

Soft Computing in Water Resources Engineering

WIT*PRESS*

WIT Press publishes leading books in Science and Technology.

Visit our website for the current list of titles.

www.witpress.com

WIT*eLibrary*

Home of the Transactions of the Wessex Institute, the WIT electronic-library provides the international scientific community with immediate and permanent access to individual papers presented at WIT conferences.

Visit the WIT eLibrary at <http://library.witpress.com>

Soft Computing in Water Resources Engineering

Artificial Neural Networks, Fuzzy Logic
and Genetic Algorithms

G. Tayfur

Izmir Institute of Technology, Turkey

WITPRESS Southampton, Boston



G. Tayfur

Izmir Institute of Technology, Turkey

Published by

WIT Press

Ashurst Lodge, Ashurst, Southampton, SO40 7AA, UK

Tel: 44 (0) 238 029 3223; Fax: 44 (0) 238 029 2853

E-Mail: witpress@witpress.com

<http://www.witpress.com>

For USA, Canada and Mexico

WIT Press

25 Bridge Street, Billerica, MA 01821, USA

Tel: 978 667 5841; Fax: 978 667 7582

E-Mail: infousa@witpress.com

<http://www.witpress.com>

British Library Cataloguing-in-Publication Data

A Catalogue record for this book is available
from the British Library

ISBN:978-1-84564-636-3

eISBN: 978-1-84564-637-0

Library of Congress Catalog Card Number: 2011932561

*The texts of the papers in this volume were set
individually by the authors or under their supervision.*

No responsibility is assumed by the Publisher, the Editors and Authors for any injury and/or damage to persons or property as a matter of products liability, negligence or otherwise, or from any use or operation of any methods, products, instructions or ideas contained in the material herein. The Publisher does not necessarily endorse the ideas held, or views expressed by the Editors or Authors of the material contained in its publications.

© WIT Press 2012

Printed in Great Britain by CMP, Poole, Dorset.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the Publisher.

To my children

Sümeýra Nur

Beyza Nur

Tarik Meliksah

About the author



Dr GökmenTayfur is a professor of Civil Engineering at Izmir Institute of Technology, Turkey. He graduated from the Department of Civil Engineering, Istanbul Technical University in 1985. He had continued his MSc degree program in the same department from 1985 to 1987. Upon rewarded a graduate studies in the USA by the Turkish Ministry of Education, he had completed his MSc and PhD degrees in the Department of Civil

Engineering, University of California at Davis in 1990 and 1993, respectively. He had worked as a post doctoral researcher in the same department and in the department of LAWR in the same university from 1993 to 1995. Since 1995 he has been a faculty member in the Civil Engineering Department, Izmir Institute of Technology, Izmir, Turkey. He had spent 2004–2005 at Louisiana State University and 2007–2008 at the University of Mississippi as a visiting scholar. He has had published several book chapters, more than 50 national and international conference papers and over 40 scientific SCI journal papers. His research interest can be summarized as: Mathematical modeling, surface and subsurface flows, rainfall-runoff induced erosion, sediment transport, solute transport, chemical transport in surface and subsurface flows, application of artificial intelligence methods (ANN, Fuzzy Logic, GA) in water resources engineering problems, and river morphology.

Contents

Preface	xv
----------------------	-----------

PART I – ARTIFICIAL NEURAL NETWORKS

Chapter 1 – Introduction to Artificial Neural Networks	3
---	----------

1.1 General View	3
1.2 Biological Neuron	4
1.3 Artificial Neuron	5
1.4 Artificial Neural Network.....	6
1.4.1 History.....	6
1.4.2 General Properties of ANN	7
1.5 ANN Types.....	8
1.5.1 Architecture.....	8
1.5.2 Neuro-dynamics	9
1.6 ANN versus Other Models	9

Chapter 2 – Artificial Neuron.....	13
---	-----------

2.1 Components of Artificial Neuron	13
2.2 Methods for Computing Net Information	15
2.2.1 Summation (P) method.....	16
2.2.2 Maximum (max) method.....	16
2.2.3 Minimum (min) method	16
2.2.4 Product (Q) method	16
2.3 Activation Functions.....	16
2.3.1 Linear function	17
2.3.2 Step function.....	17
2.3.3 Rampage function.....	19
2.3.4 Gaussian function	20
2.3.5 Sigmoid function	20
2.3.6 Hyperbolic tangent function	22

Chapter 3 – Network Training	25
3.1 Pre-Training Procedures	25
3.1.1 Data Standardization	25
3.1.1.1 Standardization methods when using sigmoid function	26
3.1.1.2 Standardization methods when using hyperbolic tangent function	28
3.1.2 Network Initialization.....	28
3.2 Network Training	29
3.2.1 Back-propagation algorithm.....	30
3.2.1.1 Updating weights in output-inner layers.....	33
3.2.1.2 Updating weights in inner-input layers.....	34
3.2.1.3 Worked examples	35
3.2.2 Radial basis function	42
3.2.3 Conjugate gradient algorithm.....	44
3.2.4 Cascade correlation algorithm.....	45
3.2.5 Generalized regression algorithm.....	46
3.3 Learning Rules.....	47
3.4 Learning Parameter.....	48
Appendix	52
Exercise Problem.....	53

Chapter 4 – Model Testing	55
4.1 De-standardization of Model Output.....	55
4.2 Evaluating Model Performance.....	55
4.3 Over-training and Cross-training.....	59

Chapter 5 – Model Application in Water Resources Engineering	61
5.1 Prediction	61
5.1.1 Total suspended sediment.....	61
5.1.2 Seepage.....	67
5.1.3 Dispersion coefficient.....	74
5.1.4 Sheet sediment	77
5.1.5 Runoff at plot scale.....	79
5.1.6 Runoff at watershed scale.....	81
5.1.7 Flood hydrograph at basin scale	83
5.2 Classification.....	88
5.3 Forecasting.....	89
5.3.1 Forecasting flood hydrograph at basin scale	89

5.4 Extrapolation.....	95
5.5 Filling Gap in Time Series Data.....	96
References	100

PART II – FUZZY LOGIC ALGORITHM

Chapter 6 – Introduction to Fuzzy Logic Algorithm 109

6.1 General View.....	109
6.2 Basic Concept in Fuzzy Logic.....	110
6.3 Fuzzy Systems.....	112

Chapter 7 – Fuzzy Membership Functions, Set Operations, and Fuzzy Relations 115

7.1 Fuzzy Membership Functions.....	115
7.2 Fuzzy Set Operations.....	118
7.2.1 Set representation	118
7.2.2 Set operations	119
7.2.2.1 Union of sets.....	119
7.2.2.2 Intersection of sets	120
7.2.2.3 Complementary sets.....	122
7.2.2.4 Subsets.....	122
7.2.2.5 Operation properties of fuzzy sets	124
7.2.3 Operations unique to fuzzy sets.....	125
7.2.3.1 Concentration.....	125
7.2.3.2 Dilation	125
7.2.3.3 Normalization	126
7.2.3.4 Intensification	127
7.3 Fuzzy Relations	128
Exercise Questions	132

Chapter 8 – Constructing Fuzzy Model..... 135

8.1 Fuzzification.....	135
8.2 Fuzzy Rule Base.....	137
8.3 Fuzzy Inference Engine.....	140
8.3.1 Inference sub-process.....	140
8.3.2 Composition sub-process.....	145
8.4 Defuzzification	146
Exercise Questions	150

Chapter 9 – Fuzzy Model Application in Water Resources Engineering	151
9.1 Introduction	151
9.2 TSS Prediction	152
9.2.1 Model development	154
9.2.2 Model calibration and application	155
9.3 Sheet Sediment Prediction	157
9.3.1 Fuzzy model	157
9.3.2 Physics-based model	161
9.3.3 ANN model	163
9.4 Peak Discharge Prediction	164
9.4.1 Experimental data	164
9.4.2 ANN model training and testing	164
9.4.3 FL model calibration and validation	164
9.4.4 KWA model calibration and validation	166
9.5 Runoff Hydrograph Simulation	168
9.5.1 ANN model training and testing	168
9.5.2 FL model calibration and validation	170
9.5.3 KWA model calibration and verification	170
9.6 Hydrograph Simulation at Watershed Scale	171
9.7 Dispersion Prediction	172
9.7.1 Experimental data	173
9.7.2 Regression-based model	176
9.7.3 Fuzzy model	177
References	179

PART III – GENETIC ALGORITHMS

Chapter 10 – Genetic Algorithms (GAS)	185
10.1 Introduction	185
10.2 Basic Units of GA	186
10.3 GA Operations	188
10.3.1 Forming initial gene pool	189
10.3.2 Evaluating fitness of each chromosome	190
10.3.3 Selection	192
10.3.4 Cross-over operation	193
10.3.4.1 Single cut	194
10.3.4.2 Double cut	195
10.3.4.3 Multiple cut	195
10.3.4.4 Uniform crossing	195
10.3.4.5 Using sub-chromosome	195
10.3.4.6 Reversing	196

10.3.5 Mutation	196
Chapter 11 – Variant of Genetic Algorithm	203
11.1 Variant of Genetic Algorithms	203
11.1.1 Responsive perturbation algorithm.....	204
11.1.2 Trait-based heterogeneous populations (TbHP)	205
11.1.3 Trait-based heterogeneous populations plus (TbHP+)	207
11.2 Test Functions	211
11.3 Model Testing	217
Chapter 12 – Genetic Algorithm Model Applications in Water Resources Engineering	221
12.1 GA Application Problems	221
12.1.1 Longitudinal dispersion coefficient in natural streams.....	221
12.1.2 Hydrograph simulation.....	231
12.1.2.1 Watershed and hydrologic data.....	231
12.1.2.2 GA-RCM model implementation and calibration.....	235
12.2.2.3 Hydrograph predictions	236
12.1.3 Sensitivity analysis	240
12.1.3.1 Number of events used in calibration	240
12.1.3.2 Using shorter wave travel time events in the calibration	242
12.1.3.3 Using lower peak events in calibration	243
12.1.4 Hydrograph simulation using level data	246
12.1.4.1 Hydrograph predictions	247
12.1.5 Mean and bankfull discharge prediction.....	250
12.1.5.1 Non-linear regression method.....	251
12.1.5.2 Artificial neural networks method	251
12.1.5.3 Fuzzy method.....	252
12.1.5.4 Genetic algorithm	253
Appendix	257
References	259
Index	263

Preface

Soft computing methods have relatively a recent history, starting in early 1940s with artificial neural networks (ANNs), 1960s with fuzzy logic (FL), and 1970s with genetic algorithms (GAs). The application of these methods in water resources engineering area is even more recent, starting in early 1990s. Many studies have proven their utility across disciplines, triggering many MSc and PhD research thesis projects. As a result, many students have looked for sources to have a grasp of these methods. This has, in turn, initiated the offerings of many soft computing courses across many departments all over the world. I, myself, got into a research in this area in 2001, offered the first graduate course on soft computing methods in 2003. Since then, many students from Engineering (Material, Environmental, Civil, Mechanical, Chemical, Food, Electronics) Departments, including the Departments of Physics, City Planning, and Architecture, have taken the course. In a short period of time, I believe, such courses would be offered at an undergraduate level as well.

Soft computing algorithms can be employed individually or in conjunction with other numerical, analytical, and empirical models to solve engineering problems. They can produce quick results, making them be more attractive to the practicing engineers and managers. ANNs and GAs are data driven optimization techniques that are not restricted to the constraints of mathematical functions. Fuzzy logic, on the other hand, employs verbal statements in solving problems, thus it is in more line with human thinking. The application problems that are demonstrated in the book compare artificial intelligence methods against numerical, regression-based, empirical, and stochastic methods. These comparative examples would enable readers to qualitatively see the performance and importance of the soft computing methods.

This book can be used as a textbook for engineering students and as well as for the students in other disciplines since the great deal of the book contains

the basics of the aforementioned soft computing methods with illustrative examples. Hydrologists and hydraulic engineers can further benefit from the book since the application problems involve the ones from the water resources engineering field, ranging from prediction of the seepage path in an earthfill dam body to longitudinal dispersion coefficient in natural rivers.

Water resources planning and management has always been an important issue since especially the second half of the 20th century. This period witnessed the theoretical concepts and methodologies development, along with the computational tools and numerical methods. The numerical methods are powerful and can be very effective when detailed data is available. They can provide detailed spatial analysis in three dimensions, including temporal variation. In some cases, however, hydrologists, and hydraulic engineers prefer simple, easy-applicable, user-friendly practical methods and this is exactly what the soft computing methods deliver.

This book is designed as having three basic parts:

1. Artificial neural networks (ANN)
2. Fuzzy logic (FL) algorithm
3. Genetic algorithms (GAs)

Part I consists of five chapters. The first four chapters give the basics of an artificial neural, artificial neural networks, network training and network testing. Chapter 5 contains ANN applications in solving water resources engineering problems of prediction, interpolation, extrapolation, classification, and forecasting.

Part II involves four chapters. Chapters 6, 7, and 8 give details and basics of fuzzy logic, fuzzy membership functions, fuzzy set operations and fuzzy relations, and the components (fuzzification, fuzzy rule base, inferencing, and defuzzification) of fuzzy model. Chapter 9 presents FL applications in solving several water resources engineering problems such as the predictions of total suspended sediment (TSS), sheet sediment, peak discharge, runoff hydrograph, and dispersion.

Part III consists of three chapters. Chapters 10 and 11 give basics of GA and its variants. Chapter 12 presents several applications of GAs in water resources engineering field.

I would like to deeply thank Prof. Dr Zekai Sen of the Department of Civil Engineering, Istanbul Technical University for introducing the soft computing methods to many of us in early 2000 and making his notes available to everybody. His contribution is very much appreciated. I thank

Prof. Alexander Cheng of Civil Engineering Department, University of Mississippi for encouraging me to write the book and Dr Sinem Bezircioglu of Izmir Institute of Technology to improve its reading. Finally, I would like to once again thank Prof. Zekai Sen for thoroughly reading, and editing the book.

Gökmen Tayfur

'Be Saint like water'
Turkish Saying

'In helping and generosity, be like a river'
Mevlana