BOOKLET

M.Sc. Degree/PG Diploma in Environmental Sciences

(in line with the National Education Policy 2020)

School of Environmental Sciences
Jawaharlal Nehru University
New Delhi 110 067

April 2025

I. Summary of Master of Sciences Degree/ Post Graduate Diploma in Environmental Sciences at the School of Environmental Sciences (SES), Jawaharlal Nehru University (JNU).

The following PG programs will be offered –

M.Sc. (Environmental Sciences) (2-year)
The 2-year M.Sc. (Environmental Sciences) degree would continue as such with a significantly revised course structure in line with the spirit of National Education Policy (NEP) 2020. The minimum eligibility to join the 2-year M.Sc. program would be a 3-year B.Sc. degree in appropriate area.

PG Diploma (Environmental Sciences)
An exit option will be available for 2-year M.Sc. (Environmental Sciences) students after 1 year. Such students can leave the program with a PG Diploma in Environmental Sciences.

M.Sc. (Environmental Sciences) (1-year)
Students completing 4 years B.Sc./BS/B.Tech. degree from UG colleges/ Universities/ IISERs/IITs, and students completing 1st Year M.Sc. (Environmental Sciences) from elsewhere may be allowed to join the 2nd year (3rd semester) in M.Sc. (Environmental Sciences) program. Such students will receive M.Sc. (Environmental Sciences) within 1 year of enrolment subject to minimum CGPA requirement.

Note: *Students completing 4 years B.Sc./BS/B.Tech. degree with 75% or higher marks are eligible to join the Ph.D. program directly. They will have to complete 1-year pre-Ph.D. course work prior to confirmation in the Ph.D. program.*

II. Details of admission criteria, mode of entrance test, and minimum CGPA requirement for the confirmation of degree/diploma will be as per JNU ordinances and JNU admission guidelines revised from time to time.

Effectively, there would be 2 new Degree/Diploma programmes in Environmental Sciences in addition to the existing 2-year M.Sc. (Environmental Sciences) degree. These are enunciated below:

Admission: Students will be admitted to these programmes through national-level entrance examination as per JNU admission policy. No separate admission will be offered for any of the programmes.

Only vacant seats in 1-year M.Sc. (Environmental Sciences) degree programme will be filled.

Curriculum: The teaching programmes will run alongside the 2-year M.Sc. degree in Environmental Sciences in the School of Environmental Sciences. The programme will provide avenue to carry out high quality research project as a dissertation along with the choice-based optional courses.

1. M.Sc. (Environmental Sciences) (2-year)
The School of Environmental Sciences has revised the existing M.Sc. program – that is named as "**M.Sc. (Environmental Sciences)**" – to align its teaching programme to the National Educational Policy 2020.

2. PG Diploma in Environmental Sciences
The School of Environmental Sciences proposes to introduce an exit option for students completing 1st year M.Sc. (Environmental Sciences) – that will be named as "**PG Diploma in Environmental Sciences**" – to align its teaching programme to the National Educational Policy 2020.

Eligibility for Admission
B.Sc. (3-year) degree with a combination of at-least 3 courses from Physics, Chemistry, Mathematics, Botany, Zoology, Geology, Earth Sciences, Forestry, Agricultural Sciences, Analytical Chemistry, Microbiology, Biotechnology, Life Sciences, Geography, and Environmental Sciences as either major or minor(s) discipline in UG programme.

However, irrespective of the major or minor disciplines chosen by a student in a B.Sc./B.Tech. programme, a student is eligible for admission in M.Sc. (Environmental Sciences) if the student qualifies the National level or University level entrance examination in the discipline of the M.Sc. (Environmental Sciences) programme with minimum 60% marks.

Eligibility for award of PG Diploma (1-year) in Environmental Sciences: Students who have completed 1-year (Two semesters) of Environmental Sciences with minimum 42 credits including theory and laboratory courses and having secured a CGPA of 3.0. This programme would be offered as an exit option at the end of second semester for students pursuing the M.Sc. (Environmental Sciences) degree program in the School of Environmental Sciences, Jawaharlal Nehru University.

Exit Option for PG Diploma in Environmental Sciences: To enable students to optimally plan their future career and to enable the school of effectively run its teaching programme, the School of Environmental Sciences proposes that the students who desire to exit after 2 semesters of M.Sc. (Environmental Sciences) programme and opt for PG Diploma M.Sc. (Environmental Sciences), must fulfill the following stipulations:

1. Students must complete all the requisite credits for the first two semesters
2. Students must obtain pass grade in all courses with a minimum CGPA of 4.0

Eligibility for award of M.Sc. (Environmental Sciences) (2-year) Degree: Students who have completed 2-year (Four semesters) of Environmental Sciences with minimum 84 credits including theory, laboratory courses and Masters Dissertation, and having secured a CGPA of 4.0.

3. M.Sc. (Environmental Sciences) (1-year)

School of Environmental Sciences proposes to introduce a new teaching programme called "**M.Sc. (Environmental Sciences)**" to align its teaching programme to the National Education Policy (NEP) 2020.

Eligibility for Admission

B.Sc. (4-year) degree with a combination of at-least 3 courses from Physics, Chemistry, Mathematics, Botany, Zoology, Geology, Earth Sciences, Forestry, Agricultural Sciences, Analytical Chemistry, Microbiology, Biotechnology, Life Sciences, Geography, and Environmental Sciences as either major or minor(s) discipline in UG programme.

Students completing 1st year of M.Sc. from elsewhere may be allowed to join **M.Sc. (Environmental Sciences) (1-year)** depending on availability of seats.

However, irrespective of the major or minor disciplines chosen by a student in a B.Sc./B.Tech. programme, a student is eligible for admission in M.Sc. (Environmental Sciences) if the student qualifies the National level or University level entrance examination in the discipline of the MSc (Environmental Sciences) programme with minimum 60% marks.

Eligibility for award of M.Sc. (Environmental Sciences) (1-year) Degree: Students must have been admitted to a M.Sc. degree programme (regular mode; not distance mode) in their institution. Students must have completed 1-year M.Sc. programme in Environmental Sciences (as laid out in the JNU admission policy). The candidate must have passed with minimum 75% marks (aggregate) at the end of the 1-year M.Sc. degree programme.

M.Sc. (Environmental Sciences) Degree/PG Diploma

Semester I Total Credits (**21**)	• ES001A – Environmental Physics (2) • ES002A – Statistics (2) • ES003A – Essentials of Earth Sciences (2) • ES004A – Natural Resource Management (2) • ES005A – Environmental Chemistry (2) • ES006A – Environmental Pollution (2) • ES007A – Ecology (2) • ES008A – Environmental Biology (2) • ES009A – Analytical Techniques in Environmental Sciences (2) • ES010A – Laboratory - I (3)
Semester II Total Credits (**21**)	• ES051A – Fundamentals of Atmospheric Sciences (2) • ES052A – Energy and Environment (2) • ES053A – Natural Hazards and Disaster Management (2) • ES054A – Marine Environment (2) • ES055A – Environmental Impact Assessment (2) • ES056A – Soil Science (2) • ES057A – Biodiversity and Conservation (2) • ES058A – Environmental Microbiology and Biotechnology (2) • ES059A – Laboratory - II (3) • ES060A – Field Trip (2)
*Students can exercise an exit option at this point to receive **PG Diploma in Environmental Sciences** provided the CGPA is above 4.0*	
*Students completing 1st year of M.Sc. (Environmental Sciences) from elsewhere may be allowed to join **M.Sc. (Environmental Sciences)** depending on availability of seats.*	
Semester III Total Credits (**21**)	Any 7 courses from the listed Optional Courses. One course compulsorily from each Area. (21)
Semester IV Total Credits (**21**)	Any 4 courses from the listed Optional Courses. One course compulsorily from each Area. (12) • ES191A – Scientific Writings and Ethics (2) • ES192A – Masters Dissertation (7)
Minimum Credit requirement for 4 semester (1-4) M.Sc. in Environmental Sciences (2-year)	84
Minimum Credit requirement for 2 semester (1&2) PG Diploma in Environmental Sciences (1-year)	42
Minimum Credit requirement for 2 semester (3&4) M.Sc. in Environmental Sciences (1-year)	42

<table>
<tr><th colspan="2">OPTIONAL COURSES (3 CREDIT EACH)</th></tr>
<tr><th colspan="2">AREA – I</th></tr>
<tr><th>Semester – III</th><th>Semester – IV</th></tr>
<tr><td>• ES101A – Data Science with R
• ES102A – Indoor Air Quality and Bioaerosol Dynamics
• ES103A – Atmospheric Radiation and Applications
• ES104A – Air Quality Risk Assessment and Modelling</td><td>• ES151A – Environmental Modelling
• ES152A – Atmospheric Aerosol
• ES153A – Climate Change Modelling
• ES154A – Cloud and Precipitation Physics
• ES155A – Climatology</td></tr>
<tr><th colspan="2">AREA – II</th></tr>
<tr><td>• ES105A – Ground Water Hydrology
• ES106A – Oceanography
• ES107A – Critical Minerals for Sustainable Environment
• ES108A – Environmental Geology
• ES109A – Remote Sensing of Environment
• ES110A – Biogeochemistry</td><td>• ES156A – Geophysical Exploration
• ES157A – Pollution Geology
• ES158A – Geochemistry
• ES159A – Glaciology
• ES160A – Hydrocarbon and Environment
• ES161A – Water Resources</td></tr>
<tr><td>• ES111A – Air Pollution Chemistry
• ES112A – Water Pollution Chemistry
• ES113A – Green Chemistry</td><td>• ES162A – Solid and Hazardous Waste Management
• ES163A – Climate Change: Alterations, Adaptation and Mitigation
• ES164A – Soil Pollution Chemistry
• ES165A – Circular Economy for Sustainable Environment</td></tr>
<tr><th colspan="2">AREA – III</th></tr>
<tr><td>• ES114A – Agroecology and Sustainable Agriculture
• ES115A – Bioremediation
• ES116A – Environmental Impacts of Biochemical Processes
• ES117A – Landscape Dynamics
• ES118A – Environmental Molecular Biology
• ES119A – Microbial Ecology
• ES120A – Pollution Biology
• ES121A – Radiation Biology</td><td>• ES166A – Ecosystem Services and Valuation
• ES167A – Environmental and Occupational Health
• ES168A – Environmental Nanotechnology
• ES169A – Forest Ecology
• ES170A – Geospatial Modelling
• ES171A – Microbes and Climate Change
• ES172A – Sustainability Science
• ES173A – Xenobiotics and Human Health
• ES174A – Biorefineries;</td></tr>
<tr><th colspan="2">AREA – IV</th></tr>
<tr><td colspan="2">All (core and optional) courses may require new course numbers as per the rules of JNU evaluation branch.</td></tr>
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ES001A – ENVIRONMENTAL PHYSICS (2 Credits)

Introduction to Environmental Physics: Concept and scope of environmental Physics with respect to human environment; built environment; urban environment-urban heat islands; global environment, Sound and Acoustics, Energy For living; **Transport of heat, mass and momentum:** Laws of thermodynamics, irreversible thermodynamics and entropy. Wind chill, Hypothermia, Heat balance (steady and transient), Electromagnetic Radiation, Thermal regulation in buildings- Thermal insulation, Thermal conduction effects, Convection effects, Radiation effects, U-values, Energy use and efficiency in buildings; **Fluid dynamics and turbulence:** Navier – Stokes and Euler equations, geo-potential form, first and second Bernouli's theorem. Diffusion coefficients, Laminar and Turbulence Flow, Reynolds Number, Thermal convection-Rayleigh–Benard convection**,** Double-diffusive convection; **Terrestrial radiation and micrometeorology:** Surface energy fluxes, terrestrial radiation – long wave and net radiation, canopy processes and canopy resistances, surface layer scaling and aerodynamic resistances, K-theory for turbulent diffusion.

ES002A – STATISTICS (2 Credits)

Basics of Data and Statistics: Scales of measurements, discrete and continuous variables, data grouping in classes and frequency tables, histograms, concept of statistical distribution, measures for characterizing a distribution – central tendency, dispersion, skewness and kurtosis, moments; **Probability Theory:** Sample spaces and events, probability, the axioms of probability, mutually exclusive events and the law of addition of probabilities, independent events and the law of multiplication of probabilities, conditional probability, Bayes' Theorem, random variables, discrete and continuous probability distributions – binomial, Poisson and normal (Gaussian) distributions; **Test of Hypothesis**: Hypothesis testing – parametric and non-parametric test (means, difference of means, proportions, difference of proportion, variances, ratio of variances); **Sampling Theory:** Sample and population, random sampling methods, sampling distribution, standard error, level of significance, central limit theorem, null and alternative hypothesis, Z-test for hypothesis testing, Type-I and Type-II errors, t-test, chi-square test, F-test for analysis of variance; **Exploring Relationships:** Scatter plots, correlation analysis, testing the significance of correlation coefficient, bivariate and multivariate linear regression analysis, coefficient of determination, sample and population regression functions.

ES003A – ESSENTIALS OF EARTH SCIENCES (2 Credits)

Introduction: Science of geology, Origin of the solar system and differentiation of early earth, Earth as a dynamic planet, Earth's spheres-surface, atmosphere and hydrosphere, Exploring the interior of Earth with seismic waves, layers and composition of earth, Geological time scale and Uniformitarianism. Geological study and benefits. Plate tectonic theory and plate boundaries, continental drift and evidences; **Rock cycle and processes:** Solid matter (elements and atoms), Concept of minerals and their properties, rock-forming minerals. Concept of the rock cycle, magma generation and fractional crystallization-Bowen's reaction series. Formation and classification of various rock types. Identification of mineral and rock specimens. Economic importance of minerals and rocks; **Geomorphic Landforms:** Overview of exogenic and endogenic geomorphic processes, Endogenic Processes- Diastrophic Forces (mountain building) and Movements & Sudden Forces and Movements (volcano, earthquake, landslide), Exogenic Processes- Weathering: mechanical, chemical, and biological, agents of weathering, controlling factors of rate of weathering, Erosion, transportation and deposition of sediments by running water, wind and glaciers; **Fundamentals of Structural Geology:** Attitude of beds, orogenic processes and formation of structures, terminology and classification of- folds, faults, joints, unconformity, outlier, and inlier.

ES004A – NATURAL RESOURCE MANAGEMENT (2 Credits)

Introduction: Evolution and history of resource management, concepts and classification of natural resources. Availability, distributions and uses of natural resources: land, water, soil, minerals, forest and animals. Principles and approaches of natural resource management. Integrated natural resource management strategy. Scale of natural resource management; **Energy Resources and Environment:** Conventional and Non- conventional fossil fuels: coal, petroleum, natural gas, coal bed methane, shale gas and gas hydrates- resource and reserves, critical mineral resources and their application in green energy technology, Nuclear Energy: nuclear reactors. Renewable energy resources: geothermal energy, tidal energy; solar energy, wind energy. Hydrogen as an alternate fuel; **Economic Mineral Resources and Environment:** Concepts of economic, critical and strategic minerals resource and their geological processes of formation, occurrences, distributions and their utility in modern technology. Overview of economic mineral exploration techniques, environmental dynamics associated with extractions and utilizations of economic mineral resources; **Practices of Natural Resource Management**: Concepts of sustainability and sustainable development. Recycling and reusing critical minerals from e-waste, Urban planning and environmental management. Concepts of green building. Land, soil, water, forest, minerals and energy conservation practices. Legal framework in natural resource management.

ES005A – ENVIRONMENTAL CHEMISTRY (Credits: 2)

Fundamentals of Environmental Chemistry: Classification of Elements, Chemical bonding, chemical reactions and equations, Stoichiometry, Gibbs' energy, chemical potential, chemical kinetics, chemical equilibria, solubility of gases in water; **Basic Concepts from Organic Chemistry**: Organic functional groups, classes of organic compounds. Free radical reactions, catalytic processes; **Fundamentals of Atmospheric Chemistry**: Elemental cycles (C, N, S, O) and their environmental significance, Fossil fuels: their types, properties, combustion and environmental implications; **Composition of Air**: Particles, ions and radicals in the atmosphere. Chemical speciation. Chemical processes in the formation of inorganic and organic particulate matters, thermochemical and photochemical reactions in the atmosphere, oxygen and ozone chemistry, Greenhouse gases and climatic changes, Chlorofluorocarbons and their substitutes. Photochemical smog. Acid Rain; **Fundamentals of Soil Chemistry:** Soil formation and chemical characteristics, chemistry of soil acidity, chemistry of saline and sodic Soils, Cation and anion exchange reactions in soil, Chemical characterization of soil: cation exchange capacity (CEC), Exchangeable sodium percentage (ESP), Sodium adsorption ratio (SAR), Soil decontamination; **Fundamentals of Aquatic Chemistry**: Hydrological cycle: source and uses of water, unusual properties of water, water quality standards, Analytical methods for water quality analysis (DO, oxidation-reduction potential, pH, Electron Activity and pE, Ionic strength, alkalinity, hardness, BOD, COD, TOC) carbon dioxide, bicarbonate, and carbonate system (DIC), Role of soaps, detergents, and phosphorus fertilizers in eutrophication; **Nature, Sources and Environmental Chemistry of Hazardous Wastes:** Chemical classes of hazardous waste: Flammable, Combustible, Reactive, Corrosive and Toxic substances, Environmental Chemistry of Hazardous Wastes, Transport, effects and fates of hazardous wastes and their chemical treatment, Toxicity Characteristic Leaching Procedure (TCLP); **Chemistry of persistent organic pollutants (POPs)**: Chemical properties of POPs, UN Criteria and Stockholm Convention on POPs, partition coefficient for organics (K_d, K_{OC}, K_{OM}, K_{OW}), pesticides usage, toxicity and their environmental degradation, Persistent toxic substances (PTS).

ES006A – ENVIRONMENTAL POLLUTION (Credits: 2)

Fundamental concepts: Science of pollution, definitions, environmental interactions, Linkage between economic development and environmental pollution, Human population dimensions. Definition of pollution, sources and derivers of pollution, Different types of pollution- Air, Water and soil, concepts of source sink and receptor, residence time of pollutants, temporal and spatial scales of pollution, basics of sustainable development and sustainability; **Air pollution:** Sources, nature and types of air pollutants, their behavior in the atmosphere. Air quality standards, Photochemical smog, acid rain cause and impact, overview and basics of troposphere and stratospheric ozone, Effects of air pollutants on humans, animals, plants and properties; **Water Pollution:** Sources and types of pollutants, basic essential parameters (DO, BOD, CBOD, NBOD, salinity, turbidity, alkalinity pH etc.) for water quality, classification of water types, eutrophication: causes, effects and remediation, lake turnover and stratification, Mass balance approach for pollutants, basic of metals and metalloids in water pollution, effects, water pollution treatment; **Soil Pollution and solid waste:** Sources (insecticides, pesticides, invasive species, fertilizers, industrial emission etc.) and mine burden, mine tailing, acidity/salinity and sodicity of soils, soil erosion, impacts and remediation methods, Solid waste: generation, collection, environmental effects and safe disposal practices, E-waste, microplastics; **Noise pollution, Marine pollution and radioactive pollution; Environmental education:** Awareness and attitude and national and international initiatives to combat environmental pollution.

ES007A – ECOLOGY (2 Credits)

Ecology, organizational levels, trophic dynamics and limiting factors: Concept of ecology, level of organization, trophic structure and control approaches, food chain and food web, energy flow models, ecological efficiencies, ecological pyramids, law of limiting factor, Shelford's law of tolerance, ecological adaptations; **Ecosystem Ecology:** Ecosystem concept, open and closed ecosystem, ecosystem structure, biotic and abiotic components and interactions, functions of the ecosystem - concept of productivity and patterns, autochthonous and allochthonous production, nutrient cycling, general model of nutrient cycling, ecosystem types- aquatic- marine and freshwater, terrestrial, biomes; **Biomes:** Concept, Classification and distribution. Characteristics of different Biomes: Tundra, Taiga, Grassland, Deciduous Forest biome, Highland Alpine Biome, Chapparal, Savanna, Tropical Rain Forest; **Population Ecology:** Population, unitary and modular organism, ramet, genet, population characteristics, age structure and pyramid, population growth, life table, population regulation, metapopulation concept, life history and tradeoffs, Grime's triangle of life history strategies, Concept of home range and territory; **Community Ecology**: Concepts of community, community organization and characteristics, Community structure, community functional classification, community interactions, key stone species, ecotone, competitive exclusion and coexistence, ecological niche, ecological succession, resource partitioning and character displacement, Lotka Volterra Model, community diversity -stability- complexity relationship, plant communities, life forms, community gradient and boundaries, equilibrium theory of Island biogeography.

ES008A – ENVIRONMENTAL BIOLOGY (2 Credits)

Introductions to Cells and Metabolic Processes: Cell structures and functions, membrane structure and transport origin. Biomolecules: protein, lipids, carbohydrates, DNA and RNA; Metabolic processes; Enzymes: enzyme kinetics and regulations; **Thermodynamics of Biological Processes:** Basics of thermodynamics and its role in biological systems; Gibbs Free Energy, Entropy, and Enthalpy in biochemical reactions; ATP hydrolysis and energy transfer in Cells; Bioenergetics in cellular processes: Respiration, Photosynthesis, and Metabolism; **Ecotoxicology**: Principles of Environmental Toxicology; Adverse effects of toxicants on the living system. Factors influencing toxicity and route of administration causing abnormal response to chemicals; Uses of exposure assessment: Dose-response relationship; Frequency response and cumulative response; Statistical concepts in toxicology; Basis of selective toxicity: Metabolism, Uptake and biotransformation of environmental contaminants, Activation, Detoxification and; Diversity of pollutant biodegradation.

ES009A – ANALYTICAL TECHNIQUES IN ENVIRONMENTAL SCIENCES (2 credits)

Quality of Environmental Measurements: Calculations used in analytical chemistry; Precision and Accuracy of Environmental Analyses; Errors in chemical analysis; Sampling, Standardization, and Calibration; Absorption Laws, Deviations from Beer's law, Methods of calibration, Calibration with Standards, Method of Standard Additions, Internal Standard calibration, Errors Associated with Beer's Law Relationships, Limit of Detection (LOD), Limit of Quantification and Sensitivity; Significant figures; **Classical Methods of Analysis:** Gravimetric and Volumetric Methods (volumetric titration, standard solution, endpoint, and the equivalence point in a titration, primary and secondary standard, standardize reagents, back-titrations, titration errors, gravimetric titrations); **Quantitative Optical Spectroscopic Methods:** Introduction to Spectrochemical Methods (electronic, vibrational, and rotational transitions); Basic principles of Molecular Ultraviolet/ Visible Molecular (UV-Vis) absorption spectroscopy, Atomic absorption Spectroscopy (AAS), Inductive Coupled Plasma Atomic Emission Spectroscopy (ICP-AES), Inductive coupled plasma Mass-spectrometry (ICP-MS), Atomic fluorescence spectroscopy (AFS), X-ray fluorescence (XRF) spectroscopy (EDXRF and WDXRF); **Qualitative Optical Spectroscopic Methods**: Infrared (IR) spectroscopy, Raman spectroscopy, Nuclear magnetic Resonance (NMR) Spectroscopy, X-ray Diffraction (XRD); **Separation Methods**: Gas chromatography (GC), High Performance Liquid Chromatography (HPLC), Thin-Layer (Planar) (TLC) chromatography; **Mass Spectrometry**: Gas chromatography Mass Spectrometry (GC-MS); **Microscopic and Surface Analysis**: Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM).

ES010A – LABORATORY – I (3 Credits)

Advanced laboratory skills required to undertake environmental biotic-abiotic interaction, monitoring, analysis and interpretation. This program has a multidisciplinary approach that integrates the environmental scientific issues by conducting laboratory experiments on ecosystem studies, biodiversity analysis, natural resource, environmental services, geochemical analysis, air pollution and its tolerance indexing, microbial culture and interaction, toxicity determination, water and waste water analysis, assessment of agricultural soil and health, solid waste analysis, climate change modeling and risk assessments.

ES051A – FUNDAMENTALS OF ATMOSPHERIC SCIENCES (2 Credits)

Overview of Atmosphere and Earth's Radiation Budget: Evolution of Earth's atmosphere, Vertical structure of atmosphere, Concept of atmospheric temperature, pressure and density, Chemical composition of atmosphere, Aerosols, Spectrum of radiation, Blackbody radiation, Plank Function, Stefan-Boltzmann law, Wien's Displacement law, Kirchhoff law, Absorption, scattering and emission, Earth's radiation balance, Radiative forcing; **Atmospheric Thermodynamics:** Gas Laws, Virtual Temperature, Hydrostatic Equation, Thermodynamics' laws, Adiabatic Processes, Dry adiabatic lapse rate, Potential temperature, Water vapour in air (mixing ratio, specific humidity, relative humidity etc.), Saturated adiabatic lapse rate, Equivalent potential temperature, Atmospheric stability, SkewT–lnP thermodynamic diagrams; **Atmospheric Dynamics:** Kinematic properties of atmospheric flow, Continuity equation (conservation of mass), Vorticity and divergence, Deformation, Streamline and wind trajectories, Forces in atmosphere (real and apparent), Conservation of momentum, Geostrophic balance, Gradient wind, Thermal wind, Barotropic and Baroclinic atmosphere; **General Circulation and Weather Systems:** Global atmospheric circulation, Hadley, Ferrel and Polar Circulation, Walker Circulation, Trade Winds, Jet Steams, El-Nino & La-Nina, Tropical Cyclone, Indian Monsoon.

ES052A – ENERGY AND ENVIRONMENT (2 Credits)

Energy Resources and Their Exploitation: Energy resources and exploitation methods, sun as a source of nature of its radiation, conventional energy sources, non-conventional energy sources: principles of hydroelectric power, tidal energy, wind energy, geothermal energy, solar energy (collectors, photovoltaics, solar ponds), and nuclear energy (fission and fusion),

Magnetohydrodynamic power (MHD) generation: theory, technology, and limitations, Global energy consumption patterns and their associated environmental consequences, including CO_2 emissions, climate change implications, and energy sustainability, Carbon capture and storage (CCS): Emerging energy technology; **Environmental Impacts of Energy Production:** Environmental impacts of energy production and consumption: CO_2 emissions, and the greenhouse effect, environmental degradation caused by energy production, energy production's contributions to global warming, Case studies of energy exploitation's ecological impacts: coal mining, oil extraction, and the environmental footprint, Costa Rica's carbon-neutral initiatives, Future energy trends: smart cities, energy storage, and electric vehicles, Environmental policies for energy management and sustainable energy transitions; **Radiation and Its Interaction with Living Systems:** Radiation interaction with biological systems: stochastic (random) and non-stochastic (deterministic) effects, Delayed radiation effects: dose from the environment and nuclear radiation, ultraviolet radiation, Pathway analysis for radiation exposure: internal and external radiation exposure pathways, radioactive age dating; **Radiation Safety, Risk Assessment, and Nuclear Safety:** Advanced concepts in radiation risk assessment: dose-response relationships, radiation protection standards, Evaluation of radioactivity and dose assessment methodologies: environmental radiation dose calculations, Radiation safety protocols and international standards: regulation and management by the International Atomic Energy Agency (IAEA) and World Health Organisation (WHO), nuclear safety and hazards, the long-term environmental impact of radioactive waste, Case studies on nuclear incidents: Chernobyl, Fukushima, and Three Mile Island, Advanced nuclear waste management: containment, reprocessing, and safe disposal techniques.

ES053A – NATURAL HAZARDS AND DISASTER MANAGEMENT (2 Credits)

Introduction: Definition of hazards, disaster, Natural phenomena, risk, vulnerability, endemic, epidemic and pandemic. Hazard types and Hazard classification. Hazard zonation and mapping- Risk Reduction Measures. Continental drift and plate tectonics; **Disaster management**: Causal factors of disasters. Compound and complex disasters and displaced persons. Fundamentals of disaster management. Phases of disaster management. Disaster mitigation options and actions. Relationship between disaster and development. Disasters – India scenario; **Natural Hazards** (***Terrestrial or Endogenous***): *Volcanoes* – origin, causes, types of lava flows, prediction of volcanoes, volcanic hazards and risk, Disaster preparedness and mitigation, Environmental impacts of volcanoes. *Earthquakes* – cause, effects of earthquake, Human caused earthquakes, seismic zones in India, preparedness and mitigation, Earthquake resistant buildings. *Earth movements* – Slope stability, Importance of landslide, classification and types of landslides, causes of landslides and subsidence, landslide mitigation and preventive measures. *Groundwater*: hydro-geohazards, groundwater fed surface flooding, Natural toxic groundwater; **Natural Hazards** (***Atmospheric or Exogenous***): *Floods*: Flood types, river hazards, flood hazard zoning, Flood preparedness and mitigation. *Coastal*: Sea waves and currents, Tropical cyclones, coastal erosion, shoreline protection from waves. *Cold waves*: safety risks and cold induced health issues, cold weather hazard preparedness and mitigation, Response to cold weather hazards. *Heat waves*: Heat induced illness, Preparedness and mitigation, prevention of heatstroke. *Fires*: Wild fire causes and its classification, Effects, Early warning system. Environmental impacts of wild fire. *Drought*: Classification and causes of drought, Effects, preparedness and mitigation.

ES054A – MARINE ENVIRONMENT (2 Credits)

Introduction to the Marine Environment: Overview of marine ecosystems, Importance of marine environment in global systems, Ocean zones and their characteristics, Classification- open ocean- shallow marine and deep-sea environment; **Know our oceans:** Composition of seawater, Ocean circulation and currents, waves, and tides, Heat and energy distribution, Impact of physical processes on marine life, Beaches, coastal dunes, barrier islands, cliffed coast- deltas, coastline, estuaries, mangroves, lagoons, salt marshes, coral reefs; **Ocean sediments and environment:** Marine sediments- clay minerals- biogenic silica- evaporites, Ocean acidification and its effects, Marine sediments and Paleoenvironment; **Marine Biodiversity:** Marine food webs and trophic levels, biogeochemical cycles, Biodiversity and adaptation in marine organisms; **Human Impact on the Marine Environment:** Pollution: Plastics, oil spills, and heavy metals, Overfishing and bycatch, Climate change and its effects on sea levels and ecosystems; **Marine Resource Management and Conservation:** Marine protected areas and their role, Sustainable fisheries and aquaculture practices, International policies and frameworks (e.g., UNCLOS, MARPOL)

ES055A – ENVIRONMENTAL IMPACT ASSESSMENT (Credits: 2)

Introduction to EIA: History and evolution of EIA, Environmental Regulations and Policies, EIA Process, Category A and Category B projects and activities, Stages of Environmental Assessment (IEE and EIA), Impact assessment and classification (Rapid EIA, CIA, IIA, SEA, LCA, Regional and sectorial EIA); **Methodologies and various aspects of EIA**: Social and Cultural Impact Assessment, Environmental Risk Assessment, Ecological Impact Assessment of Air and Water Quality Assessment, Noise and Vibration Assessment, Health Impact Assessment, steps and methods of EIA (screening, scoping, Baseline data accumulation, impact assessments, public consultation, EIS preparation, mitigation, review, decision making, monitoring and auditing), Climate Change and EIA, SEAC, TOR; **Methods and Techniques**: Ad hoc method, Matrix method, Networks methods, Map Overlay methods; **Environmental Management Systems**: ISO 14001 and other EMS

frameworks, Environmental auditing and monitoring, Advances in EIA methodologies. EMP, EIA manuals, project sectors and activities, EIA Notifications with emphasis on MoEFCC; **Case Studies and Projects:** Real-world EIA examples and project reviews, Group projects and assessments, Incorporating sustainability principles, Life cycle analysis and green design, Preparation of EIA reports, Documentation standards and best practices, Ethical dilemmas in EIA, Environmental justice and equity.

ES056A – SOIL SCIENCE (Credits: 2)

Introduction- Definition of soil, soil formation, factors of soil formation. Soil in the critical zone. Soil classification; **Soil mineralogy and weathering**- Soil forming rocks and minerals, weathering of rocks and minerals, processes of weathering and factors affecting them, clay mineralogy-structure and classification. Weathering Engine, profile development and soil composition; **Soil physical properties**- Soil separates and particle size distribution, soil texture and structure- Bulk density, particle density, pore space, soil air, soil temperature, soil water, soil consistence. Significance of physical properties to plant growth; **Soil chemical properties-** Soil colloids- organic and inorganic colloids, clay minerals chemistry, ion exchange reactions, cation exchange capacity, Point Zero Neutral Charge; **Soil organic matter**- Decomposition, humus formation, significance on soil fertility. Biological properties of soil, nutrient availability.

ES057A – BIODIVERSITY AND CONSERVATION (2 credits)

Introduction to Biodiversity: Definition, Scope, and Significance- Convention on Biological Diversity (CBD), Cartagena Protocol on Biosafety; Nagoya protocol of Biodiversity, Kumming Montreal Global Biodiversity Framework (KMGBF), SDGs and Biodiversity, Levels of Biodiversity: Genetic, Species, and Ecosystem Diversity, Gradients of Biodiversity and key hypothesis, Patterns of Biodiversity- Biodiversity Hotspots; **Measurement and Assessment of Biodiversity:** Methods for Measuring Biodiversity, Tools for Biodiversity Assessment (e.g., Quadrat Sampling, Line Transects, and GIS), Indicators of Biodiversity status, Species composition; diversity and Index; Species area curve Disturbance and species diversity; Diversity-Stability-Complexity relationships, Biodiversity Indices (Shannon-Weiner, Simpson's Index, etc.); **Biodiversity loss and Threats:** Biodiversity loss and crises, Natural and Anthropogenic Threats, Habitat Loss, degradation and Fragmentation, Invasive Species, Climate Change and its Impact on Biodiversity, Overexploitation and Pollution, Biotic resistance hypothesis, Extinction of species, IUCN red list categories and criteria; **Biodiversity Conservation Strategies:** Criteria to implement conservation strategy; Minimum and effective Population size; In-Situ and Ex-Situ Conservation Approaches**,** Role of Protected Areas: National Parks, Wildlife Sanctuaries, Biosphere Reserves**,** Community-Based Conservation**,** Ecosystem-Based Adaptation and Mitigation, Advances in Biodiversity Conservation, Biodiversity Offsets and Green Finance; **International and National treaties, legal frameworks:** International treaties, Legal Frameworks for Biodiversity Conservation (e.g., Wildlife Protection Act, Biodiversity Act), Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES); Millenium Ecosystem Assessment (MEA); IPR, WWF; WCU, CITES and TRAFFIC.

ES058A – ENVIRONMENTAL MICROBIOLOGY AND BIOTECHNOLOGY (2 Credits)

Environmental Microbiology - Importance of microbes in our environment; Microbial cell structure and function with special emphasis on *Bacteria* and *Archaea*; Microbial nutrition, growth, and laboratory culture methods; Microbial growth control; Environmental factors affecting microbial growth and adaptations to extreme environments; Microbial evolution, phylogeny, and diversity in natural habitats; **Fundamentals of Environmental Biotechnology:** Bioremediation: Plants and Microbes in *In Situ* and *Ex Situ* Remediation; Bio-pesticides: Mode of action and environmental benefits; Bio-fertilizers; Bio-composting: Role of microbes and earthworms in organic waste recycling. Bioplastics; Biosurfactants: Microbial production of biosurfactants and their applications; **Energy and Resource Recovery in Environmental Biotechnology:** Biofuels: biodiesel, bioethanol, and biogas; Microbial Fuel Cells (MFCs); Environmental Monitoring Using Biosensors; Bioleaching - Microbial extraction of metals from ores, Applications in mining and e-waste recycling; Bioindicators

ES059A – LABORATORY – II (3 Credits)

Advanced laboratory skills required to undertake environmental biotic-abiotic interaction, monitoring, analysis and interpretation. This program has a multidisciplinary approach that integrates the environmental scientific issues by conducting laboratory experiments on ecosystem studies, biodiversity analysis, natural resource, environmental services, geochemical analysis, air pollution and its tolerance indexing, microbial culture and interaction, toxicity determination, water and waste water analysis, assessment of agricultural soil and health, solid waste analysis, climate change modeling and risk assessments.

ES060A – FIELD TRIP (2 Credits)

The School of Environmental Sciences conducts field training for M.Sc. students to get hands-on exposure on various environmental issues such as geological observations, industrial visits, ecological reserves, pollution aspects of air, water and soil as well as their interaction with biomes.

ES101A – DATA SCIENCE WITH R (3 Credits)

Introduction to R: Installing R and R-Studio, R-Studio Overview, working in the Console, Working Directory, Getting Help in R and Quitting R-Studio. Creating Variables, Basic Data Types in R – numeric, integer, complex, character and logical. R Operators – Arithmetic, Assignment, Comparison, Logical. Built-in Math Functions, R Comments, R packages – Installing and loading, Writing R-Scripts; **Data Structures and Accessing Data:** Basic Data Structures in R - Vectors, Matrices, Lists, Factors and Data frames. Commands useful for understanding data structure, Reading and Writing Data in R, Downloading and Importing Data in R from external world; **Working with Data:** Working with Missing Data, Extracting Subsets, Renaming Columns, Attaching / Detaching, Tabulating Data: Constructing Simple Frequency Tables, Working with Dates and Times, Data Transformation, Creating functions; **Control Structures in R:** If-else conditional statements, Loops-for, while, repeat, nested loops; **Data Visualization:** Plotting in R – Bar charts, Pie Charts, Line Plots, Scatter Plots, Box Plots, Histograms. Using the ggplot2 package to visualize data, applying themes from ggthemes to refine and customize charts and graphs; **Statistical Analysis with R:** Measures of central tendency, Measures of variability, Skewness and kurtosis Summary functions, describe functions, and descriptive statistics by group, Correlation and Regression.

ES102A – INDOOR AIR QUALITY AND BIOAEROSOLS DYNAMICS (3 Credits)

Introduction: Bioaerosol Introduction, composition, bioaerosols as bacteria, viruses, fungi, pollen, Bioaerosol generation, bioaerosols generation by natural and human activities, Aerobiology; **Characterization**: Bioaerosol transport, Bioaerosols in workplace and hospitals, Bioaerosol sampling, Inertial and non-inertial sampling, Bioaerosol characterization and analysis; **Environmental Bioaerosols**: Bioaerosols in built and natural environments, Bioaerosol's impact lth, toxicity and pharmacology, effect of bioaerosols on atmosphere and climate, Control technologies; **Indoor Air Introduction**: Indoor air pollution introduction, Sources and types of Indoor air pollution, Indoor Particles, Combustion Products and Fibres, Volatile and semi volatile Organic Compounds, Indoor Gas-Phase Chemistry, Indoor Photochemistry, Indoor Surface Chemistry; **Sources**: consumer products as source, Indoor Chemical Exposure, Sick-building syndrome, Multiple Chemical Sensitivity, Personal Cloud Effect, Health Impacts of Indoor air Quality, Occupation health; **Transport and control**: Control technologies, Transport and fate of Indoor air pollutants, Material Balance Model, Measurement methods, Control strategies for Indoor air pollution.

ES103A – ATMOSPHERIC RADIATION AND APPLICATIONS (3 Credits)

Basics of atmospheric radiation: Electromagnetic Spectrum, Solid angle, Radiometric Quantities, Scattering concepts, line broadening, absorption of line formation, Beer – Bouguer – Lambert Law; **Solar Radiation:** Basics – zenith angle, azimuth angle, hour angle and solar declination, Sun-Earth geometry, solar constant, solar insolation and its distribution, solar constant determination – ground based and satellite measurements; **Absorption and scattering:** Atmospheric molecular absorption, absorption in UV, Visible and Near IR, Theoretical development of Rayleigh and Lorenz–Mie scattering, Phase function, scattering cross section, and polarizability, blue sky and sky polarization; **Radiative transfer:** General radiative transfer equation – direct and diffused radiation, single scattering approximation, diffusion approximation, atmospheric solar heating rates, thermal infrared spectrum and the greenhouse effect, atmospheric infrared cooling rates; **Radiation and Climate:** Radiation budget at the surface and from space, radiative equilibrium, radiative – convective equilibrium – heat budget, convective adjustment; **Radiation in Climate Modelling:** Radiation in one dimensional models, radiation in energy balance climate models, Radiative forcing in energy balance climate models, radiation in global climate models and ENSO.

ES104A – AIR QUALITY RISK ASSESSMENT AND MODELING (3 Credits)

Introduction to Air Quality and Health Risks: Overview of air pollutants: sources, types, and characteristics, Health impacts of air pollution: acute and chronic effects, Air Pollution toxicology and exposure pathways of air pollution, Regulatory frameworks and guidelines; **Health Risk Assessment Framework:** Risk assessment process: hazard identification, dose-response assessment, Dose rate of air pollutants, lowest observed adverse effect levels (LOAELs) of air pollutants, disability-adjusted life years (DALY) years of life lost (YLL) associated with air pollution, exposure assessment and risk characterization, Quantitative and qualitative risk assessment of criteria pollutants; **Air Quality Modeling and Exposure Assessment:** Air quality monitoring and data interpretation, Overview of various air quality models, Exposure assessment techniques: ambient monitoring, personal exposure monitoring, and time-activity patterns, Air pollution Health Risk Assessment (AP-HRA) Tools, Applications of Machine learning and GIS in air pollution modeling; **Health Impact Assessment and Uncertainty Analysis:** Linking air

quality models with epidemiological data, Short-term and long-term health effects of air pollution, Quantifying health impacts (morbidity and mortality), Cancer and non-cancer risk assessment, Hazards Quotient, Excess Risk, Relative risk, Sensitivity and uncertainty analysis in risk assessments of air pollutants; **Data sources and risk assessment:** Types of data sources: ground-based monitoring, satellite data, remote sensing of air pollution, Hands-on application of modeling techniques and risk assessment using real-world data, Regional and global perspectives on air quality management and mitigation strategies; **Emerging Challenges and Future Directions of Air pollution:** Impact of indoor air quality and emerging pollutants, Risk assessment model to evaluate the health impacts of air pollution, Exploring the impact of climate change on air quality and health, Innovations in monitoring technologies and predictive modelling, Integrating public health perspectives into air quality policy and planning.

ES105A – GROUNDWATER HYDROLOGY (3 Credits)

Introduction: Difference between hydrology and hydrogeology. Hydrological cycle and groundwater in the hydrological cycle. Groundwater as a resource and its utilization. Over-exploitation of groundwater and their effects on the environment. Water logging problems in India. Groundwater problems related to foundation work, mining, reservoirs, tunnels and landslides. Influence of climate change in groundwater. Groundwater provinces of India; **Occurrence of Groundwater and its movement**: Origin and age of the groundwater. Rock properties affecting groundwater. Vertical distribution of groundwater. Geological formation as aquifers. Types of aquifers and Springs. Groundwater resources in permafrost and desert regions. Darcy's law and its validity. Aquifer (hydrologic) properties such as porosity, hydraulic conductivity, transmissivity and storage coefficient. water table contour maps and flow net analysis. Radioisotopes and groundwater tracers. Contaminant migration in groundwater; **Water wells and groundwater exploration**: Groundwater well design, construction, completion and development. Horizontal wells and qanats. Surface (geologic and geophysical methods) and sub-surface investigations (logging methods). Causative factors on groundwater level fluctuations and Land subsidence; **Groundwater quality**: Physio-Chemical characteristics of groundwater and its Sources of salinity. Water quality criteria for different uses. Groundwater quality and pollution problems in different geological formations. Occurrence of saline water intrusion and Ghyben-Herzberg relation. Control of saline water intrusion. Sources and causes of groundwater pollution; **Groundwater management and artificial recharge**: Concepts of Basin management and basin investigation. Conjunctive use and watershed management. Artificial Recharge to Groundwater (direct and indirect recharge methods). Urban and rural rainwater harvesting systems. Groundwater legislation.

ES106A – OCEANOGRAPHY (3 Credits)

Introduction to Oceanography: Origin of the Ocean. Age of the Earth and Ocean. Distribution of oceans around the globe. Historical overview of oceanography, Voyages and Expeditions. Contemporary Oceanography and its future trends using modern technology; **Earth Structure, Plate Tectonics and Ocean Basins:** Earthquakes and Earth's interior, plate tectonics, continental drift, seafloor spreading, mid-ocean ridges, seamounts, guyots, rifted margin tectonics, subduction zones and the topography of the ocean floor, Ocean sedimentation; **Water and Ocean Structure:** Composition of seawater, Physical, Chemical and Biological aspects of seawater, Salinity, Stratification of oceans, Heat and energy distribution, Surface water and moderation of global temperature, and propagation of sound and light through the oceans; **Ocean-environment and Hazards:** Sea level, Ocean hazards, Cyclones, storm surges, Landslides, Tsunamis, Extreme events Impact of physical processes on marine life, Ocean acidification and its consequences; **Ocean-Atmosphere Interaction:** Ocean Circulation, Atmospheric Circulation, Ocean currents, Waves, Tides, Thermohaline circulation, El-Nino, La-Nina and Southern Oscillations.

ES107A – CRITICAL MINERALS FOR SUSTAINABLE ENVIRONMENT (3 Credits)

Introduction: Concept and classification of critical minerals, Importance in modern society, geological processes of formation, geochemistry of critical minerals, Indian and global distribution of key occurrences and deposits of critical minerals, Demand and supply dynamics of critical minerals; **Exploration and Extraction Techniques:** Exploration techniques for critical minerals: geological, geophysical, geochemical, and remote sensing methods, Sampling techniques, challenges in exploration of critical minerals, role of AI and Machine Learning (ML), mining and beneficiation processes with global case studies (e.g., lithium, cobalt, rare earth elements), Graphite: a vital critical mineral for the modern world; Advanced analytical techniques of critical mineral studies; **Applications in Clean and Green Technology:** Importance of critical minerals in modern technology and renewable (green) energy, Geology of platinum group elements (PGE) and their role in fuel cell technology, Geology of Lithium and Cobalt: Applications in Electric Vehicles and Battery Storage Systems, Geology of Rare Earth Elements (REEs) and Their Implications for Wind Turbines and Electric Motors; **Climate Change and Energy Transition:** Mineral requirements for clean energy transitions, overview of global energy systems and decarbonization strategies, climate benefits from energy transition, role of critical minerals in environmental sustainability, future demand and technological innovations in green energy, Polymetallic nodules (PMNs) from Deep Sea as new avenues; **Sustainable Practices:** Development of eco-friendly alternatives and synthetic substitutes, Recycling and reusing critical minerals from e-waste, Environmental considerations in sourcing, mining and recycling, Urban Mining: Opportunities and challenges, Reduction of carbon footprint,

Government Policies and Initiatives for Critical Minerals studies.

ES108A – ENVIRONMENTAL GEOLOGY (3 Credits)

Introduction: Philosophy and fundamental concepts, salient points about the Earth, the origin and internal structure of Earth: Earth's layers, methods to guess the Earth's interior, discontinuities of Earth, characteristics of crust, mantle and core, historical development of understanding about Earth's interior. Basic principles of stratigraphy and sedimentation. Geological timescale and its environmental implications; **Minerals and Rocks:** Minerals: definition, physical and chemical properties. basic crystal systems, classification of minerals, silicate structures and common rock-forming minerals. Three rock laws, formation and classification of rocks, Igneous rocks: evolution and types of magma, structure, common igneous textures and classifications based on mineral and chemical compositions. Sedimentary rocks: fundamental properties of sedimentary rocks, grain size classification of clastic sediments, sorting and roundness, Classification of sedimentary rocks-clastic, chemical and organic and sedimentary environments. Metamorphic rocks: process of metamorphism, protolith, metamorphic texture, grade and facies, type of metamorphism, index minerals, nomenclature of metamorphic rocks, and metamorphic environments. Geological significance of rocks; **Impact of Geological Processes:** Concepts of seafloor spreading, plate tectonics, mountain building, rock deformation- the evolution of continents. Geological Processes and Interaction with Humans-Forecasting and Mitigation: Earthquakes, volcanoes, slope processes, landslides, subsidence, rivers and floods, coastal processes and related hazards. Impact of extraterrestrial objects and mass extinction; **Environment, Society and Future:** Introduction, resources and pollution: natural resources and their exploitation, past, present and future environmental issues and their effect on the earth and our society, geological perspective of environmental health, air pollution and waste management, environmental analysis, case studies of various historical events in Earth's history, modern tools and techniques in environmental geology.

ES109A – REMOTE SENSING OF ENVIRONMENT (3 Credits)

Fundamentals of Remote Sensing: Principles and Basic Concepts, Electromagnetic Radiation Principles and Models, Atmospheric Energy-Matter Interaction- Scattering, Refraction, Absorption, Transmission, Atmospheric windows. Terrain Energy-Matter Interaction – Hemispherical Responses and Radian Flux Density, Radiative transfer equation, absorption by atmospheric gases and aerosols. Interaction of EMR with Earth Surface - Radiance, irradiance, reflectance, albedo, and brightness temperature concepts, Spectral reflectance curves, Spectral, Spatial, Temporal and Radiometric resolutions. Platforms; **Satellite Remote Sensing**: Satellite Orbits: Geostationary satellites; Polar Sun-synchronous satellites; Sensor: Types and characteristics; Overview of satellites related to environmental remote sensing: LANDSAT, SPOT, IRS, Terra/Aqua, Sentinel, INSAT, MODIS, VIIRS, CALIPSO, CloudSat, TRMM; Remote Sensing Systems: Mutli-spectral, Infrared, Microwave, RADAR, LiDAR, Hyperspectral; **Applications of Remote sensing**: Ocean (Coastal dynamics: coastal sites- erosion and sediment transport, sea level rise, oil spill areas), Land (LULC, forest cover and type, deforestations, urban area, UHI), Geology (structural, lithological, and geomorphological: geological structures, rock-types and landforms-fluvial, volcanic, tectonic), Water resources (surface waters bodies: lakes, ponds, and rivers. ground water exploration and potential areas for ground water recharge and rain water harvesting), Atmosphere (Temperature and Humidity, Detection of cloud height, optical depth and phase, Aerosols: AOD and size distribution, Trace Gases (O_3, CO_2, CH_4, and NO_2), Precipitation and water vapor), Environmental and disaster management (earthquake, volcanoes, landslides, floods and drought). Resource evaluation (Soils, minerals, forest and agriculture).

ES110A – BIOGEOCHEMISTRY (3 Credits)

Introduction: Overview of biogeochemistry and its importance; biogeochemical provinces; understanding the earth as a chemical system; scale of endeavor; Lovelock's Gaia; Origin- of elements, solar system and earth, atmosphere and ocean, and life; metabolic pathway; rock weathering process, weathering rates; soil chemical reactions; terrestrial ecosystems-photosynthesis, respiration and detritus; soil organic matter and global change; ocean and global change; **Biogeochemical characteristics:** Biogeochemical characteristics of- lakes, ponds, streams and rivers, mangroves, salt marsh and estuaries; wetland and its type; wetland soil; wetland vegetation; wetland and water quality; productivity and limiting nutrients; sediment; Biogeochemical reaction in the troposphere and stratosphere; **Global biogeochemical cycles:** Biogeochemical cycling on land plants, vegetation and soil; Global cycle of carbon, nitrogen, oxygen, sulfur, phosphorous, mercury, iron and manganese; **Human impact on biogeochemistry and case studies:** Impact on global biogeochemical cycles; elevated carbon dioxide and global warming; global climate change; sea level rise; saltwater intrusion; eutrophication; water infrastructure; acid rain; Case studies- climate change and pollution.

ES111A – AIR POLLUTION CHEMISTRY (3 Credits)

Air Pollution and Air Auality: Chemical and physical attributes of the atmosphere, Concept of clean atmosphere, Sources and emissions of air pollutants, Types and important properties of air pollutants, Air quality standards and air quality index, residence time, Transport and fate of pollutants, Spatial and temporal aspects of air pollution; **Aerosols:** definitions, mass volume distribution**,** geochemical aspects of aerosols, OC and BC, radiative forcing; **Effects of Air Pollution:** on human health, plants, animals and materials, Greenhouse effect, Dew, fog and rainwater chemistry, Acid rain chemistry and impacts, Indoor air pollution; **Ozone in Atmosphere:** Photochemical reactions in troposphere, CFCs: name, nomenclature, source and reactions, Chemistry of Troposphere ozone, photochemical smog and stratospheric ozone chemistry, ozone hole and Polar stratospheric cloud; **Air Pollution Meteorology:** Mixing heights, Wind roses, Temperature Inversion conditions, Long range transport, Plume behavior, Air pollution dispersion; **Land-atmosphere-ocean Interactions**: Biogeochemical aspects of air pollutants, Carbon sequestration; **Sampling and Control Techniques:** sampling and analysis of air pollutants, abatement of Air pollution control technologies.

ES112A – WATER POLLUTION CHEMISTRY (3 Credits)

Water Pollution Chemistry: Types and sources of water pollution, Chemistry of natural and man-made pollutants affecting water quality; **Water Quality and Standards:** Physico-chemical properties of water, Overview of water use: water stress, water scarcity and water risk; Classification of water, water footprints, Water quality standards: Guidelines from WHO, EPA, and BIS, Maximum Contaminant Levels (MCLs), Maximum Contaminant Level Goals (MCLGs) Basic principles of contaminant behavior in the environment; Hydrologic cycle; **Water and Wastewater Sampling and Analysis:** Public water system, Comprehensive overview of sampling techniques, protocols, and best practices, sampling issues, Designing the sampling Program, Quality control and assurance (QA/QC) in water quality monitoring; **Measurement of Water and Wastewater Quality Parameters:** In-depth analysis of major physicochemical and bacteriological parameters, their Role in water quality assessment, and practical applications in monitoring and treatment; **Water and Wastewater Treatment Technologies**: Unit processes and operations in water and wastewater treatment, Pre-treatment, Preliminary treatment, Primary treatment, Secondary treatment, Tertiary and/or advanced treatment, Engineered and natural processes for wastewater treatment. Principles and design of groundwater, surface water and industrial wastewater treatment facilities. Principles of water softening, Coagulation and flocculation, Sedimentation, Chemical precipitation, Filtration, Ion exchange, Adsorption, Membrane processes, Advanced oxidation processes, Air-stripping, Disinfection, and other advanced treatment processes, purposes, benefits, and limitations of major physicochemical and biochemical processes in water and wastewater treatment.

ES113A – GREEN CHEMISTRY (3 Credits)

Introduction and Principles of Green Chemistry: Definition and importance of Green Chemistry, Goals of Green Chemistry and challenges in achieving them, Sustainable resource consumption, Principles of Green Chemistry, with explanations and examples; **Designing Eco-Friendly Alternative Chemical Synthesis:** Green approaches to synthesis design, Waste and byproduct prevention, Maximizing material incorporation in final products, Green synthesis of nanoparticles; **Green Chemical Strategies for Sustainable Development:** Green Chemistry metrics, Atom Economy, E-factor, and Reaction Mass Efficiency (RME); Material footprint analysis, Recycling and reclaiming materials: Criteria and analysis of atom economy and E-factor, Green solvents and reaction media: Ionic liquids, supercritical CO_2, water, fluorous-phase chemistry, solvent-free, and solid-phase chemistry, Catalysis and biocatalysis, Cleaner production techniques; **Eco-Friendly Waste Treatment Approaches:** Heterogeneous and homogeneous photocatalysis, Photo-oxidation and direct photodegradation, Gas-phase detoxification, Green polymers and bioplastics, Biomass and bio-based materials, Composting biodegradable waste, Equipment and applications; **Alternative Energy Sources:** Microwave ovens as reactors- Theory of microwave heating. Ultrasound reactors for chemical synthesis-Theory of ultrasound. Photochemistry and electrochemistry.

ES114A – AGROECOLOGY AND SUSTAINABLE AGRICULTURE (3 Credits)

Introduction to Agroecology and Sustainable Agriculture: Global and local challenges for agroecosystem sustainability, conventional and sustainable agriculture, Agroecology concept, evolution, element and principles, Agroecology for Global Challenges; **Agroecosystems and Food Systems:** Agro-climatic and agroecological zones, Overview of agroecosystems, Food security and food system, World agricultural heritage systems; **Agroecology and Agroecosystem Management:** Agroecology for soil, water light, temperature, Humidity and Rainfall, Wind, Fire management, Autoecological agroecology in agroecosystems; Agrobiodiversity, Integrated pest management, Carbon sequestration and climate resilient agricultural practices, Successful agroecological systems worldwide; **Transitioning Agroecosystems to Sustainability:** Agroecosystem transition to sustainability; Principles and practices for designing sustainable farming systems, Participatory action research in farming communities, Integration of local knowledge into farming systems design. Tools for assessing agroecological performance of agroecosystems; Indicators of Sustainability; **Agroecology Economic and Social Dimensions:** Economic viability of sustainable agriculture; Market Innovations in Agroecology, Social justice and equity in farming communities; Food Sovereignty, Policy frameworks supporting sustainable agriculture; **Policy and Global Frameworks for Agroecology:**

National and international policies supporting agroecology, Agroecology's role in achieving SDGs (Sustainable Development Goals), Policy innovations to enhance agroecological practices.

ES115A – BIOREMEDIATION (3 Credits)

Biomass Valorization and Extremophilic Microorganisms: Biomass valorization: Concept, strategies, and industrial applications; Role of extremophilic microorganisms in waste treatment; Methane production from agro-industrial wastes: Mechanisms and technologies; **Industrial Enzymes and Microbial Processes:** Characterization and production of industrial enzymes; Bio-composting: Microbial processes and vermicomposting; Production of biofertilizers and biopesticides: Biotechnological methods; **Biodegradation and Biomining:** Role of microbes in biodegradation processes; Petroleum pollutant biodegradation: Mechanisms and challenges; Biomining: Microbial role in metal recovery from ores; **Green Energy and Biofuels:** Green energy: Overview and significance; Mechanisms of biofuel production: Bioethanol, biobutanol, biodiesel, and biogas; Microbial contributions to bioenergy systems; **Bioremediation and Phytoremediation:** Bioremediation: Concepts, mechanisms, and case studies, Applications of bioremediation in controlling environmental pollution; Phytoremediation: Types (phytoextraction, phytodegradation, etc.) and mechanisms; Case studies on successful phytoremediation projects; **Wastewater Treatment Strategies:** Domestic wastewater treatment: Microbial applications; Industrial wastewater treatment: Biotechnological approaches and challenges; Microbiological methods for effective waste treatment.

ES116A – ENVIRONMENTAL IMPACTS OF BIOCHEMICAL PROCESSES (3 Credits)

Overview of Biochemical Processes: Introduction to different biochemical processes and its' impacts on environmental health; Origin and scope of biochemistry in the field of environmental influences; **Common Bioenergetics:** Free energy change; Biological oxidation-reduction reactions; Phosphoryl group transfer and ATP; Enzyme kinetics as an approach to understand environmental impacts on biological system; Effects of electron transport system in plants/animal metabolism and biological control system of energetic application; Oxidative phosphorylation; **Harvesting Light Energy**: Photosynthesis and Photorespiration; Photochemical events in light driven electron flows; Different pathways and its environmental regulation; Impact of abiotic factors due to environmental changes in Calvin Cycle; Integration of carbohydrate metabolism in plant cell; Applicable features of secondary plant metabolism; **Overview of Nitrogen Metabolism**: Biochemistry of nitrogen fixation: Nitrate assimilation, incorporation and regulation with relevance to environmental factors. Biosynthesis of amino acids under allosteric control; Hormonal regulation in fuel metabolism, Effects of environmental factors; **Metabolic Regulations**: Toxins of plant origin and induction of stress metabolites in plants. Systemic biochemical responses towards environmental toxicants in different organs. Environmental impact on the immune system. Biochemical effects of drugs, food additives and contaminants. Biochemical effects of air, water, soil pollutants. Application of biochemistry on analytical, clinical and regulatory biology.

ES117A – LANDSCAPE DYNAMICS (3 credits)

Concepts of Ecosystem and Landscape - Global Change, Ecosystem and Landscape as Dynamic Systems, Structure and Function, Resistance and Resilience, Equilibrium, Feedback System, Planetary Boundaries, Ecosystem Approach and Landscape Approach; **Landscape Ecology** - Related theories, Scope, Concepts of scale & Hierarchy, resolutions, extent and mapping units; Major landscapes/ecosystems of the World, Landscape elements - patch; Pattern and processes, Gradient concept of landscapes; **Quantifying landscape patterns** - Concept of landscape metrics and interpretation, Calculation of metrics and issues of multiple metrics, Introduction to landscape models, Spatial-statistics - semi-variograms and auto-correlograms; **Agents of patterns** - Physical and biotic processes, disturbances; Temporal patterns in landscape dynamics - fragmentation, edge effects, connectivity, invasion, Applying landscape metrics; **Landscape Dynamics** – Predictive modelling (Cellular Automata, Markov, Agent based modelling). Landscape Analysis - GARP/MaxEnt/Random Forest (RF), Support Vector Machine (SVM). National and Global Programs.

ES118A – ENVIRONMENTAL MOLECULAR BIOLOGY (3 credits)

Molecular Biology for Environmental Challenges: Application of molecular biology to address the environmental problems. Molecular responses to pollutants, toxins, and climate change stressors. Genotyping, and phylogenetic analyses, and explore their significance and application in ecological and evolutionary research; **Genomics and Bioinformatics in Environmental Science**: Next-generation sequencing, metagenomics, and computational approaches to analyze environmental DNA (eDNA). High-throughput sequencing (HTS) for biodiversity monitoring, Molecular Cloning and development of genetically engineered crops for sustainable farming. CRISPR, synthetic biology, and genetic engineering

applications in conservation and environmental management; **Molecular Approaches for Biodiversity and Evolution**: DNA barcoding, species identification, and population genetics; genetic diversity and population genetics, molecular systematics molecular ecology, and molecular evolution. Microsatellites and single nucleotide polymorphisms (SNPs), Whole-genome sequencing for population studies.

ES119A – MICROBIAL ECOLOGY (3 Credits)

Microbial Diversity and Natural Habitats: Microbial metabolism; Microbial metabolic and ecological diversity; Methods in microbial ecology; Natural microbial habitats - air, terrestrial, and aquatic environments; Natural microbial communities - microbial mats and biofilms including microbial communication - quorum sensing; **Microbial biogeochemistry and Geomicrobiology:** Microbial processes of nutrient cycling; Introduction to geomicrobiology; Microbial ecology of the built environment – biomining, acid mine drainage bio-weathering, biodeterioration, biocorrosion; **Microbial Interactions:** Microbial mutualisms: microbe-microbe, plant-microbe, animal-microbe, and the healthy human microbiome; Microbial disease ecology; transmission of major microbial infectious diseases in the environment – air-borne, person-to-person contact-borne, vector-borne, soil-borne, water-borne and food-borne diseases; Microbial bioterrorism.

ES120A – POLLUTION BIOLOGY (3 Credits)

Introduction to the Concept: Pollutants vs. resources; cycling of materials, tolerance ranges, carrying capacity, bioaccumulation, biomagnification; Overview on genetic pollution; **Air Pollution and Health Impacts:** Physical, chemical, and biological pollution; Trace metals in inhaled air samples: Impact on plants and human health; Airborne pathogens: human diseases and impacts on plants. Mechanisms and metabolic pathways: Oxidative stress, cytokine pathways, lipid metabolism; **Water Pollution and Health Impacts:** Classification of water pollutants; Biological assessment of water quality; Microbial indicators and biomonitoring; Responses of plants and animals to water pollution: associated mechanisms and metabolic pathways; Eutrophication – causes and control; Acidification, persistent organic pollutants, heavy metals, and oil – sources, and impact on aquatic life; **Soil Pollution and Associated Risks:** Responses of plants to soil pollution; Changes in soil characteristics by waste disposal; Impacts of pesticide on soil and effects on plants and animals; Harmful impacts of heavy metal contamination in the soil; Mycorrhiza and heavy metal tolerance; Radioactive pollutants: source, biological effects on organisms; Role of enzymes in maintaining soil health; **Noise Pollution and Health Impacts**: Sources, weighting networks. Measurement of noise indices, Noise dose and noise pollution standards. Noise control and abatement measures: active and passive methods. Vibrations measurements. Impact of noise and vibrations on human health.

ES121A – RADIATION BIOLOGY (3 Credits)

Radiation Concepts and Detection: Overview of radiation: Types, sources, and properties. Radiation detection and dosimetry. Specific Absorption Rate (SAR) measurements and their importance in assessing exposure levels; **Health Effects of Radiation Exposure:** Acute and Chronic Radiation Syndrome, Dose-response relationships and their relevance in risk assessment. Biological effects: Chromosomal aberrations, oxidative stress, and DNA damage and repair. Effects on specific organs: Impacts on the central nervous system and the reproductive system; **Radiation Impact on Ecosystems and Long-term Risks**: Loss of biodiversity due to radiation exposure. Mutation accumulation and implications for species survival. Radioactive waste disposal and its management challenges; **Radiation Safety and Exposure Guidelines:** Regulatory standards and safety norms for radiation exposure. Strategies for minimizing exposure in occupational, medical and general public settings;

ES191A – SCIENTIFIC WRITING AND ETHICS (2 Credits)

Introduction to Ethics - Moral and Ethical Questions. Ethics in writing - ownership of data, reproducibility and accountability. Scientific integrity, informed consent, and ethical committees. **Research -** meaning, objectives, and significance; **Types of research** - qualitative vs. quantitative, cross-sectional, longitudinal, pure, applied, evaluation, historical, survey, exploratory, and case study. Type of Research Articles; **Methods of Research -** Developing a topic, gathering sources, organizing and writing review of literature; **Writing style and structure -** Overall structure and value of outlines, screening material for inclusion in manuscripts. Active vs. passive voice, Punctuation, including commas, apostrophes, semicolons, and colons, avoiding duplication and repetition; **Research Writing Process** - significance, layout and components (introduction, methods, results, discussion and conclusion). **Types of research output -** research papers, reviews, perspective papers, short communication papers theses, conference (poster and oral presentations), and project reports. Research stage, manuscript planning stage, manuscript preparation stage, importance of research paper title, authorship, abstract (textual, graphical and video), keywords and phrases, highlights, acknowledgements, competing interests, references, bibliography, tables, and illustrations, supplementary material. Publishing process; **Metrics and citations -** Impact factor, Cite Score, h-index, i10 index, i20 index and citation index; **Research ethics in practices** -

Referencing and documentation, copyright, plagiarism, royalty, intellectual property rights (IPR). Ethical AI usage in academic research.

ES192A – M.Sc. DISSERTATION (7 Credits)

Student pursuing MSc (Environmental Sciences) will be allotted a Supervisor for doing dissertation work; The student has to be in constant contact with the supervisor and attend the laboratory regularly to fulfil all dissertation and credit requirements. Each student should meet their supervisor regularly and inform the progress related to dissertation work; A synopsis/proposal will be prepared by the student in close consultation with the Supervisor. This will be submitted in beginning of the Semester - IV. At the end of the semester, the student will be submitting a dissertation and making a presentation of the work for viva-voce; All the submission made by the student, synopsis/proposal and final copy of dissertation, are to be in accordance with the latest UGC regulation in this regard. (At present UGC Regulations, 2018); Each student has to obtain the Similarity Report for their MSc synopsis/proposal and final copy of dissertation by approaching the same facility provided by JNU Library.

ES151A – ENVIRONMENTAL MODELING (3 Credits)

Basics of Data and Statistics: Role of Modeling in Environmental Sciences, Model Classification- Deterministic and Stochastic Models, Steady State and Dynamic Models, Steps involved in modeling, Mass balancing, energy balancing; **Deterministic Models – 1:** Exponential growth model, logistic model, model of competition between two species – method of isoclines, Lotka-Volterra Prey-Predator Model, Leslie Matrix model; **Deterministic Models – 2:** Streeter-Phelps Oxygen Sag Model, Gaussian Plume Dispersion Model, Epidemiological Models; **Stochastic Models -1:** Multiple Linear Regression Modeling – Principle of Ordinary Least Squares, homoscedasticity, multicollinearity, specification bias; curvilinear regression, binary logistic regression and logit analysis; **Stochastic Models -2:** Time Series Forecasting – Components of time series, Exponential Smoothing Models, Moving Average Models, Auto-regressive Models, Stationary time series, Autocorrelation Function and Partial Autocorrelation function, Autoregressive Integrated Moving Average Models; **Model Performance Evaluation:** Mean Absolute Percentage Error, Root Mean Square Error, Normalized Mean Square Error, Fractional Bias, Index of Agreement.

ES152A – ATMOSPHERIC AEROSOLS (3 Credits)

Introduction: Introduction to Atmospheric Aerosols, Number, mass and size distribution of aerosols, Discrete and Continuous Particle Size Distribution, Chemistry of atmospheric aerosols, Nucleation; condensation and agglomeration of aerosols; **Sources:** Sources of aerosols, Aerosols from Internal Combustion Engines, Density of Aerosols, particle deposition by gravitation; deposition and impaction, Phoretic effect, monolayer and multilayer re-suspension; **Aerosols and Environment**: Urban Aerosols, Aerosols from Combustion processes, Aerosols in work place and indoor atmosphere, Photochemistry and secondary aerosols Surface activity of Aerosols, Soot, Radioactive Aerosols (natural and anthropogenic) and Radionuclides; **Properties**: Global Aerosol Distributions, Extinction of Radiation by Aerosols, Aerosols and Clouds, Rayleigh and Mie Scattering, Sampling of aerosols, Electric properties of aerosols, Radiative (climate) Forcing due to various aerosols, Coagulation (monodispersion, polydispersion and kinematic) of aerosols; **Monitoring**: Active; passive and Ground based remote sensing of aerosols, Lambert-Bear-Bougoer's law, Aerosol Optical Depth, Lidar, Effect of aerosol on Climate Change; **Health Impacts and control**: Respiratory effect of inhaled aerosols, Toxicology of Aerosols, Mechanism of Lung injury, Epidemiology of Aerosol Exposure, Pharmaceutical Aerosols and Drug Delivery, Bioaerosols, Nanoaerosols, Filtration of aerosols, Electrostatic Precipitator.

ES153A – CLIMATE CHANGE MODELLING (3 Credits)

Physical processes: Conservation of momentum, conservation of mass, equation of state for ideal gases, conservation of energy and conservation of water mass; **Global climate systems:** Basics of radiative forcing, atmospheric and ocean circulations, land surface processes, teleconnections; **Climate sensitivity and feedbacks:** Global warming, quazi resonant amplification, atmospheric blocking, sudden stratospheric warming, climate feedbacks: Radiative, ocean heat, vegetation and ice/snow; **Large scale circulations in climate models:** Equation of motion, different types of grids in climate models, spectral models, stream function, zonal meridional circulation, atmosphere – ocean interactions -thermal and hydrometeorological boundary conditions; **Climate models:** General circulation models, sequence of operation of GCMs, solving dynamics, calculating the physics, initial and boundary value problems; **Developments in climate models:** Energy balance models, intermediate complexity models, coupled models – earth system models.

ES154A – CLOUD AND PRECIPITATION PHYSICS (3 Credits)

Basics of Cloud Physics: Overview of clouds and its classification, Mixing and convection, Vapor Pressure, Saturation and supersaturation, Lifting condensation level, Level of free convection, Equilibrium level, CAPE, CIN, Lifting of air parcels;

Properties of Clouds: Sizes of cloud and cloud system, cloud droplet spectra, Likelihood of ice and precipitation in clouds, Microstructure of cumulus, stratus and large continental storm clouds; **Formation of Cloud Droplets and Growth of Droplets in Warm Phase Clouds:** Nucleation processes: Homogeneous and heterogeneous nucleation, Role of aerosols as cloud condensation nuclei and ice nuclei; Growth of cloud droplets: Condensation and diffusional growth; Curvature and solute effect; Koehler Curve, Role of supersaturation and vapor pressure. Collision and coalescence processes: Growth of raindrops in warm clouds, Stochastic processes and collection efficiency; **Growth of Droplets in Cold and Mixed Phase Clouds:** Ice microphysics: Formation of ice crystals and their growth mechanisms, Aggregation, riming, and secondary ice processes, Ice-phase precipitation mechanisms (snow, sleet, hail). Mixed-phase clouds: Bergeron-Findeisen process and its role in precipitation enhancement; **Precipitation Processes:** Rain and snow: Drop-size distribution, Drop break-up, distribution of snowflakes with size, aggregation and breakup of snowflakes; Stratiform precipitation, Shower, Precipitation theories, Mesoscalestructure of Rain, Precipitation rate and efficiency; **Cloud-Climate Interactions:** Role of clouds in the Earth's radiation budget: Shortwave and longwave radiation effects, Cloud radiative forcing and feedbacks; Aerosol-cloud-precipitation interactions: Indirect aerosol effects (Twomey and Albrecht Effects), Impact on precipitation patterns. Cloud responses to climate change: Trends in cloud cover and types, Implications for global and regional hydrology.

ES155A – CLIMATOLOGY (3 Credits)

Introduction to Climatology: Overview of climatology and its scope, Scales of motions, Climate controls, Concept of weather and climate, Climate variables and their distribution, Global climatic features, Latitudinal and seasonal variations of Insolation, Role of Earth's energy budget in climate, Temperature variation due to earth-atmosphere and sun interaction; **Climate Dynamics:** General circulation models, Large-scale dynamics of the ocean and atmosphere, Rossby wave and Intra-Gravity waves, Air masses and fronts: sources, origin and classification of air masses; and fronts, frontogenesis and frontolysis, weather systems associated with fronts, Jet streams, Centers of action: Siberian high, North Atlantic subtropical anticyclone, Arctic High; **Mesoscale and synoptic climatology:** Differential heating of land and water, Land and sea breeze, mountain/valley wind, Mesoscale mechanisms: Froud number, mesoscale convection complexes (MCCs) and systems (MCSs): Squall lines, Tropical cyclone, Climatology of cyclones and anticyclone; **Asian Monsoon:** Overview of the Asian monsoon, Factors controlling the Asian monsoon, The Asian monsoon: Global perspectives, Interannual variability and Intra-Seasonal Oscillation (ISO): Quasi-Biennial Oscillation (QBO), Indian Ocean dipole (IOD), Madden-Julian oscillation (MJO), Global impacts of the MJO, Quasi-Biweekly Oscillation (QBWO), Interaction between Asian monsoon and ENSO, climate change and Asian monsoon; W**ater balance and climate classifications:** Hydrological cycle and water budget: equations and estimation methods, Clouds and climate, Global precipitation distribution, Climate change impact on the hydrological cycle, Climate classification: Koppen's & Thornthwaite's schemes;
Climate Change and Global Scenarios: Overview of climate change: Milankovitch theory of climate change, Causes, impacts, and evidence, Anthropogenic climate change: greenhouse gas emissions and industrialization, CCPI: Methodology and significance, IPCC: role in climate studies,Climate change mitigation and adaptation, Climate Forcings, From Global warming to Global boiling, Factors Driving Global Boiling, SSP-RCP Scenarios: Shared Socioeconomic Pathways (SSPs) and Representative Concentration Pathways (RCPs) for future climate projections.

ES156A – GEOPHYSICAL EXPLORATION (3 Credits)

Introduction to Geophysical Exploration: Overview of geophysical exploration and its importance. Different types of geophysical surveys: Seismic, Electrical, Magnetic, Gravity, and Electromagnetic methods. Basic concepts of wave propagation, signal types, and sources. Geophysical instrumentation overview; **Seismic Methods - Theory and Applications:** Seismic wave types (P-waves, S-waves, surface waves). Reflection and refraction seismic methods. Basic principles of seismic data acquisition (field equipment, sources, receivers). Seismic velocity, depth, and layer analysis. Applications in oil, gas, and mineral exploration; **Electrical Resistivity Methods:** Resistivity contrast and its significance in exploration. Electrical resistivity methods: Wenner, Schlumberger, Dipole-Dipole arrays. Apparatus used in resistivity measurements. Field procedures and data interpretation. Applications in groundwater and environmental exploration; **Magnetic and Gravity Methods:** Basics of gravity and magnetic field measurements. Gravimetric surveys and interpretation. Magnetic field anomalies and their interpretation. Applications in mineral exploration (e.g., iron ore, gold). Data processing and anomaly analysis; **Electromagnetic (EM) Methods:** Principle of electromagnetic induction. Ground Penetrating Radar (GPR), Time Domain Electromagnetic (TDEM), and Frequency Domain methods. Applications in shallow subsurface exploration and environmental monitoring. Data collection and interpretation; **Geophysical Data Processing and Interpretation:** Data processing techniques for seismic, magnetic, and electrical data. Signal processing and noise reduction. Inversion methods for creating subsurface models. Integrating multi-method data for exploration decision-making.

ES157A – POLLUTION GEOLOGY (3 Credit)

Introduction: overview of occurrence and concentrations of toxic elements; possible sources of toxic elements released by geogenic processes**;** mobility of chemical elements in the geological environment; societal issues of toxic elements and its

public health perception; role of minerals in health sector; **Geochemistry and process mechanism:** exposure to trace elements; classification of trace elements; potential pathways of trace elements to enter human body; essential trace elements; absorption and accumulation of trace elements in body; minerals as carriers of toxic elements, storage and excretion of toxic elements; effects of toxic elements on the human body, Isotope geochemistry and use of stable isotopes in tracing element pathways; applications of radiogenic isotopes in pollution geology; **Geological materials in the environment:** Arsenic, fluoride, selenium, chromium, Radon, U-Th – identification, sources, geochemical processes, geo-toxicity of elements and control methods; **Geogenic Diseases:** overview of geogenic diseases; airborne and waterborne geogenic diseases; Adverse effects from workplace exposures to metals such as silicosis, asbestosis, mercury poisoning, fluorosis, berylliosis, radon-induced lung cancer, coal worker's pneumoconiosis (CWP); interactions between geogenic and anthropogenic sources; government policies and initiatives in geo-environmental health issues.

ES158A – GEOCHEMISTRY (3 Credits)

Introduction: Overview of geochemistry, Atomic properties of elements, the periodic table and geochemical classification of elements; abundance of elements in the bulk earth, crust, hydrosphere, atmosphere and biosphere; introduction to mineral structures and compositions; Energy, Entropy and Fundamental Thermodynamic Concepts. Tool and techniques of geochemistry, Importance of geochemistry in geoscience. Meteorites and their geochemical significance; **Geochemical Data:** Introduction, Geological processes and their geochemical signatures- processes controlling the chemical composition of igneous rock, -sedimentary rocks, -and metamorphic rocks. Geological controls on geochemical data, Sampling: from field to laboratory preparation, Analytical methods in geochemistry. Selecting an appropriate analytical technique, Sources of error in geochemical analysis- Contamination, Calibration, Peak overlap, detecting error in geochemical data; **Analyses and Interpretation of Geochemical Data:** Introduction, major and trace elements and their partitioning during mineral formation; statistical analysis of geochemical data-average, correlation, regression, ratio correlation, trend interpretation in correlation diagrams, principle component analysis, discriminant analysis. Geochemical classification using major, trace and rare earth elements. Variation diagrams, Geological controls on the distribution of trace elements. Geochemical data interpretation and quality control and their application to geothermometry, paleoclimates and environmental studies; **Isotope Geochemistry:** Introduction, radiogenic isotopes in geochemistry, geochemical cycling- concepts with an example; radioactivity, decay of parent and growth of daughter nuclides and methods of radiometric dating; stable isotopes, their fractionation and application in paleoclimates, crustal evolution, metallogeny and environmental studies. Application of isotope geochemistry in tracing geological processes.

ES159A – GLACIOLOGY (3 Credits)

Introduction: Overview of Glaciers and Ice Sheets- Definitions, types, and distribution of glaciers, Formation and dynamics of ice, Global importance of glaciers in Earth's climate system. **Basic Concepts in Glaciology**- Glacier mass balance and energy exchange, Processes of accumulation and ablation, Glacier-climate interactions. **Glaciers in the Geological Context**- Glaciers through Earth's history. Overview of glaciological studies in Himalaya. Permafrost regions; **Glacier Dynamics and Processes: Glacial Movement**- Mechanisms of glacier flow: basal sliding, internal deformation, Ice deformation processes and stress-strain behaviour, **Glacier structures**, **Movement of glaciers and landscape evolution**- Erosion, Transportation, and Deposition by Glaciers, Glacial geomorphology: formation of valleys, moraines, drumlins, and eskers, Glacial sediment transport and till deposition. **Hydrology of Glaciers**- Subglacial drainage systems, Meltwater processes and their role in glacier dynamics, snow and ice chemistry, **Glacier-Atmosphere Interactions; Climate Change and Glaciers: Impact of Climate Change on Glaciers-** Global glacier retreat and regional differences with case studies, **Glaciers as Climate Indicators-** Ice cores and paleoclimate reconstruction, isotopic studies in glaciology, **Glaciers and Sea Level Rise-** Projections for future sea-level changes, Impacts on coastal communities and ecosystems; **Glacial Hazards-**Glacier lake outburst floods (GLOFs), Avalanches and their mitigation; **Glaciers and Water Resources-** Importance of glaciers for freshwater supply, Seasonal and long- term availability of meltwater, Artificial Augmentation of Snow/ Glacier Melt and behaviour of debris covered glacier; **Techniques in Glaciological Studies: Field and Remote Sensing Techniques-**Glacier mapping using satellite imagery, Use of LiDAR and radar in glaciological research, Ground-penetrating radar (GPR) and GPS for ice flow studies, Application of GIS in glaciological studies. **Modelling Glacier Systems-**Introduction to glacier modeling techniques, Predictive models for glacier dynamics under climate scenarios, **Global and Regional Glaciological Data Centers-**Databases and resources: World Glacier Monitoring Service (WGMS), GLIMS.

ES160A – HYDROCARBONS AND ENVIRONMENT (3 Credits)

Introduction: Petroleum & natural gas, coal, coalbed methane (CBM), shale gas and gas hydrates. Petroleum system (conventional and unconventional): source rock, cap rock and reservoir rocks. Petroleum traps and seals. Petroliferous basin of India. Environmental concerns particularly associated with hydrocarbon exploration and production; **Petroleum and natural Gas:** Petroleum and natural gas occurrences, origin (organic/inorganic theory of petroleum origin). Chemical compositions of petroleum. Maturation and transformation of organic matter into kerogen; Transformation of kerogen

into oil and gas. Generation, migration and accumulation of oil and gas; **Petroleum exploration and environment:** Environmental problems and considerations associated with petroleum exploration and production activities. The impact of drilling & production operations on soil/surface and environment. Contaminations of drilling, fracturing and completion fluids in the groundwater ecosystem. Spills in oil and natural gas fields and their effect on the environment. Hydrocarbons, global warming and climate change. Important Laws and Regulations relating to environment and safety in Exploration and Production sector; **Coal mining and environment:** Coal: coalification process, litho-types, rank, macerals and coal forming environment. Coal mining and natural resources- water, forest and land. Mine waste, acid mine drainage (AMD), coal fire; **Coal bed methane (CBM), shale gas and gas hydrates and associated environmental concerns:** Coal bed methane (CBM), shale gas and gas hydrates occurrences/origin and contributions as clean energy resources. Gas hydrate's structure, stability and possibility in context of India with possible environmental concerns. Hydro-fracturing, gas-water production and water disposal in CBM and shale gas production. Environmental problems - water quality, utilization and environmental benefits.

ES161A – WATER RESOURCES (3 Credits)

Introduction: Water resources; type of water resources; distribution of water resources; properties of natural water; importance of water resources; historical background of water resources; global water balance; availability of water resources in India; water resource crisis; water and economy; water regulation/policy in India; sustainable development goal 6; **Hydrologic Processes:** What is hydrology? hydrological cycle; hydrological systems; precipitation (Rainfall): various forms of precipitation and interpretation of precipitation data. Evaporation and Evapotranspiration: metrological factors, transpiration, methods of estimating evaporation from land surface. Infiltration and percolation; Infiltration capacity of the soil; factors affecting the infiltration capacity; method of determining the infiltration capacity; occurrence of surface water resources; type and distribution of surface water resources; runoff and catchment; hydrographs; **Water Resources Chemistry and Climate Change: Ion composition** of- seawater, rivers and lakes, groundwater; rainwater, salinity distribution in world surface water and their sources; natural water chemistry controlling factors; water pollution- runoff of nutrients; industrial, municipal and domestic waste, sewage discharge, mining; **Climate Change**- impact of climate change on water resources at the global and regional level; water-agri-forests and climate change links; climate finance for water; climate change and challenges for sustainable development; **Water resources management:** Background, importance and need; traditional Indian water resources management practices; Integrated Water Resources Management (IWRM); Integrated Catchment Management (ICM); role of remote sensing and GIS in water resources management; government policies/initiatives to water resources management in India; case studies of water resources management at global, regional and local scale.

ES162A – SOLID AND HAZARDOUS WASTE MANAGEMENT (3 Credits)

Basic concepts: Definition, sources, characteristics, classification of solid wastes, and impact on environmental health. Waste generation rates, Concepts of waste reduction, recycling and reuse. Collection, segregation and transport of solid wastes; **Handling and Processing:** Segregation, collection and storage of municipal solid wastes, solid waste processing technologies such as mechanical and thermal volume reduction, biological and chemical techniques for energy and other resource recovery; **Disposal Techniques:** Composting, Vermicomposting, Incineration of solid wastes, landfills: site selection, design, and operation of sanitary landfills; secure landfills and landfill bioreactors; leachate and landfill gas management; landfill closure and post-closure environmental monitoring; landfill remediation; **Hazardous wastes:** Definition, sources and characteristics: Hazardous waste categorization, generation, collection, transport, treatment and disposal methdos. Legislation on management and handling of municipal solid wastes and hazardous wastes. E-waste, Fly ash and Plastic waste, biomedical waste, construction waste, battery waste: sources, consequences and management

ES163A – CLIMATE CHANGE: ALTERATIONS, ADAPTATION AND MITIGATION (3 Credits)

Biochemical Alterations: Plants' responses - photosynthesis rates, changes in secondary metabolites, nutrient uptake and soil chemistry, hormonal responses and stress resistance. Animals' responses - changes in metabolism and energy use**,** Oxidative stress and response, reproductive chemistry, digestive biochemistry; **Eco-Shifts and Chemical Changes:** Chemical changes in oceans, marine biochemistry, disruption in biogeochemical cycles, plant-soil and marine-terrestrial interaction, pollutant transformation and bioaccumulation, soil microbial biochemical shifts, chemical basis of Biodiversity loss; **Shifts and Adaptations**: heat-Resistant photosynthetic pathways, Drought-resilient roots, Phenological shifts, Epigenetic changes, Behavioural thermoregulation among animals, Phenotypic plasticity, Migration timing and routes, Adaptation in thermal tolerance, Assisted migration and species translocation, Ecosystem resilience mechanisms, Symbiotic relationship shifts, Community composition shifts; **Advancements in Mitigation Measures:** Polymers and Biodegradable Materials, Technology and Economics of alternate energy sources, Natural Products and Phytochemistry, Nanomaterials and Nanotechnology, Organometallics, Synthetic Biology.

ES164A – SOIL POLLUTION CHEMISTRY (3 Credits)

Fundamentals of soil pollution: Definition and importance of soil pollutants, Physical and Biological Properties of Soil (texture, structure, inorganic and organic components), analysis of soil quality; **Chemistry of Soil:** Surface Exchange Reactions, Mechanisms of cation and anion exchange processes and their impact on soil fertility, Adsorption, and desorption processes, Soil Acidity its sources, Electrochemistry of Soil and its implications for nutrient cycling and pollutant behavior, Chemistry of Waterlogged Soil; **Causes of Soil Pollution:** Industrial effluents and their interactions with soil components, Major types of soil pollutants: Heavy Metal toxicity and bioavailability, Other inorganic pollutants, radionuclides, Soil Salinity and Alkalinity and their impact on soil structure and plant growth, Effects of Chemical Residues (Pesticides, Fertilizers) on Soil, Soil Pollution from Specific Chemicals: Nitrogen, phosphorus, sulfur, and micronutrients, Land Degradation and Soil Erosion; **Soil pollution and climate change:** Greenhouse Gas Production and Emission from soil (methane, nitrous oxide, and carbon dioxide), Impact on soil health, National and international acts to control soil pollution; **Soil Pollution Control:** Mitigation strategies for polluted soils, Soil micro-organisms, and their functions - degradation of pesticides and synthetic fertilizers, Mitigation of Greenhouse Gas Emissions, Agricultural practices and soil management strategies to control soil pollution, Carbon Sequestration, Mechanisms of carbon storage in soil.

ES165A – CIRCULAR ECONOMY FOR SUSTAINABLE ENVIRONMENT (3 Credits)

Circular Economy Basics: Linear and circular economy, Evolution and scope of the circular economy; Concepts and definitions; Closed loop ecosystems; System thinking; Benefits to the environment, economy and society; Sustainable procurement; Eco-design; Industrial and territorial ecology; Economics of functionality; **Principles of Circular Economy and Life Cycle Assessment:** Identification of environmental hotspots; Quantification of resource use efficiency; Assessment of End-of-Life scenario; Methodologies of life cycle assessment; Role of life cycle assessment in circular economy; Life cycle assessment and circular economy in achieving SDG; **Steps for the Transition Towards a Circular Economy:** Large-scale transition to non-polluting sources of energy; Durable products requiring less materials and energy; Incentivisation of recycling, reuse, and repair; Replacement of hazardous material and safer alternatives**; Circular Economy Implementation:** Micro level: Firm-level engineering and managerial level; Meso-level: industrial ecology, industrial symbiosis, eco-cluster, eco-industrial parks; Macro-level: general policies, plan, green and sustainable entrepreneurship; **Challenges in Implementing Circular Economy:** Achievability and desirability; Disrupting consumer's convenient; Local regulation versus the circular economy concept; Lack of infrastructure for waste treatment; Lack of recycling technology; Poor business model plan; **Case Studies from India and Other Parts of the World on Different Sectors:** Agriculture; Manufacturing; Energy; Construction; Textile.

ES166A – ECOSYSTEM SERVICES AND VALUATION (3 Credits)

Ecosystem Services and Human Well-Being: Ecosystem and Ecosystem Services (ES), Natural capital, ecosystem services types, international conventions and charters to ES; Linkages among biodiversity, ecosystem services, and human well-being; **Governance of Biodiversity and Ecosystem Services:** Governance and policies in ecosystem services; Payment for Ecosystem Services (PES); Benefit-sharing mechanisms; Community participation; Eco-certification, Geographical indication, and landscape labeling; National and international initiatives in PES; **Ecosystem Service Assessment and Monitoring:** Ecological economics, ecology and sustainability; Carrying capacity, ecological footprint; Quantification of ecosystem services: Direct and indirect approaches; Tools and techniques for assessing ecosystem services; Uncertainties in ecosystem service valuation, and challenges in applying valuation methods; Ethical considerations: equity, inclusivity, and cultural values; Trends in ecosystem service science and policy.

ES167A – ENVIRONMENTAL AND OCCUPATIONAL HEALTH (3 Credits)

Concept and Health Assessment: Basic principle of environmental health; Risk exposure and assessment; Global burden of diseases: Concept and occurrence; Disability-adjusted life year and it's assessment; Hazard evaluation; **Occupational Disease and Epidemiology**: Work and disease, Occupational lung diseases; Work-related musculoskeletal disorders; Agriculture and allied Sector, Health sector, Mining sector; Important global health programs and recent advancements in occupational health. Occupational stress and Stress physiology, Occupational epidemiology; **Overview of Industrial Hygiene:** Industrial hygiene; Industrial Toxicology: Dose effect relationships. Evaluation of toxicity and threshold limits; Occupational cancer, Basic hazards in work environment and prevention; **Occupational Health and Safety Management:** Health maintenance, Occupational health and safety measures, Recommendations of health and safety problems in the working environment; Standardization of occupational safety and health management system.

ES168A – ENVIRONMENTAL NANOTECHNOLOGY (3 Credits)

Introduction: Basics of nanomaterials; Sources and types of nanoparticles; synthesis and characterization of nanomaterials, green synthesis; Surface chemistry and unique colloidal aspects of nanomaterials; **Environmental Application**: Sensors for air and water quality monitoring; Nano-adsorbents for removing heavy metals and organic contaminants. Membrane-based technologies; Photocatalytic degradation of pollutants. Role of nanoparticles in bioremediation and soil health improvement; **Sustainable Energy Production:** Nanoparticles in solar cells, batteries, and supercapacitors**,** nano-based Microbial fuel cell technology; nanoparticle-based biofuel production, Hydrogen Production and Storage, Thermoelectric nanomaterials for waste heat recovery; **Environmental Impacts and Risk Assessment**: Toxicity and health risks of nanomaterials; Fate and transport of nanomaterials in the environment; Life cycle assessment of nanotechnology-based solutions.

ES169A – FOREST ECOLOGY (3 Credits)

Forest structure and regeneration: Structure of forest ecosystem, major forest types of the world, forest types of India, Himalayan forests, woody plant regeneration- sexual reproduction (reproductive cycle, periodicity of seed crops, dispersal, germination, and establishment), vegetative regeneration; **Primary Productivity, Litter Production, and Decomposition:** Carbon balance of trees and forest ecosystems, net primary productivity (NPP) and factors affecting it, herbivory effects on forest net primary productivity, dynamics of forest litter production and decomposition; **Nutrient Cycling, Plant Water Relations and Forest Hydrology:** nutrient cycling-nutrient additions to forest ecosystems, intra-system nutrient cycling, nutrient losses and nutrient conservation strategies, plant water relations, Forest hydrology, and forest fire; **Forest Ecosystem Management and Conservation:** Forest management systems, community participation in forest management, forest laws, role of forest management in maintaining biodiversity and ecosystem services.

ES170A – GEOSPATIAL MODELLING (3 Credits)

Geographic Information System: Definition and scope of Geographical Information System (GIS), basic concept of GIS: Geographical space, spatial data and information. Concept of earth coordinate, spheroid, datum and projection system, topographical map. Overview of Geospatial Modelling Systems, Systems-based Modelling, Geospatial Modelling and Interpretation, Legacy GIS Datasets and Emerging GIS Data Sources; **Raster-Based Modelling**: Map Algebra, Operations, Raster Data and Matrix Applications: Addition, Subtraction, Multiplication. Surface Modelling - Slope, Aspect, View Shed, Hydrological Modelling; **Vector-Based Modelling**: Regression Analysis (Linear and Logistic). Spatial Interpolation, Inverse Distance Weight (IDW), Kriging, Thin-Plate Spline, Pattern Analysis, Moran's I. Point Analysis-Density Estimation: Thiessen Polygon, Buffer Analysis. Clustering- K-Mean; **Specialized Modelling Techniques**: Data Transformations Using PCA: Eigenvectors and Eigenvalues. Cellular Automata (CA) and Agent-Based Modelling (AGB). Decision-Making Models - Single vs. Multiple Criteria, MCDM/AHP. Geoprocessing and Model Evaluation - Model Verification and Validation; **Applications and Case Studies**: Environmental Planning, Urban Development, and Resource Management.

ES171A – MICROBES AND CLIMATE CHANGE (3 Credits)

Climate Change Microbiology: Central role and global importance of microorganisms in climate change biology; Impact of climate change and responses of microorganisms in natural (marine and terrestrial), and anthropogenic (agriculture) ecosystems; Introduction to Disaster Microbiology; **Microbial Solutions to Climate Change:** Microbial mitigation of climate change – concepts and case studies; Microbes into earth system models to understand climate change; Policy recommendations towards harnessing microbes for climate change; Microbes, climate change and the bioeconomy; **Climate Epidemiology:** Pathogen ecology in climate change**;** Emerging infectious diseases (EIDs), their transmission, risk exposure and assessment; Global burden of infectious diseases - quality-adjusted life year; Demographic transition, and epidemiological transition; **Antimicrobial Resistance and One Health perspective:** Antimicrobial resistance (AMR) - Definition and causes; AMR and the environment; Intersections between climate change and AMR; Concept and examples of One Health approach; One Health approach for prevention of AMR.

ES172A – SUSTAINABILITY SCIENCE (3 Credits)

Introduction to Sustainability: Historical context and evolution of sustainability concepts, Interconnectedness of environment and sustainability, human impacts on environment and sustainability challenges, Sustainability Ethics; **Sustainability and Development:** Pillars of sustainable development and interaction, Strong and weak sustainability, Integrative concept of sustainability, Sustainable Development Goals (SDGs), and their environmental dimensions, Sustainability Development -Laws and policy; **Metrics of Sustainability:** Environmental, Social, Economic and Governance metrics, Ecological Footprint, Planetary Boundaries Framework, Earth Overshoot Day, Environmental Performance Index (EPI), Living Plant Index (LPI), Ecosystem Intactness Index, Red List Index, Corporate Social Responsibility (CSR),

Transformational Sustainability Research Methodology; **Sustainability Assessment Approaches:** Systems Approach, Sustainability Indicators, Evolution of Systems approach, Ecosystem-based Approach (EbA), Environmental, Social, and Governance (ESG) reporting, Stakeholder mapping and engagement strategies. Sustainability Communications; **Nature-based solutions (NbS), Innovations and Sustainability:** NbS concept evolution, principles, characteristics, categories and types. NbS and SDG, innovation, Strengths and Weaknesses, Sustainability, and carbon market, Sustainability assessment of NbS technologies.

ES173A – XENOBIOTICS AND HUMAN HEALTH (3 Credits)

Principles of Xenobiotics: Origin and scope of xenobiotics: responses, effects, and analysis. Introduction to different types of xenobiotics; **Xenobiotic Agents**: Toxins of plant and animal origin and its effects; Toxic effects of metals, solvents and vapors; Toxicokinetic of xenobiotic agents; Genetic cascade of variations: Carcinogens, Teratogens, Mutagens; **Systemic Xenobiotics:** Process of interaction of pollutants with biological systems and its responses; Degradation of pollutants inside the cellular system; Epidemiology of environmental pollutants; **Regulatory Processes of Xenobiotics**: Bioconversion of pollutants: active vs. inactive process; Enzymatic degradation of xenobiotics by monooxygenases; Role of cytochrome P_{450}; Assessment of toxicants and carcinogens; Estimation and analysis of carcinogens; **Toxicogenomics**: Population genetics and xenobiotic interrelationship. Pharmacogenomics: Correlating gene expression with drug efficacy and toxicity.

ES174A – BIOREFINERIES (3 Credits)

Introduction to Biorefineries: Definition and Classification of Biorefineries: Overview of biorefinery concepts, Types of biorefineries: lignocellulosic, algal, and waste-based biorefineries; Comparison Between Biorefineries and Traditional Oil Refineries; Process Integration and Product Diversification: Role of process integration in maximizing resource efficiency, Diversification of products (biofuels, biochemicals, biomaterials; **Biomass Feedstocks and Conversion Technologies:** Lignocellulosic biomass; Pretreatment methods, Enzymatic hydrolysis and fermentation processes, Value-added products: bioethanol, bioplastics, and biochemicals; Algal Biorefineries; Waste-to-Energy: Conversion of agricultural and industrial waste to bioenergy, Technologies for biogas, biohydrogen, and biochar production, Challenges and opportunities in waste valorization, Advances in Biomass Conversion Technologies: Emerging catalytic and thermochemical conversion methods, Integration of renewable energy systems in biorefineries; **Biorefineries and the Circular Economy:** Principles of the Circular Economy and Resource Efficiency: Circular economy concepts and their relevance to biorefineries; Resource efficiency through waste valorization and recycling; Integration of Biorefineries in Circular Economic Models; Life Cycle Assessment (LCA) of Biorefinery Systems: Principles and tools for LCA, Environmental impact assessment of biorefineries; Case Studies on Biorefineries; **Sustainability and Future Trends in Biorefineries:** Sustainability Assessment for Biorefineries: Indicators of environmental, economic; Economic Feasibility and Techno-Economic Assessment: Cost analysis of biorefinery operations, Strategies to enhance economic viability; Social and Regulatory Considerations: Policy frameworks for promoting biorefineries; Technological and Economic Barriers: Challenges in scaling up biorefinery technologies; Future Trends and Innovations: Emerging bioproducts and market opportunities, Role of digitalization and automation in biorefineries, Integration of biorefineries in global circular economy models.