UNIVERSITI PUTRA MALAYSIA

MODELING FLOOD OCCURENCES USING SOFT COMPUTING TECHNIQUE IN SOUTHERN STRIP OF CASPIAN SEA WATERSHED

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By

SATTAR CHAVOSHI BORUJENI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

February 2012

DEDICATION

I dedicate this thesis to my beloved parents especially my mother who went to an endless trip when I started PhD and my father who taught me that the best kind of knowledge to have is that which is learned for its own sake. I also dedicate this thesis to my siblings and wife who have put up with these many years of research. Without their patience, understanding, support, and most of all love, the completion of this work would not have been possible.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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February 2012

Chair: Associate Professor Wan Nor Azmin Sulaiman, PhD

Faculty: Environmental Studies

Modeling of hydrological process has been increasingly complicated since we need to take into consideration an increasing number of descriptive variables. In recent years soft computing methods like fuzzy logic and genetic algorithm are being used in modeling complex processes of hydrologic events. The complex non linear behavior of flood and short record of observed data in the region makes the study of flood problematic. This thesis aims to apply soft computing techniques including fuzzy logic, neural network and genetic algorithm on different aspects of flood modeling including hydrological homogeneity and flood prediction in southern Caspian Sea Watersheds. This area with 42400 square kilometers has been affected by severe floods causing damages to human life and properties. A total of 61 hydrometric stations and 31 weather stations with 44 years observed data (1961-2005) are available in the study area. Delineation of homogeneous regions in terms of flood behavior was the initial step of this thesis which was achieved by several methods. The conventional methods of homogeneity i.e. hard clustering (hierarchical and non-hierarchical clustering, K-

means) and soft clustering (Fuzzy C-means and Kohonen) were studied and compared by L-moment techniques. Factor analysis using principle component analysis (PCA) with an orthogonal rotation method, varimax factor rotation have resulted in 4 out of 15 parameters namely area, mean elevation, Gravelius factor and shape factor. In conventional hard clustering approach, the number of clusters was determined by hierarchical clustering and two-step cluster analysis; then the sites were allocated to the appropriate cluster by k-means clustering method. In soft clustering approach, Kohonen network was employed to find the number of clusters and then the allocation of sites to the appropriate cluster was performed by using fuzzy c-means method. As a conclusion of regionalization, 38, 13 and 10 catchments were allocated to 3 specified regions. Assessment of homogeneity in this region was achieved and approved by three proposed heterogeneity measures i.e. $H_{L_{cv}}$, $H_{L_{ck}}$, $H_{L_{cs}}$ with 1.94, 1.13 and 0.71, respectively. In order to fully investigate the homogeneity (h) of catchments and overcome incompatibility that may happen on boundaries of cluster groups, a new method was used which utilizes physical and climatic parameters as well as flood seasonality and geographical location. This approach was based on fuzzy expert system (FES) using Fuzzy Toolbox of MATLAB software. Genetic algorithm (GA) was employed to adjust parameters of FES and optimize the system. Results obtained by this method were compared to the conventional methods. Since 3 L-moment criteria obtained by this method were significantly lower than previous methods it can be concluded that FES has better performance. After defining homogeneous region in the study area, flood models were developed. A total of 24 sites which were eligible in terms of adequate rainfall and runoff observed data were selected in this region. This area contains 604 pairs of observed data which was grouped into 60%, 20% and 20% for training, validation and testing, respectively. The most popular network in hydrology i.e. Multilayer Feedforward Back Propagation (MLFFBP) was used. Among the available learning algorithms in the Neural Network Toolbox of MATLAB, three algorithms, gradient descent back propagation (TRAINGD), gradient descent with adaptive learning rule back propagation (TRAINGDA) and the Levenberg-Marquardt (TRAINLM) were studied. Three algorithms of Linear (PURELIN), hyperbolic tangent sigmoid (TANSIG) and logistic sigmoid (LOGSIG) activation functions were selected for output layer. The hidden layer includes 1 layer with different neurons. Based on the mentioned criteria several scenarios were defined and compared which resulted to a structure of 8-10-1 with the Levenberg-Marquardt (LM) as the training algorithm and logistic sigmoid function in the output layer. This study found that FES technique is a powerful solution to make pooling groups as a promising approach that satisfies the high homogeneity of the catchments. The application of FES optimized by GA on regionalization creates opportunities for further researches which utilizes different types of optimization like Ant Colony Optimization (ACO), ANN's, Particle Swarm Optimization (PSO) and Imperialist Competitive Algorithm (ICA).

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah

TEKNIK PENGKOMPUTERAN LEMBUT BAGI PEMODELAN BANJIR BAGI LEMBANGAN DISELATAN LAUT CASPIAN

Oleh

SATTAR CHAVOSHI BORUJENI

Februari 2012

Pengerusi: Prafosor Madya Wan Nor Azmin Sulaiman, PhD

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Akhir-akhir ini soft computing digunakan dalam pemodelan proses kompleks kejadian hidrologi kerana ia boleh mempertimbangkan penambahan jumlah pembolehubah diskriptif. Tesis ini bertujuan untuk menilai pelaksanaan soft computing untuk mewujudkan peta kehomogenan hidrologi dan prestasi ramalan banjir kawasan secara perbandingannya dengan teknik konvensional. Kawasan kajian merangkumi jalur selatan lembangan Laut Caspian selmarseluas 42,400 kilometer persegi sering ledi terjejas oleh banjir yang teruk dan menyebabkan kerosakan tak terhingga bagi kehidupan manusia dan harta. Sebanyak 61 stesen hidrometri dan 31 stesen cuaca dengan 44 tahun data cerapan (1961-2005) beroperasi di kawasan kajian. Untuk mengatasi masalah yang timbul daripada kurangnya pengetahuan terhadap perilaku kompleks banjir, soft computing digunakan. Teknik ini membolehkan pelbagai sumber pengurusan data memahami proses-proses hidrologi yang kompleks dengan tidak perlu terlebih dahulu memahami hubungan yang tepat antara komponen-komponennya. Kod program khusus di persekitaran MATLAB yang meliputi teknik soft computing yang diterapkan dalam kajian ini telah dibangunkan. Delineasi kawasan-kawasan homogen dalam hal perilaku

banjir dicapai dengan dua pendekatan yang berbeza termasuk teknik konvensional dan baru. Awalnya, 16 pembolehubah fizikal lembongan yang boleh mengakibat banjir serantau dikenalpasti. Prinsip bahagian analisis (PCA) telah diaplikasi dan secara signifikan berkurang menjadi empat pembolehubah iaitu luas, purata ketinggian, faktor Gravelius dan faktor bentuk. Berdasarkan faktor-faktor ini, kaedah konvensional bagi kehomogenan delineasi melibatkan kaedah kluster hierarki dan tak-hirarki, purata-K, purata-Fuzzy C dan Kohonen dikaji dan hasilnya disahkan oleh teknik L-momen. Tiga daerah yang berbeza homogen dikenalpasti masing-masing meliputi 38, 13 dan 10 tadahan. Alternatifnya, untuk menyiasat kehomogenan tadahan dan mengatasi ketidaksesuaian yang mungkin terjadi pada batas kumpulan kluster, sebuah rangka kerja baru pada pencirian kehomogenan berdasarkan wilayah pengaruh (ROI) dibentangkan. Pendekatan alternatif Sistem Pakar Fuzzy (FES) ini memanfaatkan pendekatan pembolehubah yang lebih luas yang meliputi parameter fizikal dan iklim serta banjir bermusim dan lokasi geografi. Antara muka fuzzy yang digunakan dalam kajian ini disebut kaedah Mamdani. Untuk menghasilkan set fuzzy fungsi keahlian Gaussian digunakan. Sejumlah 9 aturan telah ditakrifkan dan dikodkan. Sebagai langkah terakhir, algoritma genetik (GA) digunakan untuk menyesuaikan parameter FES dan mengoptimumkan sistem. Output yang dihasilkan adalah wilayah pengaruh (ROI) untuk setiap tadahan iaitu ruang maya untuk setiap tadahan yang secara jelas meliputi tadahan homogen. Keputusan yang diperolehi dengan kaedah ini disahkan oleh langkah-langkah heterogenan L-momen. Sejak tiga kriteria L-momen diperolehi dengan kaedah ini lebih rendah pada nilai daripada kaedah konvensional dapat disimpulkan bahawa FES lebih hebat daripada kaedah konvensional untuk mendefinisikan wilayah kehomogenan banjir. Setelah mendefinisikan wilayah homogen di kawasan kajian, model banjir berdasarkan

ANN dan teknik regresi berganda dibangunkan. Sejumlah 24 tadahan yang memenuhi syarat dengan hujan yang dan data cerapan yang mencukupi telah dipilih dalam wilayah ini. Untuk analisis ANN, 356 pasang data cerapan dikumpulkan menjadi 60%, 20% dan 20% untuk latihan, validasi dan ujian. Satu multilayer feedforward back propagation (MLFFBP) digunakan yang meliputi 8 lapisan input, satu tersembunyi dan satu lapisan output. Jumlah neuron pada lapisan tersembunyi diperolehi secara cuba dan ralat. Di antara algoritma belajar yang ada, tiga algoritma, gradient descent back propagation (TRAINGD), gradient descent dengan adaptive learning rule back propagation (TRAINGDA) dan Levenberg-Marquardt (TRAINLM) telah dikaji dan dibandingkan. Tiga algoritma Linear (PURELIN), sigmoid tangen hiperbolik (TANSIG) dan logistik sigmoid (LOGSIG) fungsi pengaktifan dipilih untuk lapisan output. Berdasarkan kombinasi fungsi pengaktifan yang berbeza dalam lapisan input dan output dan juga berbeza jumlah neuron dalam lapisan tersembunyi beberapa senario ditakrifkan dan dibandingkan. Rangkaian optimum ditentukan dengan menggunakan fungsi penilaian yang memaksimumkan pekali korelasi antara nilai-nilai sasaran dan anggaran air larian. Keputusan menunjukkan bahawa struktur 8-10-1 dengan Levenberg-Marquardt (LM) sebagai algoritma latihan dan fungsi sigmoid logistik di lapisan output mempunyai prestasi yang optimum. Sebuah model regresi berganda yang berkaitan antara pembolehubah bebas (luas, ketinggian purata, faktor bentuk, faktor Gravelius, purata hujan tahunan, hujan semasa kejadian banjir, hujan terdahulu, hujan tahunan maksimum) dan pembolehubah bergantung (aliran puncak) diwujudkan. Namun, hanya empat daripada lapan pembolehubah yang digunakan dalam ANN dapat diterapkan dalam model regresi. Namun, prestasi model adalah sekitar 69% iaitu kurang berbanding dengan prestasi yang diperolehi oleh ANN (82%).

Sebagai penemuan baru dari tesis ini, satu metodologi telah dibentangkan untuk regionalisasi yang mengatasi kaedah konvensional seperti menggunakan pembolehubah baru banjir bermusim dan lokasi geografi. Sistem pakar fuzzy dioptimumkan dengan algoritma genetik boleh menyebabkan meningkatkan ketepatan statistik untuk kajian hidrologi kawasan seperti frekuensi banjir serantau dan menyediakan peta yang lebih terperinci tentang kawasan serupa hidrologi. Juga rawatan ketaksamaan dalam model ANN telah mengatasi model regresi di kawasan kajian di mana kaedah terdahulu adalah kerana bermasalah dengan kurangnya pengetahuan terhadap perilaku kompleks banjir. Hasil utama dari tesis ini jelas menunjukkan bahawa ada ruang untuk pembaikan lebih lanjut dalam penilaian regionalisasi kawasan hidrologi dan peramalan banjir di kawasan tersebut.

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I would like to thank all of those people who helped make this thesis possible. First, I wish to thank my supervisor, Associate Prof. Dr. Wan Nor Azmin Sulaiman for all his guidance, encouragement, support, patience and his continuous efforts to provide me feedback and instructions and helping me to increase the depth of my knowledge on hydrology. It was an honor to be supervised by him and thanks for believing in me and my abilities.

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Last but not least, I wish to convey my sincere thanks and love to my family for their sacrifices and patience throughout the duration of my study.

APPROVAL

I certify that a Thesis Examination Committee has met on 16.Feb.2012 to conduct the final examination of SATTAR CHAVOSHI BORUJENI on his Doctor of Philosophy thesis entitled "Modeling Flood Occurrences Using Soft Computing Techniques in Southern Caspian Sea Watersheds" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at University Putra Malaysia or at any other institutions.

SATTAR CHAVOSHI BORUJENI

Date: 16 Feburry 2010

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LIST OF ABBREVIATIONS

Abbreviation	Full name
ANFIS	Adaptive Neuro-Fuzzy Inferences System
AIC	Akaike Information Criteria
ANOVA	Analysis of Variance
AI	Artificial Intelligence
ANN	Artificial Neural Network
ARMA	Auto Regressive Moving Average Models
BP	Back Propagation
BTS	Barlett's Test of Sphericity
BIC	Bayesian Information Criteria
BL	Boltzmann Learning
CL	Competitive Learning
DEM	Digital Elevation Model
ECL	Error Correlation Learning
FFBPANN	Feed Forward Back Propagation Artificial Neural Network
FFA	Flood Frequency Analysis
FCA	Fuzzy Cluster Analysis
FCM	Fuzzy C-means
FES	Fuzzy Expert System
GA	Genetic Algorithm
GEV	Generalized Extreme Value
GP	Generalized Pareto
GL	Generalized Logistic

GIS	Geographical Information Systems
GDX	Gradient Descent with Adaptive Learning Rate and Momentum
GDM	Gradient Descent with Momentum
HL	Hebbian Learning
Hi	Heterogeneity Measures
IDW	Inverse Distance Weighting
KMO	Kaiser-Meyer-Olkin Measure of Sampling Adequacy
K	Kappa
KANN	Kohonen Artificial Neural Networks
SOFM	Kohonen's Self Organizing Feature Map
LM	Levenberg–Marquardt Algorithm
LLSSIM	Linear Least Square Simplex Training Algorithm
L	Logistic
LPE3	Log Pearson Type 3
MF	Membership Function
MAE	Mean Absolute Error
MSE	Mean Squared Error
MLFFBP	Multilayer Feed Forward ANN
MLP	Multi Layer Perceptron
MLRP	Multiple Regression Model
NLR	Nonlinear Regression
NLR-R	Nonlinear Regression with Regionalization Approach

N	Normal
POT	Peaks Over Threshold
PE3	Pearson Type 3
PCA	Principle Component Analysis
RBF	Radial Basis Function
RFFA	Regional Flood Frequency Analysis
ROI	Region of Influence
RMSE	Root Mean Square Error
SOM	Self Organization Map
TAMAB	The Company of Water Resources Research
LN3	Three-Parameter Log Normal
CGF	The Fletcher-Reeves Conjugate Gradient
LN2	Two-Parameter Log-Normal
BGF	Quasi-Newton
W	Wakeby

LIST OF NOTATIONS

Notation	Full Name
Q_t	Annual Maximum Peak Discharge (cubic meter per second)
A	Area (square kilometers)
CR	Circularity Ratio
CC	Compactness Coefficient
Di	Discordance Index
EP	Equivalent Precipitation or Precipitation Causes Flood (millimeter)
EH	Extremely high homogeneity
EL	Extremely Low homogeneity
FF	Form Factor
G	Gravelius Factor
Hi	Heterogeneity Measures
H_{LCK}	Heterogeneity Measures of Linear Coefficient of Kurtosis
H_{LCS}	Heterogeneity Measures of Linear Coefficient of Skewness
H_{LCV}	Heterogeneity Measures of Linear Coefficient of Variance
H	High homogeneity

Lcv	Linear Coefficient of Variation
Lkur	Linear Kurtosis
L-Moment	Linear Momentum
Lskew	Linear Skewness
LL	Longest Length (meter)
L	Low Homogeneity
MRL	Main River Length (kilometer)
MxE	Maximum Elevation (meter)
MAP	Mean Annual Precipitation (millimeter)
ME	Mean Elevation (meter)
M	Medium Homogeneity
MnE	Minimum Elevation (meter)
P	Perimeter (kilometer)
RS	River Slope (percent)
SF	Shape Factor
S	Slope (percent)
TC	Time of Concentration by Kerpich Method (minute)
VH	Very High Homogeneity
VL	Very Low Homogeneity

V	Weighted Standard Deviation
W	Width (meter)

CHAPTER 1

INTRODUCTION

1.1 General

Sustainable management of water resources involves not only the appropriate utilization of water resources, but also the minimization of the unfavorable impact of water excess or deficiency. The forecasting of such extremes is of great practical importance in hydrological process. Flood, as one of the most destructive natural hazards, either in terms of property damage or loss of human life, has been of major concern to hydrologists. The worldwide study of flood events indicates their increasing trend making flood control as a challenging key problem. Study of the magnitude and frequency of floods is the initial step in flood control. It is needed for a wide range of engineering projects, especially hydraulic design projects such as dams, bridges, culverts, water supply systems and flood control structures.

The natural behavior of flood-generating systems which probably take place at any area may differ on both temporal and spatial scales. Time is explained using a discrete scale (annual maxima) or on a continuous basis, while location can be treated as points or regions. Studies of flood mechanisms in a specific area involve both temporal and spatial analysis. There are several methods for estimating flood quantiles in a region which can be classified in two main groups of at-site and regional flood frequency analysis. Selection of the appropriate approach relies on the data availability, the form of the distribution and the estimation procedure used. The first group of methods is based on single station analysis and uses only at-site data.

This method is recommended for the gauged catchments which have long records of stream flow observation. In the general procedure of at–site flood frequency analysis, the observed flow data is fitted to a specific probability distribution and the required flood quantile from the distribution is obtained according to the specified exceedence probability. The second method is based on a regional concept which applies combination of at-site data and neighboring gauged catchments. This method is appropriate where there is no stream flow record or the length of the observed data at sites of interest is much shorter than the return period of interest.

In recent decades, hydrologists have tended to use models as an efficient approach to delineating flood behavior. A model is a description or simulation of reality, used to derive behavior of hydrologic processes. It usually aims to investigate special assumptions about the nature of the real world system, then to forecast the behavior of the system under natural conditions (Beven, 1989). Modeling of hydrological processes has become increasingly complicated since we need to take into consideration an increasing number of descriptive variables. Soil, topography, land-use, rainfall and flow are some of the variables for which spatial measurement is difficult.

In recent years soft computing are being used in modeling complex combinations of hydrologic events. Soft computing is defined as a group of methods which are used to develop intelligent systems for simulating complex problems in the real world. Fuzzy logic, neural networks and genetic algorithm are the main methods of soft computing. One of the most important advantages of soft computing is that it allows multi-source data management. It provides the possibility of collecting information from a large source of data, which is significantly important for comprehending complex hydrological processes. Consequently, if significant factors are determined, without knowledge of the exact relationships, soft computing methods are able to perform an appropriate fitting function by using multiple parameters based on the existing information and use this to predict the possible relationships in the future (Raclot and Puech, 2003). Due to the above mentioned advantages of soft computing, many researchers have applied it on their studies in recent years (Maier and Dandy, 2000; Dolling and Varas, 2001; Wright and Dastorani, 2001; Patrick et al., 2002; Zhang et al., 2002; Coppola et al., 2003; Sing and Datta, 2004; Daliakopoulos, 2005; Tayfur and Singh, 2006; Garbrecht, 2006; Antar et al., 2006; Srinivasulu and Jain, 2006; Tayfur et al., 2007; Manisha et al., 2008).

This thesis aims to apply soft computing techniques on different aspects of flood modeling including hydrological homogeneity and flood prediction. As a new finding on hydrological homogeneity and in order to fully understand it, a fuzzy expert system algorithm proposed by Shu and Burn (2004) is applied which utilizes catchment descriptors, geographical location and flood seasonality simultaneously. This technique is significantly superior to conventional methods such as clustering which are based on only one of the mentioned variables. Also, an artificial neural network (ANN) is used to model rainfall-runoff relationship in the homogenous region. As an attempt to design the optimum topology of ANN in the study area, different scenarios are tested and compared. The results obtained by this study can be used for further watershed studies and practices like designing hydraulic structures or water resources projects.

1.2 Statement of the problem

There are three types of problem in the study area, namely occurrence of flood events, insufficient observed data and the complex behavior of floods. Flooding is a significant natural disaster in southern Caspian Sea Watersheds. Several records of flash floods, which caused severe impacts on human's life and properties as well as environment, have been recorded in the area. There is a need for characterization of flood quantile in the region. The preliminary need on the study of flood mechanism is to reduce the risk of occurrence and its consequences and it is not feasible without local data and information. The insufficient numbers of hydrologic and weather station records makes the study of floods and their impacts problematic such that any prediction without a lengthy flood record would not be reliable. Moreover flooding is an inherently uncertain natural process which involves a complex interaction with drainage basin components like soil, topography and rainfall. Thus it cannot be described as a linear process and conventional methods like regression or empirical equations fail to simulate it. To address these problems, soft computing which allows multi-source data management to comprehend complex hydrological processes is typically used without need to understand the exact relationships between the components. Previous methods of regionalization in this study were based on physical attributes of the basins. In order to fully investigate the homogeneity (h) of catchments and overcome the incompatibility that may happen on the boundaries of cluster groups, a new method is needed which utilizes physical and climatic parameters (c) as well as flood seasonality (s) and geographical location (g).

In a summary, the research problem is to apply soft computing techniques to improve different aspects of flood modeling including hydrological homogeneity and flood quantiles estimation. There is a need for a fuzzy expert system algorithm optimized by genetic algorithm to minimize heterogeneity of the specified regions.

1.3 Objectives

The principal aim of this thesis was to employ soft computing concepts including fuzzy logic, neural network and genetic algorithm to develop methods for improved flood quantile estimation. This aim can be achieved through the following specific objectives:

1. To compare the conventional methods and fuzzy expert system for regionalization of homogeneous catchments
2. Delineation of homogeneous regions in terms of flood behavior and specify best distribution function for flood quantiles
3. Modeling flood for gauged catchments in the study area using artificial neural network
4. Development of regional approach for estimating flood quantiles in ungauged catchments

1.4 Contribution of the research

In this research soft computing techniques including fuzzy logic and genetic algorithm were employed to find the catchments similar to the site of interest based on the region of influence concepts. A fuzzy expert system algorithm optimized by genetic algorithm was developed to minimize the L-moments heterogeneity statistics of the specified regions.

1.5 Scope of the study

This thesis deals with two aspects of flood modeling viz. regionalization of homogeneous sites and determination of relationship between rainfall and runoff in the homogenous region. The study area is the Southern Strip of the Caspian Sea Watershed of 42,400 square kilometers. This has economically been of the most concern due to a permanent river network as well as productive farmlands, rangelands and forests. Sixty one catchments each with one hydrometric station at the outlet were selected for the study. A Geographic Information System, ARCGIS software, was used to derive the basin attributes. Geostatistical techniques were applied to map rainfall throughout the study area and determine the mean annual rainfall of each catchment. Factor analysis was used to determine the most important factors in connection with floods in the study area. These parameters were then used in different methods of regionalization. Using catchment descriptors two conventional approaches of regionalization i.e. hard clustering (K-means) and soft clustering (FCM and Kohonen) were studied and compared. Then as an alternative aiming to fully determine the homogeneity of catchments, a new approach based on fuzzy expert system (FES) was applied. It is superior to the conventional approaches because utilizes catchment descriptors, flood seasonality and geographical location simultaneously. In order to adjust parameters of the FES a genetic algorithm (GA) was applied. The accuracy of the methods was then compared by proposed L-moments criteria and the homogenous groups of sites were delineated.

Summarizing results of regionalization methods would achieve the first objective of the research. Rainfall-runoff relations were modeled by using artificial neural network techniques. In order to specify the optimum topology of the neural network in the study area, several scenarios based on different training algorithms were studied and evaluated. Results obtained by ANN would be compared to those from multiple regression models to achieve other defined objectives of the research.

1.6 Thesis Organization

This thesis is ordered in accordance with the formal format of UPM instructions for thesis preparation as below.

Following the Introduction in Chapter 1, Chapter 2 on Literature Review deals with the background information on flood studies in the world. It begins with an introduction about natural disasters in the world followed by the records of flood events in Iran and specifically in the study area. Then basic concepts of flood frequency are introduced. Several methods of regionalization and flood estimation are discussed and finally the application of soft computing in flood modeling is addressed.

In Chapter 3, the study area is described and the important criteria for selecting the study area are mentioned. Physical, climatic and hydrologic characteristics of the study area are illustrated and data availability is also summarized. Then the methodology of the research is discussed by means of several flowcharts.

Chapter 4 highlights the results obtained by this research. It encompasses multiple tables and figures to help understanding of new findings of the research.

Chapter 5 finalizes the thesis with conclusion, contribution to knowledge and a number of recommendations to improve and expand on this work.

The main body of the thesis is attached to appendices including tables and graphs for each result as well as MATLAB code written for this research.

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