## **Table of Contents**

ACKNOWLEDGMENTS	III
ABSTRACT	V
DEUTSCHE KURZFASSUNG	XI
TABLE OF CONTENTS	XV
LIST OF FIGURES	XXI
LIST OF TABLES	XXVII
ABBREVIATIONS	XXIX
1. INTRODUCTION	1
1.1 GENERAL	1
1.2 DESCRIPTION OF THE STUDY AREA	
1.3 Objectives and Organization of the Dissertation	4
2. STUDY OF CLIMATE CHANGE IN THE RUHR RIVER BASIN CONCERNING THE	OCCURRENCE
OF DROUGHT	
	7
2.1 CLIMATE IS CHANGING	
2.3 DATA AND METHODOLOGY	
2.3.1. Data Collection	
2.3.2 Analysis of Hydrological Hine Series	
2.3.3 1 Methods of Trend Identification:	17
2.3.4 Missing Data Calculation	
2.3.5 Homogeneity testing	
2 3 5 1 Absolute Homogeneity Tests	
2.3.5.1.1 Buishand Range Test:	
2.3.5.1.2 Von Neumann ratio test:	
2.3.5.2 Relative Homogeneity Tests	
2.4 TEMPERATURE ANALYSIS	
2.4.1 Mean Daily Temperature	
2.4.2 Maximum and Minimum Mean Daily Temperature	
2.4.2 Maximum and Minimum Mean Daily Temperature 2.4.3 Warm and Cold Days	
2.4.2 Maximum and Minimum Mean Daily Temperature 2.4.3 Warm and Cold Days 2.5 Precipitation Analysis	27 29
2.4.2 Maximum and Minimum Mean Daily Temperature 2.4.3 Warm and Cold Days 2.5 PRECIPITATION ANALYSIS 2.5.1 Distribution Changes and Trends	27 
<ul> <li>2.4.2 Maximum and Minimum Mean Daily Temperature</li></ul>	



тне
41
45
48
51
60
60
67

4.4.1	Background Information on Drought Forecasting	69
4.4.2	ARIMA Model	71
4.4	2.2.1 Definition of ARIMA Model	71
4.4	2.2.2 Description of ARIMA Representation	71
4.4	2.3 Description of Seasonal ARIMA Representation	72
4.4	.2.4 The Art of ARIMA Model Building	73
4.4.3	Development of an ARIMA Model to fit the SPI_3 Time Series	76
4.4	3.3.1 Computation of the Standardized Precipitation Index SPI_3	76
4.4	3.2 Model Identification	77
4.4	.3.3 Parameters Estimation	78
4.4	.3.4 Diagnostic Check	79
4.4	.3.5 Drought Forecasting From Selected Models	82
4.4.4	Development of an ARIMA Model to Fit the SPI_6 Time Series	86
4.4	.4.1 Model Identification	86
4.4	.3.2 Parameters Estimation	88
4.4	.4.3 Diagnostic Check	88
4.4	.4.4 Drought Forecasting with Selected Models	90
4.5 CON	CLUSION	93
5. STOCHA	STIC SIMULATION OF MONTHLY STREAMFLOW	95
5.1 INTRO	ODUCTION	95
5.2. DES	CRIPTION OF MODELS	96
5.2.1	Thomas-Fiering Model	96
5.2.2	Monte Carlo Simulation	97
5.2	.2.1 Gamma Distribution	98
5.2	.2.2 Pearson and Johnson Systems of Distribution	98
5.3 Appl	ICATION TO ACTUAL STREAMFLOW DATA	99
5.3.1	Applications and Data	99
5.3.2	Stochastic Generation of Streamflow Series	100
5.3	.2.1 Generation of monthly streamflow series using Thomas-Fiering simulation	100
5.3	.2.2 Generation of monthly streamflow series using Monte Carlo Simulation	. 105
5. <b>3</b> .3	Comparison between the results of the Thomas-Fiering Model and the Monte Ca	rlo
Simul		
	ation Model	. 111
5.4 Dete	ation Model	. 111 . 113
5.4 DETE 5.5 Cond	ation Model CTION OF DRY PERIODS CLUSION	. 111 . 113 . 113
5.4 Dete 5.5 Cond 6. RESERV	ation Model. CTION OF DRY PERIODS CLUSION OIR SYSTEM OPTIMIZATION DURING DROUGHT EVENTS	. 111 . 113 . 113 . 113 . <b>115</b>
5.4 Dete 5.5 Cond 6. RESERV 6.1 BACK	ation Model. CTION OF DRY PERIODS CLUSION OIR SYSTEM OPTIMIZATION DURING DROUGHT EVENTS IGROUND	. 111 . 113 . 113 . 113 . 115
5.4 Dete 5.5 Cond 6. RESERV 6.1 BACK 6.2 Deve	ation Model. CTION OF DRY PERIODS. CLUSION OIR SYSTEM OPTIMIZATION DURING DROUGHT EVENTS GROUND COPMENT OF A RESERVOIR OPTIMIZATION MODEL IN THE CONTEXT OF DROUGHT	. 111 . 113 . 113 . 113 . 115 . 115 . 117

xviii Tabl	e of Contents
6.2.2 Constraints	
6.2.3 Model Application Using Genetic Algorithm	120
6.2.3.1 Comparison between the Results of the Developed Model and Actua	l Historical
Data	124
6.2.3.2 Comparison between Alternative Optimization Methods	127
6.3 CONCLUSION	129
7. STOCHASTIC SIMULATION OF RESERVOIR OPERATION USING ADAPTIVE NEURO	-FUZZY
INFERENCE SYSTEMS	
74.0	121
7.1 BACKGROUND	
7.2 FUNDAMENTAL FUZZY SYSTEM FOR RESERVOIR OPERATION MODEL	
7.3 ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM	
7.4 SIMULATION OF RESERVOIR OPERATION USING ADAPTIVE NEURO-POZZY INFERENCE SYSTE	M3 (ANFIS) 126
7.4.1 Data Hand in this Church.	
7.4.1 Data Usea in this Study	130
7.4.2 Methodology	
7.4.3 Nodeling of Neservoir Operation - Cuse1. Release of next month	
7.4.3.1 Selection of ANEIS Model	139
7.4.3.2 Selection of ANFIS Model.	142
7.4.3.3 Fuzzincation of inputs and ANFIS-based Learning Models	1/2
7.4.3.5 Simulation of the Receiver Operation Using the Selected Medal	
7.4.3.5 Simulation of the Reservoir Operation Using the Selected Model	
7.4.4 Modeling of Personair Operation - Case 2: Pelages of the Current Month	
7.4.4 Modeling of Reservoir Operation—Case2. Release of the Current Month	mulation
Models	155
7 5 CONCLUSION	155
8. DROUGHT MANAGEMENT PLAN	159
8.1 INTRODUCTION	159
8.2 CLASSIFICATION OF DROUGHT IMPACTS	160
8.3 DROUGHT AND WATER SCARCITY	161
8.4 DROUGHT MANAGEMENT IN THE EUROPEAN UNION (EU)	
8.4.1 Drought Management in Spain	
8.5 DEVELOPING A DROUGHT MANAGEMENT PLAN FOR THE RUHR BASIN	
8.5.1 Definition of a Drought Management Plan (DMP)	164
8.5.2 Stages of a Drought Management Plan	
8.5.2.1 Drought Watch	165
8.5.2.2 Drought Warning	166
8.5.2.3 Drought Emergency	

8.5.3 Drought Response	
8.5.3.1 Drought Watch	
8.5.3.2 Drought Warning	
8.5.3.3 Drought Emergency	
8.5.4 Case Study	172
8.5.4.1 Case Study (year 1976)	175
8.5.4.2 Case Study (year 1996)	178
8.5.4.3 Case Study (year 2003)	182
8.6 Conclusion	189
9. CONCLUSIONS AND RECOMMENDATIONS	191
9.1 SUMMARY AND CONCLUSIONS	191
9.2 RECOMMENDATIONS	194
REFERENCES	197
APPENDIX A	207
SOFTWARE FOR THE CALCULATION AND ANALYSIS OF THE STANDARDIZED	PRECIPITATION
INDEX	207
A.1 Possibilities of SPI_Analysis	207
A.2 MATHEMATICAL CORE OF SPI_ANALYSIS	207
A.3 How to Start an Application	208
A.4. REQUIRED INFORMATION CONTENT OF DATA SERIES	209
A.5 CALCULATION OF THE SPI INDEX	210
A.5.1. Define Input Data Series	210
A.5.2. SPI Index for Consecutive Months	210
A.5.3. SPI Index for a Specified Month	213
A.5.4 Detection of Extreme Events	215
APPENDIX B	217
SOFTWARE PACKAGE FOR METEOROLOGICAL DROUGHT FORECASTING US	NG STOCHASTIC
MODELS	217
B.1 INTRODUCTION	217
B.2 Possibilities of Drought_Forecasting	217
B.3 MATHEMATICAL CORE OF THE DEVELOPED PROGRAM	
B.4 APPLICATIONS OF THE PROGRAM	
B.5. REQUIRED INFORMATION CONTENT OF DATA SERIES	219
B.6 MODEL IDENTIFICATION (SPI_6)	219
B.7 Estimation and Optimization of the Parameters (Non-Seasonal and Seaso	DNAL PARAMETERS,
P, Q, AND P, Q)	220
B.7.1 Seasonal Model SARMA (p, q) (P, Q)5	220

xx Tat	ble of Contents
B.7.2 Estimation of the Model Parameters	222
B.8 DIAGNOSTIC CHECKING	223
B.9 FORECASTING OF THE SPI INDEX FROM SELECTED MODELS	225
B.10 CALIBRATION AND ACCURACY OF THE DEVELOPED PROGRAM (DROUGHT_FORECASTING)	) 226
B.10.1 Models Verification &Validation	226
B.10.2 Accuracy of the Developed program	
B.10.2.1 Comparison between the results of the ARIMA Model obtained by	1
Drought_Forecasting& SPSS	
B.10.2.2 Comparison between the results of the SARIMA Model obtained b	у
Drought_Forecasting& SPSS	
APPENDIX C: RESULTS OF SPI FORECASTING (SPI_12 AND SPI_24)	
C.1 SPI_12	
C.2 SPI_24	
APPENDIX D: SAMPLE OF INPUT DATA OF SCENARIO NUMBER 1 IN	THE
OPTIMIZATION MODEL	
CURRICULUM VITAE	