CURRICULUM FOR 4-YEAR B.Tech. (ENVIRONMENTAL ENGINEERING) PROGRAMME FOR THE ACADEMIC YEAR 2024-25

Environmental Science and Engineering Department

Indian Institute of Technology Bombay

CREDIT STRUCTURE SUMMARY TABLE

Category	Sum of credits
Basic Sciences and Mathematics	30
BTP/Equivalent Elective courses	18
Category	0
Department Core	60
Department Electives	18
Department Lab and SLP/PT/Works Visit	18
Engineering Sciences and skills	20
Flexible Elective	30
HASMED Core	20
HASMED Elective	12
HS 200 and ES 200 [a]	Not required for ESED students
Non - Credited compulsory Courses	-
STEM Elective	18
Grand Total	**244**

[a] In place of ES/HS 200 as per the suggestions of UGPC and Implementation Committee interdisciplinary STEM elective is added.

Semester 1			
Course code	**Course name**	**Category**	**Credits**
DIC 1 (ES 101)	Introduction to Environmental Science & Engineering	Department Core	6
MA 109	Calculus I	Basic Sciences and Mathematics	4
MA 111	Calculus II	Basic Sciences and Mathematics	4
CH 105	Organic & Inorganic Chemistry	Basic Sciences and Mathematics	4
CH 107	Physical Chemistry	Basic Sciences and Mathematics	4
MS 101	Makerspace	Engineering Sciences and skills	8
CH 117	Chemistry lab	Basic Sciences and Mathematics	3
NOCS 01	NCC/NSS/NSO	Non - Credited compulsory Courses	-
GC 101	Gender sensitization course	Non - Credited compulsory Courses	-
TA 101	TA Course	Non - Credited compulsory Courses	-
			33

Semester 2			
Course code	**Course name**	**Category**	**Credits**
DIC 2 (ES 204)*	Environmental Chemistry	Department Core	6
MA 106	Linear Algebra	Basic Sciences and Mathematics	4
MA 108	Differential Equations	Basic Sciences and Mathematics	4
PH 117	Physics lab	Basic Sciences and Mathematics	3
CS 101	Computer programming	Engineering Sciences and skills	6
HSS/IDC/ENT	Introduction to HASMED	HASMED Core	8
NOCS 01	NCC/NSS/NSO	Non - Credited compulsory Courses	-
Note: * Course code needs to be changed by the Academic Section according to the year/semester			**31**

Semester 3			
Course code	**Course name**	**Category**	**Credits**
ES 2xx	AI and Data Science	Engineering Sciences and skills	6
EC 101	Economics	HASMED Core	6
ES 201	Applied Environmental Microbiology and Ecology	Department Core	6
ES 317*	Fundamentals of Air Pollution Science and Engineering	Department Core	6
ES 253 and ES 351*	Environmental Microbiology Laboratory (half semester) + Air Pollution Monitoring Laboratory (half semester)	Department Lab and SLP/PT/Works Visit	6
Note: * Course code needs to be changed by the Academic Section according to the year/semester			**30**

Semester 4			
Course code	**Course name**	**Category**	**Credits**
DE 250	Design Thinking	HASMED Core	6
ES 203*	Water and Wastewater Engineering	Department Core	6
ES 664*	Environmental Systems Modelling	Department Core	6
ES 208	Mass Transfer Processes in Environmental Systems	Department Core	6
ES 252 and ES 319*	Environmental Chemistry Lab (half-semester) + Computational Laboratory for Environmental Engineers (half-semester)	Department Lab and SLP/PT/Works Visit	6
Note: * Course code needs to be changed by the Academic Section according to the year/semester			**30**

Semester 5			
Course code	**Course name**	**Category**	**Credits**
ES 216*	GIS Aided Environmental Planning and Management	Department Core	6
ES 315	Solid Waste Management – Basic Principles and Technical Aspects	Department Core	6
ES 657*	Water Resources and Environmental Hydraulics	Department Core	6
	HASMED Elective-1	HASMED Elective	6
ES 308 and ES 451*	Solid and Hazardous Waste Laboratory (half-semester) + Environmental Field Studies (half-semester)	Department Lab and SLP/PT/Works Visit	6
Note: * Course code needs to be changed by the Academic Section according to the year/semester			**30**

Semester 6			
Course code	**Course name**	**Category**	**Credits**
-	Department Elective - 1	Department Electives	6
-	Department Elective - 2	Department Electives	6
-	Flexible Elective - 1	Flexible Elective	6
-	HASMED Elective-2	HASMED Elective	6
-	Interdisciplinary STEM Elective-1	STEM Elective	6
The Department Elective in Spring Semester is to be chosen from **Group-2**			**30**

Semester 7			
Course code	**Course name**	**Category**	**Credits**
-	Department Elective - 3	Department Electives	6
-	Flexible Elective - 2	Flexible Elective	6
-	BTP-1/Departmental Elective - 4	BTP/Equivalent Elective courses	6
-	Interdisciplinary STEM Elective-2	STEM Elective	6
-	Interdisciplinary STEM Elective-3	STEM Elective	6
The Department Elective in Autumn Semester is to be chosen from **Group-1**			**30**

Semester 8			
Course code	**Course name**	**Category**	**Credits**
-	Flexible Elective - 3	Flexible Elective	6
-	Flexible Elective - 4	Flexible Elective	6
-	BTP - 2 / Dept Electives - 5 and 6	BTP/Equivalent Elective courses	12
-	Flexible Elective - 5	Flexible Elective	6
The Department Elective in Spring Semester is to be chosen from **Group-2**			30

Electives list (Group-1: Autumn semester)
Environmental Health & Safety (ES 601)*
Atmospheric Processes and Climate Change (ES 649)*
Physico-chemical Treatment Technologies (ES 639)*
Environmental Impact Assessment (ES 653)#
Environmental Law & Policy (ES 645)#
Environmental Management (ES 655)*
Environmental Nanotechnology (ES 630)*
Introduction to Risk Analysis (CM 801)#
Simulation & Optimization Techniques in Environmental Systems (ES 407)#
*** Interdisciplinary STEM elective (No core prerequisite)**
 # Advanced elective

Electives list (Group-2: Spring semester)
Biological Treatment Technologies (ES 666)#
Air Pollution Control Technologies (ES 672)#
Planning and Design of Environmental Engineering Facilities (ES 404, to be revised to 6 credit)#
Bioremediation- Principles and Applications (ES 656)#
Industrial Pollution Prevention and Clean Technologies (ES 644)#
Industrial Wastewater Management and Reuse (ES 642)*
Environmental Change and Sustainable Development (ES 658)*
Environmental Statistics (ES 670)#
Hazardous Waste Management (ES 624)#
Membrane Processes (ES 676)#
Groundwater Flow and Contaminant Transport through porous media (ES 654)*
Numerical methods for Environmental Systems (ES 682)#
Energy and Environmental Sustainability (ES 321)*
Aerosol Science and Engineering (ES 674)#
*** Interdisciplinary STEM elective (No core prerequisite)**
 # Advanced elective

Course details are provided in the Annexure

Annexure
Course details

ES 101 (DIC-1)
Introduction to Environmental Science & Engineering 3 0 0 6

History of Environmental Science and Engineering; Biography of Renowned Environmental Scientists and Professionals; Natural Resources; Renewable and Non-renewable Energy Sources; Introduction to Environmental Pollution; Evolution of Pollution Control Strategies and Environmental Infrastructure; Major Environmental Episodes; Evolution of Environmental Acts and Policies; Environmental Ethics; Sustainability Concepts; Recent Research and Future Prospects in the field of Environment.

Texts/References

Cunningham W.P. and Cunningham M.A., Principles of Environmental Science, Tata McGraw-Hill Publishing Company, New Delhi, 2002.

Jackson, A.R.W. and Jackson, J.M. Environmental Sciences: The Environment and Human Impact, Longman Publishers, 1996.

Masters, G.M., Introduction to Environmental Engineering and Science, Prentice Hall, 2008, New Delhi.

Rosencranz, A., Divan, S. and Noble, M.L., Environmental Law and Policy in India: Cases, Materials and Statutes, Tripathi Pvt. Ltd, Bombay, 1992.

Environmental Studies: A Practitioner's Approach by by S. J Arceivala and S. R Asolekar, Tata McGraw- Hill Education Private Limited, 2012

Asolekar, S. R. and Gopichandran, R. Preventive Environmental Management - An Indian Perspective Foundation Books Pvt. Ltd., New Delhi (the Indian association of Cambridge University Press, UK), 2005.

Invited Talks from Environment Experts; Recorded Videos and Reference Study Material.

ES 204 (DIC-2)
ENVIRONMENTAL CHEMISTRY **3 0 0 6**

(Course number needs to be changed)

Aquatic Chemistry: Chemical equilibria and kinetics fundamentals; Acids and bases; Titrations; Acidity; Alkalinity; Buffers and buffer intensity; Chemical equilibrium calculations; pC-pH diagram. Precipitation and dissolution; Water softening and water conditioning; Langelier index; Solubility diagram; Coexistence of phases in equilibrium; Complexation of metal ions and organic complexes in natural water. Oxidation and reduction reactions stoichiometry; Redox couples; pE-pH diagrams; Redox control in natural systems; Basic concepts of organic and colloid chemistry. Soil Chemistry : Weathering reactions; Structure and surface reactions of clays and oxides; Forces at soil-water interfaces. Atmospheric Chemistry: Chemical equilibria and kinetics; Photodissociation and free radical reactions; Chemistry of precipitation; Acid rain.

Texts/References

Sawyer, C.N., McCarty, P.L., and Parkin, G.F., Chemistry for Environmental Engineering, 5th Edition, McGraw-Hill, Inc., New York, 2003

Manahan, S.E., Fundamentals of Environmental Chemistry, Lewis Publishers, Inc., Boca Raton, 1993 Sposito, G., Surface Chemistry of Soils, Oxford University Press, New York, 1984

Stumm, W., and Morgan, J.J., Aquatic Chemistry : An introduction Emphasizing Chemical Equilibria in Natural Waters, 2nd Edition, Wiley Intersciences, New York, 1981

ES 201
APPLIED ENVIRONMENTAL MICROBIOLOGY AND ECOLOGY 3 0 0 6

Ecology and Ecosystems: Structure and function of ecosystems; Biogeochemical cycles and role of microorganisms

Structure of prokaryotic and eukaryotic cells; Types of microorganisms; metabolic classification of microorganisms; Cell chemistry; Cell biology

Biochemical thermodynamics and bioenergetics; Enzyme kinetics and regulation; Microbial metabolism and biochemistry; Microbial nutrition, growth and growth kinetics; Role of antibiotics; Bacterial genetics

Microbial ecology and diversity; Microbial diversity and niches in wastewater treatment systems and groundwater systems

Microbiological aspects of drinking water and drinking water distribution systems; Indicator organisms; Disinfection processes

Microbial degradation of xenobiotic organic compounds; and Bioremediation.

Texts/References

Madigan M.T., Bender K. S., Buckley, D.H., Sattley, W.M., Stahl, D.A. Brock's Biology of Microorganisms,
15th Ed, ASM Press, NY, 2018.

Maier, R.M., Pepper, I.L., Gerba C.P., Environmental Microbiology, 2nd Ed. Academic Press, 2009 Bitton, G., Wastewater Microbiology, 3rd Ed., Wiley-Liss Inc., New York, 2005

Jackson, A.R.W. and Jackson, J.M., Environmental Science: The Natural Environment and Human Impact, 2nd Ed., Pearson Education, 2000.

ES 317
FUNDAMENTALS OF AIR POLLUTION SCIENCE AND ENGINEERING 3 0 0 6

Composition and structure of atmosphere; Air pollutants: Gaseous/Particulate; Health effects; Air quality standards and regulations; Sources of air pollutants; Particle size distributions; Monitoring of air pollutants; Principles of industrial air pollution control methods for gaseous and particulate; Modelling (Gaussian Dispersion); Air quality management; Climate effect of air pollutants; Atmospheric chemistry of ozone; Indoor air pollution.

Texts/References

De Nevers, N., Air Pollution Control Engineering, McGraw Hill, New Delhi, 1995.

Hinds, W.C., Aerosol Technology: Principles, Behaviour and Measurements of Airborne Particles, Wiley: NY, 1982.

Masters, G.M., and Ela, W.P., Introduction to Environmental Engineering, 3rd Edition, Pearson New International Edition, Pearson Education Inc., Noida, India, 2013.

Nathanson,J.A. and Schneider R.A., , Basic Environmental Technology, 6th Edition, Pearson Education Inc., Noida, India, 2017

Seinfeld, J. H. and Pandis, S N., Atmospheric Chemistry and Physics: from Air Pollution to Climate Change, John Wiley, New York, 1998.

ES 253
ENVIRONMENTAL MICROBIOLOGY LABORATORY **0 0 3 3**

Microscopy; Staining and detection of microbes; Methods of enumerating microbes; Multiple tube fermentation technique; Membrane filter technique.

Texts/References

Pepper, I. L., Gerba, C. P., Brendecke, J. W. (1995), Environmental Microbiology-A Laboratory Manual, Academic Press Inc., San Diego, USA.

Csuros, M. and Csuros, C. (1999), Microbiological Examination of Water and Wastewater, Lewis Publishers, CRC Press, Boca Raton, Florida, USA

ESED Lab Manuals.

ES 351
AIR POLLUTION MONITORING LABORATORY 0 0 3 3

Air pollution measurements: Measurement design and methods; Principles and instruments for particulate and gaseous pollutant measurements; Meteorological measurements.

Texts/References

Kulkarni, P., Baron, P.A. and Willeke, K. (2011), Aerosol Measurement: Principles, Techniques, and Applications. 3rd Edition Wiley, Hoboken.

Cohen B.S. and McCammon C.S.,(2001), Air Sampling Instruments for Evaluation of Atmospheric Contaminants, American Conference of Governmental and Industrial Hygienists, Cincinnati, OH

Cohen, B.S., and Hering, S.V. (Eds), Air Sampling Instruments for Evaluation of Atmospheric Contaminants, 8th Ed., ACGIH, 1995.

Hinds, W.C., Aerosol Technology : Properties, Behaviour and Measurements of Air borne Particles, Wiley-Interscience, New York.

Kenneth, E., Noll and Terry L. Miller, Air Monitoring Survey Design, Ann Arbor Science, 1977.

ES 203
WATER AND WASTEWATER ENGINEERING **3 0 0 6**

(Course number needs to be changed)

Introduction to water and wastewater technology; water quality and effluent standards; Water demand forecasting; Determination of reservoir capacity; Water pollution; Environmental hydraulics; Water distribution systems; Wastewater collection; Water and Wastewater treatment: physical, chemical and biological unit operations; Sludge disposal.

Texts/References

Peavy, H. S., Rowe, D. R., and Tchobanoglous, G. (1985), Environmental Engineering, McGraw Hill Book Company, Singapore.

Masters, G.M. (1995), Introduction to Environmental Engineering and Science, Second Indian Reprint, Prentice Hall, New Delhi.

Nathanson, J.A. (2003), Basic Environmental Technology: Water supply, waste management and pollution control, Prentice-Hall of India, New Delhi.

Garg, S. K and Garg, R. (1996), Sewage disposal and air pollution engineering, Khanna Publishers, Delhi.

Manual on Sewerage and Sewage Treatment (1993), 2nd Edition; Ministry of Urban Development, New Delhi.

Manual on Water Supply and Treatment (1991), 3rd Edition, Ministry of Urban Development, New Delhi.

ES 664
ENVIRONMENTAL SYSTEMS MODELLING **3 0 0 6**

Introduction to air quality models; Meteorology; Atmospheric stability and turbulence; Gaussian plume model and modifications; Numerical models, Urban diffusion models, Calibration and sensitivity analysis; Applications of public domain models and software, Global radiation balance and climatic changes. Transport and fate of pollutant in aquatic systems; Introduction to river, estuarine and lake hydrodynamics; Stratification and eutrophication of lakes; Dissolved oxygen model for streams; Temperature models. Transport and fate of pollutants in soils and ground water; Utility of environmental models for forecasting. Computational methods in environmental modelling.

Texts/References

Seinfeld, J.H., and Pandis, S.N., Atmospheric Chemistry and Physics, John Wiley and Sons, Inc., New York, 1998.

Schnoor, J.L., Environmental Modelling, Inter Sc. Publ., 1996.

Boubel, R.W., Fox, D.L., Turner, D.B., and. Stern, A.C., Fundamentals of Air Pollution, Academic Press, New York, 1994.

Thomann, R.V., and Muller, J.A., Principles of Surface Water Quality Modelling and Control, Harper International Edition, N.D., 1987.

Tchobanoglous, G., and Schroeder, E.D., Water Quality, Addison – Wesley Publishing Company, Reading, Massachusetts, 1987

ES 208
MASS TRANSFER PROCESS IN ENVIRONMENTAL SYSTEMS 3 0 0 6

Environmental systems and processes: natural and engineered systems of environmental significance, character and scale, quantification, reactions, reactors, material balance relationship, initial and boundary conditions, mass balance-based process models.
Macro transport and micro transport processes: advective and dispersive transport mass & momentum balance, Reynolds number, Prandtl hypothesis, dispersion coefficient and flux expressions, diffusive mass transfer, Ficks Law, diffusivity estimation, interphones mass transfer, boundary layers, mass transfer coefficients, film Model, penetration and surface renewal model, development of mass transfer correlations.
Energetics in homogeneous and heterogenous system: reaction concepts, equilibrium vs Steady-state, thermodynamic relationships and functions, reaction feasibility, fugacity and chemical potential, Henry's Law, Raoult's Law, phase exchange equilibria, absorption and adsorption processes, isotherm models, species distribution among phases in environmental systems.
Rate concepts in homogenous system: mass law relationship, reaction order, rate data analysis and choice of rate expression, activation energy, complex reaction kinetics,
Reactor engineering in steady state homogenous systems: ideal reactions, CMBR, CMFR, PFR, PFDR, nonideal reactors, residence time distribution analysis.

Texts/References

Weber, W.J. Jr., Process Dynamics in Environmental Systems, John Wiley & Sons Inc, 1996.

Fogler, H.S., Elements of Chemical Reaction Engg., 2nd Ed., Prentice-Hall India, 2001.

ES 252
ENVIRONMENTAL CHEMISTRY LAB **0 0 3 3**

Water quality monitoring, Cation / anion analysis; BOD; COD; Residual chlorine analysis; Metal analysis; Instrumental methods of pollutant analysis.

Texts/References

Standard Methods for the Examination of Water and Wastewater, 19th Edition, APHA/AWWA/WPCF Publishing, Washington, D.C., 1995.

ES 319
COMPUTATIONAL LABORATORY FOR ENVIRONMENTAL ENGINEERS
0 0 3 3

Fundamentals of computers, Application of spreadsheet for scientific computation and data analysis/visualization, Use of statistical tools/software, Introduction to basic numerical methods, Hands- on practice on a programming language for developing computational models, Application of relevant software for simulating environmental systems.

Texts/References

Ghezzi C. and Jazayeri, M., Programming Language Concepts, John Wiley & Sons, 1999.

Guha, S. and Srivastava, R. Numerical Methods for Engineering and Science, Oxford University Press, New Delhi, 2010.

Supplementary Reading Materials (Selected book chapters, research papers, online resources, theory and user manuals of relevant software).

ES 216
GIS AIDED ENVIRONMENTAL PLANNING AND MANAGEMENT 1 0 4 6

Introduction, definitions and applications of GIS; Spatial data and data management: Spatial data models, architecture of type of data formats, data sources, transformation and manipulation, database structures in GIS, DEMS, DTMS, TINS and Networks; Data exploration: Query and data analysis; Spatial analysis: Cluster detection, point to continuous surface models, spatial autocorrelation; Remote sensing: fundamentals, data input and analysis; Visualization and display using graphical user interface: maps, graphs, reports, and multimedia. GIS case studies for solving typical environmental planning and management problems. Hands on training for using GIS software in GIS lab and demonstration of actual implementation of a GIS in the form of a project.

Texts/References

Zhu, Xuan, GIS for Environmental Applications: A practical approach, Routledge, 2016.

Maguire, D.J., Goodchild, M.F. and Rhind, D.W., Geographical information systems, Longman Scientific and Technical, Essex, 1991.

Goodchild, M.F., Parks, B.O. and Steyaert, L.T. Environmental modeling with GIS, Oxford University Press, New York, 1993.

Burrough, P.A. and McDonnell, R.A., Principles of geographical information systems, Oxford University Press, Oxford, 1998.

ES 315
SOLID WASTE MANAGEMENT – BASIC PRINCIPLES AND TECHNICAL ASPECTS **3 0 0 6**

Principles of municipal solid waste management: basic principles, Solid Waste Management Rules (2016); Integrated waste management hierarchy; Sources, generation, composition and characteristics of municipal solid waste; Centralized and decentralized waste management; Technical aspects: Waste handling, collection and transfer of solid waste; Basic principles of processing and treatment of municipal solid waste – Materials recovery and recycling, composting, anaerobic digestion or biomethanation, thermal treatment and sanitary landfilling. Issues with existing dumpsites and remedial measures Special waste management including domestic hazardous waste, e-waste, biomedical waste, plastic waste, slaughterhouse waste, waste tyres, Construction & demolition waste and lead battery wastes and relevant policies Case studies in solid waste management

Texts/References

Tchobanoglous, G., Theisen, H., and Vigil, S.A., Integrated Solid Waste Management: Principles and Management Issues, McGraw Hill Book Company, Singapore, 1993.

Tchobanoglous, G., Keith, F. Handbook of Solid Waste Management. Second issue, McGraw Hill Book Company, 2002

Dewan, J.M. and Sudarshan, K. N. Solid Waste Management, Discovery Publishing Pvt. Ltd., 1999, ISBN-10: 8171413412.

Powes, P.W., How to Dispose of Toxic Substances and Industrial Waste, Noyes Data Corporation, England, 1976.

Pavoni, J.L., Handbook of Solid Waste Disposal, Solid Waste Management, Van Nostrand-Reinhold Co., 1975.

Mantell, C.L., Solid Waste Management, John Wiley, New York, 1975.

ES 657
WATER RESOURCES AND EVIRONMENTAL HYDRAULICS 3 0 0 6

Global water resources; Precipitation; Streamflow measurement; Runoff; Hydrographs; Floods and flood routing; Design of open channels; Concepts of specific energy, Hydraulic jump; Groundwater hydrology.

Definition and properties of fluids; Fluid statistics, fluid pressure and its measurement, hydrostatic force on plane, inclined and curved submerged surfaces, buoyancy and floatation; Kinematics of fluid flow; Fluid dynamics: Continuity, Momentum and energy equations, Flow through orifices, Weir and notches, Flow through pipes.

Texts/References

Chaudhry, M. H., Open channel flow, Englewood Cliffs: Prentice Hall, 1993.

French, R.H., Open Channel Hydraulics, McGraw Hill Book Co., New York 1986.

Linsley, R.K. and Paulhus, J.L.H., Water Resources Engineering, McGraw Hill Book Co., 1992.

Streeter, V.L. and Wylie, E. B., Fluid Mechanics, McGraw Hill Book Co.,1983.

Subramanya, K., 2013. Engineering Hydrology, 4e. Tata McGraw-Hill Education.

ES 308
SOLID AND HAZARDOUS WASTE LABORATORY **0 0 3 3**

Characterization and testing of solid wastes. Characterization and testing of hazardous waste

Texts/References

CPHEEO Manual on Municipal Solid Waste Management, 2000.

ES 451
ENVIRONMENTAL FIELD STUDIES **0 0 3 3**

Environmental Quality Assessment: Measurement of various environmental quality parameters for selected area/matrix to determine the environmental quality status.

Ecology: Measurement and calculation of biodiversity indices based on plants and animals; Net and gross primary productivity, community respiration rate; Field Trips.

Socio-economic Survey: Population distribution, health status, perception of environment.

Visit to industrial units or treatment schemes to understand and undertake assessment to relate basic principles, Preparation of field study report.

Texts/References

Artiola, Janick F. (Ed.), Environmental Monitoring and Characterization, Elsevier Academic Press, 2004.

Khopkar, S.M., Environmental Pollution, Monitoring and Control, New Age Intl., New Delhi, 2004.

Standard Methods for the Examination of Water and Wastewater, 20th ed., Washington, D.C., American Public Health Association, 1998.

Lodge, J.P., Jr., (Ed.) Methods of Air Sampling and Analysis, 3rd ed., Lewis Publishers, 1988.

Smith, R. L. (1996), Study guide to accompany ecology and field biology, 5th edition, Menlo Park, California, USA, Benjamin Cummings

Krebs C.J. (1999), Ecological methodology, 2nd edition, Menlo Park, California, USA, Benjamin Cummings

The Department Elective in Autumn Semesters is to be chosen from Group-1.

Electives list (Group-1: Autumn semester)

Environmental Health & Safety (ES 601)*

Atmospheric Processes and Climate Change (ES 649)*

Physico-chemical Treatment Technologies (ES 639)*

Environmental Impact Assessment (ES 653)#

Environmental Law & Policy (ES 645)#

Environmental Management (ES 655)*

Environmental Nanotechnology (ES 630)*

Introduction to Risk Analysis (CM 801)#

Simulation & Optimization Techniques in Environmental Systems (ES 407)#

*** Interdisciplinary STEM elective (No core prerequisite)**

 # Advanced elective

ES 601
HEALTH SAFETY AND ENVIRONMENT **3 0 0 6**
[Interdisciplinary STEM elective]

Regulations for Environment, Health and Safety **:** Factories Act and Rules, Environmental Pollution Act, Oil Industry Safety Directorate (OISD), Indian Electricity Acts and Rules, Mines Acts and Rules, Workmen Compensation Act, OSHA Standards, IS & BS Standards, API standards

Occupational Health and Hygiene: Physical Hazards: Noise and vibration, Instrumentation, Surveying procedure, Health effects, Control measures (stress, exposure and radiation effects).
Chemical Hazards: Recognition of hazards, TLV for air, gas and chemical contaminants. Demonstration of equipment for the assessment of physical and chemical hazards.

Occupational Health: Concept and spectrum of health, industrial toxicology, toxicity

Safety Management
Safety performance: As per Indian and International standards
Hazard analysis: Cost effectiveness in hazard elimination – logical analysis – HAZOP
Probabilistic reliability considerations, estimating probability in time, mathematical calculation of probability, reliability determination.
Safety management techniques: Safety inspection – safety action, safety survey disaster control.

Environmental Pollution Control
Air pollution: Classification and properties of air pollutants, sources, control, dispersion of air pollutants.
Water pollution: Classification – effect on receiving bodies, chemical, physical and biological treatment method.
Solid Waste Management: Method of collection, disposal, land filling.

Texts/References

IS codes: IS 5903, IS 807, IS 2760, IS 14469, IS 13367-1, IS 5324, IS 7167, IS 7155, IS1800, IS 3521.

Handbook of Occupational Health and Safety, NIC, Chicago, 1982.

Encyclopedia of Occupational Health and Safety, Vol. I and II. International Labour Organisation, Geneva, 1985.

McCornick, E.J. and Sanders, M.S., Human Factors in Engineering and Design, Tata McGraw Hill, 1982. Accident Preventional Manual, NSC Chicago, 1982.

Henrich, H.W., Industrial Accident Prevention, McGraw Hill, 1980.

Less, F.P., Loss Prevention in Process Industries, Butterworth, New Delhi, 1986.

ES 649
ATMOSPHERIC PROCESSES AND CLIMATE CHANGE 3 0 0 6
[Interdisciplinary STEM elective]

Structure of atmosphere, composition, global cycles and lifetimes; Atmospheric chemistry: troposphere and stratospheric; Atmospheric aerosols: properties, chemistry and processes. Meso and macro scale atmospheric and meteorological processes; Global circulation models. Radiation balance, direct and indirect effects of pollutants; climate change implications; policies and international protocols.

Texts/References

Seinfeld, J. H., and Pandis, S N., Atmospheric Chemistry and Physics : from Air Pollution to Climate Change, John Wiley, New York, 1998.

Almeida, G.A., Koepke, P., and Shettle, E.P., Atmospheric Aerosols : Global Climatoloty and Radiative Characteristics, A. Deepak Publishing, Virginia, 1981.

Charlson, R.J., and Heintzenberg, O.J. (Eds.), Aerosol Forcing of Climate, John Wiley and Sons, N.Y., 1995.

ES 639
PHYSICO-CHEMICAL TREATMENT TECHNOLOGIES **3 0 0 6**
[Interdisciplinary STEM elective]

Overview of mass transfer and reactor concepts; Mass transport mechanisms; Ideal reactors, non-idealities, Mass balance in various reactor configurations.

Particle separation processes; Coagulation and flocculation processes, Particle surface charge, surface potential and stability of colloidal dispersions; Sedimentation and flotation processes, Gravity thickeners, clarifiers and flotation systems; Filtration and Ultrafiltration Processes, Modeling approaches for rapid sand filters.

Solute separation processes; Gas transfer processes, Diffused and surface Aeration and Air stripping of volatile contaminants in packed tower; Adsorption and ion exchange processes, sorption isotherm models and rates considerations, Sorption in completely mixed and packed bed reactors; Precipitation processes; Reverse osmosis and electrodialysis.

Species transformation processes; Chemical oxidation / reduction processes, disinfection using chlorine and UV.

Texts/References

Weber, W. J. Jr., Environmental Systems and Processes: Principles, Modeling and Design, John Wiley and Sons Inc., New York, 2001

Weber, W. J. Jr., and DiGiano, F.A., Process Dynamics in Environmental Systems, John Wiley and Sons Inc., New York, 1996

Weber, W. J. Jr., Physicochemical Processes for Water Quality Control, John Wiley and Sons Inc., New York, 1972

Metcalf & Eddy, Inc, Tchobanoglous G. and Burton, F.L., Wastewater Engineering: Treatment, Disposal and Reuse, 4th ed., Tata McGraw Hill, New Delhi, 2003

ES 653
ENVIRONMENTAL IMPACT ASSESSMENT **3 0 0 6**
[# Advanced elective]

Evolution of EIA; EIA at project; Regional and policy levels; Strategic EIA; EIA process; Screening and scoping criteria; Rapid and comprehensive EIA.
Legislative and environmental clearance procedures in India and other countries, Siting criteria; CRZ; Public participation; Resettlement and rehabilitation.

Practical applications of EIA; EIA methodologies; Baseline data collection; Prediction and assessment of impacts on physical, biological and socio-economic environment; Environmental management plan; Post project monitoring, EIA report and EIS; Review process.

Case studies on project, regional and sectoral EIA.

Specialised areas like environmental health impact assessment; Environmental risk analysis; Economic valuation methods; Cost-benefit analysis; Expert system and GIS applications; Uncertainties.

Texts/References

World Bank, 'Environmental Assessment Source Book', Environment Dept., Washington D.C., 1991.

Rau, G.J. and Wooten, C.D., Environmental Impact Analysis Handbook, McGraw Hill, New York, 1980.

Canter, L., Environmental Impact Assessment, McGraw Hill, New York, 1996.

ES 645
ENVIRONMENTAL LAW AND POLICY **3 0 0 6**
[# Advanced elective]

Models of environmental management; Incentives; Context; Theories of corporate strategy and environmental policy; Environmental guidelines and charters; Auditing, Monitoring; Reporting, economics and accounting; Local economic development and environmental management; Role of government; Law and policies beyond environmentalism; Sustainability issues; Role of government and non-government organizations and citizens.

Texts/References

Hawken, P., Ecology and Commerce, Harper Business, New York, 1993.

Rosencranz, A., Divan, S. and Noble, M.L., Environmental Law and Policy in India : Cases, Materials and Statutes, Tripathi Pvt. Ltd, Bombay, 1992.

Welford, R., Corporate Environmental Management, Earthscan Publications Ltd., London, 1988.

Asolekar, S. R. and Gopichandran, R. Preventive Environmental Management - An Indian Perspective Foundation Books Pvt. Ltd., New Delhi (the Indian association of Cambridge University Press, UK), 2005.

Various policy statements and Laws of the Government of India

ES 655
ENVIRONMENTAL MANAGEMENT **3 0 0 6**
[Interdisciplinary STEM elective]

Environmental regulations and policies; Environmental protection laws and acts; Corporate and international charters and protocols; Environment Risk assessment; Industrial ecology, Pollution prevention and Waste minimization; Sustainable development; Life cycle assessment; Environmental auditing; Eco-labelling of products; Performance indicators.
Environmental management systems particularly IS 14000 series.

Texts/References

Welford, R., Corporate Environmental Management, Earthscan Publications Limited, London, 1996.

Sayre, D., Inside ISO 14000: Competitive Advantage of Environmental Management, St. Louis Press, Florida, 1996.

Graedel, T.E. and Allenby, B.R., Industrial Ecology, Englewood Cliffs: Prentice Hall, New Jersey, 1995.

Rosencranz, A., Divan, S. and Noble, M.L., Environmental Law and Policy in India : Cases, Materials and Statutes, Tripathi Pvt. Ltd, Bombay, 1992.

Asolekar, S. R. and Gopichandran, R. Preventive Environmental Management - An Indian Perspective Foundation Books Pvt. Ltd., New Delhi (the Indian association of Cambridge University Press, UK), 2005.

ES 630
Environmental Nanotechnology **3 0 0 6**
[Interdisciplinary STEM elective]

Introduction of nanotechnology and overview of nanomaterials in the environment; Nanomaterial synthesis, fabrication, and characterization of nanomaterials; Characterization techniques for nanomaterials; Surface chemistry and colloidal aspects of nanomaterials; Catalytic behavior of nanomaterials; Toxicity and ecotoxicity of nanomaterials; Applications of nanomaterials: Water, soil, and air purification and sensing; Case studies for Iron nanoparticle, bimetallic, and other carbon-based nanoparticles in desalination and wastewater treatment, and environmental remediation application; Ethical issues of nanotechnology

Texts/References

Environmental Nanotechnology: Applications and Impacts of Nanomaterials by Wiesner and Bottero (2007), McGraw Hill Professional, 2007;

Hasselhov and Kaegi, Analysis and Characterization of Manufactured Nanoparticles in Aquatic Environments from Environmental and Human Health Impacts of Nanotechnology, 2009, eds. Lead and smith, Blackwell Publishing

Poole C P and Owens F J, Introduction to Nanotechnology, Wiley-Interscience 2003.

Cao G, Nanostructures and Nanomaterials: Synthesis, properties and applications, Imperial College Press 2004.

Thedore, l., Kunz, r.g., Nanotechnology: Environmental Implications And Solutions, John Wiley & Sons Inc. 2005.

Sellers Ve Diğ, Nanotechnology and the Environment, Crc Press, 2009.

Cloete Ve Diğ, Nanotechnology In Water Treatment Applications, Caister Academic Press, UK, 2010.

Masciangioli, T., Zhang, W., Environmental Technologies At Nanoscale. Environmental Science and Technology, March, 102-107, 2004.

CM 801
Introduction to Risk Analysis **3 0 0 6**
[# Advanced elective]

Science of systems and concept of risk – introduction, systems engineering, concepts of risk assessment and management, applications to water resources; Steps of risk characterization - hazard identification, exposure assessment, vulnerability analysis, risk mapping, example of risk characterization to natural hazards, risk assessment as a distributed process: example of Monte-Carlo techniques in human health and ecological risk assessments; Uncertainty analysis – introduction, uncertainty taxonomy, sensitivity analysis, probabilistic uncertainty, fuzzy systems, interval analysis, risk-based decision making; Risk filtering and ranking – introduction, past efforts in risk filtering, methodological framework of filtering and ranking, different ranking methods, case studies; Multi-objective trade-off analysis – introduction, examples of multiple environmental objectives, surrogate worth trade-off, characterizing a proper noninferior solution; Decision-tree analysis – introduction, methodological approach, differences between single and multiple objective decision trees.

Texts/References

Bedford, T., Roger M. Cooke (2003) "Probabilistic risk analysis: foundations and Methods." Cambridge University Press.

Daniel M. Byrd III, C. Richard Cothern (2000) "Introduction to risk analysis: a systematic approach to science-based decision making." Rockville, MD, USA: Government Institutes F. S. Hillier & G. J. Lieberman (2002) 302223

Introduction to Operations Research302224 McGraw-Hill Science/Engineering/Math, 7th edition. Yacov Y. Haimes, (2004) "Risk modeling, assessment, and management." John Wiley & Sons.

ES 407
SIMULATION AND OPTIMIZATION TECHNIQUES IN ENVIRONMENTAL SYSTEMS **3 0 0 6**
[# Advanced elective]

Constrained and unconstrained optimization; Kuhn-Tucker conditions; Linear programming; Dynamic programming; Review of probability theory-random variables, probability distributions; Stochastic optimization-chance constrained linear programming, stochastic dynamic programming; Applications in environmental and water resources engineering-storage yield analysis, water allocation, multipurpose reservoir operation for hydropower, flood control and irrigation, river water quality management, solid waste management; Use of advanced optimization techniques in Environmental systems-Fuzzy optimization, Interval optimization, Nonlinear search algorithms-Genetic Algorithms and Probabilistic Global Search Laussane.

Texts/References

Hillier, F.S. and Lieberman, G.J., Introduction to Operations Research, 7th edition, McGraw-Hill Science/Engineering/Math, 2002.

Kieffer, J.L.M., Didrit, O. and Walter, E., Applied Interval Analysis, Springer-Verlag, London, 2001.

Loucks, D.P., Stedinger, J.R. and Haith, D.A., Water Resources Systems Planning and Analysis, Prentice Hall, 1981.

Mays, L.W. and Tung, Y-K., Hydrosystems Engineering and Management, Intl. editions,1992. Ross, S.M., Introduction to Probability Models, 8th edition, Elsevier, 2004.

Ross, T.J., Fuzzy Logic with Engineering Applications, 2nd edition, Wiley, 2004.

Taha, H.A., Operations Research an Introduction, 8th edition, Pearson Prentice Hall, 2006.

The Department Elective in Spring Semesters is to be chosen from Group-2.

Electives list (Group-2: Spring semester)

Biological Treatment Technologies (ES 666)#

Air Pollution Control Technologies (ES 672)#

Planning and Design of Environmental Engineering Facilities (ES 404, to be revised to 6 credit)#

Bioremediation- Principles and Applications (ES 656)#

Industrial Pollution Prevention and Clean Technologies (ES 644)#

Industrial Wastewater Management and Reuse (ES 642)*

Environmental Change and Sustainable Development (ES 658)*

Environmental Statistics (ES 670)#

Hazardous Waste Management (ES 624)#

Membrane Processes (ES 676)#

Groundwater Flow and Contaminant Transport through porous media (ES 654)*

Numerical methods for Environmental Systems (ES 682)#

Energy and Environmental Sustainability (ES 321)*

Aerosol Science and Engineering (ES 674)#

*** Interdisciplinary STEM elective (No core prerequisite)**

 # Advanced elective

ES 666
BIOLOGICAL TREATMENT TECHNOLOGIES **3 0 0 6**
[# Advanced elective]

Classification of biochemical operations; Stoichiometry and kinetics of biochemical operations; Modelling of suspended growth systems (basic model for CSTRs; Extensions of the basic model; Methods of biomass recycle and retainment; Techniques for evaluation of kinetic and stoichiometric parameters; Multiple microbial activities in reactors); Design and evaluation of suspended growth processes (guiding principles; Iterative nature of process design and evaluation; Basic decisions during design; Levels of design; Factors to be considered during design); Biological nutrient removal (carbon, nitrogen and phosphorous removal); Anaerobic treatment (process options, components of anaerobic reactions that influence process design); Attached growth reactors (process description and applications); Biodegradation of xenobiotic organic chemicals.

Texts/References

Arceivala, S. J. and Asolekar, S. R., Wastewater Treatment for Pollution Control, 3rd Edition, McGraw- Hill Education (India) Pvt. Ltd., New Delhi, 2006.

Metcalf & Eddy, Inc, Tchobanoglous G. and Burton, F.L., Wastewater Engineering: Treatment, Disposal and Reuse, 4th Edition, Tata McGraw Hill, New Delhi, 2003.

Gray, N. F., Biology of Wastewater Treatment, Oxford University Press, London, 1989.

ES 672
AIR POLLUTION CONTROL TECHNOLOGIES **3 0 0 6**
[# Advanced elective]

Industrial sources of air pollution; Behaviour of pollutants in atmosphere; Emission factors, regulations, control strategies and policies; Choosing appropriate APC technology.

Particulate Pollutant Control: Settling chambers – laminar and turbulent flow; Filtration – interception; Impaction; Convective diffusion; Collection of particles by cylindrical fibres and granular beds; Electrostatic precipitation – field and diffusion charging; Electrical migration velocity; Cyclones – laminar and turbulent flow; Wet collectors; Design and drawing of various particle control devices.

Gaseous Pollutant Control : Gas absorption in tray and packed towers; Stage efficiency; Liquid/gas rates; Equilibrium number of stages/packed height; Absorption with/without chemical reaction; Adsorption in fixed beds; Breakthrough; Wet scrubbers; Condensation and combustion; Design and drawing of various pollutant control devices.

Control of specific pollutants: Control technologies for removal of SO2, NOx, VOC. Control technologies for motor vehicles.

Texts/References

McCabe, W. L., Smith, J.C., and Harriott, P. W. L., Unit Operations of Chemical Engineering, McGraw Hill, New York, 1993.

Buonicore, A.J., and Davis, W.T., Air Pollution Engineering Manual, van Nostrand-Reinhold, New York, 1992.

Flagan, R.C., and Seinfeld, J.H., Fundamentals of Air Pollution Engineering, Prentice Hall, New Jersey, 1988.

Reynolds, J.P., Jeris, J., and Theodore, L., Handbook of Chemical and Environmental Engineering Calculations, Wiley Interscience, New Jersey, 2007.

Mycock, J.C., McKenna, J.D. and Theodore, L., Handbook of Air Pollution Control Engineering and Technology, CRC, LEWIS Publishers, Boca Raton, Florida, 1995.

Cooper, C.D., and Alley, F.C., Air Pollution Control – A Design Approach, Waveland Press Inc., Prospect Heights, IL, 1986.

ES 404
PLANNING AND DESIGN OF ENVIRONMENTAL ENGINEERING FACILITIES
[# Advanced elective] 1 0 3 6

Planning, design and drawing of water supply systems, water treatment units and sludge treatmentunits.

Planning, design and drawing of wastewater collection system, wastewater treatment units and sludgetreatment units

Texts/References

CPHEEO Manual on Water Supply and Treatment, 1999.

Bhole, A.G., Design of water treatment plants, IWWA, Nagpur Centre, 2003. CPHEEO Manual on Sewarage and Sewage Treatment, 1993.

Metcalf & Eddy, Inc, Tchobanoglous G. and Burton, F.L., Wastewater Engineering: Treatment, Disposaland Reuse, 4th ed., Tata McGraw Hill, New Delhi, 2003.

Qasim, S.R., Wastewater treatment Plants – Planning, design and operation, CRC Press, 2nd Edition,1999.

ES 656
BIOREMEDIATION – PRINCIPLES AND APPLICATIONS **3 0 0 6**
[# Advanced elective]

Current bioremediation practice and applications; Microbial systems of bioremediation; Factors influencing bioremediation (environmental factors, physical factors and chemical factors); Genetic responses of microorganisms to the presence of pollutants (plasmid coded inducible degradative enzymes); Application of genetically engineered microorganisms for hazardous waste management; Microbial transformation reactions (aerobic and anaerobic biotransformations); Microbial detoxification of specialty chemicals (insecticides, herbicides, fungicides, polychlorinated biphenyls, heavy metals); Bioremediation systems and processes (solid, liquid and slurry phase bioremediation); Microbial cleaning of gases (biofiltration and bioscrubbing); In situ bioremediation; Laboratory scale biotreatability studies for bioremediation; Management of bioremediation project.

Text/References

Baker, K H., and Herson, D. S., Bioremediation, McGraw-Hill Publishing Company, New York, 1994

Eweis, J. B., Ergas, S. J., Chang D. P. Y., and Schroeder E. D., Bioremediation Principles, McGraw-Hill Publishing Company, Singapore, 1998.

Cookson, J.T. Jr., Bioremediation Engineering – Design and Application, McGraw Hill Publishing Company, New York, USA, 1995

Young, L.Y., and Cerniglia, C.E., Microbial Transformation and Degradation of Toxic Organic Chemicals, Wiley–liss Publishers, New York, USA, 1995

ES 644
INDUSTRIAL POLLUTION PREVENTION AND CLEAN TECHNOLOGIES
[# Advanced elective] **3 0 0 6**

Principles and techniques for industrial pollution prevention and waste minimization; Nature and characteristics of industrial wastes; Prevention versus control of industrial pollution; Source reduction tools and techniques: raw material substitution, toxic use reduction and elimination, process modification and procedural changes; Recycling and reuse; Opportunities and barriers to cleaner technologies; Pollution prevention economics.

Waste audits, emission inventories and waste management hierarchy for process industries; Material balance approach; Material and process mapping approach; Emission sources; Estimation of fugitive emissions; Environmental impact of VOCs; Energy and resource (material and water) audits for efficient usage and conservation.

Unit operations in separation technology; Pollution prevention for unit operations: Boilers and Heat Exchangers; Storage tanks; Distillation columns; Application of separation technologies for pollution prevention; Process optimization for cleaner industrial processes: Flowsheet analysis—qualitative and quantitative approaches using mass exchange networks; Thermodynamic constraints to waste minimization; Holistic and critical technology assessment; Environmental performance indicators; Concept of industrial ecology and symbiosis of eco-parks.

Case studies on industrial applications of cleaner technologies in chemical, metallurgical, pulp and paper, textile, electroplating, leather, dairy, cement and other industries.

Texts/ References

Bishop, P.E., Pollution Prevention: Fundamentals and Practice, McGraw Hill, 2000.
Freeman, H. M., Industrial Pollution Prevention Handbook, McGraw Hill, 1995.

Allen, D.T., and Rosselot, K.S., Pollution Prevention for Chemical Processes, John Wiley, 1997.

Allen, D.T., Bakshani, N., and Rosselot, K.S., Pollution Prevention: Homework and Design Problems for Engineering Curricula, American Institute for Pollution Prevention.

Johansson, A., Clean Technology, Lewis Publishers, 1992.

Theodore, L., and McGuinn, Y. C., Pollution prevention, Van Nostrand Reinhold, NewYork, 1992.

Asolekar, S. R. and Gopichandran, R. Preventive Environmental Management - An Indian Perspective Foundation Books Pvt. Ltd., New Delhi (the Indian association of Cambridge University Press, UK), 2005.

ES 642
INDUSTRIAL WASTEWATER MANAGEMENT AND REUSE 3 0 0 6
[Interdisciplinary STEM elective]

Tertiary treatment of industrial wastewater including removal of nitrate, sulphate, phosphorous, pathogens, color, odor, TDS, COD and residual BOD; Sector specific issues in management of industrial wastewater including petrochemical, textile, food processing, pharmaceutical, fertilizer, pesticides etc.; Policy and legislation including challenges posed by various sectors of industries and legislation framework and regulation in India; Case studies.

Texts/References

Asolekar, S.R., Ecocentric Technologies for Recycle and Reuse of Municipal and Industrial Effluents. A monograph published by the QIP-CDP Office of IIT, Bombay, 2005.

Eckenfelder, W.W. Jr., Industrial Water Pollution Control, 3rd Edition, McGraw Hill International Edition, Singapore, 2000.

Metcalf & Eddy, Inc, Tchobanoglous G. and Burton, F.L., Wastewater Engineering: Treatment, Disposal and Reuse, 4th Edition, Tata McGraw Hill, New Delhi, 2003.

Arceivala, S. J. and Asolekar, S. R., Wastewater Treatment for Pollution Control, 3rd Edition, McGraw Hill Education (India) Pvt. Ltd., New Delhi, 2006.

Various review papers and selected readings prescribed by the instructor.

ES 658
ENVIRONMENTAL CHANGE AND SUSTAINABLE DEVELOPMENT 3 0 0 6
[Interdisciplinary STEM elective]

Issues of sustainability: food, materials and energy resources, demands, policies, ethics; Paradigms of agricultural/industrial age, population, limits to growth; Current debates on the issues of sustainability; Relationships of ecological, economic and social systems; Engineering tools for assessment and design for environment and sustainability; Relevance of traditional paradigms for rural India.

Texts/References

LEAD India (Editor) Rio to Johannesburg: India's Experience in Sustainable Development, Orient Longman, Hyderabad, 2002.

Lee, N., and Kirkpatrick, C., (Eds), Sustainable Development and Integrated Appraisal in a Developing World, Edward, Elgar, UK, 2000.

Chopra, K., and Kadekodi, G.K., Operationalisting Sustainable Development, Sage Publication, New Delhi, 1999.

Roy, K.C., Sen R.K. and Tisdell, C.A., Environment and Sustainable Agricultural Development (Volumes I and II), New Age International Pvt. Ltd., New Delhi, 1996.

Kirkby, J., O'Keefe, P., and Timberlake, L. (Eds.), The Earthscan Reader in Sustainable Development, Earthscan Publications, London, 1995.

Asolekar, S. R. and Gopichandran, R. Preventive Environmental Management - An Indian Perspective Foundation Books Pvt. Ltd., New Delhi (the Indian association of Cambridge University Press, UK), 2005.

ES 670
ENVIRONMENTAL STATISTICS **3 0 0 6**
[# Advanced elective]

Overview of statistics and probability; Statistics in the context of environmental analysis; Probability
concepts and probability distributions; conditional probability and Bayes' theorem

Fundamentals of data analysis; Measurement uncertainty: Precision and accuracy; Reproducibility/repeatability; Types of Error, Normal error curve; Error propagation; Quality assurance and quality control; Confidence intervals. Hypothesis testing for equality of mean and standard deviation: t-test, chi-square test and F-test; Errors in hypothesis testing.

Experiment design and analysis of variance; ANOVA concepts; Completely randomized design; Randomized block design; Two-way factorial design; Variance component analysis; Factorial and fractional factorial design; Significance of interaction between factors.

Regression versus correlation; Autocorrelation in data; Linear versus non-linear regression models; Linear least-squares regression; Precision of parameter estimates, coefficient of determination: inherent limitations; Non-parametric statistics; Exercises using the statistical package SYSTAT.

Texts/References

Berthouex, P.M. and Brown, L.C., Statistics for Environmental Engineers, Lewis Publishers, CRC Press, Boca Raton, 1994.

Mendenhall, W. and Beaver, R.J., Introduction to Probability and Statistics, 8th Ed., PWS-Kent Publishing Co, Boston, 1991.

Ott, W.R. Environmental Statistics and Data Analysis, Lewis Publishers, New Jersey, 1995.

Maxwell, S.E. and Delaney, H.D. Designing Experiments and Analysing Data—A Model Comparison Perspective, Wadsworth Publishing Company, California, 1990.

ES 624
HAZARDOUS WASTE MANAGEMENT **3 0 0 6**
[# Advanced elective]

Hazardous Waste Fundamentals: Definition; Landmark episodes; Classification; Generation.

Regulatory process : Hazardous Waste (Management and Handling) Rules and Amendments, Guidelines for HWM from MoEF, New Delhi, Regulatory framework in the USA and EU, Basal Convention and other international statutes.

Process: Physicochemical properties; Energy and mass balances; Fate and transport of contaminants; Toxicology

Current Management Practices: Environmental audit; Pollution prevention; Facility development and operations.

Treatment and Disposal Methods: Physicochemical processes; Biological processes; Stabilization and solidification; Thermal methods; Land disposal.

Remediation of Contaminated Sites: Quantitative risk assessment; Site and subsurface characterization; Containment, Remedial alternatives.

Texts/References

LaGrega, M.D., Buckingham, P.L., and Evans, J.C., Hazardous Waste Management, McGraw-Hill International Editions, New York. 1994.

Freeman, H.W., Standard Handbook of Hazardous Waste Treatment and Disposal, McGraw Hill, New York, 1989.

Martin, E.J. and Johnson, J.H., Hazardous Waste Management Engineering, van Nostrand-Reinhold, New York, 1987.

Wentz, C.A., Hazardous Waste Management, 2nd Edition, McGraw Hill, New York, 1995

ES 676
MEMBRANE PROCESSES **3 0 0 6**
[Interdisciplinary STEM elective]

Introduction to processes and materials, Phenomena governing process operation; driving forces, concentration polarization, hydrodynamics, sealing, fouling, Module configurations, Applications.

Reverse Osmosis fundamentals, process design and operation: municipal and industrial applications. Desalination of sea water, pure/ultrapure water production. Fouling and pretreatment, CAD for RO design.

Electrodialysis, Definition of process operation conditions from first principles. Water and industrial wastewater applications with reference to recent case studies.

Nanofiltration and ultrafiltration applications. NF for surface water treatment. UF in ultrapure and potable water production and in membrane bioreactors.

Dead-end cartridge filtration applications in potable and pure water treatment. Choice of media: filtration mechanism, filter media structure.

Texts/References

Hillis, P., Membrane technology in water and wastewater treatment edited by Royal Society of Chemistry, Cambridge, 2000.

Belfort, Georges, Synthetic membrane processes: fundamentals and water applications edited by Academic Press, Orlando, 1984.

Noble, R.D., and Stern, S.A., Membrane Separation Technology – Principles and Appliations, Amsterdam, Elsevier, 1995.

Mallevialle, J., Odendaal, P.E., and Wiesner, M.R., Water Treatment Membrane Process, New York, McGraw Hill, 1996.

ES 654
GROUNDWATER FLOW AND CONTAMINANT TRANSPORT THROUGH POROUS MEDIA **3 0 0 6**
[Interdisciplinary STEM elective]

Water movement in the subsurface; Groundwater and the hydrologic cycle; The groundwater environment; Types of aquifers; Sources of contamination; Saturated flow: continuity equation; Darcy's Law; Equation of flow; Analytical solutions and numerical modeling; Unsaturated flow; Ground water sampling methods and analyses.

Transport of contaminants; Transport equation; Dispersion and diffusion in porous media; Reaction terms; Analytical solutions; Soil chemistry; Groundwater quality; Common soil minerals and components; Forces at soil-water interfaces; Adsorption and surface complexation models; Interaction of non-polar compounds with soils; Soil chemical kinetics; Modelling Groundwater Pollution; Coupling of contaminant-soil interactions with transport; Reaction and transport of trace metals, ligands and nonpolar organic solutes.

Texts/ References

Todd, D.K., Groundwater Geology, 2nd Ed., John Wiley, NY, 2001

Domenico, P.A., and Schwartz, F.W., Physical and Chemical Hydrogeology, John Wiley and Sons, New York, 1990.

Grathwohl, P., Diffusion in Natural Porous Media: Contaminant Transport, Sorption-desorption and Dissolution Kinetics, Kluwer Academic, Boston, 1998

Appelo, C.A.J., and Postma, D., Geochemistry, Groundwater and Pollution, A.A. Balkema Publishers, Rotterdam, 1993.

Freeze, R.A., and Cherry, J.A., Groundwater, Prentice Hall, Englewood Cliffs, New Jersey, 1979.

ES 682
NUMERICAL METHODS FOR ENVIRONMENTAL SYSTEMS 2 0 2 6
[# Advanced elective]

Numerical differentiation and Integration, Numerical methods and techniques for solving ordinary, partial differential equations, nonlinear equations; Matrices Eigenvalues and Eigenvectors, Finite difference method: schemes – implicit and explicit types. Accuracy, convergence and stability, method of characteristics, Finite element method- variational and weighted residual formulations; Introduction and hands-on practice on popular / available numerical tools and software; Applications to Environmental systems viz. water, air, wastewater and groundwater systems.

Texts/References

Salvadori, Mario G. and Baron, Melvin C. Numerical methods in engineering, Prentice-Hall of India, New Delhi, 1993.

Bathe, K.J. and Wilson, E.L., Numerical methods in finite element analysis, Prentice Hall, New Jersey, 1999.

Bajpai, A.C., Numerical methods for engineers and scientists, Wiley Interscience, New York, 1977. Rozsa 1P., Numerical methods, North-Holland Pub., Amsterdam, 1980.
Noble, Ben, Numerical methods, Oliver and Boyd, Edinburgh, 1964.

Buchanan, James L. and Turner, Peter R., Numerical methods and analysis, McGraw-Hill, New York, 1992.

Reddy, J.N., Introduction to the finite element method, McGraw-Hill, New York, 1985.

Desai, Chandrakant S. and Abel, John F., Introduction to the finite element method: a numerical method for engineering analysis, Van Nostrand Reinhold, New York, 1972.

ES 321
ENERGY AND ENVIRONMENTAL SUSTAINABILITY 3 0 0 6
[Interdisciplinary STEM elective]

Interlinkages of Energy and Environment Energy and Climate Change, Global Issues

Introduction to Fuels, Combustion Principles for Gas, Liquid and Solid Fuels Electricity Generation and Environmental Pollution

Alternative Energy Sources, Economics, Sustainability Waste to Energy Technologies, Bioenergy, Carbon Capture and Reuse,

Transport and Environment: Current and Emerging Transportation Vehicle Technologies Energy-Environment and India, Energy Policy and Environmental Impacts

Texts/References

Flagan, R.C., and Seinfeld, J.H., Fundamentals of Air Pollution Engineering, Prentice Hall, New Jersey, 1988.

Fowler, J.M., Energy and the Environment, McGraw Hill, New York, 1975.

Franchi, John R., Energy: Technology and directions for the future Elsevier Academic Press, 2004. ISBN: 0-12-248-291-3

Kanury, A.M., Introduction to Combustion Phenomena, Gordon and Breach Science Publishers, New York, 1992.

Tester, Jefferson W., Elisabeth M. Drake, Michael J. Driscoll, Michael W. Golay, and William A. Peters. Sustainable Energy: Choosing Among Options. 2nd edition. MIT Press, 2012. ISBN: 9780262017473.

ES 674
AEROSOL SCIENCE AND ENGINEERING **3 0 0 6**
[# Advanced elective]

Physics of aerosols: size and size distributions, mechanics of motion, agglomeration, diffusion, electrical effects and light scattering. Applications to sampling, deposition, and visibility. Particle formation and growth dynamics, aerosol reactor design engineering, and applications to environmental aerosols, catalysis, combustion, instrumentation, pharmaceuticals and powder production

Texts/References

Friedlander, S.K., Smoke Dust and Haze, Oxford University Press, New York, 2000.

Hinds, W C., Aerosol Technology: Properties, Behavior and Measurement of Airborne Particles, Wiley- Interscience, New York, 1999.

Seinfeld, J H and Pandis, S N., Atmospheric Chemistry and Physics: from Air Pollution to Climate Change, John Wiley, New York, 1998.