sudan, notable examples of in-situ conservation sites include Dinder National Park, Radom National Park, and the Al Sabaloga Wildlife Reserve.

This form of conservation is critical as it helps preserve the genetic diversity of endangered species, supports ecosystem functioning, provides natural resources for human use, offers field-based educational and training opportunities for biology students, and facilitates ecological and conservation research by scientists (Figure 17).

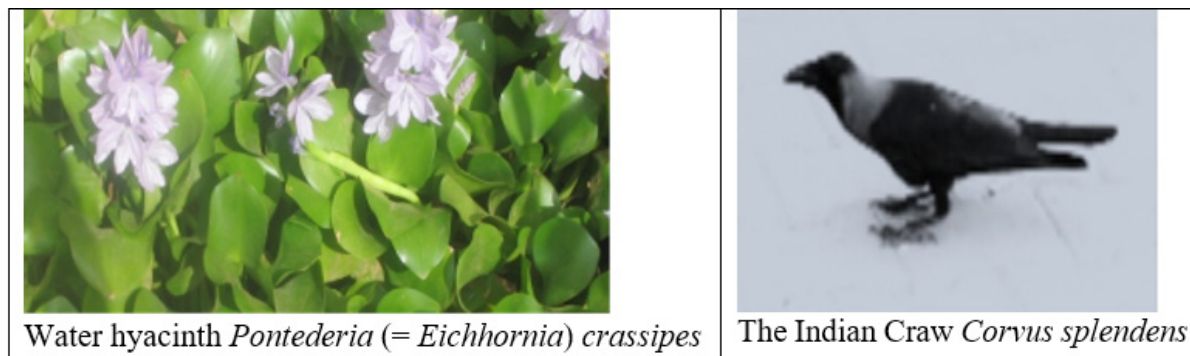


Figure 17:

Integrated pest management (IPM) is a scientifically based, ecologically sensitive approach to controlling pest populations through a combination of complementary strategies. These include mechanical, cultural, biological, and chemical control methods, applied in a coordinated manner to minimize risks to human health and the environment.

The IPM process begins with accurate pest identification and analyzing their life cycles and behavior to determine the most effective control measures, followed by monitoring pest populations. If chemical control is necessary, it is applied with careful consideration of its effects on non-target organisms, ecosystem balance, and human health.

The ultimate goal of IPM is to maintain pest populations below economically damaging levels while reducing reliance on chemical pesticides, thereby limiting the negative impacts of pesticide residues and environmental contamination.

Island is a landmass that is entirely surrounded by water. When several islands are geographically associated, they form an archipelago, such as the Suakin Archipelago in the Red Sea. Some archipelagos make up entire nations, such as the Maldives, Comoros, Malta, the Philippines, and Indonesia.

Islands can occur in various water bodies: Oceans (e.g., Madagascar in the Indian Ocean), Seas (e.g., Suakin in the Red Sea), Lakes (e.g., Ukerewe Island in Lake Victoria), and Rivers (e.g., Tuti Island in the Nile River).

In some cases, artificial islands are created by human engineering, such as Flevopolder in the Netherlands, which is the largest man-made island in the world, covering an area of approximately 600km².

Additionally, when large dams are constructed, the resulting reservoir can submerge parts of the landscape. Mountain peaks or elevated land may remain above the water surface, forming new islands. This phenomenon occurred in Lake Nubia, where several such islands emerged, including Maka al-Nasir (Figure 18).

Just ecological transition refers to the process of shifting towards a sustainable, low-carbon, and environmentally responsible economy in a way that is equitable and inclusive. It ensures that the social, economic, and environmental dimensions of sustainability are addressed simultaneously, and that no community or group is disproportionately disadvantaged during the transition. This approach integrates principles of environmental justice, social equity, and labor rights, aiming to protect vulnerable populations, create decent green jobs, and foster resilience in the face of climate and ecological challenges.

Lagoon is a shallow, often calm, body of water that is partially or completely separated from a larger sea or ocean by natural barriers such as sandbars, rock formations, barrier reefs, islands, peninsulas, or occasionally dense stands of mangrove vegetation.

Lagoons are typically categorized into two main types:

1. Coastal lagoons are located along continental or island shores, usually separated from the open sea by barrier formations.
2. Atoll lagoons are found within coral atolls, surrounded by a ring-shaped coral reef that encloses the water body.

Lagoons play important ecological roles, serving as habitats for diverse aquatic species, nurseries for fish, and buffers against coastal erosion (Figure 19).



Figure 19:

Landfill gas is a mixture of gases generated as a byproduct of the anaerobic decomposition of organic waste in landfills. The primary constituents of landfill gas include carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S).

These gases can migrate through the surrounding soil and subsurface layers, potentially accumulating in nearby structures, where they may displace oxygen and pose health and safety risks. Ammonia and hydrogen sulfide are largely responsible for the strong odors associated with landfills. Methane is highly flammable, and in certain instances, it has been found in indoor environments at concentrations exceeding safety thresholds, creating an explosion hazard.

Proper gas collection, monitoring, and control systems are essential to mitigate environmental and public health impact.

Landscape refers to the physical and biological features of the Earth's surface, including natural elements such as coastlines, deserts, rivers, lakes, floodplains, hills, and mountains, as well as living organisms (biota) and human-made structures (infrastructure). Landscapes embody the interaction between natural processes and human activities, reflecting cultural heritage, ecological characteristics, and aesthetic values (Figure 20).

Lithosphere refers to the rigid, outermost shell of the Earth, encompassing the continental crust and the oceanic crust, including the seafloor. It plays a crucial role in supporting terrestrial ecosystems and serves as the foundation for all land-based life. Approximately 28% of the lithosphere is exposed directly to the atmosphere, representing the landmasses of the continents.

Mangrove are specialized tropical coastal plants adapted to saline environments and periodic tidal inundation. Certain mangrove stands are naturally sheltered from intense wave action by geographic features such as barrier reefs, islands, or bays. The soil in mangrove ecosystems is typically fine-textured and rich in organic matter, functioning as an effective sink for heavy metals. These ecosystems provide essential habitat and resources for a variety of marine and terrestrial organisms.



Figure 20: Inkifal lagoon, 160km north Port Sudan

Globally, around 50 species of mangroves have been identified; however, along the Sudanese coastline, only *Avicennia marina* is present. Mangroves possess specialized aerial roots called pneumatophores that facilitate oxygen intake in waterlogged soils, and they regulate salt through transpiration processes. Moreover, mangroves are highly efficient carbon sinks, storing more carbon per unit area than many terrestrial forests. They also serve a critical ecological function by protecting coastlines from erosion caused by waves, storm surges, and terrestrial water runoff (Figure 21).

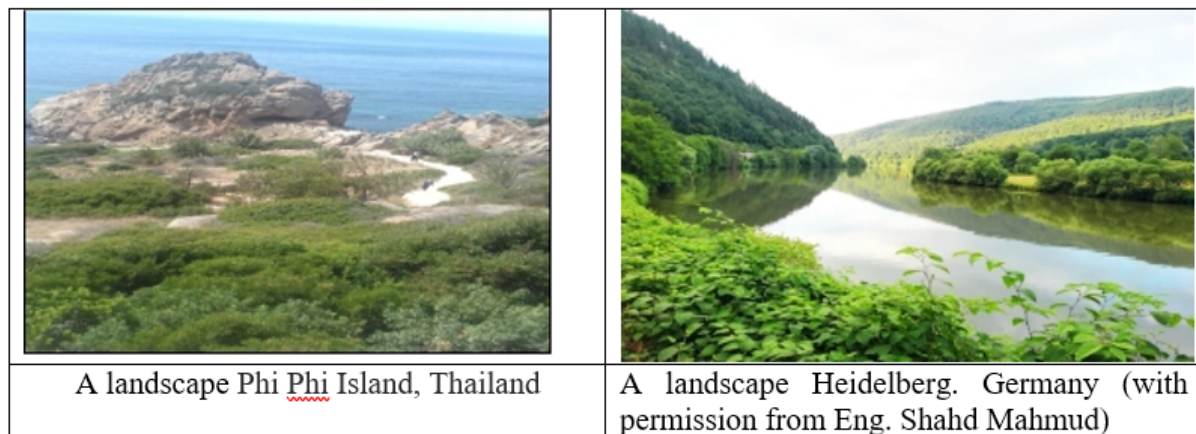


Figure 21:

Marine debris refers to any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment. This debris includes plastics, metals, glass, rubber, and other materials that accumulate in oceans, seas, and coastal areas. Marine debris poses significant environmental threats by harming marine organisms through ingestion or entanglement, disrupting habitats, and introducing toxic substances into ecosystems. Addressing marine debris is essential for preserving marine biodiversity and maintaining the health of oceanic environments.

Marine protected areas (MPAs) are designated zones within seas or oceans that are managed for the conservation of marine ecosystems, biodiversity, and cultural resources. MPAs may consist entirely of marine environments such as islands or atolls (e.g., *Sanganeb Atoll*, officially designated in 1990) or may be partially enclosed by land, as in the case of *Mukkawar Island* and *Dunqonab Bay Marine National Park*, which was gazette in 2004. These two MPAs are connected by a marine corridor spanning approximately 401,136 hectares, serving as a buffer and ecological linkage between the two sites.

Sanganeb Atoll is recognized for hosting the most diverse marine biodiversity in the central Red Sea, featuring 13 distinct biogeographic reef zones. It provides habitat for numerous species of conservation concern, including sharks, manta rays, and sea turtles. *Dungonab Bay* supports a globally significant population of dugongs and hosts various species of seabirds. In 2016, both *Sanganeb Atoll* and *Dungonab Bay–Mukkawar Island* were inscribed as a UNESCO World Heritage Site in recognition of their ecological and biological importance.

Marine Science Parks are specialized facilities designed to foster innovation, scientific research, and environmental education related to marine ecosystems. These parks often feature public engagement infrastructure such as underwater glass tunnels, allowing visitors to observe marine life in situ. By raising public awareness and appreciation for marine biodiversity, science parks play an important role in promoting the conservation and sustainable use of marine resources.

Meadows are an open terrestrial ecosystem characterized predominantly by the presence of native grasses and herbaceous plant species. It may arise naturally through ecological succession or be anthropogenically maintained through land clearing and controlled grazing. Meadows function as important habitats supporting a diverse array of flora and fauna, including herbivorous and carnivorous wildlife. They serve ecological roles such as providing forage for livestock, supporting pollinators, and offering resources like wildflowers, medicinal herbs, and food plants. Additionally, meadows contribute to reproductive and nesting activities and may serve as temporary refuges for various animal species (Figure 22).

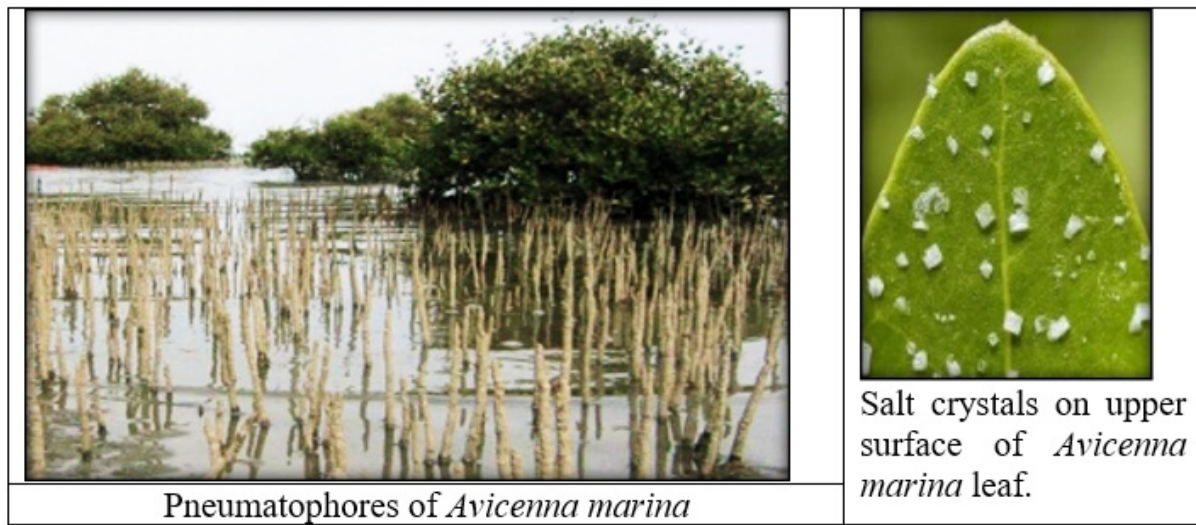


Figure 22:

Medical waste incinerators are high-temperature combustion system designed to safely dispose of both infectious and non-infectious waste generated by hospitals, medical and veterinary facilities, and research institutions. The process thermally decomposes organic materials, reducing waste volume and neutralizing potentially hazardous biological agents.

Meiofauna are microscopic, benthic invertebrates that inhabit the interstitial spaces of sediments in aquatic environments, particularly in marine and freshwater ecosystems. Representative taxa include oligochaetes, polychaetes, free-living marine nematodes, ostracods, isopods, amphipods, and early developmental stages of crustaceans such as nauplii. These organisms play a critical ecological role by facilitating the vertical transport of organic matter and nutrients between sediment layers and the overlying water column, thus influencing sediment structure and ecosystem functioning.

Methane (CH₄) is a colorless, odorless greenhouse gas produced primarily through anaerobic microbial decomposition of organic matter in environments such as landfills, wetlands, and the digestive tracts of ruminants. It is a major component of natural gas and serves as an important source of energy for domestic and industrial applications.

Meteorological variables are quantitative measurements that describe the state of the atmosphere at a given location and time. Standard variables include temperature, relative humidity, wind speed, wind direction and altitude, cloud cover, precipitation, solar radiation, atmospheric pressure and density, and sea surface conditions. These parameters are essential for weather forecasting and climate modeling. Factors influencing regional meteorological conditions include latitude, distance from oceans, ocean currents, topography, and climatic phenomena such as El Niño.

Microgravity refers to the condition in which objects appear to be weightless and experience very small accelerations due to gravity. This state occurs when an object is in free fall, such as in orbit around Earth, where the force of gravity is not absent but significantly reduced due to continuous free-falling motion. The prefix “micro-” indicates that the residual gravitational acceleration is on the order of one-millionth (10^{-6}) of Earth’s gravity (1g). In this environment, physical and biological systems behave differently than they do under normal gravity, affecting fluid dynamics, combustion, cellular processes, and human physiology.

Monsoon is a seasonal atmospheric phenomenon characterized by a reversal of prevailing wind patterns, typically associated with heavy rainfall in tropical and subtropical regions. Major global monsoon systems include the West African, Asia-Australian, North American, and South American monsoons. These systems are critical to regional agriculture, water supply, and ecological dynamics.

Movement of contaminants refers to the transport and dispersion of pollutants through environmental media such as air, soil, groundwater, and surface water. This process is influenced by physical, chemical, and biological factors, and it plays a central role in environmental risk assessment and pollution management.

Multiple use refers to the integrated and sustainable management of natural resources—such as land, forests, and aquatic systems—for concurrent utilization across various functions. This approach supports the simultaneous delivery of ecological, economic, and social services. For instance, a single land area may be managed for livestock grazing, watershed protection, wildlife habitat conservation, recreational activities, and timber production. Similarly, water bodies may serve multiple functions, including potable water supply, fisheries, and recreational use. The principle of multiple use seeks to optimize resource efficiency while maintaining ecological integrity and meeting diverse human needs.

Municipal solid waste (MSW) encompasses the heterogeneous mixture of everyday discarded materials generated by residential, commercial, institutional, and public sectors. Common constituents include organic waste (e.g., food scraps), paper products, glass, metals, plastics, and packaging materials. MSW management involves the collection, transportation, treatment, and disposal of these wastes, with an increasing emphasis on waste minimization, recycling, and resource recovery to reduce environmental impacts.

National parks are scientific institutions comprising multiple buildings and exhibition halls designed to display and preserve parts of extensive biological, geological, and paleontological collections. In many cases, these collections contain millions of specimens representing vast spans of evolutionary and ecological history over millions of years.

In Dinder National Park (DNP), fishing is permitted only during a restricted post-flood period and solely within designated low-risk zones to minimize ecological disturbance. Similarly, Sanganeb Atoll serves as a marine national park, characterized by its unique marine ecosystems and highly diverse coral reef habitats (Figure 23).

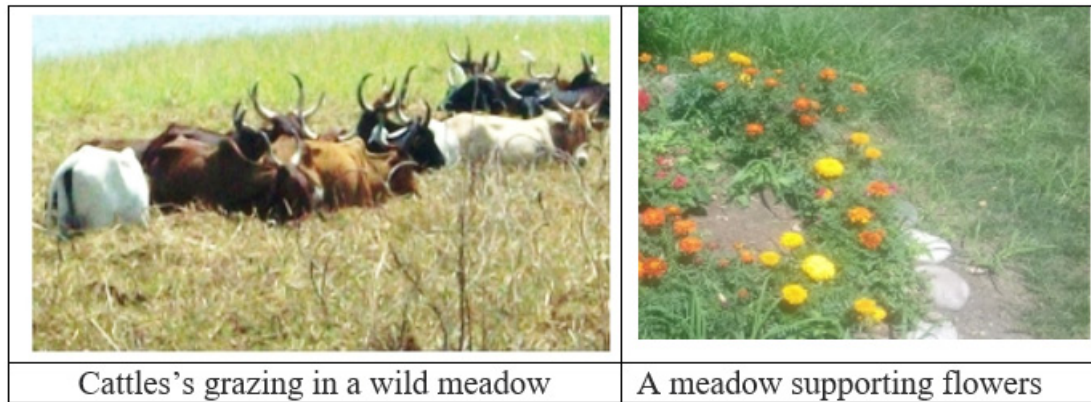


Figure 23:

Natural history museums are scientific institutions comprising multiple buildings and exhibition halls designed to display and preserve parts of extensive biological, geological, and paleontological collections. In many cases, these collections contain millions of specimens representing vast spans of evolutionary and ecological history over millions of years.

Natural history museums serve as critical centers for scientific research and education. In several of these institutions, systematic research is conducted in fields such as taxonomy, ecology, and conservation biology. The collections provide essential data for studying long-term changes in biodiversity and for analyzing the combined effects of natural processes and human activities on ecosystems and geographic patterns over time.

Nature-based solutions refer to actions aimed at protecting, sustainably managing, and restoring natural and/or modified ecosystems to address societal challenges in an effective and adaptive way, while simultaneously enhancing human well-being and supporting biodiversity benefits. These solutions are broader than ecosystem-based approaches, encompassing additional benefits such as biodiversity conservation, improved water quality and quantity, and sustainable land management. Examples include reforestation, wetland restoration, green urban infrastructure, and sustainable agriculture practices.

Niche concept suggests that ecological communities are composed of multiple distinct niches, each uniquely occupied by a particular species. A niche defines the functional role of an organism within its community, encompassing its specific environmental and physiological requirements, as well as its biotic interactions with other organisms. These interactions may include commensalism, predation, and competition, all of which influence the organism's survival, reproduction, and spatial distribution (Figure 24).

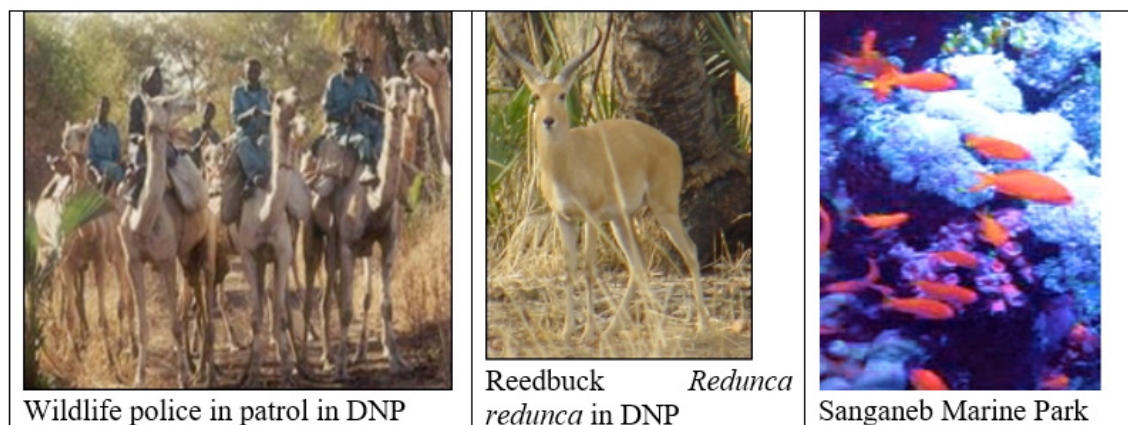


Figure 24:

Nitrogen oxides refer to a group of colorless, reactive gases primarily composed of nitric oxide (NO) and nitrogen dioxide (NO₂). They are emitted both through natural processes and anthropogenic activities, particularly as by-products of fuel combustion. In the atmosphere, nitric oxide is readily oxidized to nitrogen dioxide, a major air pollutant. Nitrogen oxides contribute significantly to the formation of photochemical smog, acid rain, and stratospheric ozone depletion.

Non-Renewable Resource are naturally occurring substances that exists in limited quantities and cannot be replenished once exhausted. Examples include fossil fuels (coal, oil, natural gas), nuclear materials, mineral deposits, and fossil groundwater in confined aquifers.

Nutrients are organic and inorganic compounds assimilated by organisms to support metabolic functions and growth. Decomposers such as bacteria, fungi, and certain animals derive nutrients from dead or living organic matter. Photosynthetic organisms like algae and plants synthesize nutrients using solar energy. Nutrients are transferred through trophic levels in the food chain, supplying energy and essential elements. The oxidation of carbohydrates, fats, and proteins during metabolism releases energy and produces water and carbon dioxide as by-products.

Oasis is a naturally or artificially sustained fertile zone in arid or semi-arid regions, typically supported by groundwater sources such as springs or wells. Oases support vegetation, wildlife, and human settlements. In Sudan, there are 67 known oases with varying salinity levels, 17 of which have a high-water table. Some, like Nukhaila, are inhabited by nomadic populations, while Lagiya Arbain and Lagiya Urman dried up due to declining water availability.

Oceanic trenches are elongated, narrow deep depressions on the ocean floor formed at zones where tectonic plates join. They may extend thousands of km in length, 50–100 km in width and 11 km in depth, such as the Mariana Trench in the Pacific Ocean. Due to extreme pressure and darkness, photosynthetic life is absent, and ecosystems rely on chemosynthetic bacteria. Faunal species include the ping-pong tree sponge, benthocodon jellyfish, zombie worms, telescope octopus, goblin sharks, frilled sharks, barreleye fish, and the seadevil anglerfish.

Organic farming is an agricultural system that employs ecologically based pest and soil management techniques. It uses treated organic inputs such as compost, animal manure, green manure, and fish bycatch to maintain soil fertility and produce chemical-free food. Natural predators are employed for biological pest control instead of synthetic agrochemicals. Organic farming enhances biodiversity, soil health, and environmental sustainability.

Overgrazing occurs when the grazing pressure by livestock exceeds the regenerative capacity of rangelands. Prolonged or intensive overgrazing can lead to significant degradation, including soil erosion, nutrient loss, vegetation decline, and reduced land productivity. Eventually, the soil structure may break down, increasing susceptibility to desertification and ecosystem collapse.

		
Dragonfly <i>Pantala flavescens</i> waiting to ambush a nectar feeding insect	<i>Myrmeleon</i> sp. larvae waiting for an insect to fall in the trap	A spider trap in <i>Balanitus ageptiaca</i> , Source: Sara M. AlMukhtar and A/Atti Omer

Figure 25:

Overhunting refers to the excessive and unsustainable exploitation of wildlife populations through hunting activities. It leads to significant declines in population sizes, disrupts reproductive cycles, and may drive species to local or global extinction. Overhunting poses a major threat to biodiversity by reducing species richness, altering ecosystem dynamics, and impairing the natural balance between predator and prey populations (Figure 25).

Ozone is a gaseous molecule (O_3) that forms a layer within the stratosphere, approximately 15–30km above Earth's surface. This ozone layer plays a critical role in shielding living organisms from harmful ultraviolet (UV) radiation by absorbing the majority of the sun's biologically damaging UV-B rays. However, this protective layer is undergoing depletion, primarily due to the emission of anthropogenic greenhouse gases, particularly chlorofluorocarbons (CFCs). These compounds are widely used in aerosols, refrigeration systems, air conditioners, detergents, and fire extinguishers. In contrast, ozone present at ground level acts as an air pollutant, posing health risks especially to vulnerable groups such as children, the elderly, and individuals with respiratory conditions like asthma.

Palaearctic region is one of the major zoogeographic regions, encompassing the entirety of Europe and northern Asia, including North Africa and the temperate zones of Asia, north of the Oriental region. It hosts a diverse range of fauna, notably avian species, many of which undertake seasonal migrations to warmer climates in sub-Saharan Africa during the winter months.

Pathogens are microorganisms, including viruses, bacteria, fungi, and parasites, that have the potential to cause disease in humans, animals, and plants. These organisms can invade host systems via various routes such as inhalation, ingestion, or transdermal penetration. Common entry points include mucous membranes of the mouth, nose, and eyes; skin breaches (wounds); urogenital openings; and through vectors such as insect bites.

Peninsula is a geographical landform characterized by being surrounded by water on three sides while remaining connected to the mainland. Peninsulas are found on every continent and vary significantly in size. For instance, Bishop Rock, the world's smallest peninsula, covers only 720m², while the Arabian Peninsula, the largest, spans approximately 3.2 million km².

Perennial Water refers to freshwater bodies that maintain continuous surface flow or presence throughout the year. In lotic systems, this includes streams and rivers with year-round flow. In lentic systems, it pertains to standing water bodies such as lakes and ponds that retain water permanently.

Pesticides are chemical agents designed to kill, inhibit, or repel pests that threaten agricultural productivity, public health, or stored biological commodities. They are formulated in solid, liquid, or gaseous forms and target specific organisms such as weeds (herbicides), fungi (fungicides), insects (insecticides), and rodents (rodenticides). Herbicides constitute roughly 50% of global pesticide usage. Most pesticides are composed of organophosphorus or chlorinated compounds. In public health, they are essential for controlling disease vectors, while in agriculture, they safeguard crops against pests. Despite their utility, pesticides pose significant environmental and health hazards. They contaminate air, soil, and water, and can bioaccumulate in human tissues, adversely affecting the nervous system and liver. Non-target organisms, including beneficial insects and soil fauna, are also impacted. In avian species, pesticide exposure is linked to reduced eggshell thickness. Additionally, pesticide overuse can lead to the emergence of resistant pest species and long-term soil degradation.

Photosynthesis is a biochemical process through which light energy is harnessed, in the presence of chlorophyll, water (H_2O), and carbon dioxide (CO_2), to synthesize carbohydrates and release molecular oxygen (O_2) as a byproduct. This process is carried out by cyanobacteria, algae, and higher plants, as well as certain photosynthetic bacteria and archaea.

The carbohydrates produced serve as a form of chemical energy, primarily stored in the form of simple sugars, starch, or cellulose, until they are metabolized via cellular respiration to meet the energy demands of the organism.

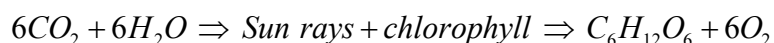
In plants and algae, photosynthesis occurs in specialized organelles known as chloroplasts, where chlorophyll absorbs light energy to initiate the reaction. In photosynthetic bacteria, such as purple and green sulfur bacteria, light absorption occurs via bacteriochlorophyll embedded in the plasma membrane. Some archaea, such as Halobacterium species, utilize a different light-absorbing pigment, bacteriorhodopsin, which absorbs green light and drives the synthesis of adenosine triphosphate (ATP) through photophosphorylation, although this is not considered oxygenic photosynthesis.

Photosynthesis is divided into two main stages: light-dependent and light-independent reactions.

During the light-dependent reactions, light energy is used to photolyze water molecules, resulting in the release of oxygen, and the generation of ATP and reduced nicotinamide adenine dinucleotide phosphate (NADPH). These energy carriers are essential for the subsequent biochemical reactions.

In the light-independent reactions (Calvin cycle), ATP and NADPH are utilized to fix atmospheric CO₂ into organic molecules, primarily carbohydrates.

In some anoxygenic photosynthetic bacteria, hydrogen sulfide (H₂S) is used as an electron donor instead of water. In these organisms, sulfur is released as a byproduct instead of oxygen, and hydrogen is used to reduce NADP⁺ to NADPH for carbon fixation.



Pollution is the introduction of harmful substances or energy forms, known as pollutants, into the natural environment, resulting in adverse effects on air, soil, and water quality, as well as on ecosystems and human health. Pollution may originate from natural sources, such as volcanic eruptions (e.g., ash and gases), or from human-made activities, including solid waste disposal, industrial emissions, vehicle exhaust, agricultural runoff, and urban development.

Pollutants are classified based on their physical state or nature into the following categories:

Solid pollutants: e.g., plastic waste, metal scraps, municipal garbage; Liquid pollutants: e.g., oil spills, sewage, industrial effluents; Gaseous pollutants: e.g., carbon monoxide, sulfur dioxide, smog, volatile organic compounds (VOCs); Thermal pollution: Discharge of heated water or air into natural systems, affecting temperature-sensitive organisms; Radioactive pollution: Release of ionizing radiation from nuclear activities or radioactive materials; Noise pollution: Excessive or harmful sound levels from traffic, industry, or construction, and Visual pollution: Unattractive or obstructive visual elements in landscapes, such as billboards, power lines, and litter.

The accumulation and persistence of pollutants can disrupt ecological balance, contaminate natural resources, and pose significant risks to biodiversity and public health (Figure 26).



Figure 26:

Potable water refers to surface or groundwater that meets safe drinking water standards, typically defined by metrological or regulatory guidelines (e.g., WHO, EPA).

Water is rendered potable after eliminating pathogenic microorganisms, chemical contaminants, and fecal matter, ensuring its safety for human consumption.

Primary producers are autotrophic organisms capable of synthesizing organic compounds from carbon dioxide (CO_2) and water (H_2O) using solar energy in the presence of chlorophyll, via the process of photosynthesis. These include cyanobacteria, algae, and green plants, which form the base of the food chain by producing carbohydrates that serve as an energy source for primary consumers (herbivores). The carbohydrates produced are also precursors to cellulose, a structural polysaccharide that constitutes the primary component of plant cell walls.

Produced water is the water extracted during the process of crude oil production, as most oil-bearing formations contains significant amounts of water. This water consists of a mixture of oil, solids, and chemicals used during the extraction process. The composition of produced water can vary depending on the geological formation and the production techniques used.

Given the potential environmental risks associated with the discharge of produced water, regulations often mandate its treatment before it can be reused for non-domestic purposes, such as afforestation, or safely discharged into the environment. Proper treatment is essential to remove contaminants and ensure that the water meets quality standards for its intended use (Figure 27).



Figure 27: Pollutants in Sunut forest, Khartoum

Productivity gaps refer to the difference between the potential and actual capacity of a landscape (including terrestrial, freshwater, and marine ecosystems) to produce goods for human use or consumption. A productivity gap arises when these ecosystems cannot meet the basic or sufficient needs of people, especially the most vulnerable. In agriculture, this gap is measured as the difference in output value per hectare of managed land.

Public Hearing is a formal, structured process conducted to collect and record feedback from local communities and relevant stakeholders—including community leaders—regarding a proposed development project within their region. This participatory mechanism is a critical component of environmental and social impact assessments. It ensures that potential concerns, suggestions, and objections are documented and considered prior to decision-making or project implementation. Conducting public hearings helps minimize adverse impacts on local populations, native biota, and surrounding ecosystems (Figure 28).

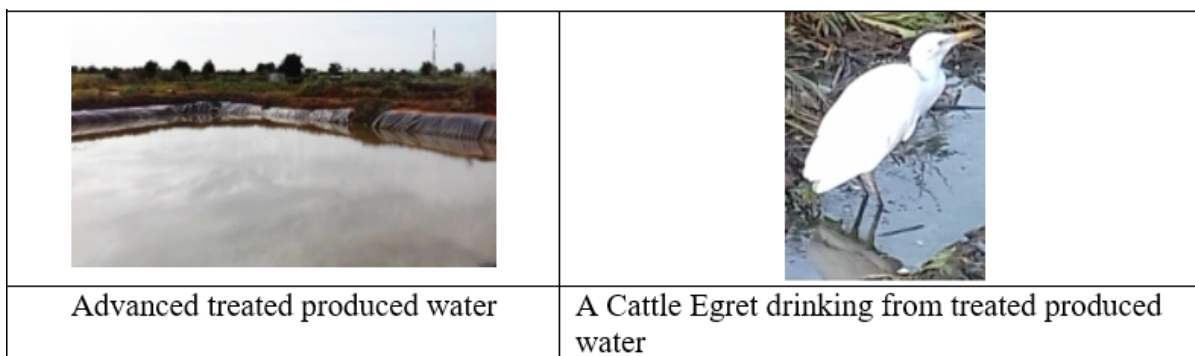


Figure 28:

Radiation refers to the emission and propagation of energy in the form of electromagnetic waves or particles from a source. Common sources include solar radiation (light and heat), microwave ovens (microwaves), medical imaging equipment (X-rays), and radioactive materials (gamma rays). High doses of ionizing radiation can damage cellular structures, particularly DNA, potentially leading to mutations, cancer, or other health effects.

Infrared radiation, emitted by the sun, Earth's surface, and various objects and gases, is absorbed by greenhouse gases such as CO₂ and CH₄. This absorption traps heat in the atmosphere, contributing to the greenhouse effect and global warming.

Short-wave infrared radiation may cause thermal burns, headaches, nausea, and dizziness, while prolonged exposure to mid-range infrared radiation can increase the risk of cataracts.

Ultraviolet (UV) radiation, from both solar and artificial sources, plays a beneficial role in vitamin D synthesis but poses health risks such as skin aging, eye damage, and increased risk of skin cancer.

Radiation exposure refers to the amount of ionizing radiation absorbed by an organism, object, or material over a specific period of time. Ionizing radiation has sufficient energy to remove tightly bound electrons from atoms or molecules, potentially causing cellular damage, DNA mutations, or system-level biological effects. Sources of radiation exposure include natural background radiation (from cosmic rays, terrestrial sources, and radon gas), medical imaging procedures (such as X-rays and CT scans), nuclear industry operations, and space environments. The extent of biological impact depends on the dose, dose rate, radiation type, and exposure duration. Radiation dose is commonly measured in sieverts (Sv), which accounts for both the energy absorbed and the biological effect of the radiation.

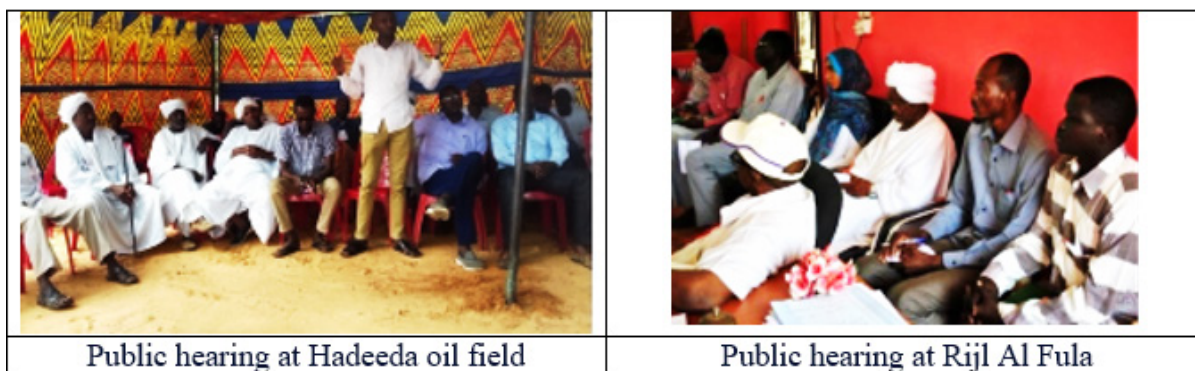


Figure 29:

Radioactive waste is the byproduct of activities involving radioactive materials, such as energy generation in nuclear reactors, medical applications, or scientific research. It contains radioactive isotopes that emit ionizing radiation during decay. This waste

is often co-disposed with other hazardous materials from hospitals, laboratories, or power plants. To ensure safety, radioactive waste is collected in sealed, lead-lined containers and disposed of in specially designed subterranean storage facilities to prevent environmental contamination (Figure 29).

Rainwater harvesting is the process of collecting and storing precipitation runoff—typically from rooftops—for later use. The captured water is stored in tanks, underground wells, aquifers, or reservoirs. It can be used for irrigation, livestock watering, flushing toilets, washing vehicles and clothes, and domestic heating. If properly filtered and treated to remove pollutants such as dust, soot, or bird droppings, the water may be suitable for potable use. This method also contributes to groundwater recharge and supports the expansion of green spaces.

Ramsar convention (1971), wetlands are areas where water whether natural or artificial, permanent or temporary, covers the soil or is present near the surface. This water can be static or flowing, fresh, brackish, or saline, and includes marine areas where the depth at low tide does not exceed 6m. Wetlands encompass swamps, marshes, peatlands, shallow lakes, and river estuaries.

These ecosystems are vital for sustaining biodiversity, providing habitats for both resident and migratory birds, and serving as breeding grounds for various species, including endangered ones. Wetlands improve water quality, store essential nutrients, and help prevent shoreline erosion. They offer economic benefits, support scientific research, and provide educational opportunities. However, many wetlands are under threat from pollution, overhunting, and drainage for urban development.

Recycling involves the collection, separation, and processing of materials such as plastics, paper, aluminum, and iron from waste streams to be reused in the production of new products. Organic waste is often subjected to anaerobic digestion to produce compost or organic fertilizers. Solid waste is sorted mechanically, metals are separated magnetically, and remaining materials may be sorted manually. In some countries, waste producers are required by law to segregate different waste types into appropriate containers. Recycling reduces pressure on landfills and incinerators, offers economic benefits, and helps protect the environment.

Reef etiquette refers to the set of guidelines and best practices designed to minimize human impact on coral reef ecosystems during recreational or research activities. These guidelines include avoiding physical contact with corals and marine organisms, not disturbing the natural habitat, properly disposing of waste, and maintaining safe distances to prevent damage. Adhering to reef etiquette is essential for preserving the biodiversity, structural integrity, and ecological functions of coral reefs, which are highly sensitive and vulnerable marine environments.

Remediation refers to the processes of removing, treating, containing, or otherwise managing environmental contamination from hazardous substances. These substances may pose significant risks to air, soil, or water quality. Remediation measures are often mandated by environmental regulations as a prerequisite for land development projects. Techniques may include excavation, chemical neutralization, bioremediation, or physical containment of pollutants.

Renewable energy is derived from naturally replenishing sources that are regenerated faster than they are consumed. These sources include solar radiation, wind, hydropower, ocean currents and tides, geothermal energy, and biomass (treated organic waste). Renewable energy is utilized for electricity generation, heating and cooling systems, and transportation. While most sources are sustainable, biomass sustainability depends on the rate of harvesting and land use practices. Renewable energy provides a cleaner alternative to fossil fuels, significantly reducing greenhouse gas emissions, air pollution, and acid rain.

Responsible party refers to the individual, organization, or entity legally identified by regulatory authorities as accountable for the contamination of a site and therefore liable for the costs associated with its cleanup and restoration.

Riparian habitats are ecological zones located along the margins of rivers, streams, and lakes. These areas are typically characterized by high soil fertility and biodiversity. Due to their unique hydrological and ecological conditions, riparian zones support dense vegetation and diverse species communities, making them crucial for ecosystem productivity and stability.

Risk assessment is the process of evaluating the probability and potential consequences of harmful events resulting from exposure to environmental or industrial hazards. It involves both qualitative and quantitative analyses to determine the level of risk to human health and ecosystems. Based on the findings, mitigation strategies and safety measures are developed to reduce or prevent adverse outcomes.

Sanitary landfilling is a controlled waste disposal method designed to isolate waste from the environment, particularly soil and groundwater, until it is rendered biologically inert through anaerobic decomposition. Waste is deposited in engineered landfills—such as natural depressions or abandoned mines—that are located away from urban areas. Different types of waste (municipal, industrial, hazardous, and special waste) are disposed of in separate, designated landfill sites, each equipped with containment and monitoring systems to prevent environmental contamination.

Seagrasses are submerged, flowering marine angiosperms that grow primarily in shallow coastal and brackish waters. These aquatic plants form dense underwater meadows that serve as critical habitats for a wide range of marine organisms. They provide food and shelter for various species, including commercially important shellfish and finfish, thereby supporting both local food security and global fisheries trade.

In addition to their biological importance, seagrass ecosystems offer essential ecological services such as enhancing biodiversity, stabilizing sediments, improving water quality through nutrient cycling, and protecting shorelines by reducing wave energy and preventing coastal erosion (Figure 30).



Figure 30: Seagrass meadow, Red Sea.

Seed dormancy is an adaptive survival strategy that prevents seeds from germinating under unfavorable environmental conditions. It is often regulated by physical barriers such as impermeable seed coats, which inhibit water uptake and gas exchange, thereby delaying germination until conditions become optimal for seedling establishment.

Sediment matter consists of particulate materials that are naturally produced through the weathering and erosion of rocks. These particles are transported by agents such as wind, water, ice, or gravity and eventually settle in low-lying areas, forming sediment deposits on riverbeds, lake bottoms, or ocean floors.

Septic system is an on-site wastewater treatment system comprising a septic tank and a soil absorption (drain) field. Wastewater from households flows into the septic tank—typically made of concrete, fiberglass, or plastic—where anaerobic bacteria break down organic matter, forming sludge and scum layers. Only clarified effluent exits the tank to percolate through the soil, where further natural filtration and biodegradation occur.

Sewage treatment plants are engineered facilities designed to remove contaminants from domestic wastewater. The system consists of pipelines, chambers, and treatment units that collectively process sewage to produce treated effluent safe for environmental discharge or reuse in non-potable applications such as irrigation or industrial use. These facilities play a critical role in preventing water pollution from untreated sewage.

Sludge is a semi-solid byproduct generated from various treatment processes, including wastewater treatment. It contains a mixture of water, solid particles, organic matter, and microorganisms. Sludge is typically subjected to anaerobic digestion to produce biogas, and the remaining material may be dried and used as a nutrient-rich organic fertilizer.

Smoke is a visible suspension of carbon-based particles in the air, resulting from incomplete combustion of organic materials. It originates from sources such as stoves, engines, tobacco, firewood, and fumigation. While used culturally in rituals, preservation, and communication, smoke—especially in enclosed spaces—poses severe health risks due to toxic gases like carbon monoxide and hydrogen cyanide.

Soil microbiota comprises diverse microscopic and macroscopic organisms including bacteria, fungi, earthworms, and insects. These organisms play a key role in soil fertility by decomposing organic matter, fixing nitrogen, and mineralizing nutrients. Additionally, they compete with and suppress root pathogens. Soil fauna like earthworms and ants improve aeration and water retention by creating tunnels, thereby promoting healthy plant growth.

Solid waste includes non-liquid residues such as dried sludge, filters, and discarded materials from industrial, commercial, mining, agricultural, and residential activities. Household solid waste may include food scraps, paper, glass, plastics, and metal containers. In some countries, these materials are sorted at the source to facilitate recycling and reduce landfill use.

Soot is a fine black particulate matter composed of impure carbon, formed by the incomplete combustion of hydrocarbon-based fuels. It is a significant air pollutant associated with respiratory illnesses and an increased risk of various cancers, particularly those affecting the lungs.

Space environment refers to the physical conditions that exist beyond Earth's atmosphere, including interplanetary and interstellar regions. It is characterized by a near-vacuum state with extremely low pressure and density, absence of breathable atmosphere, wide temperature fluctuations, microgravity, and high levels of ionizing radiation. Additional features include solar wind, cosmic rays, charged particles trapped in planetary magnetic fields, and varying levels of electromagnetic radiation. The space environment poses unique challenges to both human physiology and mechanical systems, affecting everything from cellular processes and fluid dynamics to the integrity of spacecraft materials and electronics. Understanding and mitigating the effects of this environment are essential for the success of long-duration space missions.

Spatial planning is a public process that involves analyzing and organizing the spatial and temporal distribution of human activities across geographic areas to achieve ecological, economic, and social objectives defined through a political process. It includes approaches such as land-use planning and marine spatial planning.

Spring is a natural discharge point where groundwater flows from an aquifer to the Earth's surface, thereby forming surface water. Springs may appear as small seeps with minimal discharge or as continuous, high-flow water sources. The temperature of spring water depends on its depth and geothermal gradient; when originating from geothermally heated rocks, spring water can reach temperatures between 65–85 °C, as observed in locations such as Akasha (near the tail of Lake Nubia), Quella (Jebel Marra), and El Harra (Wadi Azum) (Figure 31).

Some springs, like Ga'ab Al Sawani southwest of Dongola, may discharge mildly saline water, depending on the geological composition of the surrounding strata.



Figure 31:

Stabilization of Soil Organic Matter: Soil organic matter can undergo natural stabilization processes that enhance its resistance to microbial decomposition. This occurs through physical mechanisms such as micro-aggregation involving silt and clay particles, as well as through chemical processes involving the formation of stable organo-mineral complexes. Stabilization contributes to increased shear strength of the soil and enhances its overall load-bearing capacity.

Stagnant Water refers to water bodies lacking flow and oxygen exchange, creating an anaerobic environment. Such conditions favor the proliferation of bacteria, fungi, and disease vectors, including mosquitoes. These habitats also support a diverse assemblage of insects, many of which serve as prey for insectivorous birds and bats.

Stakeholders from an environmental and ecological perspective, stakeholders include policymakers, private sector representatives, scientists, landowners, and natural resource users. Active stakeholder participation facilitates the identification and prioritization of environmental and social issues and supports the development of mitigation strategies to address associated risks.

Storm is a meteorological disturbance characterized by extreme atmospheric conditions such as high winds, sandstorms, cyclonic activity, precipitation (rain or snow), and electrical discharges (thunderstorms).

Surface Water refers to all forms of water that collect and move over the Earth's surface, including streams, rivers, canals, lakes, wetlands, seas, and oceans.

Suspended solids in water including surface water, wastewater, or effluents—reduce dissolved oxygen levels and raise water temperatures, which can impair the survival of aquatic organisms such as juvenile fish. Accumulation of solids in riverbeds may impede water flow and diminish the storage capacity of reservoirs. Elevated concentrations of suspended particulates reduce light penetration, thereby inhibiting photosynthetic activity in submerged and emergent aquatic vegetation.

Supply chains encompass all activities involved in producing and delivering a product or service from origin to final use. They begin with the extraction and sourcing of raw materials, followed by manufacturing, processing, storage, and transportation. The process concludes with the distribution of finished products or services to consumers, ensuring the efficient flow of materials, information, and goods throughout the entire production network.

Sympatric refers to species, subspecies, or populations that occur within the same geographic area and share overlapping habitats, either completely or partially. Because they coexist in the same region, they have opportunities for ecological interactions such as competition, predation, resource sharing, or reproduction, making sympatry an important concept in ecology, evolution, and species distribution studies.

Swamps are wetland ecosystems distinguished by waterlogged soils and the presence of standing or slow-moving water for prolonged periods, either seasonally or throughout the year. These environments are dominated by hydrophytic woody vegetation, including water-tolerant trees, shrubs, and other plants adapted to saturated soil conditions. Swamps occur in a variety of settings, including freshwater, brackish, and saltwater environments, depending on local hydrology, climate, and proximity to coastal or inland water bodies. They serve as important transitional zones between terrestrial and aquatic ecosystems, supporting high levels of biodiversity by providing habitat, breeding grounds, and food resources for numerous plant and animal species. In addition to their ecological importance, swamps contribute to water purification, flood mitigation, groundwater recharge, and carbon storage by trapping sediments, filtering pollutants, and storing organic matter. These valuable ecosystems also help stabilize shorelines and maintain water quality, making them essential components of healthy landscapes and resilient environmental systems (Figure 32)



Figure 32: Jongeli swamps, South Sudan..

Temperate zone is a climatic zone characterized by moderate temperatures, with conditions that are generally neither extremely hot nor severely cold throughout the year. Earth has two major temperate zones: the Northern Temperate Zone, extending between the Tropic of Cancer and the Arctic Circle, and the Southern Temperate Zone, located between the Tropic of Capricorn and the Antarctic Circle. These regions experience distinct seasonal changes, including spring, summer, autumn, and winter, although the intensity of each season varies with latitude and local geography. Temperate climates are typically associated with moderate and relatively consistent precipitation, which supports diverse ecosystems such as forests, grasslands, wetlands, and agricultural landscapes. While rainfall is usually well distributed across the year, some areas may periodically experience drought due to regional climatic variability. The combination of moderate temperatures, seasonal patterns, and adequate moisture makes temperate regions favorable for high biodiversity, human settlement, and productive agricultural activities (Figure 33).

Termite mounds are robust, porous structures composed of soil particles bound together by the saliva of worker termites. These mounds serve as nesting sites for termite colonies and play a critical role in maintaining internal microclimatic conditions. Their porosity facilitates effective ventilation of the subterranean nest through an intricate system of tunnels and air passages, allowing for stable temperature and humidity levels within the mound.

Abandoned termite mounds often become shelters for various small animals, including lizards, snakes, and mongooses, while larger animals such as jackals and hyenas may excavate burrows within them. The vertical column of soil in the mound reflects mineral redistribution, where the color of the mound indicates specific mineral content: reddish hues suggest iron presence, while pale gray tones indicate aluminum. Notably, the soil from deeper layers is transported and deposited at the surface during mound construction (Figure 34).

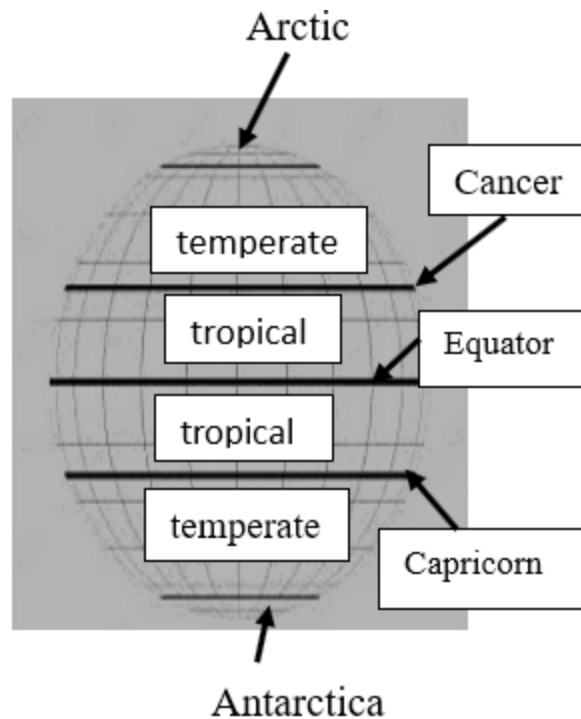


Figure 33: Main geographical regions of the world.

Source: Google

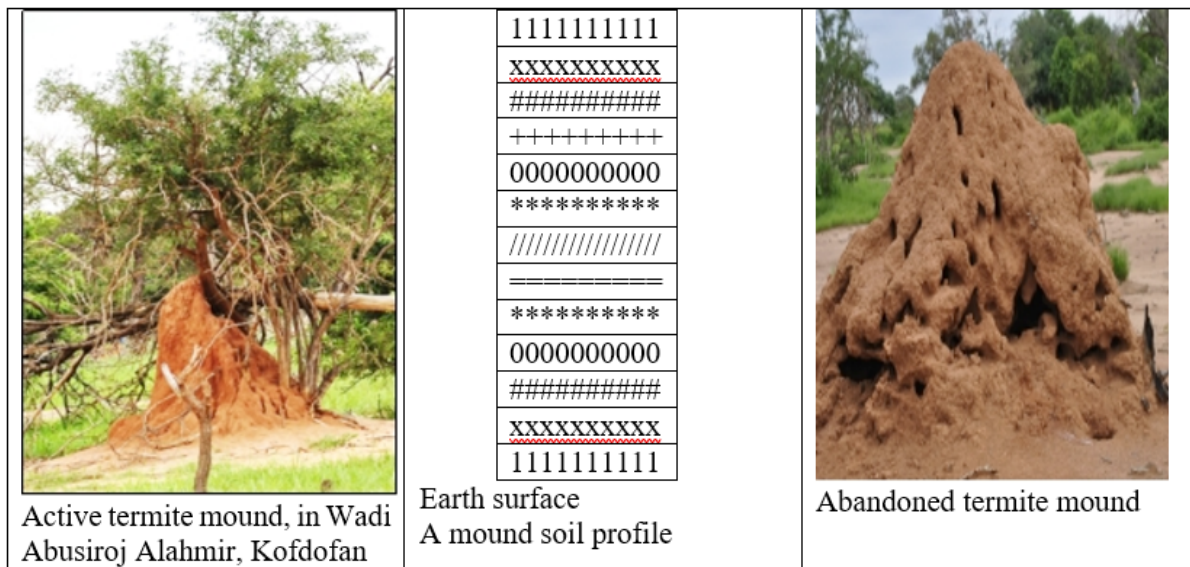


Figure 34:

Thermocline is a distinct layer within a body of water, such as an ocean or a lake, where the temperature changes rapidly with depth. This temperature gradient separates the warmer, well-mixed surface water from the colder, deeper water below. The thermocline affects marine life distribution, water density, and nutrient mixing. It typically forms due to solar heating at the surface and limited mixing between water layers.

Transboundary protected areas are ecological regions that span across the political boundaries of two or more countries and require joint management to ensure the conservation of biodiversity and ecosystem integrity. Effective management of TPAs necessitates cross-border collaboration, with shared strategies and governance frameworks that support ecological connectivity and the free movement of wildlife, particularly migratory species.

It is essential that while wildlife corridors are maintained across borders, strict controls are enforced to prevent the transboundary movement of hazardous materials that could pose risks to human and environmental health. When such cooperative frameworks are implemented, ecosystems within adjacent protected areas—such as Dinder National Park (Sudan) and Alatish National Park (Ethiopia)—can be effectively conserved, enhancing regional biodiversity, ecological resilience, and transboundary environmental security (Figure 35).



Figure 35: Source: wikipedia.org/wiki/Dinder

Tropical regions are located between the Tropic of Cancer and the Tropic of Capricorn, encompass tropical rainforests and savannas. These regions are characterized by consistently high temperatures and substantial annual rainfall. The ecosystems within the tropics are among the most biologically diverse on Earth, supporting a vast array of flora and fauna. The high primary productivity and ecological complexity make tropical regions critical for global biodiversity and climate regulation.

Trophic cascade is an ecological phenomenon triggered by the addition or removal of top predators, resulting in reciprocal changes in the populations of species at different trophic levels within a food web. These changes often lead to significant alterations in ecosystem structure and nutrient cycling. In a classic trophic cascade, the removal of a top predator (e.g., lions) leads to an increase in herbivore populations (e.g., gazelles), which in turn causes overgrazing and a decline in plant biomass (e.g., shrubs and young trees).

There are three types of trophic cascades: Top-down cascade: Initiated by changes in predator populations. Bottom-up cascade: Driven by changes in nutrient availability or primary producer abundance. Reciprocal cascade: Involves feedback between multiple trophic levels.

Turbidity measures the presence of suspended particles such as silt and organic matter in water. It is determined by the degree to which these particles scatter light; higher scattering indicates higher turbidity. Elevated turbidity levels reduce light penetration, impairing photosynthesis in submerged aquatic plants. This leads to decreased plant growth and lower dissolved oxygen availability for aquatic organisms.

Tsunami is a sequence of massive ocean waves triggered primarily by undersea earthquakes or volcanic eruptions. As the waves approach the coastline, they increase in height, sometimes reaching up to 30 meters. Upon landfall, tsunamis can devastate coastal ecosystems, destroy native biota, and severely disrupt local biodiversity. Approximately 80% of tsunamis occur within the Pacific Ocean basin.

Ultraviolet (UV) Radiation: High-energy solar radiation that can significantly affect living organisms, ecosystems, and atmospheric chemistry. Excessive exposure to UV radiation can damage DNA, increase the risk of skin cancer and cataracts in humans, suppress immune function, reduce crop productivity, harm phytoplankton and marine life, and disrupt terrestrial and aquatic ecosystems. It also influences atmospheric chemical reactions, including the formation and breakdown of ozone.

Umbrella Species: An umbrella species is a species whose conservation indirectly protects many other plants and animals living in the same habitat because preserving its large habitat also safeguards the ecosystems they depend on. For example, conserving the lion protects forests that provide habitat for elephants, deer, birds, and countless other species.

Unfragmented habitat: An unfragmented habitat is a large, continuous natural area that remains intact without being divided into isolated patches by human activities such as roads, agriculture, or urban development. These habitats maintain ecological connectivity, allowing species to move, reproduce, and sustain healthy populations. For example, extensive tracts of the Amazon rainforest contain areas of largely unfragmented habitat that support exceptional biodiversity.

Urbanization: It is the expansion of cities and built infrastructure, transforming natural landscapes into urban environments. This process often reduces biodiversity, fragments habitats, alters ecosystem functions, and increases pollution. For example, rapid urbanization in Bengaluru, India, has led to the loss of wetlands and green spaces, contributing to declining biodiversity, urban flooding, and deterioration of ecosystem services.

Urban ecosystem: It is an ecosystem dominated by human-built infrastructure and the interactions between humans, plants, animals, and microorganisms. It examines ecological processes operating within cities, including energy flow, nutrient cycling, and biodiversity. Urban ecosystems also encompass urban forests, parks, and other green spaces that enhance ecosystem services by improving air quality, regulating microclimates, supporting biodiversity, and promoting human well-being.

Used oil, particularly from vehicles and machinery, poses significant environmental risks if improperly disposed of. It can contaminate water and soil ecosystems. However, when collected and processed correctly, used oil can be recycled for use as lubricants, industrial fuel, or raw materials. Even used oil filters can be recycled for their metal content to be used in various manufacturing processes.

Use value: This refers to the benefits that humans or other organisms obtain from natural resources and ecosystems through direct or indirect use. In environmental science, it includes ecosystem services such as food, freshwater, timber, and recreation; for example, mangrove forests provide fish, coastal protection, and ecotourism opportunities. It also describes the utilization of natural resources by organisms or humans; for example, honeybees use flowering plants as a source of nectar and pollen. In movement ecology, use value represents the probability distribution of an animal's space use within its home range; for example, GPS tracking shows elephants frequently use waterholes and feeding areas during seasonal movements.

Vacant niche: An ecological role or habitat that is unoccupied by any species but has the potential to be filled.

Vagrant species: A species found outside its normal geographic range, often temporarily due to unusual dispersal or environmental conditions.

Vapor pressure deficit: The difference between the amount of moisture in the air and the maximum it can hold; an important factor affecting plant water loss, growth, and ecosystem productivity.

Vector: A vector is any living organism (including humans, animals, or microorganisms) that transmits infectious pathogens to a susceptible host. Vectors are categorized as biological or mechanical. Biological vectors, like female mosquitoes, transmit diseases such as malaria, dengue fever, and West Nile virus, with the pathogens undergoing development within the vector. Mechanical vectors, like flies, passively transfer pathogens by physical contact, often through contaminated surfaces or food.

Vegetation cover: The proportion of land surface covered by plants, which helps reduce erosion, regulate climate, and support biodiversity.

Vegetation index: A numerical indicator, often derived from satellite imagery (e.g., NDVI), used to assess plant health and density.

Vernal pool: A seasonal wetland that fills with water during rainy periods and dries out later, providing important habitat for specialized species.

Viable population: A population large and healthy enough to survive and reproduce over the long term without facing a high risk of extinction.

Virulence: The degree to which a pathogen can cause disease, influencing wildlife population dynamics and ecosystem health.

Volatile organic compounds: Carbon-containing chemicals that easily evaporate into the atmosphere and can contribute to air pollution and ozone formation. Some are naturally released by plants such as Terpenes released by pine trees and other plants. These compounds give forests their characteristic smell and can react in the atmosphere to contribute to ozone formation. While others originate from human activities such as gasoline fumes, vehicle exhaust, paint solvents, and industrial processes. These can contribute to air pollution and is harmful to human health.

Volcanism: The movement of magma and volcanic gases from Earth's interior to the surface, shaping landscapes and influencing climate and ecosystems by fine particles of rock and minerals 'volcanic ash' ejected during volcanic eruptions that can affect air quality, soil fertility, water resources, and ecosystems.

Vulnerability. The susceptibility of species, ecosystems, or communities to environmental stressors such as climate change, habitat loss, or pollution.

Vulnerable species: A species classified as facing a high risk of extinction in the wild if current threats continue.

Water body refers to any substantial accumulation of water, including rivers, lakes, streams, seas, oceans, ponds, and wetlands. It can also refer to frozen water forms such as glaciers and snowpacks. Water bodies serve as critical habitats, freshwater sources, and components of the global hydrological cycle.

Water conductivity refers to the capacity of water to conduct heat, electricity, and dissolved ions. High thermal conductivity reduces oxygen solubility, negatively affecting aquatic life. Elevated electrical conductivity impairs osmoregulation in fish. Rising water temperatures increase ion mobility and mineral solubility, thereby raising conductivity and making it harder for aquatic organisms to maintain fluid balance.

Wastewater management is essential for both ecological sustainability and public health. Through a combination of physical, chemical, and biological processes, wastewater treatment reduces contaminants and mitigates its potential hazards to ecosystems and human populations. One of the primary concerns is the presence of suspended solids, which, if left untreated, decompose and deplete dissolved oxygen levels, negatively impacting aquatic life.

The treatment process typically involves three main stages:

1. Primary treatment involves physical removal of coarse materials such as floating debris, gravel, and sand using fine metal screens or meshes.

2. Secondary treatment is achieved by biological degradation of organic matter using aeration and microbial processes, followed by filtration to separate biodegradable material.

3. Tertiary treatment is advanced purification targeting the removal of nutrients such as nitrogen and phosphorus, along with any remaining suspended solids.

Properly managed treated wastewater, can be safely reused in non-potable applications, such as afforestation, irrigation, and industrial processes, contributing to water conservation strategies.

Water waves are disturbances that travel along the interface between water and air, primarily generated by wind, seismic activity, or gravitational interactions. These waves can be classified based on their generating forces, wavelength, and behavior in different water depths. The main types include:

1. Capillary wave are small, short-wavelength waves (less than 1.7 cm) generated by light winds or surface tension. Surface tension acts as the primary restoring force.

2. Gravity waves are larger than capillary waves, gravity waves are primarily restored by gravity. They include most wind-generated waves seen on oceans and lakes.

3. Wind waves are subset of gravity waves, these are generated by the local wind and grow in size and energy with wind duration, speed, and fetch.

4. Swell waves are long-period gravity waves that have traveled beyond their area of origin. They are more uniform and regular than local wind waves.

5. Seismic Sea waves (Tsunamis) are generated by underwater seismic activity (earthquakes, landslides, or volcanic eruptions), tsunamis are long-wavelength waves that can travel across entire ocean basins with minimal energy loss.

6. Tidal waves are caused by the gravitational pull of the Moon and Sun. They are predictable and cyclical, not related to seismic activity.

7. Internal waves occur within the ocean at the interface between layers of different densities (due to temperature or salinity gradients).

Wastewater, containing various dissolved and suspended contaminants, requires treatment to remove pollutants. Treatment involves physical, chemical, and biological processes that purify the water to meet health and environmental safety standards, including suitability for drinking or reuse.

Watershed is a geographic area that channels surface water resulting from rainfall and snowmelt runoff into streams, rivers, or other water channels. The watershed of a lake includes all inflowing tributaries and the land draining into them. On a broader scale, drainage basins consist of interconnected watersheds of multiple river systems.

Weathering refers to the natural processes that lead to the breakdown or dissolution of rocks, soil, wood, and artificial materials through physical, chemical, or biological mechanisms.

1. Mechanical (physical) weathering involves the disintegration of rocks and soil without changing their chemical composition. This process is driven by factors such as water, ice (freeze-thaw cycles), pressure release, and temperature fluctuations.

2. Chemical weathering occurs when rocks undergo chemical changes due to reactions with water, acids (e.g., acid rain), and gases like oxygen. This weakens the rock structure, often leading to fragmentation.

3. Biological weathering is largely mechanical and is caused by living organisms. For instance, plant roots can grow into cracks in rocks, exerting pressure that splits them apart. Burrowing animals like rodents also contribute by disturbing and breaking rock material during digging activities.

4. Human activities such as tunneling, mining, and the extraction of construction materials also accelerate mechanical weathering, especially in mountainous regions.

Wildlife Administration is a governmental directorate responsible for overseeing national programs, projects, and activities related to wildlife conservation and management. Its supervisory role includes evaluating the effectiveness of operations, budget allocations, staff performance, and the condition of habitats, particularly those supporting game species. The administration ensures that essential resources—such as food, water, shelter, and adequate space—are continuously available to sustain wildlife populations. It also coordinates and collaborates with relevant agencies, organizations, and stakeholders involved in wildlife protection and biodiversity conservation.

White water refers to turbulent sections of rivers or streams where the water flow is characterized by high velocity and aerated, foamy water with varying directions. This phenomenon occurs when water flows over rocks, outcrops, ledges, or steep gradients, causing water to mix with air and form bubbles, which gives the water its clear whitish appearance.

This turbulence enhances gas exchange between the atmosphere and the water body, often increasing dissolved oxygen levels, which is beneficial to aquatic life adapted to high-energy, well-oxygenated conditions. These habitats also play a role in rate of sediment transport and the physical shaping of river channels.

White water zones are important for hydrological and erosion studies, and are white-water rafting. Its dynamic nature can also pose risks to human safety and infrastructure (Figure 36 & 37).



Figure 36: White water in a Caucasian river.



Figure 37: White water in the sixth cataract, the Nile.

Wilderness areas are regions that remain uncultivated, uninhabited, and largely free from human disturbance, supporting naturally developed communities of species. This definition applies to both terrestrial and aquatic environments.

Working environment refers to the combination of physical and social conditions in which individuals perform their jobs, either independently or as employees. An effective working environment promotes worker well-being, job satisfaction, mutual trust, and healthy interpersonal relationships. Such environments can be traditional, modern, or flexible in structure. Key elements—such as safety, cooperation, fairness, accountability, and trust—are essential for organizational success. Enhanced cooperation in the workplace leads to higher productivity, innovation, and mutual benefits for both employees and the organization.

Xenobiota: Non-native organisms introduced into an ecosystem, which may affect local biodiversity.

Xeric: Describes a very dry environment or habitat with little available water, such as the Sahara Desert ecosystem.

Xerophytes: These are plant species specifically adapted to survive and thrive in arid and desert environments characterized by low water availability and high temperatures. These plants exhibit a variety of morphological and physiological adaptations that minimize water loss and maximize water storage. Their key adaptations include:

1. Long or thickened leaves capable of storing water.
2. Microscopic stomata that reduce transpiration by limiting water vapor loss.
3. Deep and widespread root systems that enhance the plant's ability to access underground water sources.
4. In some species, leaves are modified into spines to reduce surface area and deter herbivores.
5. In others, leaves are coated with a waxy cuticle to minimize water evaporation.
6. Certain xerophytes also store water in succulent stems.

Common examples of xerophytic plants include cacti and pineapple (Ananas comosus), both of which exhibit multiple drought-resistance features (Figure 38).

		
<i>A Cactus sp.</i>	<i>A xerophyte, Erkowit</i>	A desert scrub, Nevada (Source: eng. Ahmed Gasim Ahmed)

Figure 38:

Xylophagous Describes organisms that feed on wood, such as termites, bark beetles, carpenter ants, white-rot fungi and brown-rot. These play vital roles in decomposition and nutrient cycling.

Zebra Mussel: An invasive (*Dreissena polymorpha*) freshwater species that can alter aquatic ecosystems by competing with native species and changing nutrient cycles pattern.

Zonation: The arrangement of different plant and animal communities into distinct zones due to changes in environmental conditions. For instance, the lake zonation includes littoral zone dominated by reeds, cattails, frogs, insects; limnetic zone colonized by plankton and fish, and profundal zone where bottom-dwelling organisms adapted to low light. In forests zonation, the canopy is characterized by tall trees, monkeys, birds. In the understory smaller trees and shrubs dominates, while ferns, fungi, insects, and decomposer are found in the forest floor.

Zoogeography: The study of the geographic distribution of animals and how species are spread across different regions of the world.

Zoonosis: A disease that can be transmitted from animals to humans, often influenced by environmental and ecological conditions.

Notable examples are: Rabies transmitted to humans through the bite or saliva of infected animals, such as dogs, bats, and wild mammals, Avian influenza (Bird flu), Lyme disease through the bite of infected ticks, Ebola virus disease and COVID-19.

Zooplankton: Tiny aquatic animals that drift in water and form an important part of aquatic food chains by feeding on phytoplankton.

Zoos are managed and enclosed facility where live animals are kept and exhibited to the public for educational, recreational, and scientific purposes. Animals are housed in designated enclosures that simulate aspects of their natural habitats. These enclosures are regularly maintained, and animals are provided with appropriate food, water, and veterinary care.

Vegetation, particularly trees, is intentionally incorporated to offer shade, regulate microclimate, and enhance animal welfare. Each enclosure is typically labeled with the animal's common name, scientific name, and geographical origin.

While some zoos are specialized for example, aquariums (fish zoos) or aviaries (bird zoos), the majority maintain a diverse collection of terrestrial and aquatic species. Zoos play a vital role in biodiversity conservation, public education, captive breeding programs, and scientific research aimed at understanding animal behavior, health, and habitat needs (Figure 39).

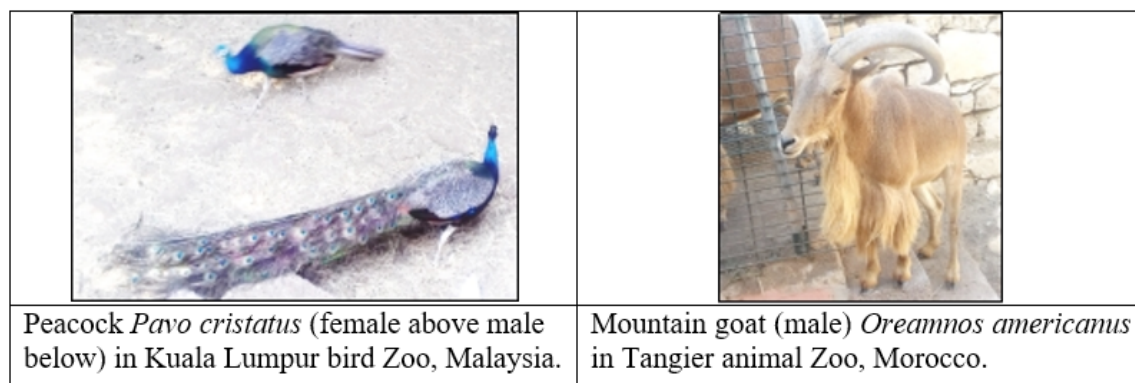


Figure 39:

Zooxanthellae are unicellular, yellowish-brown symbiotic dinoflagellates that possess two unequal flagella and exhibit both plant-like (photosynthetic) and protozoan characteristics. These microorganisms reside intracellularly within the cytoplasm of many marine invertebrates, particularly reef-building corals.

Through the process of photosynthesis, zooxanthellae produce carbohydrates, which serve as an essential energy source for their host. Corals utilize these carbohydrates to facilitate the deposition of calcium carbonate (CaCO_3), which is critical for the formation and maintenance of their exoskeletal structure. This symbiotic relationship is fundamental to the growth and stability of coral reef ecosystems.

Zygomycetes: A group of fungi involved in decomposition, helping recycle nutrients in soil ecosystems. Examples are: *Rhizopus stolonifer* common zygomycete fungus that grows on bread and decaying plant material; *Mucor* sp., decompose dead plants, fruits, and other organic materials; *Pilobolus* sp., grow on animal dung and *Entomophthora* sp., infect insects.

Conclusion

In light of the above, this book is a deliberate attempt to close the widening knowledge gap in environmental concepts by presenting scientifically reliable, clearly structured material that helps readers of all backgrounds understand the foundations of contemporary environmental thinking. By offering this reference, we aim to support environmental learning, equip researchers, practitioners, and policymakers with a deeper grasp of complex ecological challenges, and strengthen the quality of decisions, strategies, and actions directed toward sustainable development. Today, safeguarding the environment is neither optional nor deferrable; it is a collective duty demanding scientific literacy, integrated understanding, and genuine engagement. These terms cover a range of topics in ecology, conservation biology, environmental science, hydrology, forestry, and climate science. Among the terms, abiotic and biotic factors, acid rains, alien species, desertification, sustainability, geographical zones and pollution are some of the most commonly encountered in environmental literature. These terms represent key concepts used to understand environmental systems and challenges. For example, desertification occurs when fertile land becomes barren due to overgrazing and drought, as seen in parts of the Sahel region of Africa, highlighting the need for sustainability and effective conservation practices.

It is our hope that this work contributes meaningfully to that responsibility, even if modestly, by fostering awareness and encouraging thoughtful, informed participation in efforts to protect our shared planet. We trust it will inspire continued learning and responsible action for future generations.

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