CURRICULUM FOR 5-YEAR
B.Tech. (ENVIRONMENTAL ENGINEERING) and
M.Tech. (ENVIRONMENTAL TECHNOLOGY & MANAGEMENT) PROGRAMME
YEAR 2020-21

Environmental Science and Engineering Department
IIT Bombay

CREDIT STRUCTURE FOR 5-YEAR
B.Tech. (ENVIRONMENTAL ENGINEERING) and
M.Tech. (ENVIRONMENTAL TECHNOLOGY & MANAGEMENT) PROGRAMME

Semester	Credits Required										Total Credits
	Basic Sciences and Mathematics		Engineering Sciences		HSS	Institute Electives	Departmental Credits				
	Theory	Lab	Theory	Lab			Core Theory	Labs	Electives	Supervised Learning	
I	22 (28)	3	6 (0)	4	0	0	0	0	0	0	35
II	26 (20)	3	0 (6)	5	0	0	0	0	0	0	34
III	0	0	14	0	6	0	18	0	0	0	38
IV	6	0	0	0	0	0	18+6*	7	0	0	37
V	0	0	0	0	6	0	30+6*	3	0	0	45
VI	0	0	0	0	0	6	12+6*	6	6	3 (Seminar)	39
VII	0	0	0	0	0	6	18+6*	3	6	0	39
VIII	0	0	0	0	0	0	24	5	12	0	41
Subtotal (B. Tech.)	**60**		**29**		**12**	**12**	**120+24***	**24**	**24**	**3**	**308**
IX	0	0	0	0	0	0	6	0	0	36 (Project)	42
X	0	0	0	0	0	0	0	0	0	36 (Project)	36
Subtotal (M. Tech.)	**0**	**0**	**0**	**0**	**0**	**0**	**6**	**0**	**0**	**72**	**78**
TOTAL	**60**		**29**		**12**	**12**	**126+24***	**24**	**24**	**75**	**386**

*Honors level course

First Year : First Semester

		HOURS PER WEEK			1
Code	**Name of the Course**	**Lectures**	**Tutorials**	**Practicals**	**Credits**
MA 105	Calculus	3	1	0	8
CH 105	Organic & Inorganic Chemistry	2	0	0	4
CS 101/ BB 101	Computer Programming and Utilization / Biology	2	0	2	6
PH 107	Quantum Physics & Applications	2	1	0	6
PH 117/ CH 117	Physics Laboratory / Chemistry Laboratory	0	0	3	3
ME 113	Workshop Practice	0	0	4	4
CH 107	Physical Chemistry	2	0	0	4
NC 101	NCC	PP/NP			
NO 101	NSO	PP/NP			
NS 101	NSS	PP/NP			
		11	**2**	**9**	**35**

First Year : Second Semester

		HOURS PER WEEK			2
Code	**Name of the Course**	**Lectures**	**Tutorials**	**Practicals**	**Credits**
MA 106	Linear Algebra	2	0	0	4
MA 108	Ordinary Differential Equations-1	2	0	0	4
PH 108	Electricity & Magnetism	2	1	0	6
ES 102	Water Quality Management	2	1	0	6
CS 101/ BB 101	Computer Programming and Utilization / Biology	2	0	2	6
PH 117/ CH 117	Physics Laboratory / Chemistry Laboratory	0	0	3	3
ME 119	Engineering Graphics and Drawing	0	1	3	5
NC 102	NCC	PP/NP			
NO 102	NSO	PP/NP			
NS 102	NSS	PP/NP			
		10	**3**	**8**	**34**

Second Year: First Semester

	HOURS PER WEEK	3

Code	Name of the Course	Lectures	Tutorials	Practicals	Credits
EE 101	Introduction to Electrical and Electronics Circuits	3	1	0	8
HS 101	Economics	2	1	0	6
ES 209	Data Analysis & Interpretation	2	1	0	6
ES 202	Fundamentals of Environmental Chemistry	3	0	0	6
ES 201	Applied Environmental Microbiology and Ecology	3	0	0	6
ES 208	Mass Transfer Processes in Environmental Systems	3	0	0	6
		16	**3**	**0**	**38**

Second Year: Second Semester

	HOURS PER WEEK	4

Code	Name of the Course	Lectures	Tutorials	Practicals	Credits
ES 210	Introduction to Solid Mechanics	3	0	0	6
ES 206	Water Resources and Open Channel Flow	3	0	0	6
ES 212	Environmental Geodesy	3	0	0	6
ES 200 + HS 200	Environmental Studies	3	0	0	6
ES 252	Environmental Chemistry Laboratory	0	0	3	3
ES 253	Environmental Microbiology Lab	0	0.5	3	4
ES 216	GIS Aided Environmental Planning and Management	1	0	4	6
		13	**0.5**	**10**	**37**

Third Year: First Semester

		HOURS PER WEEK			5
Code	**Name of the Course**	**Lectures**	**Tutorials**	**Practicals**	**Credits**
HS 301 HS 303 HS 305 HS 307	Philosophy Psychology Reading Literature Sociology	3	0	0	6
ES 307	Wastewater Engineering	3	0	0	6
ES 315	Solid Waste Management – Basic Principles and Technical Aspects	3	0	0	6
ES 317	Fundamentals of Air Pollution Science and Engineering	3	0	0	6
ES 301	Introduction to Fluid Mechanics	3	0	0	6
ES 319	Computational Laboratory for Environmental Engineers	0	0	3	3
ES 321	Energy and Environmental Sustainability	3	0	0	6
ES 302	Environmental Biotechnology	3	0	0	6
		21	**0**	**3**	**45**

Third Year: Second Semester

		HOURS PER WEEK			**6**
Code	**Name of the Course**	**Lectures**	**Tutorials**	**Practicals**	**Credits**
ES 666	Biological Treatment Technologies	3	0	0	6
ES 308	Solid and Hazardous Waste Laboratory	0	0	3	3
ES 682	Numerical Methods for Environmental Systems	2	0	2	6
ES 674	Aerosol Science and Engineering	3	0	0	6
ES 351	Air Pollution Monitoring Lab	0	0	3	3
	Department Elective-I	3	0	0	6
	Institute Elective-I	2 (3)	1 (0)	0	6
ES 312	Seminar				3
		13 (14)	**1 (0)**	**8**	**39**

Fourth Year: First Semester

	HOURS PER WEEK	7

Code	Name of the Course	Lectures	Tutorials	Practicals	Credits
ES 655	Environmental Management	3	0	0	6
ES 639	Physico-chemical Treatment Technologies	3	0	0	6
ES 653	Environmental Impact Assessment	3	0	0	6
ES 451	Environmental Field Studies	0	0	3	3
ES 407	Simulation & Optimization Techniques in Environmental Systems	3	0	0	6
	Department Elective-II / R&D Project	3	0	0	6
	Institute Elective-II	2 (3)	1 (0)	0	6
		17 (18)	**1 (0)**	**3**	**39**

Fourth Year: Second Semester

	HOURS PER WEEK	8

Code	Name of the Course	Lectures	Tutorials	Practicals	Credits
ES 672	Air Pollution Control Technologies	3	0	0	6
ES 624	Hazardous Waste Management	3	0	0	6
ES 664	Environmental Systems Modelling	3	0	0	6
ES 404	Planning and Design of Environmental Engineering Facilities	1	0	3	5
ES 642	Industrial Wastewater Management and Reuse	3	0	0	6
	Department Elective-III / R&D Project	3	0	0	6
	Department Elective-IV	3	0	0	6
		19	**0**	**3**	**41**

Fifth Year: First Semester

	HOURS PER WEEK	9

Code	Name of the Course	Lectures	Tutorials	Practicals	Credits
ES 645	Environmental Law and Policy	3	0	0	6
ES 593	Dual Degree Project Stage I	0	0	0	36
		3	**0**	**0**	**42**

Fifth Year: Second Semester

	HOURS PER WEEK	10

Code	Name of the Course	Lectures	Tutorials	Practicals	Credits
ES 594	Dual Degree Project II Stage	0	0	0	36
		0	**0**	**0**	**36**

List of Departmental Electives

ES 601	Environmental Health and Safety	3 0 0 6
ES 644	Industrial Pollution Prevention and Clean Technologies	3 0 0 6
ES 658	Environmental Change and Sustainable Development	3 0 0 6
ES 649	Atmospheric Processes and Climate Change	3 0 0 6
ES 654	Groundwater Flow and Contaminant Transport through Porous Media	3 0 0 6
ES 656	Bioremediation - Principles and Applications	3 0 0 6
ES 643	Environmental Statistics and Experiment Design	3 0 0 6
ES 676	Membrane Processes	3 0 0 6
ES 678	Soil Science	3 0 0 6

Up to two R&D projects may be taken in lieu of two Departmental Electives.

List of PG Level Courses

ES 655	Environmental Management	3 0 0 6
ES 672	Air Pollution Control Technologies	3 0 0 6
ES 624	Hazardous Waste Management	3 0 0 6
ES 645	Environmental Law and Policy	3 0 0 6

List of Honors Level Courses

ES 214	GIS for Environmental Planning and Management	3 0 0 6
ES 321	Energy and Environmental Sustainability	3 0 0 6
ES 674	Aerosol Science and Engineering	3 0 0 6
ES 407	Simulation & Optimization Techniques in Environmental Systems	3 0 0 6

COURSE DETAILS

ES 102 WATER QUALITY MANAGEMENT **2 1 0 6**

Water Demand and Quality: Historical introduction to the water and wastewater environment; water quality standards and parameters; assessment of water quality; types of water demand; estimating quantity of water; forecasting population, design period and factors affecting it. Collection and Conveyance of Water: Selecting source(s), various kinds of intake; design of intake structure; design of pumping main; economic sizing of pumping mains. Water Treatment Processes: Clarification - principles of sedimentation; types of settling; discrete particle settling; design of primary sedimentation tank; flocculent type; design of secondary settling tank. Coagulation and flocculation - purpose and action of coagulants. Filtration - theory of granular media filtration; types of filters; slow sand filter and rapid sand filter; mechanism of filtration; modes of operation and operational problems; negative head and air binding phenomena; dual and multimedia filtration. Disinfection - chlorine dioxide; chloramines; ozonation; UV radiation; chlorination. Treatment of groundwater - iron and manganese removal; fluoride removal. Water Distribution Systems: Methods of distribution; design of water distribution systems.

Text/References

Nathanson, J.A., Basic Environmental Technology, Prentice Hall of India, New Delhi, 2002.
Masters, G.M., Introduction to Environmental Engineering and Science, Prentice Hall, India, 1995.
Peavy, H.S., Rowe, D.R., and Tchobanoglous, G., Environmental Engineering, McGraw Hill, Singapore, 1985.
Gray, N.F., Water Technology – An Introduction for Environmental Scientists and Engineers, Elsevier, A division of Reed Elsevier India Private Limited, New Delhi, 2006.

Prerequisites

None

ES 200 ENVIRONMENTAL STUDIES 3 0 0 3

Multidisciplinary nature of environmental studies; Natural Resources: Forest, Water, Mineral, Energy, Land; Sustainable development; Ecosystems; Biodiversity and its conservation.
Environmental Pollution: Air, Water, Soil, Solid and Hazardous Waste Management; Environment and human health; Environmental Legislation.
Global Issues: Climate change, global warming, acid rain, ozone layer depletion.
Social Issues and the Environment: Environmental ethics and economics; Resettlement and rehabilitation of people.

Text/References

Cunningham W.P. and Cunningham M.A., Principles of Environmental Science, Tata McGraw-Hill Publishing Company, New Delhi, 2002.
Dasgupta, P. and Maler, G. (eds.), The Environment and Emerging Development Issues, Vol. I, Oxford University Press, New Delhi, 1997.
Jackson, A.R.W. and Jackson, J.M. Environmental Sciences: The Environment and Human Impact, Longman Publishers, 1996.
Nathanson, J.A., Basic Environmental Technology, Prentice Hall of India, New Delhi, 2002.
Redclift, M. and Woodgate, G. (eds.), International Handbook of Environmental Sociology, Edward Edgar, 1997.
Srivastava, K.P., An Introduction to Environmental Study, Kalyani Publishers, Ludhiana, 2002.

Prerequisites

None

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.

Text/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

Prerequisites

None

ES 202 FUNDAMENTALS OF ENVIRONMENTAL CHEMISTRY 3 0 0 6

Basics of chemistry for Environmental Engineers: Chemical Bonds, reactivity, equilibrium, order and kinetics of chemical reactions, Compound Formation, Importance and nature of Acids, Bases, and Salts, pH, solubility & precipitation, surface and colloidal chemistry, oxidation-reduction reactions,
Water chemistry: Phenomenon like Dissolution, precipitation, complexation, buffering capacity, chelation reactions occurring in natural aquatic systems (Surface and ground water)
pH & acid base equilibrium in natural water
Pollutants in natural aquatic systems
Major water quality parameters Case studies: Toxins (Pesticides, PCBs etc.) in water & Nutrient loading
Atmospheric chemistry: Atmospheric structure & composition;
Different air pollutants & their reactions in the troposphere;
Photochemistry and aqueous chemistry in the atmosphere
Energy balance in the atmosphere & importance of Metrology for pollution accumulation & dispersion
Stratospheric chemistry: Ozone layer formation & destruction, PSCs, other important phenomenon
Case study: Urban air pollution, heat island, smog & ground level ozone, GHG & climate change
Soil Chemistry: Nature & composition of soil, weathering phenomenon; important reactions at soil surface, Fertilizers & nutrient enrichment, soil pollutants, nutrient loss & degradation of quality, soil-water interface reactions.
Case study: Soil pollution by solid waste
Ocean Chemistry: Ocean composition, Ocean as CO2 reservoir, salt-water balance, ocean-air interactions

Text/References

Swayer, C.N., McCarty, C.N. and Parkin, G.F., Chemistry for Environmental Engineering; 4th Ed., Tata McGraw-Hill, New Delhi, 2000.
Manahan, S.E., Fundamentals of Environmental Chemistry, Lewis Publishers, Inc. Boca Raton, 1993.
Snoeyink, V.L. and Jenkins, D., Water Chemistry, John Wiley, New York, 1980.
Sposito, G., Surface Chemistry of soils, Oxford University Press, NY, 1984.
Andrews, J. E., Brimblecombe, P., Jickells, T.D., Liss, P.S. and Reid, B.J., An Introduction to Environmental Chemistry, Blackwell Publishing, 2004.

Prerequisites

None

ES 203 (Minor) WATER AND WASTEWATER ENGINEERING 3 0 0 6

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.

Text/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.

Maximum Registered Students 40

Prerequisites (no prerequisite for minor courses as per the Institute rule)

None

ES 204 (Minor) ENVIRONMENTAL CHEMISTRY 3 0 0 6

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; Photo-dissociation and free radical reactions; Chemistry of precipitation; Acid rain.

Text/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.

Maximum Registered Students 20

Prerequisites (no prerequisite for minor courses as per the Institute rule)

None

ES 206 WATER RESOURCES AND OPEN CHANNEL FLOW 3 0 0 6

Precipitation; Streamflow measurement; Runoff; Hydrographs; Floods and flood routing; Basic classification and design of open channels; Concepts of specific energy, specific force and critical depth; Gradually varied flow; Hydraulic jump; Control channel and transitions; Dispersion in open channels; Groundwater

Text/References

French, R.H., Open Channel Hydraulics, McGraw Hill Book Co., New York, 1986.
Chaudhry, M. H., Open Channel Flow, Englewood Cliffs : Prentice Hall, 1993.
Chanson, H., Hydraulics of open channel flow: an introduction, Oxford : Butterworth-Heinemann, 1999.
Subramanya, K., Engineering hydrology, New Delhi: Tata McGraw Hill Co, 1994.
Brebbia, C.A. and Pinder, G.F., Advances in water resources, CML Pub., 1980.
Linsley, R.K. and Paulhus, J.L.H., Water Resources Engineering, McGraw Hill Book Co., 1992.

Prerequisites

None

ES 208 MASS TRANSFER PROCESSES 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, Interphase 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.

Text/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., Process Dynamics in Environmental Systems, John Wiley & Sons Inc., 1996.
Fogler, H.S., Elements of Chemical Reaction Engg., 2nd Ed., Prentice-Hall India, 2001.

Prerequisites

None

ES 209 DATA ANALYSIS AND INTERPRETATION 2 1 0 6

Sources of data, data representation, measurement of data, gathering of data and design of experiments, errors in measurement bias and random error); multivariate data and regression; posing statistical hypothesis.
Elementary probability and statistics (random variables, distribution, central limit theorem), population sampling, confidence intervals; elementary hypothesis testing; exposure to standard models of physical processes, parameter estimation using least squares.

Text/References

Montgomery, D.C. and Runger, G.C., Applied Statistics and Probability for Engineers, John Wiley and Sons, 2003.
Mendenhall, W., Beaver, R.J. and Beaver, B.M. Introduction to Probability and Statistics, 14th Ed., Brooks/Cole, Cengage Learning, 2012.

Prerequisites

None

ES 210 INTRODUCTION TO SOLID MECHANICS 3 0 0 6

Rigid and deformable solids; Method of sections for evaluating internal forces in bodies - review of free body diagrams; Concept of stress - normal and shear stresses; State of stress; Concept of strain - normal and shear strains; State of strain; Hookes law; Constitutive relations; Axially loaded members, force and deflections; Indeterminate systems and compatibility conditions; Simple indeterminate systems and lack of fit problems; Generalized Hookes law; Stress in cylindrical and spherical shells; Thin-Walled Pressure Vessels; Torsion of circular shafts - determinate and simple indeterminate systems. Elastic theory of bending of beams; Shear force and bending moment diagrams; Bending and shearing stresses in beams of symmetrical cross-section; Concept of shear flow and shear centre; Principle of superposition and its limitations. Transformation of plane stress and strain; Principal stresses and strains; Mohrs circle. Bending deflection of beams by direct integration method; Application of direct integration method to simple indeterminate systems. Elastic buckling of compression members.

Text/References

Beer, F.P., Johnston, E.R. and DeWolf, J.T., Mechanics of Materials, 3rd Ed., Tata McGraw Hill, New Delhi, 2004.
Popov, E.P., Engineering Mechanics of Solids, 2nd Ed., Prentice Hill, New Delhi, 1999.
Shames, I.H. and Pitarresi, J.M., Introduction to the Solid Mechanics, 3rd Ed., Prentice Hill, New Delhi, 1989.
Gere, J.M., Mechanics of Materials, 5th Ed., Brooks/Cole, Chennai, 2001.
Crandall, S.H., Dhal, N.C. and Lardner, T.J., Mechanics of Solids: An Introduction, McGraw Hill, Tokyo, 1994.
Kazimi, S.M.A., Solid Mechanics, Tata McGraw-Hill, New Delhi, 1981.

Prerequisites

None

ES 253 ENVIRONMENTAL MICROBIOLOGY LABORATORY 0 0.5 3 4

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

Text/References

Pepper, I. L., Gerba, C. P. and Brendecke, J. W., Environmental Microbiology- A Laboratory Manual, Academic Press Inc., San Diego, USA, 1995.
Csuros, M. and Csuros, C., Microbiological Examination of Water and Wastewater, Lewis Publishers, CRC Press, Boca Raton, Florida, USA, 1999.
ESED Lab Manuals.

Prerequisites

None

ES 212 ENVIRONMENTAL GEODESY 3 0 0 6

Fundamentals of Surveying, Levelling and Levelling Instruments, Traversing compass, theodolite and plane table, Tachometry triangulation, Contouring, Errors and adjustments, Area and volumes measurements.

Text/References

Punmia, B.C., Surveying, 11th edition, Vol. I and II, Laxmi Publishers, New Delhi, 1988.
Davis, R.E., Foote, F.S. and Kelly, J.W., Surveying; Theory and Practice, 7th edition, McGraw-Hill Book Co., NY, 1980.
Clark, D., Plane and Geodetic Surveying, Constable, London, Vol. I and III.

Prerequisites

None

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

Introduction, definitions and uses of GIS, Hardware for GIS, Architecture of type of data formats, various tasks of GIS: input: sources such as topographic, hydrographic, military, remote sensing, satellites, resource surveys; verification, transformation and manipulation; storage of spatial data and database structures in GIS; Query and data analysis and spatial modeling: DEMS, DTMS, Surfaces, TINS and Networks ; Visualization and display using graphical user interface: maps, graphs, reports, integration with three dimensional views, photographic images and multimedia.
Applications of GIS and 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.

Text/References

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.
DeMers, M.N., Fundamentals of geographic information systems, John Wiley, New York, 1997.
Burrough, P.A. and McDonnell, R.A., Principles of geographical information systems, Oxford University Press, Oxford, 1998.
Delaney, J., Geographical information systems: an introduction, Oxford University Press, Oxford, 1999.

Prerequisites

None

ES 252 ENVIRONMENTAL CHEMISTRY LABORATORY 0 0 3 3

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

Text/References

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

Prerequisites

None

ES 301 INTRODUCTION TO FLUID MECHANICS 3 0 0 6

Definition and Properties of fluids; Fluid pressure and its measurement; Hydrostatic force on plane, inclined and curved submerged surfaces; Buoyancy and Floatation; Kinematics of fluid flow:; Fluid dynamics: Flow through orifices; weir and notches; Flow through pipes; Flow of compressible Fluids; Continuity, Momentum and Energy Equations; Hydraulic machines.

Text/References

Streeter, V.L. and Wylie, E. B., Fluid Mechanics, McGraw Hill Book Co.,1983.
Subramanya, K., Open Channel Hydraulics, Tata McGraw Hill Co., 1998.
Giles, R. V., Schaum's outline of theory and problems of fluid mechanics and hydraulics, Schaum publication, New York, 1994.

Prerequisites

None

ES 302 ENVIRONMENTAL BIOTECHNOLOGY 3 0 0 6

Nature of biological processes and their application to industries such as fermentation technology; enzyme technology and their environmental applications:
Bioprocesses for cleaner production, sustainable development and economic benefits: biobleaching in pulp and paper industries; bioleaching (biomining) of ores for recovery of precious metals; cleaner biotechnologies in oil agro industries
Biological fuel generation: Biohydrogen, biomethanation and alcohol production
Biotechnology for enhancing agricultural productivity: Bioinsecticides- structure, function and mode of action
Cleaner production activities in Asia: Case studies on demonstration projects, Pollution control biotechnology: Application of microorganisms, enzymes and plants (phytoremediation) for treatment of domestic and industrial wastewater and soil; immobilized microorganisms in waste treatment; use of immobilized cells and enzymes as biosensors;
Genetic engineering: Introduction to recombinant DNA technology, safety, social, moral and ethical considerations; applications of recombinant technology for enhanced biodegradation and engineer organism with novel catabolic capabilities; detection of pathogens and parasites in wastewater and environmental samples using nucleic acid probes and polymerase chain reaction (PCR).
Public perception of biotechnology, protection of biotechnological inventions, looking to the future of biotechnology.

Text/References

Bhattacharya, B. C. and Banerjee R., (2007) Environmental Biotechnology, Oxford University Press, India
Vallero, D.A.V., (2010) Environmental Biotechnology: A Biosystems Approach, 2nd Ed., Elsevier.
Smith, J. E. (2004) Biotechnology, 3rd Edition, Cambridge University Press, UK

Prerequisites

None

ES 303 (Minor) MUNICIPAL SOLID AND BIOMEDICAL WASTE MANAGEMENT 3 0 0 6

Solid waste management: Sources, Composition and Properties of Municipal Solid Waste, Engineering principles; Generation of solid waste; Onsite handling, storage and processing including segregation; Collection of solid waste; Transfer and transport; Processing technique and equipment; Recovery of resources; Conversion products and energy; Composting; Recycling; Incineration and pyrolysis; Disposal of solid waste including sanitary landfill, planning, siting, design, closure and post-closure monitoring; Regional/Integrated solid waste management related issues. Biomedical waste : Regulatory framework, categorization; generation, collection, transport, treatment and disposal.

Text/References

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

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.

Maximum Registered Students 20

Prerequisites (no prerequisite for minor courses as per the Institute rule)

None

ES 306 (Minor) ENVIRONMENTAL SYSTEMS MODELLING 3 0 0 6

Definition; Classification; Examples of models for environmental systems. 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 soil and ground water; Utility of environmental models for forecasting. Computational methods in environmental modelling.

Text/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., Schroeder, E.D., Water Quality, Addison – Wesley Publishing Company, Reading, Massachusetts, 1987.

Maximum Registered Students 05

Prerequisites (no prerequisite for minor courses as per the Institute rule)

None

ES 307 WASTEWATER ENGINEERING 3 0 0 6

Wastewater Generation, Wastewater Collection in Urban Areas: Design of Sanitary Sewer, Design of Storm Water Sewers, Construction of Wastewater Conveyance System, Sewer material and Joints, Sewer Appurtenances, Sewage Pumping Station, Construction of Sewers, Operation and Maintenance of Municipal Sewer System, Municipal Wastewater Treatment Plant: Screening, Grit Chambers, Sedimentation, Activated Sludge Process, Trickling Filters, Sludge Disposal, Disposal of Effluent, Few Typical Examples

Text/References

Masters, G.M., Introduction to Environmental Engineering and Science, Prentice Hall, India, 1995.
McGhee, T.J., Water Supply and Sewerage, McGraw Hill, Singapore, 1995.
Peavy, H.S., Rowe, D.R., and Tchobanoglous, G., Environmental Engineering, McGraw Hill, Singapore, 1985.
Davis, M.L. and Cornwell, D.A., Introduction to Environmental Engineering, McGraw Hill, Singapore, 1991.
Metcalf & Eddy, Inc, Tchobanoglous G. and Burton, F.L., Wastewater Engineering: Treatment, Disposal and Reuse, 4th ed., Tata McGraw Hill, New Delhi, 2003.

Prerequisites

None

ES 308 SOLID AND HAZARDOUS WASTE LABORATORY 0 0 3 3

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

Text/References

CPHEEO Manual on Municipal Solid Waste Management, 2000.

Prerequisites

None

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

Text/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.

Prerequisites

None

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.

Text/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.

Prerequisites

None

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.

Text/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)

Prerequisites

None

ES 321 ENERGY AND ENVIRONMENTAL SUSTAINABILITY 3 0 0 6

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

Text/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.

Prerequisites

None

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.

Text/References

I.S. Codes: IS 5182, IS 11255, IS 8829, IS 3028.
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.

Prerequisites

None

ES 401 (Minor) ENVIRONMENTAL MANAGEMENT 3 0 0 6

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. Successful Case Studies.

Text/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.

Maximum Registered Students 10

Prerequisites (no prerequisite for minor courses as per the Institute rule)

None

ES 404 PLANNING AND DESIGN OF ENVIRONMENTAL ENGINEERING FACILITIES **1 0 3 5**

Planning, design and drawing of water supply systems, water treatment units and sludge treatment units.
Planning, design and drawing of wastewater collection system, wastewater treatment units and sludge treatment 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, Disposal and Reuse, 4th ed., Tata McGraw Hill, New Delhi, 2003.
Qasim, S.R., Wastewater treatment Plants – Planning, design and operation, CRC Press, 2nd Edition, 1999.

Prerequisites

ES 307: Wastewater Engineering

ES 407 SIMULATION AND OPTIMIZATION TECHNIQUES IN ENVIRONMENTAL SYSTEMS **3 0 0 6**

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.

Prerequisites

None

ES 444 (Minor) INDUSTRIAL POLLUTION PREVENTION AND CLEAN TECHNOLOGIES **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.

Text/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.

Maximum Registered Students 10

Prerequisites (no prerequisite for minor courses as per the Institute rule)

None

Remarks: ES 444 and ES 458 is offered in alternate year

ES 451 ENVIRONMENTAL FIELD STUDIES 0 0 3 3

Study of natural setting: description of the location with drawing; recording temperature, light, sound & rainfall; description of soil properties (physical, chemical and biological) and soil profiling; extraction, isolation and enumeration of bacteria, fungi, protozoans, nematodes, micro-arthropods; description of number and kinds of plants and animals; identification of organisms into genus and species; recording and measuring emergence and growth of plants ; analysis of vegetation data, frequency; descriptions of animals found at ground level as compared to 12 inches above or 3 inches below ground; measurement and calculation of biodiversity indices based on plants and animals. Observations of interactions (interdependence) among organisms: prey-predator relationship; pollination and seed dispersal; social interactions and structures; symbiotic relationships (such as plants and fungi) Field trips, movie screening, photography, audio-video recordings of plants, animals and microorganisms; backyard bird watching, design of bird feeders to attract birds, observations of bird behaviour, factors that affect them, inter and intra species behaviour, habitats and niche; presentation of findings: posterboard, graphicwork, artwork, photographs, audio-video recordings, personal thoughts and comments during the field work. Methods for sampling of population, determining population size, distribution of organisms. Ecological methods and Analyses: basic ecological research protocols; ecological informatics using state-of-the-art data management tools (GPS and GIS use); introduction to measures of energy flux, nutrient and carbon cycling in forest ecosystems
Soil and water ecotoxicology and pollution

Texts/References:

Begon M., Ecology: From individuals to ecosystems, 4th edition, Malden, MA : Blackwell Publishers, 2006.
Quinn, G.P. and Keough, M.J., Experimental design and data analysis for biologists, Cambridge University Press, 2002.
Smith, R.L. and Smith, T.M., Ecology & field biology, San Francisco, USA, Benjamin Cummings, 2001.
Krebs C.J., Ecological methodology, 2nd edition, Menlo Park, California, USA, Benjamin Cummings, 1999.
Smith, R.L., Study guide to accompany ecology and field biology, 5th edition, Menlo Park, California, USA, B Benjamin Cummings, 1996.
Smith, R.L., Ecology and field biology, 5th edition, New York, USA, HarperCollins College Publishers, 1996.

Prerequisites

None

ES 458 (Minor) ENVIRONMENTAL CHANGE AND SUSTAINABLE DEVELOPMENT 3 0 0 6

(previously the course number was ES 658)

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.

Text/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.

Maximum Registered Students 10

Prerequisites (no prerequisite for minor courses as per the Institute rule)

None

Remarks: ES 444 and ES 458 will be offered in alternate year

ES 601 ENVIRONMENTAL HEALTH AND SAFETY 3 0 0 6

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

Occupational Health and Hygiene: Physical hazards - Noise and vibration, Ionizing and non-ionizing radiations, Health effects, surveying methods, Control measures and protective equipment Chemical Hazards – Hazard identification, TLV for air, gas and chemical contaminants, Assessment of physical and chemical hazards; Occupational Health - Workplace health hazards, Industrial toxicology, and Risk assessment.

Safety performance: Indian and International standards; Hazard analysis - Cost effectiveness in hazard elimination, logical analysis – HAZOP; Probabilistic reliability considerations.

Safety management techniques: Safety inspection – safety action, safety survey disaster control, Fire hazard and firefighting, Case study in construction, chemical and oil/gas industry.

Environmental Monitoring and Pollution Control:

Environmental exposure standards, Human exposure and dose assessment, Study designs, Environmental monitoring of air, water, food, soil and microorganisms, Personal monitoring.

Air, Water and Solid waste pollutants' classification, major sources, control and mitigation and transport in the environment.

Texts/References:

Tillman C., Principles of Occupational Health and Hygiene, Allen & Unwin, NSW, Australia, 2008

Berglund M., Elinder C.-G., Jarup L. Human Exposure Assessment, World Health Organization (WHO), Geneva, 2001

Leelakrishnan P., Environmental Law in India, LexisNexis, Gurgaon, India, 2016

Panda B., Industrial Safety, Health Environment and Security, University Sciences Press, New Delhi, 2013

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

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

Prerequisites

None

ES 624 HAZARDOUS WASTE MANAGEMENT 3 0 0 6

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.

Prerequisites

None

ES 639 PHYSICO-CHEMICAL TREATMENT TECHNOLOGIES 3 0 0 6

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.

Prerequisites

None

ES 642 INDUSTRIAL WASTEWATER MANAGEMENT AND REUSE 3 0 0 6

Tertiary treatment of industrial wastewater including removal of nitrate, sulfate, 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:

Eckenfelder, W.W. Jr., Industrial Water Pollution Control, 3rd Edition, McGraw Hill International Edition, Singapore, 2000.
Arceivala, S.J. and Asolekar, S.R., Wastewater Treatment for Pollution Control and Reuse, 3rd Edition, Tata McGraw Publishing Co. Ltd., New Delhi, 2006.
Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal and Reuse. 3rd Edition, McGraw-Hill Book Company, Singapore, 1991.

Prerequisites

None

ES 643 ENVIRONMENTAL STATISTICS AND EXPERIMENT DESIGN 3 0 0 6

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., Beaver, R.J. and Beaver, B.M. Introduction to Probability and Statistics, 14th Ed., Brooks/Cole, Cengage Learning, 2012.
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.

Prerequisites

None

ES 644 INDUSTRIAL POLLUTION PREVENTION AND CLEAN TECHNOLOGIES **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:

Asolekar, S.R. and Gopichandran, R. "Preventive Environmental Management – An Indian Perspective" Foundation Books Pvt. Ltd., New Delhi, 2005.

Bishop, P.E., Pollution Prevention: Fundamentals And Practice, McGraw Hill, 2000.

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.

Freeman, H.M., Industrial Pollution Prevention Handbook, McGraw Hill, 1995.

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

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

Prerequisites

None

ES 645 ENVIRONMENTAL LAW AND POLICY 3 0 0 6

Environmental regulations and policies; Environmental protection laws and acts; 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.
Welford, R., Corporate Environmental Management, Earthscan Publications Ltd., London, 1988.

Prerequisites

None

ES 649 ATMOSPHERIC PROCESSES AND CLIMATE CHANGE 3 0 0 6

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.

Prerequisites

None

ES 653 ENVIRONMENTAL IMPACT ASSESSMENT 3 0 0 6

Evolution of EIA; EIA at project; Regional and policy levels; Strategic EIA; EIA process; Screening and scoping criteria; Rapid and comprehensive EIA; Specialised areas like environmental health impact assessment; Environmental risk analysis; Economic valuation methods; Cost-benefit analysis; Expert system and GIS applications; Uncertainties.

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.

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.

Prerequisites

None

ES 654 GROUNDWATER FLOW AND CONTAMINANT TRANSPORT THROUGH POROUS MEDIA 3 0 0 6

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:

Domenico, P.A., and Schwartz, F.W., Physical and Chemical Hydrogeology, John Wiley and Sons, New York, 1990.
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 Interscience, New York, 1981.
Freeze, R.A., and Cherry, J.A., Groundwater, Prentice Hall, Englewood Cliffs, New Jersey, 1979.

Prerequisites

None

ES 655 ENVIRONMENTAL MANAGEMENT 3 0 0 6

Introduction to Environmental Management; Corporate and international charters and protocols; Environment Risk assessment; Industrial ecology, Pollution prevention and Waste minimization; Sustainable development; Life cycle assessment; Environmental Management Systems, Environmental Design; Environmental auditing; Eco-labelling of products; Performance indicators.
Spatial Environmental Planning, Environmental Planning and Management at various levels of government ranging from Federal to State to Regional to Municipal levels. Planning principles, co-ordination, tools, decision making and execution. Information management instruments, planning instruments, co-ordination instruments, Nature protection and conservation. Case studies from India and other parts of the world.
Environmental management systems particularly ISO 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.

Prerequisites

None

ES 656 BIOREMEDIATION – PRINCIPLES AND APPLICATIONS 3 0 0 6

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.

Texts/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.

Prerequisites

None

ES 658 ENVIRONMENTAL CHANGE AND SUSTAINABLE DEVELOPMENT **3 0 0 6**

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:

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.

Prerequisites

None

ES 664 ENVIRONMENTAL SYSTEMS MODELLING 3 0 0 6

Definition; Classification; Examples of models for environmental systems.
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.

Prerequisites

None

ES 666 BIOLOGICAL TREATMENT TECHNOLOGIES 3 0 0 6

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.

Text/References

Arceivala, S.J. and Asolekar, S.R., Wastewater Treatment for Pollution Control and Reuse, 3rd Edition, Tata McGraw Publishing Co. Ltd., New Delhi, 2006.
Rittmann, B.E. and McCarty, P.L. (2001) Environmental Biotechnology: Principles and Applications, McGraw Hill Education, Pvt. Ltd., New Delhi.

Metcalf and Eddy, Wastewater Engineering: Treatment, Disposal and Reuse, 4thEdition, McGraw-Hill Book Company, Singapore, 2003.
Gray, N.F., Biology of Wastewater Treatment, Oxford University Press, London, 1989.

Prerequisites

ES 201: Applied Environmental Microbiology and Ecology

ES 672 AIR POLLUTION CONTROL TECHNOLOGIES 3 0 0 6

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:

de Nevers, N., Air Pollution Control Engineering, McGraw Hill Book Company, Singapore, 2000.
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.
Cheremisinoff, P., Encyclopaedia of Environmental Control Systems, Gulf Publishing Company, Houston, 1989.
Flagan, R.C., and Seinfeld, J.H., Fundamentals of Air Pollution Engineering, Prentice Hall, New Jersey, 1988.
Compilation of Air Pollutant Emission Factors, AP-42, USEPA, Washington D.C., 1984.

Prerequisites

ES 317: Fundamentals of Air Pollution Science and Engineering

ES 674 AEROSOL SCIENCE AND ENGINEERING 3 0 0 6

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.

Prerequisites

ES 317: Fundamentals of Air Pollution Science and Engineering

ES 676 MEMBRANE PROCESSES 3 0 0 6

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, Royal Society of Chemistry, Cambridge, 2000.
Belfort, G., Synthetic membrane processes: fundamentals and water applications edited by Academic Press, Orlando, 1984.

Prerequisites

None

ES 678 SOIL SCIENCE 3 0 0 6

Definition of soil and soil properties; Nature and arrangement of soil solids; Measurement of physical properties of the solid phase; Liquid phase characteristics and measurements: potential; capillarity; hysteresis; Prediction of soil moisture characteristics; Composition and properties of the air phase.
Fundamentals of unsaturated fluid flow; hydraulic conductivity measurement and prediction; Infiltration of water; Movement of non-aqueous fluids in soils; Two-phase transport properties; Richard's equation; Immiscible displacement.
Chemical composition of soils; Soil minerals—structure and surface functional groups; Mineral solubility and weathering; Surface chemistry and electric double layer; Composition and chemistry of soil organic matter; Inorganic and organic contaminant sorption processes.

Texts/References:

Jury, W.A., W.R. Gardner and W.H. Gardner, Soil Physics, 5th Ed. John Wiley, New York, 1991.
Essington, M.E., Soil and Water Chemistry—An Integrative Approach, CRC Press, Boca Raton, 2004.
Sposito, G., The Chemistry of Soils, Oxford University Press, New York, 1989.

Prerequisites

None

ES 682 NUMERICAL METHODS FOR ENVIRONMENTAL SYSTEMS 2 0 2 6

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.

Prerequisites

None