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ALLAMA IQBAL OPEN UNIVERSITY, ISLAMABAD

Course: Introduction to Environmental Science (1421) • Level: BA/BS

Semester: Autumn 2026

Assignment No. 2 (Units 5–9)

Total Marks: 100 • Pass Marks: BA 40 / BS 50

SOLVED ASSIGNMENT GUIDE

(For Study & Reference)

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Note: This guide is prepared for study and reference purposes. Students are advised to read the relevant units of the course book and write the answers in their own words in the actual assignment.

Question 1: The Hydrological Cycle and Its Human Disruption (20 Marks)

Explain the hydrological cycle and its components (evaporation, condensation, precipitation, infiltration, runoff). How do human activities disrupt this cycle? (20)

Introduction

Water is the substance on which all life depends, and it is never still. The hydrological cycle (or water cycle) is the continuous circulation of water between the oceans, the atmosphere and the land, driven by the energy of the sun and the pull of gravity. The total quantity of water on Earth is essentially fixed — roughly 1.4 billion cubic kilometres — but its distribution changes

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constantly: about 97 per cent lies in the oceans, most of the small fresh fraction is locked in ice caps, glaciers and deep groundwater, and less than one per cent is readily available in lakes, rivers, soil and the atmosphere. The cycle is therefore a natural purification and distribution system: it carries water from the sea to the highest mountains, delivers rain to farms and forests, refills wells and reservoirs, and returns water to the sea. This answer explains each component of the cycle and then examines how human activities increasingly disrupt it — a matter of urgent importance for water-stressed Pakistan.

Evaporation and Transpiration

Evaporation is the conversion of liquid water into water vapour. Solar energy heats the oceans, lakes, rivers, wet soil and other surfaces, breaking the bonds between water molecules so that they escape into the air; the oceans, covering about 71 per cent of the Earth's surface, supply roughly 86 per cent of all evaporation. Plants contribute through transpiration: roots absorb soil water, which travels to the leaves and escapes as vapour through tiny pores (stomata) during photosynthesis. The combined loss from land surfaces is called evapotranspiration, and a single large tree can transpire several hundred litres on a hot day. Evaporation is fastest where it is hot, dry, windy and sunny — conditions that explain Pakistan's very high evaporation losses from reservoirs and canals under the summer sun. Evaporation is also nature's purifier: salts and pollutants are left behind, so the vapour that rises is essentially fresh water.

Condensation and Cloud Formation

As moist air rises, it expands and cools; at the dew point its water vapour condenses — changes back into liquid — on microscopic particles of dust, salt or smoke called condensation nuclei,

forming the tiny droplets of clouds and fog. Condensation releases the latent heat absorbed during evaporation, and this energy powers storms and monsoon systems. Condensation also occurs directly on surfaces as dew and frost, which in dry regions can be an important source of moisture for plants and soil organisms. The type of cloud formed — towering cumulonimbus over heated land, layered stratus over coasts, or orographic clouds forced up mountain slopes — depends on how the air was lifted: by convection, by convergence of winds, by fronts, or by terrain.

Precipitation

When cloud droplets or ice crystals grow heavy enough to overcome rising air currents, they fall as precipitation: rain, snow, sleet, hail or drizzle. Globally, more precipitation falls on the oceans than on land, but the land's share — about a fifth of the total — sustains all terrestrial life and agriculture. Pakistan's precipitation comes mainly from two systems: the summer monsoon (July–September), bringing moist air from the Arabian Sea and Bay of Bengal, and the winter western disturbances (December–March), which deposit rain and, crucially, the Himalayan–Karakoram snow that feeds the Indus through the summer melt. The form of precipitation matters: snow is a natural reservoir that releases water slowly in spring and summer, whereas intense rain runs off quickly and can cause floods rather than recharge.

Infiltration, Percolation and Groundwater

Precipitation that reaches the ground has several fates. Part is intercepted by vegetation and evaporates again; part flows over the surface; and part infiltrates — soaks into the soil through pores and cracks. Infiltration depends on soil texture (sandy soils absorb faster than clay),

vegetation cover, slope, and how wet the soil already is. Water that infiltrates first fills soil moisture, which plants draw upon. The surplus percolates downward through the unsaturated zone to the water table, joining groundwater stored in aquifers — underground layers of sand, gravel or fractured rock. Groundwater moves very slowly, sometimes taking years or centuries to travel, and emerges as springs, feeds wells and sustains the base flow of rivers during dry seasons. It is the cycle's great savings account, buffering society against drought, and Pakistan depends on it heavily: over a million tube wells pump groundwater for irrigation, drinking and industry.

Runoff and the Return to the Sea

Runoff is the water that flows over the land surface (surface runoff) or through the upper soil (subsurface flow) into streams and rivers. Its amount increases with rainfall intensity, steep slopes, saturated or impermeable surfaces and sparse vegetation. Streams join into rivers, rivers fill lakes and wetlands, and ultimately the water returns to the ocean, completing the cycle. River flow is a mixture of quick surface runoff after storms and slow groundwater base flow, which is why healthy catchments with forests and deep soils have steadier rivers, while degraded catchments swing violently between flood and drought. The Indus and its tributaries carry Pakistan's share of this return flow to the Arabian Sea — a flow that also delivers nutrients and sediment essential to the delta's mangroves and fisheries. Energy for the whole cycle comes from the sun; gravity moves water downhill and pulls rain from clouds; residence times range from days in the atmosphere to millennia in deep aquifers and ice.

Table 1: Components of the hydrological cycle

Component	Process	Importance
Evaporation	Liquid water becomes vapour from oceans, lakes, soil	Main entry of water into the atmosphere; purifies water
Transpiration	Plants release vapour through leaves	Major share of land evapotranspiration; links cycle to forests
Condensation	Vapour forms cloud droplets on nuclei	Cloud formation; releases latent heat driving weather
Precipitation	Rain, snow, hail fall to the surface	Delivers fresh water to land; snow stores water seasonally
Infiltration	Water soaks into soil	Supplies soil moisture; begins groundwater recharge
Percolation/runoff	Water moves to aquifers and streams	Refills wells; sustains rivers; returns water to the sea

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How Human Activities Disrupt the Cycle: Land and Vegetation

Human activity now intervenes at every stage. Deforestation reduces transpiration and interception and destroys the spongy soil structure that promotes infiltration; rain then runs off the surface instead of recharging groundwater, so streams flood in the rains and dry up sooner, springs fail, and erosion carries the soil away — precisely the sequence seen in Pakistan's deforested northern catchments. Urbanization has the opposite surface effect on a grand scale: roofs, roads and concrete make cities nearly impermeable, so infiltration collapses, storm runoff multiplies, and cities such as Karachi and Lahore flood after heavy rain while the aquifers beneath them starve. Wetland drainage removes natural storage that once absorbed flood

peaks and released water slowly, and ploughing, overgrazing and compaction degrade soil infiltration across farmland and rangeland.

Disruption by Water Extraction, Storage and Diversion

Direct manipulation of water bodies is equally disruptive. Groundwater over-extraction — pumping beyond recharge — lowers water tables (in parts of Punjab and Balochistan by up to a metre a year in stressed areas), dries shallow wells, reverses flows so that polluted surface water is sucked underground, and in coastal Karachi and the Indus Delta allows seawater to intrude into aquifers. Dams and barrages, while valuable for storage and power, change the timing and quantity of downstream flow and trap sediment; the reduced flow below Kotri has shrunk the Indus Delta's mangroves and fisheries and let the sea invade farmland. Irrigation, the largest human use of water, returns part of applied water to the atmosphere but also waterlogs and salinizes soils when drainage is neglected. Inter-basin transfers, canal lining without recharge planning, and the destruction of natural floodplains all further re-engineer the cycle.

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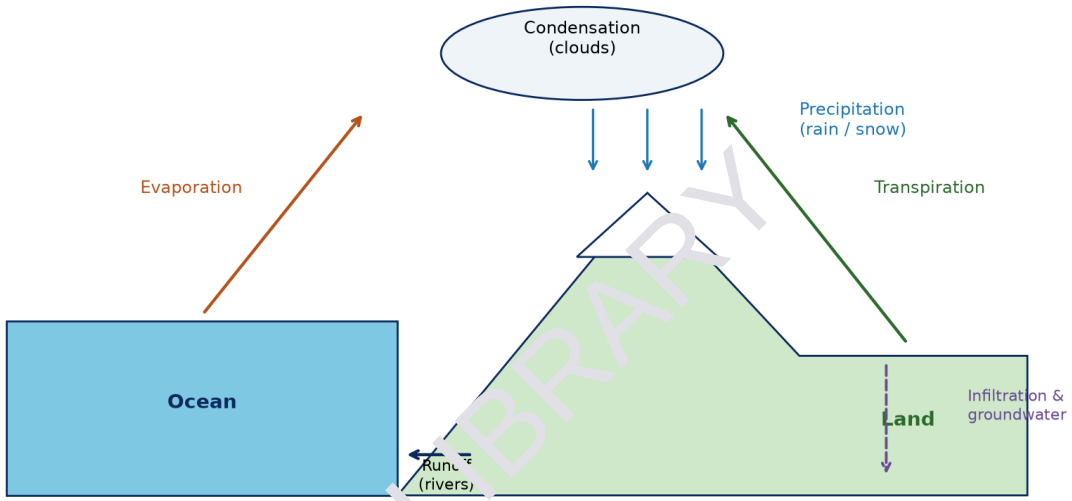

Figure 1: The hydrological cycle — evaporation, condensation, precipitation, infiltration and runoff.

Disruption by Pollution and Climate Change

Pollution disrupts the cycle qualitatively: water may complete its circuit physically but be unfit at every stage. Untreated sewage and industrial effluent contaminate rivers and, through infiltration, aquifers; agricultural chemicals wash off fields in runoff; atmospheric pollutants return to earth in acid rain. Climate change, driven by greenhouse-gas emissions, disrupts the cycle globally: warmer air holds about seven per cent more moisture per degree Celsius, intensifying both evaporation and rainfall extremes; glaciers that store Pakistan's dry-season water are retreating, promising increased flows followed by decline; snow is shifting to rain, changing seasonal storage; and sea-level rise pushes salt water into coastal aquifers and deltas. The 2022 Pakistan floods — enormously intensified monsoon rain falling on degraded catchments and encroached floodplains — showed natural and human disruptions compounding one another.

Conclusion

The hydrological cycle is a solar-powered circulation in which evaporation and transpiration lift purified water into the atmosphere, condensation builds clouds, precipitation returns water to the surface, and infiltration, percolation and runoff distribute it between soils, aquifers, rivers and the sea. Human beings disrupt this cycle by stripping vegetation, sealing surfaces with concrete, over-pumping aquifers, damming and diverting rivers, draining wetlands, polluting every store and compartment, and changing the climate itself. The remedies follow directly from the diagnosis: protect catchments and forests, harvest rainwater, recharge groundwater deliberately, use water efficiently, treat wastewater, and respect floodplains and deltas. Managing human activity so that the cycle's natural services continue is one of the central tasks of environmental science in Pakistan.

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Question 2: The Carbon Cycle: Geological and Biological Components, and the Human Impact (20 Marks)

Describe the carbon cycle, distinguishing between geological and biological components. How has human activity (e.g., burning fossil fuels, deforestation) affected atmospheric CO2 levels? (20)

Introduction

Carbon is the chemical backbone of life and a major regulator of the Earth's climate. It exists in the atmosphere (mainly as carbon dioxide, CO2, and methane), in the oceans (as dissolved CO2, bicarbonate and carbonate), in all living and dead organisms, in soils, and in the rocks of the

Earth's crust (as limestone and as coal, oil and natural gas). The carbon cycle is the movement of carbon among these reservoirs through biological, chemical and geological processes. It operates on two very different timescales: a fast biological cycle that exchanges carbon between air, plants, animals and surface ocean within days to centuries, and a slow geological cycle that stores and releases carbon through rocks over millions of years. For most of human history the two cycles were in near balance, keeping atmospheric CO2 between about 180 and 300 parts per million (ppm) for hundreds of thousands of years. In the last two centuries human activity has broken that balance, and understanding how, requires describing both components clearly.

The Biological (Fast) Carbon Cycle

The biological cycle is driven by life itself. Its engine is photosynthesis: green plants, algae and cyanobacteria absorb CO2 from the air or water and, using sunlight, convert it into sugars and plant tissue, releasing oxygen. Globally, terrestrial photosynthesis takes up roughly 120 billion tonnes of carbon a year, with a comparable uptake by marine phytoplankton. The return flow is respiration: plants, animals and microbes break down organic matter for energy and release CO2 back, and the two flows nearly balance over a year. Feeding transfers carbon along food chains — from producers to herbivores to carnivores — while death delivers carbon to the soil and sediments as dead organic matter. Decomposers (bacteria and fungi) digest most of this material and respire its carbon back to the air, but a fraction escapes decomposition and is stored: in soil organic matter and peat, in long-lived wood, and in ocean sediments where the shells and bodies of marine organisms rain down to the sea floor. The oceans also exchange CO2 physically with the atmosphere — cold surface water absorbs CO2 and carries it into the

deep ocean (the 'solubility pump'), while the growth and sinking of plankton forms a 'biological pump'. Altogether the oceans hold about fifty times as much carbon as the atmosphere, making them the largest active reservoir and the greatest short-term regulator of atmospheric CO2.

The Geological (Slow) Carbon Cycle

The geological cycle exchanges carbon between rocks, oceans, atmosphere and the Earth's interior over timescales of thousands to hundreds of millions of years. One pathway is the weathering of silicate and carbonate rocks: rainwater, slightly acidic from dissolved CO2, slowly dissolves rocks on land, and rivers carry the resulting bicarbonate ions to the sea, where marine organisms build shells and skeletons of calcium carbonate. When these organisms die, their remains accumulate as sediments that, buried and compressed over millions of years, become limestone and dolomite — the Earth's largest carbon store, holding tens of millions of billions of tonnes. A small fraction of buried organic matter escapes decay under special conditions and is transformed by heat and pressure into fossil fuels: coal from swamp forests, oil and gas from marine plankton. Carbon returns to the atmosphere through the reverse processes: volcanic eruptions and metamorphism release CO2 from subducted rocks at plate boundaries, and uplift and erosion expose ancient carbon stores to weathering and oxidation. This slow cycle acts as the Earth's long-term thermostat: over geological time, changes in weathering rates have drawn down or replenished atmospheric CO2 and stabilized the climate, but it works far too slowly to correct disturbances on human timescales.

Table 1: Geological and biological components of the carbon cycle compared

Feature	Biological component	Geological component
Main processes	Photosynthesis, respiration, feeding, decomposition	Weathering, sedimentation, rock formation, volcanism, subduction
Main reservoirs involved	Atmosphere, living biomass, soils, surface ocean	Limestone and other rocks, fossil fuels, deep ocean, Earth's interior
Timescale	Days to a few centuries	Thousands to hundreds of millions of years
Approximate annual flow	Very large (about 120 Gt C/yr exchanged with land alone)	Very small (about 0.1–0.3 Gt C/yr)
Effect of disturbance	Changes seasonal and decade-level CO2	Sets the long-term background level of CO2

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How Human Activity Has Disturbed the Cycle

Human activity disturbs the cycle chiefly by short-circuiting the geological store. Burning fossil fuels — coal, oil and natural gas — takes carbon that geology locked away over millions of years and returns it to the atmosphere in a geological instant. Current fossil-fuel and industrial emissions are roughly 37 billion tonnes of CO2 (about 10 billion tonnes of carbon) per year, around a hundred times the natural geological release from volcanoes. Cement production adds further CO2 by calcining limestone. Deforestation and land-use change disturb the biological store in the opposite direction: when forests are felled and burned or left to rot, the carbon of trunks, roots and soil is released, while the loss of the trees removes a future uptake

capacity; land-use change contributes roughly another tenth of total human CO2 emissions. Agriculture adds methane and nitrous oxide, peatlands are drained and oxidized, and degradation of soils releases stored organic carbon.

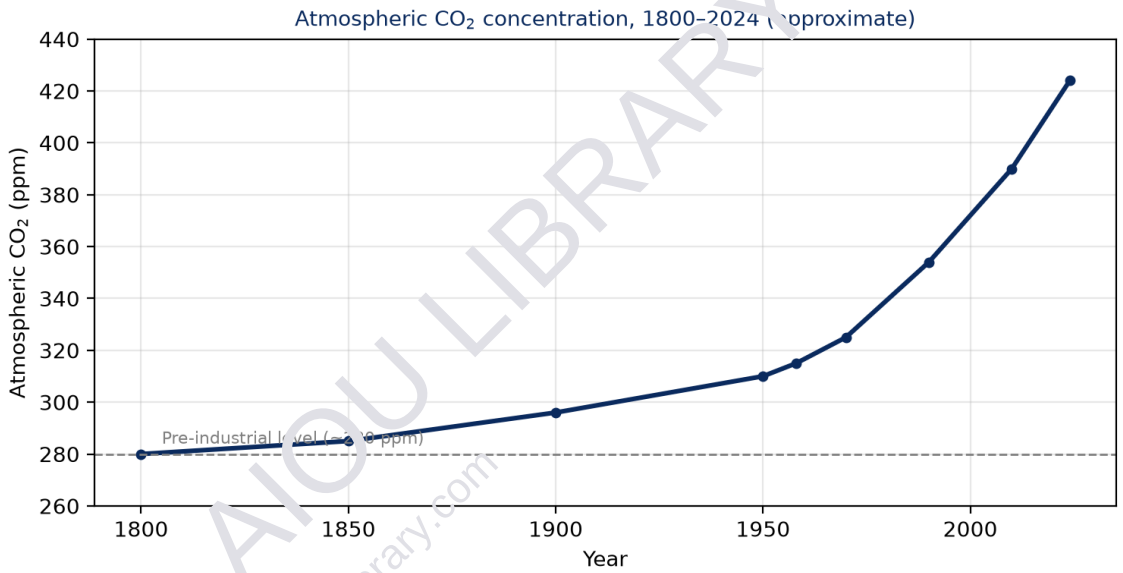

Figure 1: Rise of atmospheric carbon dioxide concentration (approximate values, after ice-core and Mauna Loa records).

The measured result is unambiguous. Ice cores show CO2 near 280 ppm before the Industrial Revolution; direct measurement at Mauna Loa, Hawaii, begun by Charles Keeling in 1958 at about 315 ppm, now records values above 420 ppm — an increase of more than 50 per cent — and the rate of increase has accelerated to about 2.5 ppm per year. Not all emitted CO2 stays airborne: roughly half is absorbed by the oceans and land vegetation (the 'airborne fraction' is about 45 per cent), but this service has a price. Ocean uptake has made surface seawater about 30 per cent more acidic since 1800 (ocean acidification), threatening corals and shell-forming organisms, and land uptake depends on forests that are themselves shrinking.

Consequences of Rising Atmospheric CO2

CO2 is a greenhouse gas: it is transparent to incoming sunlight but absorbs outgoing infrared radiation, warming the planet. The human-caused increase in CO2 (together with methane and other gases) has raised the global average temperature by about 1.2 °C since pre-industrial times. Consequences include more frequent and intense heatwaves, shifting rainfall, glacier retreat, sea-level rise, and stronger extreme events — the background conditions for Pakistan's recent heat emergencies and the intensified monsoon of 2022. Higher CO2 also fertilizes plant growth in some places, but this limited benefit is outweighed by heat, water stress and the acidification of the oceans. The fundamental problem is one of rates: nature's geological thermostat needs hundreds of thousands of years to remove the excess carbon that fossil fuels add in decades, so emissions committed today persist in the air for centuries to millennia.

Conclusion

The carbon cycle links life, air, ocean and rock. Its biological component rapidly exchanges large quantities of carbon through photosynthesis, respiration, food webs and decomposition, while its geological component stores carbon in limestone and fossil fuels and releases it through weathering and volcanism on timescales of millions of years. Human beings have overwhelmed this balance mainly by burning fossil fuels — transferring geological carbon to the air about a hundred times faster than nature releases it — and by deforestation, which releases biological carbon and weakens uptake. Atmospheric CO2 has consequently risen from about 280 ppm to above 420 ppm, driving climate change and ocean acidification. Restoring balance requires the

reverse operations: rapid reduction of fossil-fuel use, protection and restoration of forests and soils, and respect for the ocean and geological stores that took ages to build.

Question 3: Distribution of Biodiversity and the Factors Affecting Species Richness (20 Marks)

Discuss the factors that influence the distribution of biodiversity across the globe. How do climate, geography, and human activities affect species richness? (20)

Introduction

Biodiversity — the variety of life at genetic, species and ecosystem levels — is distributed very unevenly over the Earth. A single hectare of Amazonian rainforest may contain more tree species than all of Europe, while the vast Sahara or the Antarctic interior supports only a handful of hardy forms. Species richness, the number of species in a given area, is the most common measure of this variety, and its global pattern — richest near the equator, poorest toward the poles and in the driest interiors — is one of the oldest and most striking regularities in natural science. Explaining it requires examining several interacting factors: climate and the energy and water it supplies, geography in the form of area, isolation, barriers and topography, the evolutionary history of regions, and increasingly the activities of human beings, who now both impoverish most ecosystems and rearrange species around the planet. This answer discusses each factor in turn.

Climate: Energy, Water and Stability

Climate is the strongest single predictor of species richness. Solar energy and water together determine primary productivity — the rate at which plants fix carbon — and where productivity is high, more energy is available to support more individuals, more food chains and more specialized species. This 'energy–richness' relationship explains the latitudinal diversity gradient: warm, wet equatorial regions such as the Amazon, Congo Basin and Southeast Asian rainforests are the richest on Earth for plants, insects, birds and mammals, while richness falls steadily toward cold, dry or seasonal high latitudes. Temperature also works directly: ectothermic animals (insects, amphibians, reptiles) are far richer in warm climates because their activity and reproduction do not require internal heating.

The character of the climate matters as much as its averages. Stable climates that persist without extreme seasons or long-term upheaval allow species to specialize finely and coexist; the aseasonal tropics support specialists such as insects tied to a single tree species. Seasonality forces organisms to survive a hostile period, narrowing the community to generalists and migrants. Long-term climatic stability also provides time: regions that escaped the worst of the ice ages acted as refuges (refugia) where ancient lineages survived and continued to diversify, while recently glaciated lands are still being recolonized and remain relatively poor. Rainfall patterns shape richness within continents too — Mediterranean-climate regions such as the Cape Floristic Region of South Africa, though small, are extraordinarily rich in plants adapted to nutrient-poor soils and fire cycles, showing that climate interacts with soil and history.

Geography: Area, Isolation, Barriers and Topography

Geography controls richness through several mechanisms. First, area: larger areas contain more habitats and support larger populations that are less likely to go extinct, so richness rises with area — the species–area relationship — which is why continents hold more species than islands and big reserves more than small ones. Second, isolation: remote islands, though often poor in total species because few colonists arrive, frequently evolve unique endemic species found nowhere else — Darwin's finches of the Galápagos and the lemurs of Madagascar are classic cases — whereas connected mainland areas share species widely. The theory of island biogeography (MacArthur and Wilson) formalizes this: richness on an island reflects a balance between immigration (falling with distance) and extinction (falling with area).

Third, barriers and position: mountain ranges, deserts, rivers and oceans divide populations, which then evolve separately, raising global richness — the Andes and the Himalaya–Karakoram system both separate distinct biotas and generate endemism on their slopes. Fourth, topography and habitat heterogeneity: a mountainous region compresses tropical, temperate and alpine climates into a short horizontal distance, so many species with different requirements can live side by side; this is a main reason Pakistan, lying at the junction of the Palearctic and Oriental (Indo-Malayan) faunal regions and rising from the Indus Delta to K2, hosts an unusually mixed fauna — from Indus dolphins and mangrove species to snow leopards and markhor. Fifth, position at the junction of biogeographic regions and along migration flyways (such as the Indus flyway used by migratory birds) adds species seasonally. Peninsulas and ecotones — transition zones between ecosystems — similarly tend to be richer than the interiors of single uniform regions.

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Evolutionary History and Ecological Interactions

Behind climate and geography lies history. Richness depends on how long a region has had favourable conditions (time for speciation), how fast new species evolve there, and how many have gone extinct. The tropics are both a 'cradle' (high speciation) and a 'museum' (low extinction) of diversity. Ecological interactions then fine-tune the pattern: predation and competition can promote coexistence by preventing any one species from monopolizing resources — predators in rocky intertidal zones and grazing in grasslands both raise local richness; moderate disturbance (fire, flooding, grazing) maintains a mosaic of habitats at different successional stages and often maximizes richness (the intermediate disturbance idea); and mutualisms, such as those between flowering plants and pollinators, multiply niches. Soil type, altitude and local factors such as salinity explain much of the remaining patchiness at landscape scale.

Human Activities: The Great Homogenizer and Destroyer

Human activity now overrides natural patterns almost everywhere, generally reducing species richness. Habitat destruction and fragmentation are the leading causes: conversion of forests and wetlands to farms, cities and infrastructure eliminates the area and connectivity that richness requires, and the species–area relationship works in reverse — when 90 per cent of a habitat is cleared, a large share of its species is eventually lost. Overexploitation — commercial hunting, fishing and logging — removes large animals and valuable trees first, thinning food webs. Pollution kills sensitive species (amphibians, aquatic insects, lichens) and favours a few tolerant ones. Invasive alien species, transported by trade and travel, outcompete or prey upon

natives, especially on islands; the introduction of species such as the Nile perch into Lake Victoria devastated its endemic fishes. Climate change shifts the climatic zones to which species are adapted, generally poleward and uphill, faster than many organisms can move, compressing alpine and polar communities and decoupling species from the partners they depend upon.

The combined result is biotic homogenization: the distinctive local communities of the world are being replaced by a smaller set of widespread, human-tolerant species — pigeons, rats, crows, eucalyptus and a few weeds flourish everywhere while endemics vanish. Human influence is not wholly negative: protected areas, reserves and habitat restoration demonstrably retain richness (Pakistan's national parks and community-managed conservancies for markhor and ibex are local examples), and cities and gardens can support surprising numbers of adaptable species. But these are exceptions against a global trend of decline that scientists describe as a sixth mass extinction, with current extinction rates estimated at tens to hundreds of times the natural background rate.

Conclusion

The global distribution of biodiversity is the product of climate, geography, history and, now, humanity. Climate — through energy, water, seasonality and stability — sets the broad latitudinal pattern and the productivity ceiling; geography — area, isolation, barriers, topography and regional junctions — shapes how that potential is divided and multiplied; evolutionary history and ecological interactions fill in the detail. Human activities act mainly as a subtractive and homogenizing force through habitat loss, overexploitation, pollution, invasive species and climate change, though conservation can locally reverse them. Protecting species

richness therefore means protecting the conditions that generate it: large, connected, climatically varied habitats — and restraining the pressures that are erasing the pattern faster than it formed.

Question 4: Ecological Footprint and Earth's Carrying Capacity (20 Marks)

Explain the concept of ecological footprint. How does human consumption of resources exceed Earth's carrying capacity? (20)

Introduction

Every human being depends on nature for food, water, fibre, timber, energy and the absorption of wastes, yet for most of history this dependence was invisible because populations were small relative to the planet. The concept of the ecological footprint, developed by Mathis Wackernagel and William Rees at the University of British Columbia in the early 1990s and now maintained by the Global Footprint Network, makes this dependence measurable. The footprint asks a simple question: how much biologically productive land and water area does a person, city or nation require to produce what it consumes and absorb what it wastes, using prevailing technology? Comparing that demand with the Earth's biocapacity — the area actually available — shows whether humanity is living within or beyond the planet's carrying capacity, the maximum population and consumption level that ecosystems can support indefinitely. This answer explains the concept, its components and measurement, and shows how and why human consumption now exceeds the Earth's capacity, with reference to Pakistan.

The Concept and Its Components

The ecological footprint is measured in global hectares (gha) — hectares of land or water of world-average biological productivity — so that demands on different kinds of ecosystem can be added together. It has six main components. (1) Cropland footprint: the area needed to grow food, animal feed, fibre and oil crops. (2) Grazing land: the area of pasture needed for meat, milk, wool and leather. (3) Fishing grounds: the marine and inland water area needed to sustain the fish and seafood harvested. (4) Forest land: the area needed to supply timber, pulp and fuelwood. (5) Built-up land: the productive area covered by housing, industry, roads and reservoirs, which is thereby lost to production. (6) Carbon footprint: usually the largest component — the area of forest that would be needed to absorb the carbon dioxide emitted from burning fossil fuels, after allowing for the share absorbed by the oceans. The footprint of a product, a city or a whole economy is the sum of these areas for everything consumed, wherever in the world that land lies, which is why trade does not abolish footprints but merely relocates them.

Biocapacity, Carrying Capacity and Overshoot

The supply side of the account is biocapacity: the total biologically productive area available — currently about 12 billion global hectares for the whole planet, or roughly 1.5–1.6 gha per person at today's population — weighted by the real productivity of each ecosystem. Carrying capacity in this framework is reached when humanity's footprint equals global biocapacity. According to Global Footprint Network estimates, the world crossed that line in the early 1970s: humanity's footprint is now about 1.7 times the Earth's biocapacity, meaning we use the

equivalent of about 1.7 Earths. The average footprint is roughly 2.6 gha per person against the 1.6 gha per person available, though national figures differ enormously — high-income countries commonly exceed 5 gha per person, while Pakistan's footprint is under 1 gha per person, below the world average but still above Pakistan's own domestic biocapacity of roughly 0.3–0.4 gha per person, because the country's productive land per head is small and shrinking. The date each year when humanity exhausts the year's biocapacity — Earth Overshoot Day — has advanced from late December in 1970 to around late July or early August in recent years, meaning the rest of the year is lived in ecological deficit.

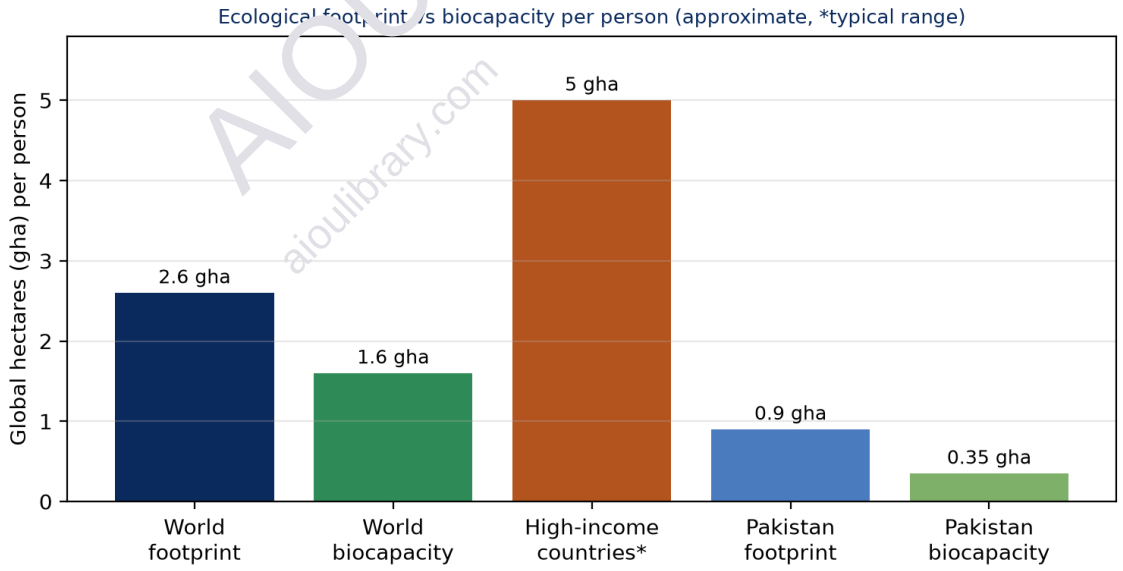

Figure 1: World ecological footprint versus biocapacity per person (approximate values after Global Footprint Network estimates).

How Consumption Exceeds Carrying Capacity

A deficit against a fixed stock can only be maintained in two ways, and humanity uses both. First, we draw down natural capital: we harvest renewable resources faster than they

regenerate — fishing stocks are caught beyond sustainable yield, forests are felled faster than they regrow, groundwater (fossil and slow-recharging aquifers) is pumped faster than rainfall replenishes it — which is like spending savings rather than income. Second, we accumulate wastes faster than nature can absorb them: carbon dioxide builds up in the atmosphere because emissions exceed the absorption capacity of oceans and forests, nutrients overload rivers and coastal seas, and plastics and persistent chemicals accumulate in soils and oceans. Neither practice can continue indefinitely: stocks shrink and sinks fill, so the overshoot is, by definition, temporary. It is financed by liquidating the natural capital on which future carrying capacity depends, which is why footprint analysts describe it as ecological debt owed to future generations and to poorer nations whose biocapacity the rich consume through trade.

Drivers: Population, Affluence and Technology

The overshoot is produced by the interaction of population, affluence (consumption per person) and technology — the relationship summarized in the IPAT identity (Impact = Population × Affluence × Technology). World population has grown from about 3.7 billion in 1970 to over 8 billion, multiplying every individual demand; simultaneously, average consumption has risen as economies grow: diets shift towards meat and dairy (which need many times more land per calorie than grains), houses and appliances multiply, private vehicles and air travel spread, and goods are replaced ever faster. Energy is the master driver: fossil fuels allowed humanity to subsidize its footprint with ancient sunlight — mechanizing agriculture, synthesizing fertilizer, pumping deep groundwater and transporting goods worldwide — while the resulting CO2 forms over half of the total footprint. Technology can reduce impact per unit of consumption (efficient engines, drip irrigation, renewable energy),

and such gains are real, but historically they have been outpaced by the growth of population and total consumption — the rebound pattern in which efficiency lowers cost and consumption rises to fill the gain.

Strengths and Limitations of the Concept

The footprint's great strength is communication: it converts dozens of pressures into one intuitive number — 'we need 1.7 Earths' — that citizens, businesses and governments can grasp, and its national accounts permit fair comparison of countries and tracking over time. It also exposes the ecological content of trade and the inequity of high-consumption lifestyles. Its limitations should be acknowledged: it is an accounting tool, not a complete measure of sustainability; it treats the carbon-absorption requirement as hypothetical forest area, which some critics consider artificial; it under-represents freshwater use, toxicity and biodiversity loss; and global-hectare aggregation hides differences between local ecosystems — a country can show a modest footprint while severely degrading a particular river or forest. It is therefore best used alongside other indicators such as water footprints, material footprints and biodiversity measures. These criticisms qualify, but do not overturn, its central finding, which several independent lines of evidence — collapsing fisheries, falling water tables, rising CO2 — confirm.

Reducing the Footprint

Bringing demand back within carrying capacity requires action on each driver. Decarbonizing energy — efficiency, solar, wind, hydro and reduced waste — attacks the largest component directly. Shifting diets modestly away from resource-intensive foods, halving food waste, and

raising farm productivity on existing land shrink the cropland and grazing components. Compact, well-serviced cities reduce built-up land and transport demand; forests must be protected and restored so that biocapacity itself grows; and stabilizing population through education, health and voluntary family planning lowers the multiplier on every component. For Pakistan, whose per-person footprint is small but whose domestic biocapacity per person is smaller still, priorities include water-efficient agriculture, protection of rangelands and forests, solar energy for its abundant sunshine, and urban planning that does not pave over prime farmland. The footprint framework shows that such measures are not austerity for its own sake but the arithmetic of living on one planet.

Conclusion

The ecological footprint measures the biologically productive area humanity appropriates for food, fibre, timber, space and carbon absorption, and compares it with biocapacity, the area the Earth can supply. Human consumption exceeds carrying capacity — currently by about 70 per cent, or 1.7 Earths — because population and per-capita consumption have grown faster than efficiency gains, and the excess is sustained only by depleting natural capital (forests, fish, soils, groundwater) and by overfilling waste sinks, above all the atmosphere. Overshoot is therefore not a permanent achievement but a borrowing from the future. The concept's value is that it quantifies this condition and points to its remedies: consume less wastefully, decarbonize energy, protect and restore ecosystems, and align population and consumption with the finite productive surface of the Earth.

Question 5: Pakistan's Major Environmental Challenges and Their Socio-Economic Impacts (20 Marks)

Discuss Pakistan's major environmental challenges, including water scarcity, deforestation, soil erosion, and pollution. What are their socio-economic impacts? (20)

Introduction

Pakistan is among the countries most exposed to environmental stress in the world. It has a large and still-growing population of over 240 million crowded onto a territory that is mostly arid or semi-arid, a single great river system on which agriculture and life depend, some of the fastest rates of deforestation and groundwater depletion in Asia, and cities whose air ranks among the most polluted on earth. It also ranks persistently among the ten countries most affected by climate extremes, although it contributes less than one per cent of global greenhouse-gas emissions. The environmental challenges — water scarcity, deforestation, soil erosion and pollution, together with waste, biodiversity loss and climate change — are not separate problems: they reinforce one another, and their costs are paid in health, livelihoods, food security and public money. This answer discusses the major challenges in turn and then analyzes their combined socio-economic impacts.

Water Scarcity and Water Quality

Water is Pakistan's most critical challenge. Per-capita surface-water availability has fallen from about 5,650 cubic metres in 1951 to around 1,000 cubic metres today, the internationally used threshold of absolute scarcity, simply because the population has multiplied while the Indus

system's flow has not. Over ninety per cent of water withdrawals go to agriculture, where flood irrigation, water-intensive crops and unlined canals waste much of the supply. Groundwater, pumped by more than a million tube wells, now supplies over half of farm water in Punjab, but extraction exceeds recharge in many areas, water tables are falling, and in Balochistan ancient karezes and wells have dried. Storage is inadequate and shrinking as Tarbela and Mangla lose capacity to siltation, and flows below Kotri have declined so much that the Indus Delta is intruded by the sea. Alongside scarcity stands quality: most surface and much groundwater is contaminated by sewage, industrial effluent, fertilizer and pesticide residues and, in places, natural arsenic and fluoride, so that even available water is often unsafe — the great majority of the population lacks access to clean drinking water.

Deforestation and Land Degradation

Pakistan's forests cover only about five per cent of its area, against the 25–33 per cent usually considered necessary for ecological balance, and they are shrinking under pressure from fuelwood demand, timber extraction, encroachment and conversion to farms and housing. The riverine forests of Sindh, the juniper forests of Ziarat (among the oldest and slowest-growing in the world) and the conifer forests of the northern mountains have all thinned badly, despite recent plantation campaigns. Deforestation is directly linked to the soil erosion examined in this course: an estimated three-quarters of the land is affected by water or wind erosion, gullies dissect the Pothohar plateau, dunes advance in Thar and Cholistan, and the Indus carries an enormous sediment load into reservoirs. Rangelands — over half the national territory — are degraded by overgrazing, and salinity and waterlogging have damaged millions of hectares of

the irrigated plain. Land degradation converts the country's basic productive asset into a wasting one.

Pollution: Air, Water and Waste

Pollution has become a daily emergency. Air pollution in Lahore, Karachi, Faisalabad and other cities regularly exceeds safe limits by large margins; the winter smog of Punjab, produced by vehicle and industrial emissions, brick kilns, power generation and the burning of crop residues combined with stagnant weather, closes schools, grounds flights and fills hospitals. Untreated municipal sewage and industrial effluents from tanneries, textile and chemical plants flow into the Ravi, Chenab, Lyari and Malir and into canals and groundwater, so rivers near cities are biologically dead in stretches. Solid waste — tens of thousands of tonnes daily in the largest cities — is mostly dumped or burned in the open; plastic waste clogs drains and waterways; and hospital and hazardous wastes are seldom segregated or treated safely. Noise pollution, though less discussed, adds to the urban health burden. Each pollutant stream connects back to water and soil: what is dumped on land or discharged to drains reappears in drinking water and food.

Climate Change and Biodiversity Loss

Overarching all these challenges is climate change. Pakistan has experienced devastating floods (2010 and 2022, the latter affecting about 33 million people and causing losses above thirty billion dollars), intensifying heatwaves (temperatures approaching 50 °C in Sindh and southern Punjab), glacial lake outburst floods in the north, and increasingly erratic monsoon and winter rainfall. Simultaneously, biodiversity is eroding: the Indus river dolphin survives only in a few river stretches, mangrove area and associated fisheries have shrunk with delta flows, wetlands

such as Manchar Lake are degraded, and many species of birds, mammals and medicinal plants are in decline. Climate stress multiplies the other problems — it intensifies water scarcity, accelerates erosion during extreme rains, worsens smog episodes' health effects, and spreads disease vectors.

Socio-Economic Impacts: Health, Livelihoods and Poverty

The socio-economic impacts begin with health. Waterborne diseases — diarrhoea, typhoid, hepatitis A and E, cholera — remain leading causes of illness and child death; air pollution drives asthma, chronic lung disease, heart disease and lost working days, with health costs and productivity losses that studies place in the range of several per cent of GDP when all environmental damage is counted. Livelihoods suffer directly: farmers lose crops and topsoil to erosion, salinity and water shortage; delta and coastal fishing communities have lost catches as flows and mangroves declined; pastoralists watch rangelands fail; and tourism suffers when lakes, forests and city air degrade. Environmental damage is regressive — the poor live in the most polluted and flood-prone places, drink the least safe water, depend most directly on common resources such as forests and fisheries, and have the fewest resources to adapt — so degradation deepens inequality. Women and children bear special burdens: carrying water over longer distances as wells dry, exposure to indoor smoke from wood and dung fuels, and lost schooling during smog and flood closures.

Socio-Economic Impacts: Economy, Food Security and Stability

At national scale the impacts are fiscal and strategic. Disaster relief and reconstruction after floods divert development budgets; silted reservoirs shorten the life of hydropower and

irrigation assets and raise energy costs; falling water tables raise farmers' pumping costs and electricity and diesel use; and poor environmental quality deters investment and skilled workers. Food security is threatened from several directions at once — erosion and salinity shrink the productive base, water scarcity caps yields, heat stress reduces wheat and livestock productivity, and extreme events destroy standing crops and stored grain, forcing expensive food imports. Environmental stress also contributes to rural–urban migration and to local conflicts over water and land, including inter-provincial disputes over water shares, which strain national cohesion. Against these costs must be set the economic sense of prevention: watershed protection, wastewater treatment, cleaner brick-kiln and vehicle technology, efficient irrigation and urban waste systems consistently cost less than the damages they avoid, and they create employment in new green sectors.

Conclusion

Pakistan's major environmental challenges — absolute water scarcity compounded by pollution of what water remains, deforestation down to about five per cent of land area, widespread soil erosion and land degradation, severe air and water pollution, mounting waste, biodiversity loss and intensifying climate extremes — form a single connected crisis rather than a list of separate problems. Their socio-economic impacts are correspondingly broad: disease and premature death, lost crops, fisheries and livelihoods, deepening poverty and inequality, heavy fiscal burdens from disasters and failing infrastructure, threats to food and water security, and social strain. Meeting them requires the full range of responses studied in this course — sound law and enforcement, watershed and forest restoration, water efficiency and storage, clean technology, environmental education and public awareness — pursued as core economic

policy, not as an afterthought, because in Pakistan the environment is not separate from the economy: it is the foundation on which the economy stands.

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