Syllabus for Two Years Programme

in

M.Sc. in Engineering Mathematics

DEPARTMENT OF MATHEMATICS

INSTITUTE OF CHEMICAL TECHNOLOGY

(University Under Section-3 of UGC Act, 1956)

Elite Status and Center for Excellence

Government of Maharashtra

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INSTITUTE OF CHEMICAL TECHNOLOGY

(University Under Section-3 of UGC Act, 1956)

DEPARTMENT OF MATHEMATICS

A. Semester wise pattern of the M.Sc. in Engineering Mathematics Course

SEMESTER I

SUBJECT CODE	SUBJECT	L	T	C	Marks
MAT 2201	Applied Linear Algebra	3	1	4	100*
MAT 2202	Advanced Calculus	3	1	4	100
MAT 2203	Differential Equations I	2	1	3	50**
MAT 2301	Applied Statistics I	3	1	4	100
MAT 2204	Algebra	3	1	4	100
MAT 2401	Numerical Methods I	2	1	3	50
MAP 2501	Computer Programming (Python/C/JAVA)	4 (L)	0	2	50
	Total	**20**	**6**	**24**	**550**

* Class tests 20 marks + Mid. Sem. 30 marks + End Sem. 50 marks
** Class tests 10 marks + Mid. Sem.15 marks + End Sem.25 marks

SEMESTER II

SUBJECT CODE	SUBJECT	L	T	C	Marks
MAT 2205	Optimization Techniques	3	1	4	100
MAT 2206	Complex Analysis and Mathematical Methods	3	1	4	100
MAT 2207	Advanced Real Analysis	3	1	4	100
MAT 2302	Applied Statistics II	3	1	4	100
MAT 2208	Differential Equations II	2	1	3	50
MAT 2402	Numerical Methods II	2	1	3	50
MAP 2502	Software Lab I	4 (L)	0	2	50
	Total	**20**	**6**	**24**	**550**

SEMESTER III

SUBJECT CODE	SUBJECT	L	T	C	Marks
MAT 2209	Number Theory	3	1	4	100
MAT 2304	Machine Learning	3	1	4	100
MAT 2102	Momentum, Heat & Mass Transfer	3	1	4	100
MAP 2503	Software Lab II	4		2	50
MAT 2303	Applied Statistics III	3	1	4	100
	Elective I	3	1	4	100
MAP 2701	Seminar	3		2	50
	Total	**22**	**5**	**24**	**600**

SEMESTER IV

SUBJECT CODE	SUBJECT	L	T	C	Marks
MAT 2305	Stochastic Processes	3	1	4	100
MAT 2105	Computational Fluid Dynamics	3	1	4	100
MAT 2210	Applied Functional Analysis	3	1	4	100
MAT 2211	Coding theory and Cryptography	3	1	4	100
MAP 2801	Project	8		4	100
	Elective II	3	1	4	100
	Total	**23**	**5**	**24**	**600**

Abbreviations

C - No. of credits per course
L – No. of lectures per week per course
T – No. of tutorial hours week per course

Evaluation and Exam patterns:

Each theory course will be evaluated based on three continuous assessment tests (20%), mid-semester (30%) and end-semester exams (50%).

Lab courses have two components of evaluation: 50% marks for class work and 50% marks of end semester assessment.

B.

Detailed Syllabus of the M.Sc. in Engineering Mathematics

SEMESTER - I

MAT 2201: APPLIED LINEAR ALGEBRA

Review of Vector Spaces, Subspaces, Linear dependence and independence, Basis and dimensions. (6 hrs)

Basic concepts in Linear Transformations, Use of elementary row operations to find coordinate of a vector, change of basis matrix, matrix of a linear transformations and subspaces associated with matrices. (8hrs)

Inner Product Spaces, Orthogonal Bases, Gram-Schmidt Orthogonalization, QR Factorization, Normed Linear Spaces. (12hrs)

Matrix Norm, condition numbers and applications. (4hrs)

Eigenvalue and Eigenvectors, Diagonalization and its applications to ODE, Dynamical Systems and Markov Chains, Positive Definite Matrices and their applications, Computation of Numerical Eigenvalues. (12hrs)

Singular Value Decomposition, Matrix Properties via SVD, Projections, Least Squares Problems, Application of SVD to Image Processing. (10hrs)

Adjoint operators, Normal, Unitary, and Self-Adjoint operators, Spectral theorem for normal operators. (8hrs)

References:

1. S. Kumaresan, Linear Algebra – A Geometric Approach, Prentice Hall India
2. Carl D. Mayer , Matrix Analysis and Applied Linear Algebra, SIAM
3. David C Lay, Linear Algebra and its Applications, Addition-Wesley
4. G. C. Cullen, Linear Algebra with Applications, Addison Wesley
5. Richard Bronson and Gabriel B. Costa, Matrix Methods, Academic Press

6. G. Strang,Linear Algebra and its Applications, Harcourt Brace Jovanish
7. Robert Beezer, Linear Algebra, a free online book.

MAT 2202: ADVANCED CALCULUS

Differential Calculus: Functions of several vari, Level Sets, Convergence of sequences of several variables, Limits and continuity, Derivatives of scalar fields, Directional derivatives, Partial derivatives, Total derivative, Gradient of scalar fields, Tangent planes.

(12hrs)

Derivatives of vector fields, curl, divergence, Chain rules for derivatives, Derivatives of functions defined implicitly, Higher order derivatives, Taylor's theorem and applications.

(8hrs)

Applications of Differential Calculus: Local Maxima, Local Minima, Saddle points, Stationary points, Lagrange's multipliers, Inverse function theorem, Implicit function theorem.
(14hrs)

Multiple Integrals: Double and triple integrals, Iterated integrals, Change of variables formula, Applications of multiple integrals to area and volume etc. (10hrs)

Line Integrals: Paths and line integrals, Fundamental theorems of calculus for line integrals, Line integrals of Vector fields, Green's theorem and its applications, Conservative Vector Fields (10hrs)

Surface Integrals: Parametric representation of a surface, Stokes' theorem, Gauss' divergence theorem (6hrs)

References:

1. T. M. Apostol, Calculus Vol. II, 2nd Ed., John Wiely& Sons, 2003.
2. T. M. Apostol, Mathematical Analysis, 2nd Ed., Narosa Pub. House
3. H. M. Edwards, Advanced Calculus-A Differential Forms Approach, Birkhäuser
4. Susane Jane Colly, Vector Calculus, 4th Edition, Pearson
5. J. E. Marsden, A. Tromba, & A. Weinstein, Basic Multivariable Calculus, Springer-Verlag

MAT 2203: DIFFERENTIAL EQUATION I

Review of first and second order ODEs. (4hrs)

Existence and Uniqueness theorems for first order ODEs. (2hrs)

Higher order Linear ODE with constant and variable coefficient. Solutions of Initial and Boundary value problems. (12hrs)

Power series method of solving ODE's and special functions, System of linear ODEs. (12hrs)

Integral Equations: Classification of Integral Equation, Converting IPV to Volterra Integral Equation and vice-versa, Converting BVP to Fredholm Integral Equation and vice-versa, Solution of Volterra and Fredholm Integral Equations using Adomian Decomposition method and successive approximation and series method. (15hrs)

References:

1. William E. Boyce, Richard C. DiPrima, Elementary Differential Equation, Wiley
2. E. A. Coddington, An Introduction to Ordinary Differential Equations, PHI
3. G. F. Simons, S. G. Krantz, Differential Equation, Theory Techniques and Practice Tata McGraw-Hill
4. Zill, Dennis G, A First Course in Differential Equations, Cengage Learning
5. Abul-Majid Wazwaj, Liner and Nonlinear Integral Equation, Springer

MAT 2301: APPLIED STATISTICS-I

Probability: Introduction to probability, axiomatic definition, Partitions, total probability and Bayes theorem. (10hrs)

Random variables and distribution functions, discrete and continuous distribution function, Multiple random variables, covariance and correlation, expectation, moments, conditional expectation, probability inequalities. (12hrs)

Some important discrete and continuous distributions, binomial, Poisson, normal, gamma, exponential etc. convergence concepts, Central limit theorem, normal and Poisson approximation to binomial. (12hrs)

Statistics: Introduction to Statistics and data description,Concept of population and sample, parameters. Concept of sampling distributions, chisquare, t and F distribution. (8hrs)

Point estimation: properties of estimators, unbiasedness, sufficiency, completeness, maximum likelihood estimation, method of moments, comparing two estimators, factorization theorem, (8hrs)

Interval estimation: confidence interval estimation, single sample and two sample confidence interval, prediction interval. (10hrs)

References:

1. P.G. Hoel, S.C. Port and C.J. Stone, Introduction to Probability, Universal Book Stall, New Delhi, 1998.

2. K. Md. Ehsanes Saleh and V. K. Rohatgi. An Introduction to Probability and Statistics. Wiley
3. G. Casella and R. L. Berger. Statistical Inference. Duxbury Press. 2011
4. W. W. Hines, D. C. Montgomery, Probability and Statistics in Engineering. John Wiley.
5. V. Robert Hogg, T. Allen Craig. Introduction to Mathematical Statistics, McMillan Publication.

MAT 2204: ALGEBRA

Groups, subgroups and factor groups.Lagrange's Theorem, Homomorphisms, normal subgroups, Quotients of groups. (10 hrs)
Basic examples of groups: symmetric groups, matrix groups, group of rigid motions of the plane and finite groups of motions. Cyclic groups, generators and relations, Cayley's Theorem (10 hrs)
Group actions, SylowTheorems,Direct products Structure Theorem for finite abelian groups. (10 hrs)
Rings: Definition and Basic concepts in rings, Examples and basic properties. Zero divisors, Integral domains, Fields, Characteristic of a ring, Quotient field of an integral domain. Subrings, Ideals, Maximal ideal, Prime ideal, definition and examples. Quotient rings, Isomorphism theorems. (15hrs)

Fields: Ring of polynomials. Prime, Irreducible elements and their properties.Eisensteins irreducibility criterion and Gauss's lemma, UFD, PID and Euclidean domains, Ring of polynomials over a field. Field extensions.Algebraic and transcendental elements, Algebraic extensions.Splitting field of a polynomial. Algebraic closure of a field (15hrs)

References:

1. J. A. Gallian Contemporary Abstract Algebra, 4th Edition, Narosa, 1999
2. Fraleigh J.B., A First Course in Abstract Algebra", 7th Ed. Pearson Education, 1994.
3. D. S. Dummit and R. M. Foote, Abstract Algebra, 2nd Edition, John Wiley, 2002.
4. M. Artin, Algebra, Prentice Hall of India, 1994.
5. G. Santhanam, Algebra, Narosa, 2016.

MAT 2401: NUMERICAL METHODS I

Error Analysis and difference table (4hrs)

Solution of Algebraic and transcendental equation: Bisection method, Secant method, Regula-Falsi method, Newton-Raphson method and convergence criteria for these methods. (6hrs)

Numerical solution of linear equations: Gauss-Jacobi, Gauss-Seidel iteration, Successive over relaxation(SOR) and under relaxation method and convergence criteria for these methods. Numerical solution of Eigenvalue problems (10hrs)

Interpolations: Lagrange Interpolation, Divided difference, Newton's backward and forward interpolation, Central difference interpolation (Hermite), Cubic Spline interpolation, Numerical Differentiation and Integration(Trapezoidal rule, Simpsons 1/3 ,3/8 rules). Gauss quadrature formula (10hrs)

Numerical solution of initial value problems (first and higher order ODE): Taylor series, Runge-Kutta explicit methods(second and forth order), Predictor–Corrector methods (Adam-Basforth, Adam-Moulton method). Stiff differential equations and its solutions with implicit methods, Numerical Stability, Convergence and truncation Errors for the different methods. (10hrs)

Numerical Solution of boundary value problems using initial value method and Shooting techniques (Newton-Raphson and Principle of superposition method). (5hrs)

Reference:

1. M. K. Jain, S. R. K. Iyengar and R.K.Jain: Numerical methods for scientific and engineering computation, Wiley Eastern Ltd. 1993, Third Edition.
2. S.S. Sastry, Introductory methods of Numerical analysis, Prentice- Hall of India, New Delhi (1998)
3. D.V. Griffiths and I.M. Smith, Numerical Methods for Engineers, Blackwell Scientific Publications (1991).
4. S.D. Conte and C. deBoor, Elementary Numerical Analysis-An Algorithmic Approach,McGraw Hill.

MAT 2501: COMPUTER PRGRAMMING (PYTHON/C/JAVA)

Introduction to one the programming languages such as Python/C/C++/JAVA, Developing computer programmes to solve different types of mathematical and engineering problems.

SEMESTER II

MAT 2205: OPTIMIZATION TECHNIQUES

Introduction to Optimization problems and formulations (3+1 hrs)

One dimensional Optimization: Golden Section method, Fibonacci search Method, Polynomial interpolation method, Iterative methods

(6+2 hrs)

Classical optimization Techniques: Unconstrained optimization, Constrained Optimizations: Penalty methods, Method of Lagrange multiplier, Kuhn-Tucker method.

(6+2 hrs)

Linear Programming: Simplex Method, Revised Simplex Method and other advanced Methods, Duality, Dual Simplex Method, Integer Programming Problems (9+3 hrs)

Unconstrained Optimization Techniques: Direct search methods such as Powel's method, Simplex method, etc. (3+1 hrs)

Gradient Search Methods: Steepest descent method, Conjugate gradient method, Newton's method, Quasi-Newton's method, DFP, BFGS method etc.

(9+3 hrs)

Dynamic Programming (3+1 hrs)
Genetic Algorithms, Simulated Annealing, Ant Colony Optimization (6+2 hrs)

References

1. Edvin K. P. Chong & Stanislab H. Zak , An Introduction to Optimization, John Wiley
2. Leunberger, Linear and Nonlinear Programming, Springer
3. Jorge Nocedal, Stephen *J.* Wright, Numerical Optimization, Springer
4. S.S. Rao, Engineering Optimization: theory and practices, New Age International Pvt. Ltd,
5. K. Deb, Optimization for Engineering Design, Prentice Hall, India
6. L. Davis, Handbook of genetic Algorithm, New York Van Nostrand Reinhold
7. Z. Michaleuwicz, Genetic Algorithm+Data Structure=Evolution Programme, Springer-Verlag
8. R. K. Belew and M. D. Foundations of Genetic Algorithms, Vose, San Francisco, CA: Morgan Kaufmann

MAT 2206: COMPLEX ANALYSIS AND MATHEMATICAL METHODS

Instruction to complex number system, stereographic projection, Analytic functions, Cauchy-Riemann Equations, Elementary functions, Conformal mappings, Fractional linear Transformations. (9+3 hrs)

Complex integration, Cauchy's theorem, Cauchy's integral formula, Liouville's theorem, Morera's Theorem, Cauchy-Goursat Theorem (9+3 hrs)

Uniform convergence of sequences and series, Taylor and Laurent series, isolated singularities and residues, Classification of singularities, Residue theorem, Evaluation of real integrals (8+4 hrs)

Maximum Modulus Principle, Argument Principle, Rouche's theorem (6+2 hrs)
Fourier series, Fourier integrals, Fourier transformsand their applications to ODE and PDE. Laplace Transforms and their applications. (12+4 hrs)

References:

1. J. B. Conway, Functions of One Complex Variable, 2nd Edition, Narosa, New Delhi, 1978.
2. T.W. Gamelin, Complex Analysis, Springer International Edition, 2001.
3. M. J. Ablowitz and A.S. Fokas Complex variables, Introduction and applications, Cambridge texts in applied mathematics.
4. Danis G. Zill & Patric D. Shanahan, Complex Analyis: A First Course with Applications, Jones and Bartlett Pub.
5. John H. Mathews & Russel D. Howell, Complex Analysis for Mathematics and Engineering , Jones and Bartlett Pub.

MAT 2207: ADVANCED REAL ANALYSIS

Sequences and series of functions, Uniform convergence, Power series and Fourier series, Weierstrass approximation theorem, Equicontinuity, Arzela-Ascoli theorem. (16 hrs)

Sigma-algebra of measurable sets. Completion of a measure. Lebesgue Measure and its properties. Non-measurable sets. Measurable functions and their properties. (12 hrs)

Review of Riemann Intergral, Integration and Convergence theorems. Lebesgue integral, Functions of bounded variation and absolutely continuous functions. (14 hrs)

Fundamental Theorem of Calculus for Lebesgue Integrals. Product measure spaces, Fubini's theorem. (10 hrs)

L^p spaces, duals of L^p spaces. Riesz Representation Theorem for C([a,b]). (8 hrs)

References

1. Ajit Kumar and S. Kumaresan, A Basic Course in Real Analysis, CRC Press, 2014
2. C.D. Aliprantis, Principle of Real Analysis, Adademic Press
3. I. K. Rana, Introduction to Measures and Integration, AMS
4. H. L. Royden, Real Analysis, 4^{th} Ed. PHI
5. Bartle, Elements of Integration and Lesbegue Measure, Wiley
6. Krishna B. Athreya and S. Lahiri, Measure theory and probability theory, Springer Texts in Statistics, Springer Verlag

MAT 2302: APPLIED STATISTICS – II

Testing of hypothesis: Type-I and type-II error, p-value, tests of hypothesis for single sample and two samples, likelihood ratio tests, tests for goodness of fit, contingency tables, relation between confidence interval and tests of hypothesis. (16 hrs)

Regression: Simple and multiple linear regression models – estimation, tests and confidence regions. Check for normality assumption. Likelihood ratio test, confidence intervals and hypotheses tests related to regression; tests for distributional assumptions. Collinearity, outliers; analysis of residuals, Selecting the best regression equation. (16hrs)

Statistical Simulation: Simulation of random variables from discrete, continuous univariate and multivariate distribution, probability integral transform, Introduction to computer intensive methods-Jack-Knife, Bootstrap, Cross-Validation, Monte-Carlo methods, Gibbs sampling. (18hrs)

Applications using R/ SPSS. (10hrs)

References:

1. D. C. Montgomery and E. A. Peck, An Introduction to Linear Regression Analysis, John Wiley and Sons
2. G. Casella and R. L. Berger. Statistical Inference. Duxbury Press. 2011
3. R.A. Johnson and D.W. Wichern, Applied Multivariate Analysis, Upper Saddle River, Prentice-Hall, N.J. 1998.
4. Held, Leonhard, SabanésBové, Daniel, Applied Statistical Inference- Likelihood and Bayes. Springer 2014.

MAT 2208: DIFFERENTIAL EQUATION II

First order linear and quasi-linear PDEs, The Cauchy problem, Classification of PDEs, Characteristics, Well-posed problems. (8 hrs)

Solutions of hyperbolic, parabolic and elliptic equations. (18 hrs)

Dirichlet and Neumann problems, Maximum principles, Green's functions for elliptic, parabolic and hyperbolic equations. (10 hrs)

Solution of parabolic, elliptic and hyperbolic equations using variable separable methods (9 hrs)

References

1. Renardy and Rogers, An introduction to PDE's, Springer-Verlag
2. W. A Strauss Partial, differential equations, An Introduction, Wiley, John & Sons
3. Dennis Zill, W. S. Wright, Advanced Engineering Mathematics, Jones & Bartlett
4. L.C. Evans, Partial differential equations, Springer

MAT 2402:NUMERICAL METHODS II

Finite difference Method: Finite difference schemes and their derivation. (4hrs)

Solution of boundary value problems (ODE) with finite difference schemes. (4hrs)

Solution of partial differential equations (parabolic and hyperbolic) using explicit and implicit finite difference methods, Numerical stability for explicit and implicit method, (10hrs)

Solution of elliptic equation using finite difference methods. (4hrs)

Basic principle of calculus of variation. Weighted residual method for solving ODE and PDE:

Collocation, Galerkin, Least square and partition methods. (10hrs)

Finite element formulation for the solution of ODE and PDE, Calculation of element matrices, assembly and solution of linear equations. (13hrs)

References

1. M.K. Jain: Numerical solution of differential equations, Wiley Eastern (1979), 2nd Ed.
2. M.K. Jain, S.R.K. Iyengar and R.K. Jain, Numerical methods for scientific and Engineering computation, New Age International.

3. S.S. Sastry, Introductory methods of Numerical analysis, Prentice- Hall of India, (1998).
4. S.C. Chapra, and P.C. Raymond, Numerical Methods for Engineers, Tata Mc Graw Hill,
5. J. N. Reddy, An Introduction to Finite Element Methods, McGraw-Hill.
6. G. D. Smith, Numerical solution of partial differential Equations: Finite difference methods, New York, NY: Clarendon Press

MAT 2502: SOFTWARE LAB I

Introduction to SageMath	(2 sessions)
Plotting graphs of various tyes of in 2D and 3D	(1session)
Solving problems in Calculus of single and mult-variables in Sage	(3 sessions)
Developing Programmes to solve basics problems in Numerical Methods	(3 sessions)
Solving problems in Linear algebra using SageMath	(4 sessions)
Solving differential Equations using SageMath	(2 sessions)

References:

- Sang-Gu Lee, Ajit Kumar, Calculus with Sage, KyongMoon Publication
- Sang-Gu Lee, Ajit Kumar, Linear Algebra with Sage free online book
- Robert Beezer, Linear Algebra, Free online book
- David Jouner, Introduction to Differential Equations Using Sage
- Anastassiou, George A., Mezei, Razvan, Numerical Analysis Using Sage

SEMESTER-III

MAT 2209: Number Theory **(4 Credits)**

Divisibility: Division Algorithms, Prime and Composite Numbers, Fibonacci and Lucas Numbers, Fermat Numbers (6+2hrs)

Greatest Common Divisor: GCD, Euclidean Algorithm, Fundamental Theorem of Arithmetic, LCM, Linear Diophantine Equations: (6+2hrs)

Congruences: Congruence modulo n, Linear Congruences, Divisibility Tests, Chinese Remainder Theorem and its applications, Wilson's, Fermat Little and Euler's Theorems with Applications (9+3hrs)

Multiplicative Functions: Euler-phi function, Tau and Sigma Functions, Perfect Numbers, Möbius Function, Mersenne Primes (6+2hrs)

Primitive Roots and Indices: Order of positive integers, Primality tests, Primitive Roots of Primes, Algebra of Indices (6+2hrs)

Quadratic Congruence: Quadratic Residues, Legendre Symbols, Quadratic Reciprocity (6+2hrs)

Continued Fractions: Finite continued Fractions, Infinite continued Fractions (3+1hrs)

Non Linear Diophantine Equations (3+1hrs)

References:

1. Elementary Number Theory with applications, Thomas Koshy, Academic Press (2007), 2nd Ed.
2. Elementary Number Theory and Its Applications, Kenneth H. Rosen, Addison Wesley (2004), 5th Ed.
3. Elementary Number Theory, G.A. Jones and J.M. Jones, Springer
4. An introduction to the Theory of Numbers, Niven and Zuckerman, Wiley

MAT 2304: Machine Learning (4 credits)

Overview of Machine learning (3+1 hrs)

Supervised learning:

Supervised learning setup. Classification errors, regularization, Linear regression, estimator bias and variance (3+1 hrs)

Logistic regression, Perceptron, Exponential family, Active learning, Non-linear Predictions, Kernels (6+2 hrs)

Gaussian Discriminant Analysis, Naive Bayes, Support vector machines (9+3 hrs)

Model selection and feature selection, Ensemble methods: Combining classifiers, bagging, boosting. (6+2 hrs)

Decision Tree and Random Forest (3+1hrs)

Unsupervised learning:

Clustering, K-means, Mixtures and the expectation maximization (EM) algorithm. Mixture of Gaussians. (6+2hrs)

Factor analysis, PCA (Principal components analysis), ICA (Independent components analysis). (6+2 hrs)

Hidden Markov models (HMMs), Artificial Neural Networks (3+1 hrs)

Note:-Each of the above methods should be demonstrated using software such as R, Python etc.

References:

1. Robert Tibshirani, and Trevor Hastie , The Elements of Statistical Learning by Jerome H. Friedman, (2001), Springer.
2. Ethem Alpaydin, Introduction to Machine Learning by (2004), The MIT Press, Cambridge.
3. Andreas C. Müller and Sarah Guido, Introduction to Machine Learning with Python: David Barber A Guide for Data Scientists, (2016), O'Reilly Media.
4. David Barber, Bayesian Reasoning and Machine Learning (2012), Cambridge University Press.
5. Ian H. Witten, Eibe Frank, Mark A. Hall, Data Mining: Practical Machine Learning Tools and Techniques by (2011), Elsevier.

MAT 2102: Momentum, Heat and Mass Transfer (4 credits)

Introduction to tensor calculus and curvilinear coordinates (6+2 hrs)

Deformation, Strain tensor, Rate of deformation tensor, material derivative, steady and unsteady flow, streamline and stream function, conservation of mass. (3+1 hrs)

Vorticity, circulation and irrotational flow, some examples of inviscid flow. (6+2 hrs)

Relation between stress and rate of strain, constitutive equation (Newtonian & Non Newtonian fluids), Stokes' hypothesis, Derivation of Navier-Stokes equation in Cartesian, Cylindrical Polar and Spherical Polar system. (6+2 hrs)

Flow in some simple cases: Fully developed flow between two parallel plates and through circular pipe, Flow between two concentric cylinders, flow between two concentric rotating cylinders. (3+1 hrs)

Dynamic similarity, derivation of boundary layer equations (using order analysis), similarity solutions for flow past a semi-infinite flat plate and wedge, momentum integral method. (6+2 hrs)

Derivation of equation of energy and mass transfer in Cartesian and cylindrical-polar coordinates, some simple cases for Heat and Mass transfer. (3+1 hrs)

Derivation of thermal boundary layer equations (using order analysis), similar and non-similar solutions for some forced, mixed and natural convection problems (using boundary layer theory). (6+2 hrs)

Theory of ordinary diffusion in liquids, diffusion with homogeneous chemical reaction, diffusion into a falling liquid films (forced convection mass transfer using boundary layer theory). (6+2 hrs)

References:

1. K. Kundu Pijush, Fluid Mechanics, Elsevier.
2. G. K. Batchelor, An Introduction to Fluid Dynamics, Cambridge University Press.
3. H. Schlichting, Klaus Gersten, Boundary-Layer Theory, Springer-Verlag.
4. S.W. Yuan, Foundations of Fluid Mechanics, Prentice Hall.
5. R. W. Whorlow, Rheological Technique, Ellis Horwood Ltd.
6. R.B. Bird, W.E. Stewart E.N., Lightfoot, Transport Phenomena , John Wiley & Sons.

7. Bennet and Myers, Momentum, Heat and Mass Transfer, Mcgraw Hill, Chemical Engineering Series, 1982.
8. I.G. Currie, Fundamental Mechanics of Fluids, Third edition, 1993, CRC Press.

MAP 2503: Software Lab II (2 credits)

Developing Programmes to solve basics problems using numerical methods

(5 sessions)

Introduction to MATLAB and numerical solution of ODE and PDE

(6 sessions)

Introduction to R and its applications to statistical methods such as, Linear regression, hypothesis testing, design of experiment, Logistic regression.

(5 sessions)

MAT 2303: Applied Statistics – III (4 credits)

Design of Experiment: Gauss-Markoff Theorem. One-way classification and two-way classification models and their analyses. (6+2hrs)

Fixed effect model, random effect model and mixed effect model in the context of factorial design, contrasts, orthogonal contrasts, (6+2hrs)

General factorial experiments, 2^Kdesign, confounding in 2^K design. (6+2 hrs)

Time Series Analysis: Numerical description of time series data, general approach to time series analysis and forecasting, (3+1 hrs)

Statistical Inference on Stationary processes – strong and weak, linear processes, linear stationary processes, AR, MA, ARMA and ARIMA, estimation of mean and covariance functions. (9+3 hrs)

Wald decomposition Theorem, Innovation algorithm, Modeling using ARMA processes, estimation of parameters testing model adequacy, Order estimation, Spectral analysis,

(6+2 hrs)

Statistical Quality Control: Methods and philosophy of statistical process control, process control charts, process capability analysis, acceptance sampling plans, process optimization with design of experiments. (9+3 hrs)

Notes: All the above concepts will be demonstrated using R/SPSS.

References:

1. P. Brockwell and R. Davis, Introduction to Time Series and Forecasting, Springer, Berlin, 2000.
2. Box, G. Jenkins and G. Reinsel, Time Series Analysis-Forecasting and Control, 3rd ed., Pearson Education, 1994.
3. C. Chatfield, The Analysis of Time Series – An Introduction, Chapman and Hall / CRC, 4th ed., 2004.
4. W. W. Hines, D. C. Montgomery, Probability and Statistics in Engineering. John Wiley.
5. D.C. Montgomery, Design and Analysis of Experiments, 3rd Ed., John Wiley & Sons, 1991.
6. Ruey S. Tsay, An Introduction to Analysis of Financial Data with R, John Wiley, 2013.

MAP 2701: Seminar **(2 credits)**

Objective: To develop the reading, writing and presentation skills of the students in a particular topic which will be assigned to them in consultation with a faculty from the department of mathematics or some other department of the institute. Further, it may lay the foundation for the home paper project in the next semester.

Evaluation method: The procedure of evaluation has three components:
As per the institute rule. (45 hrs)

ELECTIVE-I

MAT 2212: Topology **(4 credits)**

Cartesian Products, Finite Sets, Countable and Uncountable Sets, Infinite Sets and Axiom of Choice, Well Ordered Sets. (3+1 hrs)

Topological Spaces: Basis for a topology, Order topology, Subspace topology, Product topology

(6+2 hrs)

Closed and open sets, Limit Points, Continuity, Metric Topology and Quotient Topology
(9+3hrs)

Connectedness: Connected spaces, Connected, Subspaces of Real Line, Components and Local Connectedness, Simply connectedness

(6+2 hrs)

Compactness: Compact spaces, Compact Subspaces of the Real Line, Limit point compactness, Local Compactness

(6+2 hrs)

Countability Axioms, Separation axioms: Normal Spaces, Urysohn'sLemma(without proof), Titetz Extension Theorem, Metrization Theorem, Tychonoff's Theorem

(6+2 hrs)

One-point Compactification, Complete metric spaces and function spaces, Characterization of compact metric spaces, equicontinuity, Ascoli-Arzela Theorem

(6+2hrs)

Baire's Category Theorem (3+1 hrs)

If time permits, an introduction to Fundamental Groups may be covered

References

1. J. R. Munkres, Topology, 2nd Edition, Pearson Education (India), 2001.
2. M. A. Armstrong, Basic Topology, Springer (India), 2004.
3. Stefan Waldman, Topology: An introduction, Springer, 2014.
4. G. F. Simmons, Introduction to Topology and Modern Analysis, McGraw-Hill, 1963.
5. S. Kumaresan, Topology of Metric Spaces , 2nd Ed., Narosa Publishing House, 2011.

MAT 2306: Operations Research (4 credits)

Operations Research: Introduction of operation research using historical perspective
(3+1 hrs)

Linear Programming Problem: Simplex Methods, Revised simplex method, two phase simplex method, Big-M Method, Karmakar Method, Sensitivity analysis and Duality
(9+3 hrs)

Integer Programming (6+2hrs)

Dynamic programming, Characteristics of dynamic programming, Dynamic programming approach for Priority Management employment smoothening, capital budgeting, Stage Coach/Shortest Path, cargo loading and Reliability problems. (6+2 hrs)

Transportation and Assignment Problems: Transportation Problems definition, Linear form, Solution methods: North-west corner method, least cost method, Vogel's approximation method. Degeneracy in transportation, Modified Distribution method, Unbalanced problems and profit maximization problems. Transshipment Problems Assignment problems and Travelling sales man problems. (9+3 hrs)

Inventory Control: Inventory classification, Different cost associated to Inventory, Economic order quantity, Inventory models with deterministic demands, ABC analysis. (3+1 hrs)

Queuing Theory: Basis of Queuing theory, elements of queuing theory, Kendall's Notation, Operating characteristics of a queuing system, Classification of Queuing models and preliminary examples. (6+2 hrs)

Network models (3+1 hrs)

References

1. Hamdy Taha, Operations Research: An Introduction, Pearson.
2. A M Natarajan, P Balasubramani, A Tamilarasi, Operations Research, Pearson Education Inc.
3. Wayne L. Winston and M. Venkataramanan, Introduction to Mathematical Programming, 4th Ed, Cengage Learning.
4. Eiselt, H. A., Sandblom, Carl-Louis, Operations Research-A Model Based Approach, Springer.
5. Harvir Singh Kasana, Krishna Dev Kumar, Introductory Operations Researc*:* Theory and Applications, Springer.

MAT 2501: Mathematical Biology (4 credits)

Basic population growth models, concepts of birth, death and migration, concept of closed and open populations, unconstrained population growth for single species, exponential, logistic, Gompertz, ricker growth models, Allee model (9+ 3 hrs)

Harvest models, bifurcations and break points, discrete time and delay models, stable and unstable fixed points, (9 + 3 hrs)

Concepts of interacting populations, predator-prey models, host-parasitoid system, functional response, stability of equilibrium points, Poincare-Bendixson's theorem, (9 + 3 hrs)

Global bifurcations in predator-prey models, discrete time predator-prey models, competition models (9+3 hrs)

Concept of optimal control theory connected to harvest models, An overview of age-structured models and spatially structured models, concept of stochastic population models and study of some standard stochastic models in population biology.

(9 + 3 hrs)

References:

1. Mark Kot, Elements of Mathematical Ecology, Cambridge University Press, Cambridge, 2001.
2. Murray, J. D. 1989. Mathematical Biology, Springer-Verlag, Berlin.
3. Horst R. Thieme , Mathematics in Population Biology, Princeton University Press, 2003.
4. Josef Hofbauer, Karl Sigmund , Evolutionary games and population dynamics, Cambridge University Press, 1998.
5. Eric Renshaw, Modelling Biological Populations in Space and Time. Cambridge University Press, 1991
6. Stevens, M. Henry, A Primer in Ecology with R, Springer, 2009

MAT 2307: Mathematical Finance

The Time Value of Money: Compound interest with fractional compounding, NPV, IRR, and Descartes's Rule of Signs, Annuity and amortization theory, The Dividend Discount Model, Valuation of Stocks, Valuation of bonds (6+2 hrs)

Portfolio Theory: Markowitz portfolio model, Two-security portfolio, N-security portfolio, Investor utility, Diversification and the uniform Dirichlet distribution (6+2 hrs)

Capital Market Theory and Portfolio Risk Measures: The Capital Market Line, The CAPM Theorem, The Security Market Line, The Sharpe ratio, The Sortinoratio, VaR.

(9+3 hrs)

Modeling the Future Value of Risky Securities: Binomial trees, Continuous-time limit of the CRR tree, Stochastic process: Brownian motion and geometric Brownian motion, Itô's formula. (6+2 hrs)

Forwards, Futures, and Options: No arbitrage and the Law of One Price, Forwards, Futures, Option type, style, and payoff, Put-Call Parity for European options, Put-Call Parity bounds for American options.

(9+3 hrs)

The Black-Scholes-Merton Model: Black-Scholes-Merton (BSM) formula, Partial differential equation approach to the BSM formula: the BSM Partial differential equation Continuous-time, risk-neutral approach to the BSM formula, Binomial-tree approach to the BSM formula, Delta hedging, Implied volatility.

(9+3 hrs)

References:

1. S.M. Ross, An introduction to Mathematical Finance, Cambridge University Press.
2. A. J. Prakash, R. M. Bear, K. Dandapani, G.L. Gahi, T.E. Pactwa and A.M. Parchigari, The return Generating Models in Global Finance, Pergamon Press.
3. J. Hull, Options, Futures, and Other Derivatives (Pearson Prentice Hall, Upper Saddle River, 2015.
4. S. M. Ross, Applied Probability: Models with Optimization Applications, Holden-day.
5. S. Roman, Introduction to the Mathematics of Finance Springer, New York, 2004.

MAT 2308: Graph Theory and Applications **(4 credits)**

Preliminaries: Graphs, isomorphism, sub graphs, matrix representations, degree, operations on graphs, degree sequences. (3+1 hrs)

Connected graphs and shortest paths: Walks, trails, paths, connected graphs, distance, cut-vertices, cut-edges, blocks, connectivity, weighted graphs, shortest path algorithms.

(6+2hrs)

Trees: Characterizations, number of trees, minimum, spanning trees. (3+1 hrs)

Special classes of graphs: Bipartite graphs, line graphs, chordal graphs. (3+1 hrs)

Eulerian graphs: Characterization, Fleury's algorithm, Chinese-postman-problem.

(3+1 hrs)

Hamilton graphs: Necessary conditions and sufficient conditions. (3+1 hrs)

Independent sets, coverings, matching: Basic equations, matching in bipartite graphs, perfect matching, greedy and approximation algorithms. (6+2hrs)

Vertex colorings: Chromatic number and cliques, greedy coloring algorithm, coloring of chordal graphs, Brook's theorem. (6+2hrs)

Edge colorings: Gupta-Vizing theorem, Class-1 graphs and class-2 graphs, equitable edge-coloring. (3+1hrs)

Planar graphs: Basic concepts, Euler's formula, polyhedrons and planar graphs, characterizations, planarity testing, 5-color-theorem. (6+2 hrs)

Directed graphs: Out-degree, in-degree, connectivity, orientation, Eulerian directed graphs, Hamilton directed graphs, tournaments. (3+1hrs)

References

1. A. Bondy and U.S.R.Murty: Graph Theory and Applications (Freely downloadable from Bondy's website; Google-Bondy).
2. D.B.West: Introduction to Graph Theory, Prentice-Hall of India/Pearson, 2009.
3. J.A.Bondy and U.S.R.Murty: Graph Theory, Springer, 2008.
4. R.Diestel: Graph Theory, Springer(low price edition) 2000.
5. Agnarsson, Geir, and Raymond Greenlaw, Graph Theory: Modeling, Applications, and Algorithms, Pearson, 2006.
6. R. Balakrishnan, K. Ranganathan, A textbook of Graph theory. Second edition. Springer 2012.
7. Gary Chartrand, Ping, Zhang, Introduction to Graph Theory. Tata McGraw-Hill Publishing Company Limited. 2006.

SEMESTER-IV

MAT 2305: Stochastic Processes **(4 credits)**

Description and definition of Markov chains with finite and countably infinite state spaces, Classification of states, irreducibility, Ergodicity., basic limit theorems. (9 +3 hrs)

Statistical Inference: Applications to queuing models. (6+2 hrs)

Markov processes with discrete and continuous state spaces. Poisson process, pure birth process, birth and death process. Brownian motion. (9 +3 hrs)

Basic theory and applications of renewal processes, stationary processes. (6+2 hrs)

Branching processes. Markov Renewal and semi-Markov processes, regenerative processes, Martingales, Random Walks. (9+3 hrs)

Simulation exercises using Matlab/R. Applications related to finance/biology. (6+2 hrs)

References:

1. Sheldon M. Ross. Stochastic Processes, 2nd Ed, Wiley.
2. C. W. Gardiner, 2004. Handbook for Stochastic Methods for Physics, Chemistry and the Natural Sciences. Third Edition. Springer-Verlag, Berlin.
3. Karlin and Taylor. 1975. A First course in Stochastic Process. Academic Press (Volume-I).
4. Karlin and Taylor. 1975. A First course in Stochastic Process. Academic Press (Volume-II).
5. J. Medhi, Stochastic Processes, New Age International, 1994.

MAT 2105: Computational Fluid Dynamics (CFD) **(4 credits)**

Grid generation, Structures and Unstructured grid generation methods. (6+2 hrs)

Finite Volume Discretization of 1-D, 2-D and 3-D Steady and unsteady state Diffusion-type Problems. (3+1 hrs)

Solution of Systems of Linear Algebraic Equations, iterative methods, Gauss-Seidel iterative method, Multigrid method, Line by line TDMA, ADI (Alternating direction implicit) method, Stability and convergence of numerical methods. (9+3 hrs)

Finite volume discretization of convection-diffusion problem: Central difference scheme, Upwind scheme, Exponential scheme and Hybrid scheme, Power-law scheme, Generalized convection-diffusion formulation. (3+1 hrs)

Finite volume discretization of two-dimensional convection-diffusion problem, the concept of false diffusion, QUICK scheme, Discretization of the Momentum Equation: Stream Function-Vorticity approach and Primitive variable approach, staggered grid and Collocated grid, SIMPLE, SIMPLER algorithm etc. (9+3 hrs)

Important features of turbulent flows, Homogeneous turbulence and isotropic turbulence, General Properties of turbulent quantities, Reynolds averaged Navier Stokes (RANS) equation, Closure problem in turbulence: Necessity of turbulence modeling. (6+2 hrs)

Different types of turbulence model: Eddy viscosity models, Mixing length model, Turbulent kinetic energy and dissipation, The κ-ε and κ-ω models. Solution of some turbulent flow and heat transfer problems using finite volume method. (9+3 hrs)

References

1. Fletcher C.A.J, Computational Techniques for Fluid Dynamics, Volumes I & II, Springer-Verlag.
2. C. Hirsch, Numerical Computation of Internal and External Flows, Volume I & II, Wiley.
3. J. C. Tannehill, D. A. Anderson and R. H. Pletcher, Computational Fluid Mechanics and Heat Transfer, McGraw-Hill.
4. G. D. Smith, Numerical Solution of Partial Differential Equations: Finite Difference Methods, New York, NY: Clarendon Press.
5. M. Schafer-Computational engineering- Introduction to numerical methods.
6. J. N. Reddy, An Introduction to Finite element Methods, McGraw-Hill.
7. M. Farrashkhalvat, J Miles, Basic Structured Grid Generation, Elsevier.
8. S. V. Patankar, Numerical Heat Transfer and Fluid Flow, Hemisphere Pub.
9. John. D. Anderson, Jr., Computational Fluid Dynamics, The Basics with Applications, McGraw-Hill.

MAT 2210: Applied Functional Analysis **(4 credits)**

Metric spaces (6+2 hrs)

Normed spaces, Continuity of linear maps, Banach spaces (9+3 hrs)

Inner product spaces, Hilbert spaces, Dual spaces and transposes, Orthonormal basis. Projection theorem and Riesz Representation Theorem (9+3 hrs)

Hahn-Banach Extension and Separation theorems, Uniform Boundedness Principle and its applications.Closed Graph Theorem, Open Mapping Theorem and their applications. (9+3 hrs)

Banach fixed point theorem and its application to differential and integral equations.

(6+2 hrs)

Spectrum of a bounded operator, Examples of compact operators on normed spaces.

(6+2 hrs)

References:

1. E. Kreyzig, Introduction to Functional Analysis with Applications, John Wiley & Sons, New York, 1978
2. B.V. Limaye, Functional Analysis, 2nd Edition, New Age International, New Delhi, 1996.
3. C. Goffman and G. Pedrick, First Course in Functional Analysis, Prentice Hall, 1974.
4. R Bhatia , Notes on functional Analysis, Hindustan Book Agency.
5. Douglas Farenick, Fundamentals of Functional Analysis, 2016, Spinger.
6. Peter Lax, Functional Analysis, Wiley-Interscienc.

MAT 2211: Coding Theory and Cryptography **(4 credits)**

Part I (Coding Theory)

Overview of the Course, Error detection: correction and decoding: Communication channels, Maximum likelihood decoding, Hamming distance, Nearest neighbor / minimum distance decoding, Distance of a code. (6+2 hrs)

Linear codes: Vector spaces over finite fields, Linear codes, Hamming weight, Bases of linear codes, Generator matrix and parity check matrix, Equivalence of linear codes, Encoding with a linear code, Decoding of linear codes, Cossets, Nearest neighbor decoding for linear codes, Syndrome decoding. (9+3 hrs)

Cyclic codes: Definitions, Generator polynomials, Generator and parity check matrices, Decoding of cyclic codes, Burst-error-correcting codes. Some special cyclic codes: BCH codes, Definitions, Parameters of BCH codes, Decoding of BCH codes. (6+2 hrs)

Part II (Cryptography)

Introduction: Overview of course, Classical cryptography, Secret Key Encryption : Perfect Secrecy - One time pads, Stream ciphers and the Data Encryption Standard (DES), Advanced Encryption Standard (AES) - adopted September 2000. (9+3 hrs)

Public Key Encryption: Factoring and the RSA encryption, Discrete log. Diffie-Hellman Key Exchange, ElGamal encryption, Digital Signatures, One-time signatures, Rabin and ElGamal signatures schemes, Digital Signature Standard (DSS). (9+3 hrs)

Hashing: Motivation and applications, Cryptographically Secure Hashing Message Authentication Codes (MAC). HMAC, Network Security, Secure Socket Layer (SSL), I Psec.,Secret Sharing, Definition. Shamir's threshold scheme, Visual secret sharing schemes. (6+2 hrs)

References

1. Wade Trappe, Lawrence C. Washington, Introduction to Cryptography with Coding Theory, Pearson Education International.
2. Hankerson, Darrel R.-Coding Theory and Cryptography-CRC Press.
3. D. R. Hankerson, Coding Theory and Cryptography The Essentials, 2nd ed, Marcel Dekker, CRC Press.
4. Bierbrauer, Jürgen, Introduction to Coding Theory, CRS Press
5. Hans Delfs, Helmut Knebl, Introduction to Cryptography: Principles and Applications, Springer.

ELECTIVE-II

MAT 2403: Finite Element Method (4 credits)

Calculus of Variations: Variational formulation - Rayleigh-Ritz minimization (3+1 hrs)

Weighted Residual Approximations: Point collocation, Galerkin and Least Squares method. Use of trial functions to the solution of ODE and PDE. (6+2 hrs)

Finite Element Procedures: Finite Element Formulations for the solutions of ordinary and partial differential equations: Calculation of element matrices, assembly and solution of linear equations. (12+4 hrs)

Finite Elements: One dimensional and two dimensional basis functions, Lagrange and serendipity family elements for quadrilaterals and triangular shapes, coordinate transformation, integration over a Master Triangular and Rectangular elements. (9+3 hrs)

Application of Finite element Method: Finite element solution of Laplace and Poisson equations over rectangular and nonrectangular and curved domains. Applications to some problems in fluid mechanics and in other engineering problems. (15+5 hrs)

References:

1. O. C. Zienkiewiez and K. Morgan : Finite Elements and approximation, John Wieley, 1983

2. P.E. Lewis and J.P. Ward : The Finite element method- Principles and applications, Addison Weley, 1991
3. L. J. Segerlind : Applied finite element analysis (2nd Edition), John Wiley, 1984
4. J. N. Reddy, An Introduction to the Finite Element Method, McGraw Hill, NY, 2005.
5. I. J. Chung, Finite Element Analysis in Fluid Dynamics, McGraw Hill Inc., 1978

MAT 2502: Dynamical Systems (4 credits)

Linear and nonlinear discrete dynamical systems: Recurrence relations, Leslie model, Flows and maps. Phase space. Orbits. Fixed points, The logistic map, bifurcation diagram and Feigenbaum number, Graphical analysis of orbits of one-dimensional maps, Period doubling root to chaos, example from other branches. (9+3 hrs)

Planar Systems: Canonical forms, Eigenvectors defining stable and unstable manifolds, Phase portraits, Linearization and Hartman's theorem, Construction of phase plane diagram.

(9+3 hrs)

Equilibrium points, Stable and unstable nodes. Saddle point. Stable and unstable foci. Centre. Lyapunov and asymptotic stability.

(6+2 hrs)

Limit cycles: Existence and uniqueness of limit cycles in the plane, stability of limit cycles, Poincare- Bendixson theorem, worked examples from ecology, disease models.

(6+2 hrs)

Bifurcation theory: Bifurcation of nonlinear systems, Multistability, bistability, Saddle-node bifurcation. Pitchfork bifurcation, Period doubling bifurcation, Hopf bifurcation.

(9+3 hrs)

Three dimensional autonomous systems and chaos: Linear systems and canonical forms, The Lorenz equations. (6+2 hrs)

Note: The concepts may be explained using Mathematics/Matlab etc.

References:

1. Alligood, Sauer, and Yorke. 1996. Chaos: An Introduction to Dynamical Systems. Springer, Springer-Verlag New York
2. Rudiger Seydel, 2010. Practical Bifurcation and Stability analysis. Springer (3rd Ed)

3. Stephen Lynch, 2014. Dynamical Systems with Applications using MATLAB. Springer
4. Yuri A. Kuznetsov, 1998. Elements of Applied Bifurcation Theory, Second Edition, Springer
5. James T Sandefur, Discrete dynamical systems Theory and applications, Clarendon press, 1990
6. M W Hirsch and S Smale - Differential Equations, Dynamical Systems, Academic 1974
7. R. Clark Robinson. An Introduction to Dynamical Systems Continuous and Discrete, Second edition. American Mathematical Society, Rhode Island, 2016.
8. Dynamical Systems with Applications using MATLAB® Stephen Lynch (2003)

MAT 2503: Ecological Statistics (4 credits)

Philosophical considerations in ecology and statistics, linear, nonlinear regression and Bayes theorem revisited. (9+3 hrs)

Modelling occupancy and occurrence probability, modelling closed populations, Models with individual effects. (6+2 hrs)

An introduction to the use of multivariate statistics in ecological research, application of principal component analysis, cluster analysis, discriminant analysis and canonical correlation analysis with ecological data, diagnostics for assessing the assumptions.
(12+4 hrs)

Modelling interactive dynamics, stochastic simulation of individual and interactive dynamics of populations, case studies, simulation of spatial processes.
(12+4 hrs)

An introduction to spatial ecology, analysis of spatial data. (6+2 hrs)
Applications using R/SPSS.

References:

1. Song S. Qian. Environmental and Ecological Statistics with R. CRC Press. 2009
2. Benjamin M. Bolker. Ecological Models and Data in R. Princeton University Press. 2008
3. Stevens, M. Henry. A Primer of Ecology with R. Springer 2009.

4. J. Andrew Royale and Robert M. Dorazio. Hierarchical Modeling and Inference in Ecology, The Analysis of Data from Populations, Metapopulations and Communities. Elsevier 2008.
5. Michael A. McCarthy. Bayesian Methods for Ecology. Cambridge University Press. 2007
6. Stochastic Population Processes: Analysis, Approximations, Simulations Reprint Edition byEric Renshaw, Oxford University Press, 2015

MAT 2309: Network Theory (4 credits)

Introduction to Networks, Visualizing networks, Empirical Motivation: examples of networks from different areas of engineering and natural sciences. (3+1 hrs)

Networks modelling and inference, Basics of graph concepts, Understanding network data, visualizing network data, descriptive analysis of network graph characteristics, density and related notions of relative frequency, graph partitioning. (12+4 hrs)

Mathematical models for network graphs, Classical Random graph models, generalized random graph models. (12+4 hrs)

Statistical Models for Network graphs: exponential random graph model, latent network models, general formula, model fitting, and goodness of fit, modelling and prediction for processes on network graphs, introduction to dynamic networks, case studies. (18+6 hrs)

References:

1. Eric D. Kolaczyk, Gábor Csárdi, Statistical Analysis of Network Data with R. Springer 2014.
2. Eric D. Kolaczyk. Statistical Analysis of Network Data: Methods and Models. Springer 2009.
3. Matthias Dehmer, Subhash C. Basak, Statistical and Machine Learning Approaches for Network Analysis. John Wiley & Sons. 2012.
4. Stanley Wasserman, Katherine Faust. Social Network and Analysis: Methods and Application. Cambridge University Press, 1994.

MAT 2310: Multivariate Analysis (4 credits)

Review of linear algebra, review of multivariate distributions, multivariate normal distribution and its properties, distributions of linear and quadratic forms.

(12+4 hrs)

Tests for partial and multiple correlation coefficients and regression coefficients and their associated confidence regions. Data analytic illustrations. (6+2 hrs)

Wishart distribution (definition, properties). (3+1 hrs)

Construction of tests, union-intersection and likelihood ratio principles, inference on mean vector, Hotelling's T^2.MANOVA. (12+4 hrs)

Inference on covariance matrices. Discriminant analysis. Basic introduction to: principal component analysis and factor analysis. (6+2 hrs)

Practicals on the above topics using statistical packages for data analytic illustrations. (8 hrs)

References:

1. T. W. Anderson, An Introduction to Multivariate Statistical Analysis.
2. R. A. Johnson and D. W. Wichern, Applied Multivariate Statistical Analysis.
3. K. V. Mardia, J. T. Kent and J. M. Bibby, Multivariate Analysis.
4. M. S. Srivastava and C. G. Khatri, An Introduction to Multivariate Statistics.

MAT 2504: Mathematical Modelling (4 credits)

Basic concept and techniques of mathematical modeling with some examples. (3+1 hrs)

Review of numerical and analytical techniques for solving ODE and PDE. (6+2 hrs)

Modeling with ODE, continuous Dynamical System. (6+2 hrs)

Modeling with difference equation, Discrete Dynamical System. (6+2 hrs)

Dimension Analysis, Empirical (experimental) models validity, model fitting (6+2hrs)

Modeling with linear and non-linear partial differential equation. (6+2hrs)

Singular perturbation theory and application to modeling. (6+2hrs)

Mathematical modeling through calculus of variation and dynamic programming. (6+2hrs)

References:

1. J. N. Kapur, Mathematical Modeling, New Age International Publication, 1966.
2. M. M. Gibbons, A concrete approach to Mathematical modeling, John Willey & Sons.
3. M. M. Meerschaert, Mathematical Modeling, Elsevier Publication, 2007.
4. E. A. Bender, An introduction to Mathematical Modeling, CRC Press, 2002.