Study on Synthetic and Unit Hydrographs by using GIS and Artificial Intelligence Techniques

Ph.D. Thesis

in

Civil Engineering

University of Gaziantep

Supervisor

Assoc. Prof. Dr. Aytaç GÜVEN

by

Ayşe Yeter GÜNAL

December 2015

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: Study on Synthetic and Unit Hydrographs by using GIS and Artificial Intelligence Techniques

Name of the student: Ayşe Yeter GÜNAL

Exam date: 25.12.2015

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Metin BEDİR
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Doctor of Philosophy.

Prof. Dr. Mustafa GÜNAL
Head of Department

This is to certify that we have read this thesis and that in our consensus opinion it is fully adequate, in scope and quality, as a thesis for the degree of Doctor of Philosophy.

Assoc. Prof. Dr. Aytaç GÜVEN
Supervisor

Examining Committee Members:	Signature
Prof. Dr. Yalçın YÜKSEL	……………………..
Prof. Dr. Esin ÇEVİK	……………………..
Assoc. Prof. Dr. Nermin ŞARLAK	……………………..
Assoc. Prof. Dr. Aytaç GÜVEN	……………………..
Assist. Prof. Dr. Mazen KAVVAS	……………………..

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Ayşe Yeter GÜNAL

ABSTRACT

STUDY ON SYNTHETIC AND UNIT HYDROGRAPHS BY USING GIS AND ARTIFICIAL INTELLIGENCE TECHNIQUES

GÜNAL, Ayşe Yeter
Ph.D. in Civil Engineering
Supervisor: Assoc. Prof. Dr. Aytaç GÜVEN
December 2015
107 pages

In this study, unit hydrograph and synthetic unit hydrograph parameters which are q_p, t_p, t_b are calculated by using Snyder's, Mockus, SCS (Soil Conservation Service), and DSI (State Hydraulic Works) methods. First, calculations are done according to observed data. Then other methods mentioned above, which are based on both topographic map and geographic information systems (GIS) values, are used. Three catchments which are Damlıca, Vize, and Kumdere are studied. Snyder's, Mockus, SCS and DSI methods are applied in each catchment. The geomorphologic parameters of Damlıca catchment are determined by using geographic information systems. It is shown that, the geomorphologic parameters of the Damlıca catchment obtained using GIS are much more precise than those produced by conventional methods.

Linear Genetic Programming (LGP) is also proposed in predicting daily time series of river flow data. Auto regressive (AR) technique is also presented as conventional time-series model of the same discharge data. The performance of each model was compared based on the well-known statistical performance measures. The results of each model were tabulated and illustrated in time-series diagrams.

Snyder's based synthetic UHs were developed by using both digitized map and digital elevation model of a case study of a small catchment in Turkey. Multi output neural network (MONN) technique was applied to predict the three UH parameters: peak discharge (q_p), time to peak (t_p) and time base (t_b) of a number of UHs observed in the catchment based on most relevant geomorphologic and meteorological parameters. MONN was observed to outperform the conventional synthetic UH methods. The impact of the proposed MONN is that it predicts the three parameters of the UH based on a single model compared to the conventional NN technique which utilizes a model each parameter.

Key Words: Unit hydrograph, Synthetic unit hydrograph, Catchment, Linear Genetic Programming, Multi Output Neural Network.

ÖZET

CBS VE YAPAY ZEKA TEKNİKLERİ KULLANILARAK SENTETİK VE BİRİM HİDROGRAF ÇALIŞMASI

GÜNAL, Ayşe Yeter
Doktora Tezi, İnşaat Mühendisliği Bölümü
Tez Yöneticisi: Doç. Dr. Aytaç GÜVEN
Aralık 2015
107 sayfa

Bu çalışmada, birim hidrograf ve sentetik birim hidrograf parametreleri, q_p, t_p, t_b Snyder, Mockus, SCS ve DSİ metotları kullanılarak hesaplandı. Önce ölçülmüş değerler kullanılarak hesaplamalar yapıldı. Daha sonra yukarıda bahsedilen metotlar kullanılarak harita değerleri ve GIS teknikleri kullanılarak elde edilen bilgilere göre hesaplamalar yapıldı. Damlıca, Vize ve Kumdere havzalarına Snyder, Mockus, SCS ve DSİ metotları ayrı ayrı uygulandı. Damlıca havzasına ait hidrolojik parametreler GIS kullanılarak elde edilen havza değerlerine göre hesaplandı ve elde edilen sonuçlar konvansiyonel yöntemlere göre daha iyi olmuştur.

Ayrıca bir nehrin akış değerlerine ait günlük zaman serileri LGP yöntemi ile tahmin edildi. Her modelin performansı bilinen istatistiksel yöntemlere göre ölçüldü. Bu sonuçlar tablo halinde ve zaman seri diyagramları halinde verildi.

Türkiye'de küçük bir havzaya ait sentetik birim hidrograf sayısal harita ve coğrafi bilgi sistemi kullanılarak Snyder tabanlı sentetik birim hidrograflar elde edildi. Çok çıktılı sinir ağları (MONN) tekniği kullanılarak üç havzanın pik debisi q_p, pik debiye ulaşma zamanı t_p ve sönümlenme zamanı t_b birden fazla havzada ölçülmüş birim hidrografları ve havzalara en uygun jeomorfolojik ve meteorolojik parametreler kullanılarak bulundu. MONN tekniği konvansiyonel sentetik UH metotlarına göre çok daha iyi performans göstermiştir. Geliştirilen MONN metodu ile birim hidrografa ait üç parametre konvansiyonel NN tekniği ile elde edilen değerlere göre daha etkili olmuştur.

Anahtar Kelimeler: Birim hidrograf, Sentetik birim hidrograf, Havza, Lineer genetic programlama, Çok çıktılı sinir ağları.

This thesis is dedicated to my wonderful family; Dad, Mom, Husband, Brother, Sisters and our lovely and precious daughters Selin and İpek for their endless love, support and encouragement.

ACKNOWLEDGEMENTS

The author wishes to express her deepest gratitude to her supervisor Assoc. Prof. Dr. Aytaç GÜVEN for his valuable precious and excellent guidance, advice, criticism, encouragements and insight throughout the research.

The author would like to thank Prof. Dr. Yalçın YÜKSEL and Assoc. Prof. Dr. Nermin ŞARLAK for their valuable comments and providing all sorts of help through entire study period.

The author would also like to thank her husband Prof. Dr. Mustafa GÜNAL for his support and patience.

TABLE OF CONTENTS

Page

LIST OF TABLES

Pages

LIST OF FIGURES

Page

LIST OF SYMBOLS/ABREVIATIONS

A	Area
ANFIS	Adaptive Neuro Fuzzy Inference System
ANN	Artificial Neural Network
API	Antecedent Precipitation Index
CN	Number of hydrological soil cover
C_t, C_p	Snyder's method coefficients
DEM	Digital Elevation Model
DRH	Direct Runoff Hydrograph
DSI	State Hydraulic Works
F	Filtration
GANN	Geomorphology-based Artificial Neural Network
GDEM	Global Digital Elevation Model
GEA	Gene Expression Algorithm
GEP	Gene Expression Programming
GIS	Geographic Information System
GIUH	Geomorphologic Instantaneous Unit Hydrograph
GP	Genetic Programming
GTM	GIS-based Topographic Map
h	Hour
h_{avr}	Catchment average elevations
h_m	Catchment median elevation
h_{max}	Catchment max. elevation
h_{min}	Catchment min. elevation
K_c	Congestion index
L_a	Equivalent rectangular catchment
L_b	Slope index related to equivalent rectangular catchment

L_c	The distance between projection of catchment's center of gravity to main stream line to outlet of the catchment
LGP	Linear Genetic Programming
L_H	Catchment length
L_s	Main stream line length
L_u	Total stream line lengths
MLP	Multi-Layer Perception
MONN	Multi Output Neural Network
MSE	Mean Square Error
NGANN	Non-Geomorphology-based Artificial Neural Network
P	Catchment perimeter
q_p	Peak discharge
r	Catchment relief
R^2	Determination coefficient
RMSE	Root Mean Square Errors
r_n	Catchment relative relief
S	The harmonic slope of main stream line
S_1	Shape Index related to main stream line
S_2	Shape Index related to catchment length
S_3	Circularity ratio
SAM	Simple Average Method
SCS	Soil Conservation Service
SDUH	Spatially Distributed Unit Hydrographs
S_H	Catchment average slope
SOM	Self-Organizing Map
SR	Surface Runoff
S_s	Profile and the slope of the main stream line
SSNN	States Space Neural Network
SUH	Synthetic Unit Hydrographs
TAGEM	General Directorate of Agricultural Research and Policies
t_b	Base time

t_c	Collection period or concentration time
TM	Topographic Map
t_p	Peak time
t_r	Effective rainfall
UH	Unit Hydrograph
VAR	Variance
WAM	Weighted Average Method
W_H	Catchment width

CHAPTER 1

INTRODUCTION

1.1 General

Importance of water is increasing due to the high population growth and global warming in the World as well in Turkey. Moreover droughts or floods are being occurred in several parts of the country where there is no such evidence in the past. Therefore, basin and river management systems including hydrological modeling has become a very important issue in Turkey.

Mathematical models are widely used in the engineering problems to reflect what is in reality and give solutions by using advanced computer technology. Because of this, modeling is the most powerful tool while solving engineering problems. Hydrological models give more realistic solutions due to the latest development in technology. They are very beneficial, however in reality most of them have many parameters and those parameters must be adjusted for good simulation.

On the other hand another factor which affects the relation between rainfall-runoff is the prediction of the rainfall intensity and duration. The application of the model to a smaller area could increase the efficiency by using special characteristics of the area. The accuracy of the data increases when the areal rainfall data accuracy increases.

Circulating water in the hydrological cycle, rainfall, flow, such as parameter values are determined by meteorological and hydrological measurement techniques. Continuous measurement processes have been used for many years. By analyzing the data obtained from measurements of water potential of a water source, times of drought and flooding quantities of water and their frequencies can be calculated.

In Turkey, rainfall and runoff data are seldom adequate to determine unit hydrographs of drainage basins. When it is necessary to determine a unit hydrograph for a basin, therefore, one of the synthetic unit hydrograph determination methods is used. The most commonly used methods are the Snyder's, the Mockus, the State Hydraulic Works (DSI) synthetic and the U.S. Soil Conservation Service (SCS) methods. Most of these synthetic methods require some coefficients for the basin under study.

1.2 Aim of the study

In this study Damlıca, Vize, and Kumdere basins, are studied. For determining design discharges for hydraulic structures, it is necessary to determine unit hydrographs for the corresponding basins. In Turkey, suitable data to determine the unit hydrograph of a basin are not easy to find, therefore unit hydrographs are usually determined synthetically. Coefficients used in the synthetic unit hydrograph determination are taken from studies made for the specific areas in the world. In this study, synthetic unit hydrographs are obtained for a basin where rainfall-runoff data were available to determine actual unit hydrographs as well. The goals of the study are first, to compare the unit hydrographs obtained synthetically and those from observed rainfall-runoff data. Second, use GIS techniques in determining synthetic unit hydrograph and show its effectiveness. To satisfy the second goal, SCS, Synder's, Mockus and DSI synthetic unit hydrograph determination methods were chosen since the methods were very suitable for the application of GIS techniques. Also multi output neural network (MONN) is used as an artificial intelligence method for determining the parameters of unit hydrograph which are peak time t_p, base time t_b, peak discharge q_p.

1.3 Data and software used in the study

ArcGIS V.11 is software developed and sold by Environmental Systems Research Institute, Inc. (ESRI) is used in this study for finding the hydrologic parameters of the basins. Three basins are studied: Damlıca, Vize and Kumdere. The main physical characteristics of these basins like the area, shape, elevation, slope, orientation, soil type, channel networks, water storage capacity and land cover of these regions are derived by using ArcGIS software.

Neurosolutions V5.0 is used in developing neural network models.

DTREG V3.0 software is used in developing genetic programming models.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydrologic Cycle

Catchment modeling requires a clear understanding of the hydrologic cycle at catchment scale. The catchment hydrologic cycle involves many processes. Many hydrologists investigated this cycle by a number of studies. A summary of the cycle is given by Chow et al. (1988) or detail description of some processes can be found in the book of Kirby (1978). To summarize the processes, a brief description is presented and is illustrated in Figure 2.1 below.

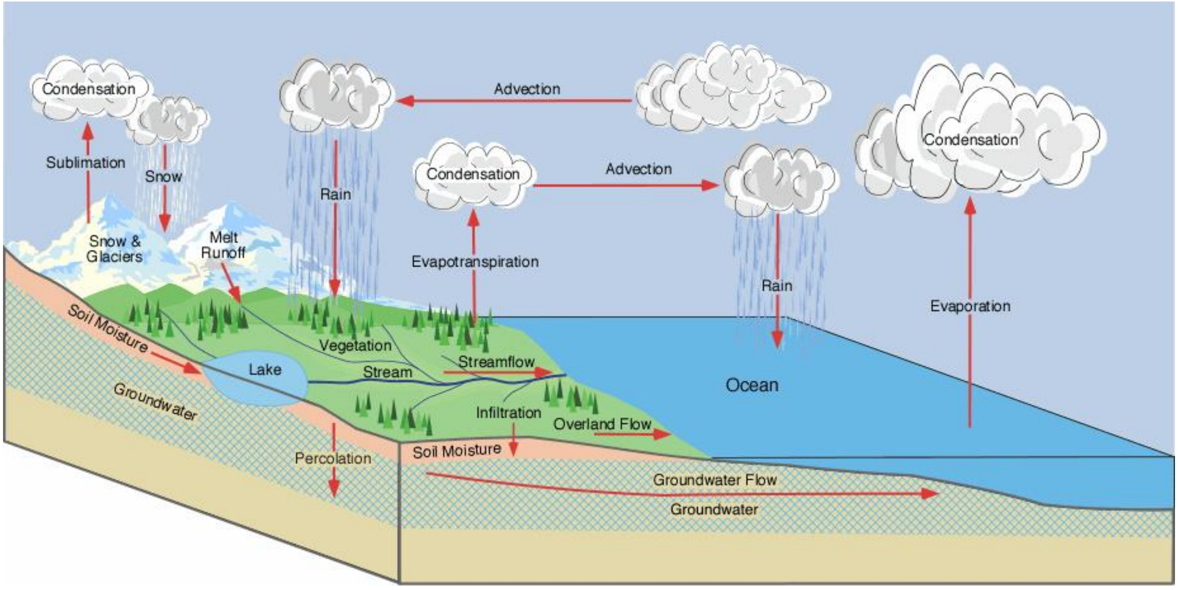

Figure 2.1 Hydrologic Cycle

Precipitation is the most essential process for the generation of runoff at a catchment scale. The distribution of precipitation varies spatially and temporally by the nature. Precipitation can be in the form of snow, hail, dew, rain and rime. In this study precipitation is considered in the form of rain only. Rainfall travels in a catchment in different directions. Due to vegetation, part of rainfall is intercepted by vegetation canopy. Interception is known as a loss function to catchment runoff depending on vegetation type, vegetation density. The rest of rainfall moves down the vegetation as stream flow, drip off the leaves, or directly falls to the ground as through fall.

2.2 Catchment Runoff Generation

Basically, the runoff generation at a catchment scale in general or hillslope scale in particular includes two main components: (1) surface runoff, (2) subsurface runoff.

The surface runoff: Flow processes include overland flow, stream flow, and channel flow which is defined as water flow over the land surface based on the differences on slope gradient. The overland flow is known as infiltration excess overland flow (Horton overland flow) or saturation overland flow (Dune flow). The Horton overland flow is generated when the rainfall intensity exceeds the infiltration capacity of the soil or by saturation mechanism where the soil becomes saturated by the perennial groundwater rising to the surface or by lateral or vertical percolation above an impending horizon (Dune, 1982). The overland flow is observed as sheet flow which then generates the rill flow. A number of the rill flow will contribute or create the stream flow which then converges into channel flow.

Subsurface runoff: Flow processes include unsaturated subsurface flow, perched subsurface flow, macro pore flow and groundwater flow. Subsurface runoff is generated since water discharged from the surface into the subsurface system. The unsaturated subsurface flow mostly is in vertical direction while the perched flow moves in lateral direction. The perched flow is generated where the shallow soil layer has much more higher hydraulic conductivity as compared to the lower one. The macro pore flow occurs where the subsurface system has macro pores such as voids, natural pipes, cracks, etc. the flow rapidly contributes to the groundwater system.

2.3 Rainfall-Runoff Modeling

Hydrology phenomena are extremely complex, and may never be fully understood. However, in the absence of perfect knowledge, they may be represented in a simplified way by means of the system concept (Chow, 1988).

2.3.1 Hydrological Models

Hydrologic modeling can be linear or non linear, time invariant or time variant, lumped or distributed, continuous or discrete. Chow et al. (1988) and Todini (1988) made a general overview of the hydrologic models using the classification criteria randomness, spatial discretization and model structure as shown in Figure 2.2.

Empirical (Statistical) models are also called as "black-box models". It uses observed discharge data to establish model structure and corresponding model parameters by fitting a function of hydrological characteristics with observed discharge using regression procedures. Empirical models completely ignore the underlying physical processes; hence they solely depend upon the information carried by observed data. Empirical models are still in use mainly due to their simplicity, but their consistency and transferability between catchments is questionable. The presently used empirical models include multiple regression, genetic programming, artificial neural network models.

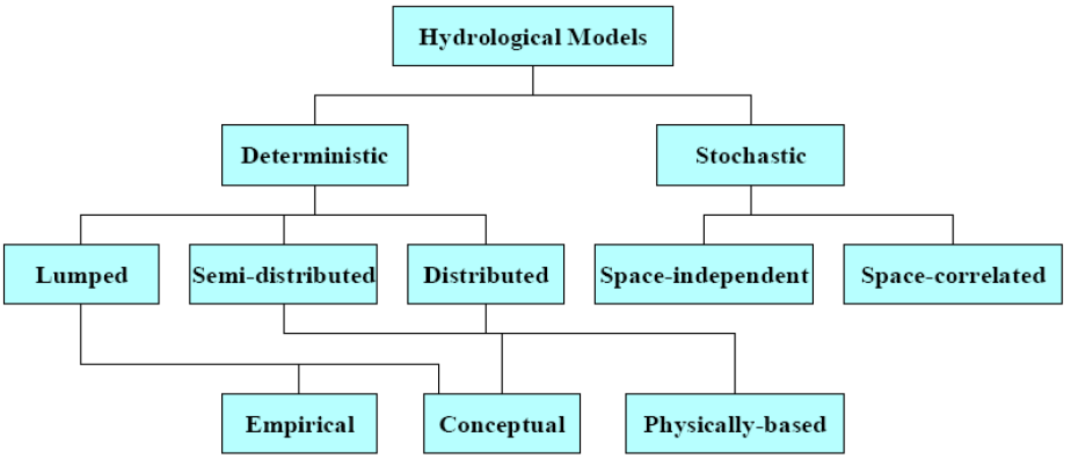

Figure 2.2 Classification of Hydrological models (Chow, 1988)

Conceptual models are built on simplified concepts derived from physical processes of rainfall runoff phenomena. In conceptual models the relationships between hydrological characteristics and responses are loosely based on the physical processes and do not use their strict representation. Parameters of conceptual models are derived by fitting the modeled discharge with observed discharge. Due to the incorporation of process knowledge, while keeping a simple structure, these models are relatively robust and reliable. Conceptual models include cascade model, geomorphologic instantaneous unit hydrograph (Rodriguez-Iturbeet al. 1979), HBV (Bergstrom, 1995) and IHACRES (Identification of unit Hydrograph And Component flows from Rainfall, Evaporation and Stream flow data) (Jakeman, 1990).

Physically based models are usually based on principles of physics such as mass balance or momentum equation. Parameters of physically based models have physical meanings and they can be derived from hydrological characteristics. However, these models are complex, data intensive and computationally demanding. In the stochastic models, the chance of occurrence of the variable is considered thus introducing the concept of probability. In the deterministic models, the chance of occurrence of the variables involved is ignored and the model is considered to follow a definite law of certainty but not any law of probability (Raghunath, 1985). In stochastic models, some or all of the inputs and parameters are represented by statistical distributions, rather than single values. A range of values is defined instead of a single value. Stochastic modeling generally requires the model to be run many times, each with different combinations of parameters or model inputs that are, perhaps, resulting in many outputs that can be analyzed to define a probability distribution of outputs. Stochastic modeling can be very useful, particularly when we are uncertain about the exact values of model parameters or model inputs, but running a model many times can be time consuming. Stochastic models are termed space-independent or space-correlated according to whether or not random variables at different points in space influence each other (Chow et al. 1988).

2.4 The Unit Hydrograph Theory

The Unit Hydrograph (UH) theory is classified in the conceptual model category and has been widely and successfully used over the past decades. First introduced by Sherman in 1932 (Chow et al. 1988) as a basic tool that represents the hydrologic response of a catchment through which effective rainfall is transformed to direct runoff, the UH is the surface runoff hydrograph resulting from one unit of rainfall excess uniformly distributed spatially and temporally over the catchment for the entire specified duration. A unit hydrograph for a storm with a single peak can be developed easily. After the base flow is removed from the total runoff hydrograph, the direct runoff hydrograph remain. The direct runoff volume is determined by integrating the direct runoff hydrograph. In order to obtain the unit hydrograph, each ordinate of the direct runoff hydrograph is divided by the runoff volume. Theoretically, unit hydrographs developed from different storms should be identical; however that is rarely the case in practice. In order to develop an average, Linsley et al. (1988) suggest that an average response may be determined by calculating the average peak flow rate and time to peak, then sketching a hydrograph shape such that it contains 1 unit of runoff, passes through the average peak, and has a shape similar to the unit hydrographs developed from the individual storm events.

Sherman (1932) used the unit hydrograph theory on watersheds ranging from 1300 km^2 to 8000 km^2. Linsley et al. (1988) recommended that the unit hydrograph only be used on watersheds less than 5000 km^2, while Ponce (1989) suggested that it should only be applied on miDSIze catchments between 2.5 km^2 and 250 km^2. Because the unit hydrograph model assumes that rainfall is uniform over an entire area, it is not applicable to large watersheds. Small catchments tend to reflect variations in the rainfall excess more than larger watersheds, because they have less channel storage than larger watersheds, thus the small catchments are less appropriate for unit hydrograph analysis (Huggins and Burney, 1982).

2.4.1 Synthetic Unit Hydrograph

Synthetic unit hydrographs, which assume uniform rainfall excess distribution and static watershed conditions, are frequently used to estimate hydrograph characteristics when observed data are unavailable. The term ‘Synthetic’ in synthetic unit hydrograph (SUH) denotes the unit hydrograph (UH) derived from watershed characteristics rather than from rainfall-runoff data. Chow et al. (1988) suggested that there are three major types of synthetic unit hydrographs. They can be:

1. Those based on a dimensionless unit hydrograph (SCS unit hydrograph).
2. Those based on models of watershed storage (Clark unit hydrograph), and
3. Those relating hydrograph characteristics (peak flow rate, base time, etc.) to watershed characteristics (Snyder's unit hydrograph).

2.4.2 SCS Dimensionless Unit Hydrograph

The dimensionless unit hydrograph developed by the Soil Conservation Service in 1972 (Chow et al., 1988), has been obtained from the unit hydrographs for a great number of watersheds of different sizes and for many different locations. The SCS dimensionless Unit hydrograph (DUH) is a synthetic unit hydrograph in which the discharge is expressed as a ratio of discharge, q, to peak discharge, q_p and the time by the ratio of time, t, to time to peak of the unit hydrograph, t_p. Given the peak discharge and the lag time for the duration of the excess rainfall, the unit hydrograph can be estimated from the synthetic dimensionless hydrograph for the given basin. The SCS suggests that the dimensionless unit hydrograph can be described in terms of an equivalent Triangular Unit Hydrograph (TUH). The values of q_p and t_p can then be estimated using this simplified triangular unit hydrograph whose height is equal to q_p and whose time base, t_b, is equal to 2.67 t_p as shown in Figure 2.3.

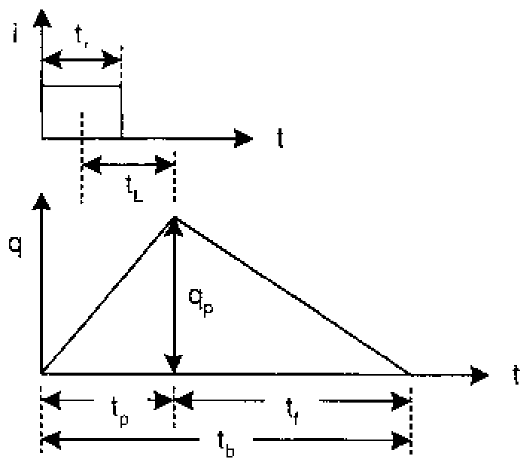

Figure 2.3 Triangular unit hydrograph (Usul, 2008)

The time is usually expressed in hours and the discharge in m^3/s/cm. After analysis of a great number of unit hydrographs, the SCS recommends recession duration of 1.67 t_p. The limitations of SCS method are: The SCS curve number method can be applied only in the case of big storm events. If the total rainfall depth is below 50 mm, the method often underestimates the direct runoff volume. Furthermore, SCS dimensionless unit hydrograph or triangular unit hydrograph provides only empirical approximation of flood runoff characteristics; its reliability is limited to the type and the size of the catchments which were used for its derivation.

2.4.3 Snyder's Synthetic Unit Hydrograph

One of the methods to obtain synthetic unit hydrograph was given by Snyder's, who selected three parameters, namely hydrograph base width, peak discharge and basin lag, as the parameters to define the unit hydrograph (Snyder, 1938). He considered the catchment characteristics such as area, shape, topography, channel slope, stream density, and channel storage as the parameters affecting the shape of the unit hydrograph after studying unit hydrographs of basins having areas between 26 to 26000 km^2 located in the Appalachian Highlands, of the United States.

2.4.4 Mockus Method

Because of simplicity in calculations and drawing triangular unit hydrograph, Mockus method is preferred often. It is applied to drainage areas which has a collection period (t_c) of 30 hours or less. Unit rainfall duration (AD) is defined according to t_c value of the basin. If t_c is between 15-30 then AD= 3, if t_c is between 10-15 then AD=2, if t_c=6 then AD=1, and if t_c is less than 3 then AD=0.5 hour.

2.5 Use of GIS and Digital Elevation Model (DEM) in Rainfall Runoff Modeling

Geographic Information Systems (GIS) can be defined as computer based tools that display, store, analyze, retrieve, and process spatial data. GIS is being more and more involved in hydrology and water resources and showing promising results. GIS provides representations of the spatial features of the earth, while hydrological models are concerned with the flow of water and its constituents over the land surface and in the subsurface environment. GIS with its upcoming advanced technology has been a great advantage to hydrological modeling. Hydrological modeling using GIS has been great developed during the last decade when people realized the utility of incorporating GIS with hydrologic modeling. Berry and Sailor

(1987) noted some of the advantages of GIS in hydrology and water resources. According to them, GIS provides a powerful tool for expressing complex spatial relationships. It provides an opportunity to fully incorporate spatial conditions into hydrologic inquiries. GIS are highly specialized database management systems for spatially distributed data.

GIS provides a digital representation of the catchment characterization used in hydrological modeling. Maidment (1996) summarized the different levels of hydrological modeling in association with GIS as follows: hydrologic assessment; hydrologic parameter determinations; hydrologic modeling inside GIS; and linking GIS and hydrologic models. Tarboton et al. (1991) introduced criteria to properly extract drainage networks, Moore et al. (1992) reviewed many application of DEM in different disciplines including hydrology. He also introduced different algorithms to extract catchments from DEM. DEM is popularly processed in ArcGIS, Arcview (Maathuis, 2006) to extract hydrologic parameters or physical characteristics of a catchment and can serve for model simulation. The reason of adopting GIS technology in hydrological models is because it allows the spatial information to be displaced in integrative ways that are readily comprehensible and visual. The spatial information collected is further subjected to continuous GIS analysis.

In this study ArcGIS package is used. It has a potential to extract the catchment characteristics easily using their DEM and calculate the hydro-geomorphologic parameters of the basin.

2.5.1 GIS Applications in Unit Hydrograph Derivation

Yılmaz (1987) found unit hydrograph values of Kocadere stream basin which is in Balıkesir-Bigadiç as q_p=1665.,4 L/s , t_p=2.44 hours, t_b=10.00 hours depending on the 25 years research. Average annual rainfall is 603.1 mm, average annual discharge is 102.26 mm

Aykanlı and Yolcu (1991) found data for 9 years research program in the Bayramiç Eğridere stream basin. Average annual rainfall is 676.8 mm, average annual discharge is 104.68 mm. One hour duration unit hydrograph values are q_p=1745 L/s, t_p=1.61 hours, t_b=10.33 hours.

Nurunnisa and Tezcan (1995) studied determining synthetic unit hydrographs and parameters for four Turkish basins. Unit hydrographs are determined for four subbasins in northwest Anatolia Turkey. Using the characteristics of these unit hydrographs and of their subbasins, Snyder's synthetic unit hydrograph coefficients are determined, and relationships between coefficients and basin characteristics are searched.

Jennifer (1997) studied development and evaluation of a GIS-based spatially distributed unit hydrograph model. Synthetic unit hydrographs, which assume uniform rainfall excess distribution and static watershed conditions, are frequently used to estimate hydrograph characteristics when observed data are unavailable. The objective of this research was to develop a spatially distributed unit hydrograph (SDUH) model that directly reflects spatial variation in the watershed in generating runoff hydrographs. Predictions were comparable to the other synthetic unit hydrograph techniques.

Balçın and Oğuz (1998) calculated unit hydrograph parameters of Tokat-Zile-Akdoğan basin after first ten years of their investigation. They found the average annual precipitation and runoff depth as 581.5 mm and 35.92 mm respectively. The parameters of 60 minutes of unit hydrograph of the basin was calculated as q_p=1551 L/s, t_p=1.35 hour, t_b=4.83 hour and Snyder's constants are calculated as C_t=0.949, C_p=0.99 and Mockus method's constants are as K=0.319, H=0.6854 respectively.

Olivera and Maidment (1999) studied (GIS)-based spatially distributed model for runoff routing. A method is proposed for routing spatially distributed excess precipitation over a watershed to produce runoff at its outlet. The land surface is represented by a (raster) digital elevation model from which the stream network is derived. A routing response function is defined for each digital elevation model cell so that water movement from cell to cell can be convolved to give a response function along a flow path and responses from all cells can be summed to give the outlet hydrograph.

Oğuz and Balçın (2000) found unit hydrograph parameters of Yozgat-Sotgun İkikara basin. They found the average annual precipitation and runoff depth as 434.4 mm and 34.58 mm respectively. The parameters of 60 minutes of unit hydrograph of the basin was calculated as q_p=1524.8 L/s, t_p=1.75 hour, t_b=6.66 hour and Snyder's method constants are calculated as C_t=0.949, C_p=0.77 and Mockus method's constants are as K=0.17, H=3.75 respectively.

Kaya (2000) calculated unit hydrograph parameters of Adıyaman-Kahta Harabe river basin after their investigation in between 1985-1999 years. They found the average annual precipitation and runoff depth as 612.9 mm and 184.09 mm respectively. The parameters of unit hydrograph of the basin was calculated as q_p=1669.0 L/s, t_p=1.90 hour and t_b=7.69 hour and Snyder's method constants are calculated as C_t=0.949, C_p=0.77 and Mockus method's constants are as K=0.17, H=3.75 respectively.

Manoj et al. (2004) studied a GIS based distributed rainfall–runoff model. A grid or cell based process oriented distributed rainfall–runoff model capable of handling the catchment heterogeneity in terms of distributed information on landuse, slope, soil and rainfall was developed and applied to isolated storm events in several catchments. Model inputs such as slope, flow direction and overland flow sequencing (drainage path) were generated for each cell of the catchment using a digital elevation model and information about landuse, soil, etc. were derived through digital analysis of satellite data and published information. Their model utilized a relationship explaining the dependence of flow resistance on depth of flow and surface roughness.

Fleurant et al. (2005) proposed an analytical model for a geomorphologic instantaneous unit hydrograph. The rainfall-runoff modeling of a river basin was divided into two processes: the production function and the transfer function. The production function determined the proportion of gross rainfall actually involved in the runoff. These models made it possible to forecast the hydrograph shape and runoff variation versus time at the basin outlet. This article is an introduction to a new GIUH model which proved to be simple and analytical.

Saghafian (2006) studied nonlinear transformation of unit hydrograph. Unit hydrograph (UH) and its numerous derivatives have been popular for estimation of flood hydrographs. Two major assumptions still overshadow UH applications. One is the linearity and the other is time invariance. Saghafian (2006) aimed to propose a nonlinear way of transforming a given UH to other general hydrographs. The case of nonlinear transformation was illustrated for a number of watershed geometries with either known kinematic wave analytic solutions or observed data. The proposed nonlinear UH transformation may thus be viewed as a major step in closing the gap between physically based and traditional UH-based surface runoff simulation approaches.

Han and Yang (2006) studied derivation of unit hydrograph using a transfer function approach. UH concept and model have been widely used in the hydrological field over the past decades. However, the estimation of such a model in practice has always been a challenge for researchers and practitioners because such a model is usually ill formed in mathematical terms. The model was termed the physically realizable transfer function.

Jena (2006) studied modeling synthetic unit hydrograph parameters with geomorphologic parameters of watersheds. This study was undertaken in two medium sized agricultural watersheds and their sub watersheds located in Midnapore and Bankura districts of West Bengal state in India. Runoff hydrographs were generated from flow data and unit hydrographs (UH) were obtained for 1 and 2 h duration. UH parameters such as time to peak (t_p), time base (t_b), and peak discharge were modeled with geomorphologic parameters of the watershed such as channel parameters as well as basin parameters. All developed models for Tarafeni watershed and its sub watersheds were tested using different statistical tests for different rainfall events. Also these models were validated for nearby Bhairabbanki watershed and its sub watersheds. These models can be suitable for small and medium agricultural sub tropical sub humid basins having similar geohydrological conditions.

Bruce et al. (2007) studied development and evaluation of a dimensionless unit hydrograph. A generalized unit hydrograph method was developed and evaluated for ungaged watersheds. A key component in this method is the value of a dimensionless storage coefficient. Procedures to estimate this coefficient were given using calibrated values from 142 rainfall-runoff events gauged in watershed located mainly in the Eastern US. Only limited success was obtained in predicting this storage coefficient. Thirty-seven independent rainfall-runoff events were used to test the proposed technique. Approximately one-half of test storms had percent errors in predicted peak flow rates that were less than 34 percent compared to percent error of 88 percent with the SCS method.

Sarangi et al. (2007) studied evaluation of three unit hydrograph models to predict the surface runoff from a Canadian watershed. The predictability of unit hydrograph models that are based on the concepts of land morphology and isochrones to generate direct runoff hydrograph (DRH) were evaluated in this paper. The intention of this study was to evaluate the models for accurate runoff prediction from ungauged watershed using the ArcGIS tool.

Salami et al. (2009) studied evaluation of synthetic unit hydrograph methods for the development of design storm hydrographs for Rivers in South-West. This report presented the establishment of appropriate method of synthetic unit hydrograph to generate ordinates for the development of design storm hydrographs for the catchment of eight selected rivers located in the South West Nigeria. Unit hydrographs were developed based on Snyder’s, Soil Conservation Service (SCS) and Gray methods; while the SCS curve Number method was used to estimate the cumulative rainfall values for storm depth of different return periods.

Gibbs et al. (2010) studied evaluation of parameter setting for two GIS based unit hydrograph models. For watersheds where flow data are unavailable, the geomorphology–hydrology relationship can be used to estimate the direct flow response to excess rainfall. Two of the most common approaches used to compute this response are Geomorphological Instantaneous Unit Hydrographs (GIUH) and Spatially Distributed Unit Hydrographs (SDUH). In the former, the hydrograph was determined from the input of morphometric parameters and an average channel velocity, where in the latter a time–area relationship was used to compute the hydrograph.

Salajegheh et al. (2010) studied the effect of physical characteristics on flood hydrograph (Case study: Western section of Jazmurian Basin). Flood causes great and uncompressible damage to people’s life and properties as well as environment each year in Iran. This research was carried out at the west section of Jazmurian basin that placed in the southeast of Iran. The results approve that with the use of physical characteristics of the basin we can determine the synthetic hydrograph. The results also show that the two- variable models have higher efficiency in estimating the discharge variables of the simulated hydrographs.

Khaleghi et al. (2011) studied efficiency of the geomorphologic instantaneous unit hydrograph method in flood hydrograph simulation. Several methods and models to simulate rainfall-runoff processes was presented, and each of them has its own advantages and disadvantages. In this study, different methods were applied to simulate the rainfall–runoff process over the Kasilian Watershed located in northern Iran, including Snyder's, SCS, Trianglar, Rosso and Geomorphoclimatic unit hydrographs. The study was intended to compare the accuracy and reliability of a geomorphologic model with Snyder's, SCS, Triangular, Rosso and Geomorphoclimatic Unit hydrographs. The comparison of calculated and observed hydrographs showed that geomorphologic model had the most direct agreement for the parameters of peak time and peak flow of direct runoff.

Bhunya et al. (2011) studied synthetic unit hydrograph methods. The study reveals that the traditional methods of SUH derivation, e.g., Snyder's, SCS. Traditional methods like Snyder's method that does not yield satisfactory results, and their application to the practical engineering problems is tedious and cumbersome.

Bakanoğulları and Günay (2011) determined the unit hydrograph elements of Vize basin. They found the average annual precipitation and runoff depth at the Vize basin as 544.2 mm and 6.04 mm respectively according to precipitation and runoff data in between 1985 and 2007 years. They calculated the average unit hydrograph by selecting 23 years unit hydrograph data. They calculated the elements of average unit hydrograph (UH_{60}) for Vize basin as q_p=354.6 L/s, t_b=14.4 hours and t_p=1.6 hours. The elements of Vize basin were compared with the other synthetic methods. They concluded that the calculated coefficients of Snyder and Mockus methods can be applied and beneficial to similar basins.

El-Hames (2012) studied an empirical method for peak discharge prediction in ungauged arid and semi-arid region catchments based on morphological parameters and SCS curve number. The developed method performed very well with catchments larger than 45 km^2 with coefficient of correlation of 0.92. However, for catchments with areas less than 45 km^2 the obtained coefficient of correlation was 0.67. Also, the developed method performed very well with either event-based or return-period-based peak discharge prediction and it can be considered a good alternative to the rational method.

Skaugen and Onof (2013) studied a rainfall-runoff model parameterized from GIS and runoff data. In this study, the dynamics of runoff were derived from the distribution of distances from points in the catchments to the nearest stream. The distribution was unique for each catchment and could be determined from a geographical information system. The distribution of distances, when celerity of (subsurface) flow was introduced, provided a distribution of travel times, or a unit hydrograph (UH). It was also shown that the new model has a more realistic representation of the subsurface hydrology.

Himanshu et al. (2013) studied remote Sensing and GIS Applications in determination of geomorphologic parameters and design flood for a Himalyan River Basin, India. The most widely and generally applied method for the prediction of flood hydrograph which was derived from a known storm in a basin area uses historical rainfall-runoff data and unit hydrographs derived from them. The results showed that more than 50 % of the catchment is snow-fed area hence, the selected site will have a continuous supply of water throughout the year making it a potentially profitable dam site. 1 hour Synthetic Unit Hydrograph peak discharge at site was found to be 878.5 m^3.

Narayan et al. (2013) studied spatially distributed unit hydrograph for Varuna river of India. Geographic Information System (GIS) was used for SDUH model which is a time-area unit hydrograph technique to develop a cumulative travel time map of the watershed based on cell by cell estimates of overland and channel flow velocities. The model included slope, land use, watershed position, channel characteristics, and rainfall excess intensity in determining flow velocities.

Seaedrashed and Guven (2013) studied estimation of geomorphological parameters of Lower Zab River-Basin by Using GIS-Based Remotely Sensed Image. This paper seeked to enhance water-based information in the region under study using the technique of GIS-based remotely sensed image that gives us more accurate results and less time consuming to process data comparing with the GIS-based Topographic Maps (GTMs). This modern technique provided powerful and cost-effective tools for managing and processing data and creating maps for water resources. This enables hydrologists and researchers to get better access to high quality hydrologic data. Thus, accurate gemorphological parameters for watersheds and catchments can be calculated.

Sule and Alabi (2013) studied application of synthetic unit hydrograph methods to construct storm hydrographs. Synthetic unit hydrograph methods were used to generate unit hydrographs for the Awun River Basin in Kwara State, Nigeria. The synthetic methods used were those of Snyder's, Soil Conservation Service (SCS), and Gray's.

Gunal and Guven (2015) studied geomorphological parameters of Damlıca catchment using GIS. The digital elevation model (DEM) of the basin is downloaded from Aster-GDEM web page and it is used in the GIS program to obtain the geomorohologic parameters of the Damlıca catchment. The extracted parameters were compared with the parameters obtained by conventional methods. Their study showed that the geomorphologic parameters of the Damlıca basin obtained using GIS are much more precise than those produced by conventional methods.

2.6 Studies on Artificial Neural Network (ANN)

Asaad (1997) studied application of a neural network technique to rainfall-runoff modeling. This paper deals with the application of a neural network technique in the context of rainfall runoff modeling. The results suggested that the neural network shows considerable promise in the context of rainfall-runoff modeling but, like all such models, has variable results.

Asaad et al. (1997) studied methods for combining the outputs of different rainfall–runoff models. This paper presents the concept of combining the estimated output of different rainfall–runoff models to produce an overall combined estimated output to be used as an alternative to that obtained from a single individual rainfall–runoff model. Three methods of combining model outputs are considered, namely the simple average method (SAM), the weighted average method (WAM) and the neural network method (NNM). The estimated discharges of five rainfall–runoff models for 11 catchments are used to test the performance of these three combination methods. The results confirm that better discharge estimates can be obtained by combining the model outputs of different models.

Yang and Rosenbaum (2001) studied artificial neural networks linked to GIS for determining sedimentology in harbours. Artificial neural networks was added as a mapping tool to a raster-based Geographical Information System to provide a predictive capability for overlay operations. This method was capable of incorporating dynamic change encompassed within existing observations.

Zhang and Govindaraju (2003) studied geomorphology-based artificial neural networks (GANNs) for estimation of direct runoff over watersheds. Focusing on the problem of estimating direct runoff over a watershed resulting from rainfall excess, the goal of this study is to develop an artificial neural network (ANN) that explicitly accounts within its architecture for the geomorphologic characteristics of the watershed. Such a geomorphology-based artificial neural network (GANN) was utilized to estimate runoff hydrographs from several storms over two Indiana watersheds. This study revealed GANNs to be promising tools for estimating direct runoff.

Pan and Wang (2004) studied state space neural networks for short term rainfall-runoff forecasting. Rainfall-runoff processes are dynamic systems that are better described by a dynamic model. In this paper, a specific dynamic neural network, called state space neural network (SSNN), was modified to perform short term rainfall-runoff forecasts.

Rajurkar et al. (2004) studied modeling of the daily rainfall-runoff relationship with artificial neural network. An approach for modeling daily flows during flood events using Artificial Neural Network (ANN) was presented. The rainfall runoff process was modeled by coupling a simple linear (black box) model. The study demonstrated that the approach adopted herein for modeling produces reasonably satisfactory results for data of catchments from different geographical locations, which thus proved its versatility. Most importantly, the substitution of the previous days runoff (being used as one of the input to the ANN by most of the previous researchers), by a term that represented the runoff estimated from a linear model and coupling the simple linear model with the ANN proved to be very much useful in modeling the rainfall-runoff relationship in the non-updating mode.

Sarangi and Bhattacharya (2005) studied comparison of Artificial Neural Network and regression models for sediment loss prediction from Banha watershed in India. Two Artificial Neural Network (ANN) models, one geomorphology-based (GANN) and another non-geomorphology-based (NGANN) for the prediction of sediment yield were developed and validated using the hydrographs and silt load data of 1995–1998 for the Banha watershed in the Upper Damodar Valley in Jharkhand state in India. The sediment loads predicted by these models were compared with those predicted by an earlier developed regression model for the same watershed. It was revealed that the feed-forward ANN model with back propagation algorithm performed well for both the GANN and NGANN models.

Sarangi et al. (2005) studied performance evaluation of ANN and geomorphology-based models for runoff and sediment yield prediction for a Canadian watershed. Artificial Neural Network and regression models were developed using watershed-scale geomorphologic parameters to predict surface runoff and sediment losses of the St. Esprit watershed, Quebec, Canada.

Jain and Srinivasulu (2006) studied integrated approach to model decomposed flow hydrograph using artificial neural network and conceptual techniques. An integrated modeling framework was proposed capable of modeling infiltration, base flow, evapotranspiration, soil moisture accounting, and certain segments of the decomposed flow hydrograph using conceptual techniques and the complex, non-linear, and dynamic rainfall-runoff process using ANN technique. Specifically, five different multi-layer perception (MLP) and two self-organizing map (SOM) models was developed. The rainfall and streamflow data derived from the Kentucky River catchment were employed to test the proposed methodology and develop all the models. The performance of all the models was evaluated using different standard statistical measures.

Kisi and Cigizoglu (2007) presented the comparison of different ANN techniques in river flow prediction. Forecasts of future events are required in many of the activities associated with the planning and operation of the components of a water resource system. This paper presented the comparison of different artificial neural network techniques in short- and long-term continuous and intermittent daily stream flow forecasting.

Rabunal et al. (2007) studied the determination of the unit hydrograph of a typical urban basin using genetic programming and artificial neural networks. An application of genetic programming (GP) and artificial neural networks in hydrology was proposed, showing how these two techniques can work together to solve the problem of modelling the effect of rain on the runoff flow in a typical urban basin. The ability of GP to include the physical basis of a problem and even to analyze the results was discussed, and a case study was included as an example.

Kasiviswanathan et al. (2013) studied constructing prediction interval for ANN rainfall runoff models based on ensemble simulations. This study presented a method of constructing prediction interval for ANN rainfall runoff models during calibration with a consideration of generating ensemble predictions. A two stage optimization procedure was envisaged in this study for construction of prediction interval for the ANN output. In Stage 1, ANN model is trained with genetic algorithm (GA) to obtain optimal set of weights and biases vector. In Stage 2, possible variability of ANN parameters (obtained in Stage 1) is optimized so as to create an ensemble of models with the consideration of minimum residual variance for the ensemble mean, while ensuring a maximum of the measured data to fall within the estimated prediction interval.

Asadi et al. (2013) studied a new hybrid artificial neural network for rainfall–runoff process modeling. The proposed model is a combination of data preprocessing methods, genetic algorithms and levenberg–marquardt algorithm for learning feed forward neural networks. The capability of the proposed method was tested by applying it to predict runoff at the Aghchai watershed. The results showed that this approach is able to predict runoff more accurately than ANN and Adaptive Neuro Fuzzy Inference System (ANFIS) models.

CHAPTER 3

STUDY AREA AND DATA COLLECTION

3.1 Study Area

The study areas are in the Marmara catchment in Turkey. In Turkey there are 25 catchments as shown in Figure 3.1. Marmara catchment is in the North West of Turkey. Catchments were selected; those are Damlıca, Vize, Kumdere. These catchments are shown in Figure 3.2.

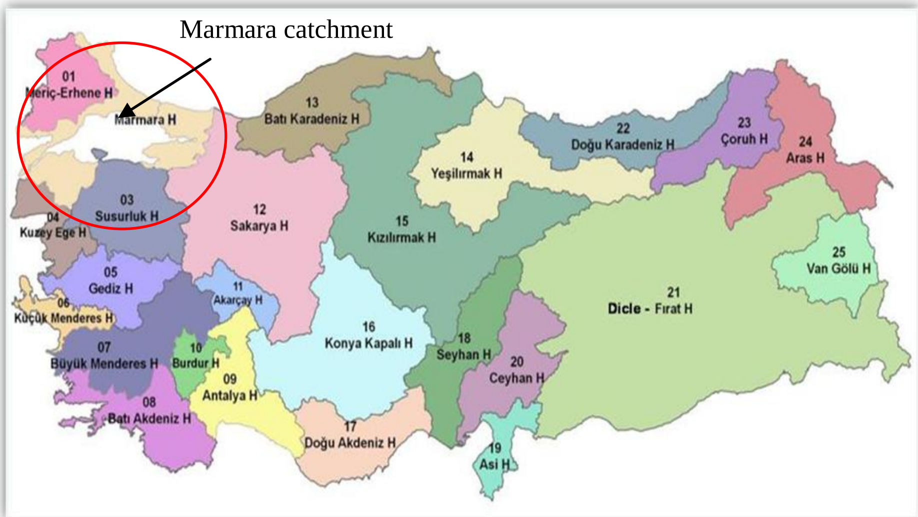

Figure 3.1 Catchments in Turkey

3.1.1 Damlıca Catchment

The Damlıca catchment is 9 km to Kumburgaz and 51 km to İstanbul. The topographic map of the Damlıca catchment is given in Figure 3.3. According to 1/25000 topographic map of the catchment, there are two second degree branches that is connected to Damlıca stream and Damlıca stream is connected to Tepecik stream and flows to the Büyükçekmece Lake. Outlet of the catchment is at 41º 06' 04'' North latitude, 28 º 25' 00'' East longitudes. Elevation above the sea level is 110 m. The area of Damlıca catchment according to the topographic map is 8.26 km^2

and 7.63 km^2 according to GIS. There are 3 recording precipitation gauges. The runoff of catchment was measured by 1 stage recording gauge installed on a triangular weir over the main waterway in the outlet of the catchment. This catchment locates at $41^0$06’04” North latitude and the $20^0$25’00” East longitude. Its average latitude is 184 m. 98.5% of the catchment is covered with vertisol great soil group, 1.5% of the catchment is covered with non calcic brown great soil group. All of the catchment area is used as a dry farming area.

Figure 3.2 Damlıca, Vize and Kumdere catchments.

3.1.2 Geomorphologic Parameters of Damlıca Catchment

Certain characteristics of the drainage watershed reflect hydrologic behavior and are therefore, useful, when quantified, in evaluating the hydrologic response of the watersheds. Physical characteristics of the drainage watershed include drainage area, watershed shape, ground slope, and centroid (i.e. centre of gravity of the watershed). Channel characteristics include channel order, channel length, channel slope, and drainage density. The geomorphologic parameters of the Damlıca catchment are given in Table 3.1.

3.1.3 Shape of Damlıca Catchment

The catchment shape may influence the hydrograph shape, especially for small watersheds. For example, if the watershed is long and narrow, then it will take longer time for water to travel from the furthest point to the outlet and the resulting hydrograph shape is flatter. For more flattened watershed, the runoff hydrograph is expected to be sharper with a greater peak and shorter duration. Numerous symmetrical and irregular forms of drainage areas are encountered in practice. Therefore, from Figure 3.3, we can say that, Damlıca is narrow elongated type of catchment.

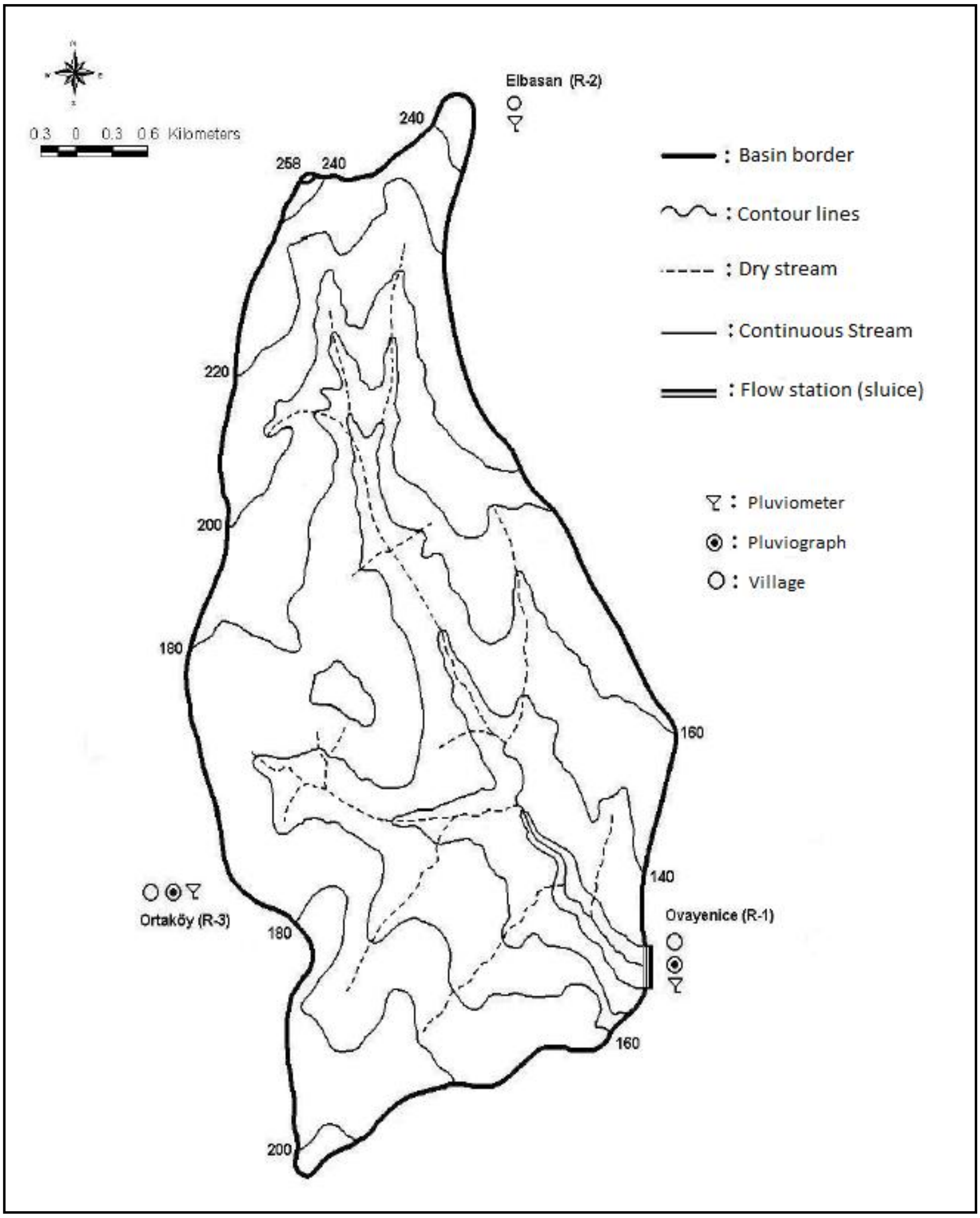

Figure 3.3 Topographic map of the Damlıca Catchment

Table 3.1 Geomorphologic parameters of Damlıca Catchment

Parameter	**Symbol**	**Value**
Area	A	8.26 km^2
Catchment perimeter	P	13.10 km
Catchment length	L_H	4.10 km
Catchment width	W_H	2.01 km
Catchment max. elevation	h_{max}	258 m
Catchment min. elevation	h_{min}	110 m
Catchment relief	r	148 m.
Catchment relative relief	r_n	0.011
Catchment Directions		Northwest-Southeast
Catchment average elevations	h_{avr}	184 m
Catchment median elevation	h_m	207 m
Catchment average slope	S_H	5.9 %
Shape Index related to main stream line	S_1	2.29
Shape Index related to catchment length	S_2	2.04
Circularity ratio	S_3	0.6
Congestion index	K_c	1.28
Equivalent rectangular catchment	L_a	4.88
Slope index related to equivalent rectangular catchment	L_b	1.69
Number of hydrological soil cover	CN	86.4
Main stream line length	L_s	4.35 km
Total stream line lengths	L_u	15.90 km
The distance between projection of catchment's center of gravity to main stream line to outlet of the catchment	L_c	1.78 km
Profile and the slope of the main stream line	S_s	2.15 %
The harmonic slope of main stream line	S	1.89 %

3.1.4 Slope of Damlıca Catchment

Catchment slope has a pronounced effect on the velocity of overland flow, watershed erosion potential, and local wind systems. Average catchment slope is defined as (Singh, 1989).

$$S = \frac{h}{L} \tag{3.1}$$

where S is the average catchment slope (m/m), h is the fall (m) (i.e. difference in maximum and minimum elevations), and L is the horizontal distance (m) over which the fall occurs. Slope of main streamline of Damlıca catchment is 1.89%.

3.1.5 Rainfall and flow observation stations in Damlıca Catchment

There are 3 rainfall observation stations R1, R2 and R3 which are close to the catchment. R1 rainfall station in the outlet of the catchment at 110 m level, second rainfall station R2 is at level of 258 m, the third one R3 is at a level of 195 m. There is an also one flow observation station at the outlet of the catchment.

3.1.6 Climate of Damlıca Catchment

The climate of the study area varies from humid to semiarid. In winters, it is cold and rainy. In summers, it is hot and seldom rainy. According to Florya meteorology station data between the years 1936-1980, maximum temperature was 38.6 ^{o}C in august, minimum temperature was -12.6 ^{o}C in January. Maximum daily precipitation was 118 mm in October in 1980. Maximum total precipitation was 935.6 mm in 1980. According to precipitation and runoff data obtained 1980 and 2006 years; the average annual precipitation was 709.2 mm and average runoff depth was 52.6 mm. The seasonal precipitation distributions for autumn, winter, spring and summer are 28.0 %, 36.7%, 23.1% and 12.2%, respectively.

3.1.7 Statistics of Damlıca Catchment Parameters

Surface runoff (SR), filtration (F), antecedent precipitation index (API), base time (t_b), time to peak (t_p), effective rainfall (t_r) and peak discharge (q_p) values and their statistics of Damlıca catchment parameters are given in Table 3.2.

Table 3.2 Statistical Parameters of Damlıca Catchment

Date	SR (mm)	F (mm/hr)	API	t_b (hours)	t_p (hours)	t_r (hours)	q_P (m^3/s/mm)
04.12.1981	0.220	2.60	57.94	16.20	4.32	1.080	0.480
15.01.1983	0.570	10.03	6.10	15.10	5.61	0.300	0.607
16.02.1984	0.420	1.27	2.91	17.13	3.00	1.250	0.607
06.03.1984	1.190	2.43	27.65	19.13	6.95	1.030	0.662
01.01.1986	0.730	4.77	14.66	18.00	4.00	1.000	0.460
02.02.1986	0.350	6.45	7.00	13.50	4.00	0.500	0.619
24.11.1988	0.530	10.94	13.45	19.50	4.50	0.500	0.440
08.12.1988	0.980	1.74	0.00	11.90	2.80	0.700	0.530
09.04.1991	3.130	5.83	16.01	9.40	3.33	2.550	0.436
01.05.1991	0.840	8.00	19.68	8.30	2.67	0.170	0.475
17.03.1992	0.960	1.95	17.43	9.20	5.60	1.280	0.418
19.04.1992	0.140	14.52	8.30	7.90	3.60	0.500	0.419
25.02.1993	0.100	3.84	9.69	8.16	3.50	0.280	0.419
01.03.1993	0.330	22.48	32.54	18.00	5.33	0.220	0.650
29.01.1994	0.050	5.20	14.68	8.28	2.59	0.500	0.490
25.02.1994	0.150	4.00	12.21	13.10	2.60	0.500	0.540
27.01.1995	0.450	6.30	10.00	6.00	2.00	0.750	0.451
30.03.1995	1.940	9.70	24.90	15.00	6.17	0.470	0.435
05.02.1996	9.360	5.30	1.42	20.50	5.51	0.580	0.467
25.02.1996	0.550	5.10	6.78	17.33	3.33	2.000	0.566
17.03.1996	0.870	2.69	2.36	17.67	5.51	0.750	0.660
28.03.1996	3.020	10.40	0.70	4.83	3.83	1.500	0.418
17.04.1996	0.230	5.90	18.64	10.00	3.75	1.330	0.425
22,.03.1997	0.730	9.24	42.16	10.50	3.50	0.170	0.500
20.05.1998	1.290	127.68	8.89	6.00	2.00	0.080	0.450
24.11.1998	0.450	35.40	22.20	19.33	2.67	0.170	0.650
18.02.2001	0.820	5.90	18.90	28.00	6.00	0.750	0.429
28.03.2004	0.200	4.09	10.80	16.17	7.00	0.170	0.430
29.01.2005	1.260	1.84	24.66	23.00	11.00	0.670	0.435
Mean (μ)	1.099	11.572	15.609	14.039	4.368	0.750	0.502
Variance (σ^2)	3.106	547.427	165.463	32.458	3.675	0.336	0.007
Std. Dv. (σ)	1.762	23.397	12.863	5.697	1.917	0.580	0.086
Min.	0.050	1.270	0.000	4.830	2.000	0.080	0.418
Max.	9.360	127.680	57.940	28.000	11.000	2.550	0.662
Range	9.310	126.410	57.940	23.170	9.000	2.470	0.244
Median	0.570	5.830	13.450	15.000	3.830	0.580	0.467

3.1.8 Vize Catchment

Vize catchment is located at the south of Vize county of Kırklareli province. The Vize catchment is in the boundary of Topçuköy village and 11 km to Vize village. Area of the catchment is 4.64 km² according to topographic map. The topographic map of the Vize catchment is given in Figure 3.4. According to 1/25000 topographic map of the catchment, Vize stream is a 5th degree branch that is flows to the Meriç river. Outlet of the catchment is at 41º 30’ 53’’ North latitude, 27 º 41’ 20’’ East longitudes. Elevation above the sea level is 185 m. The catchment shape from Figure 3.4, we can say that, Vize is elongated type of catchment. Vize Catchment slope is 0.587 %. The geomorphologic parameters of the Vize catchment are given in Table 3.3.

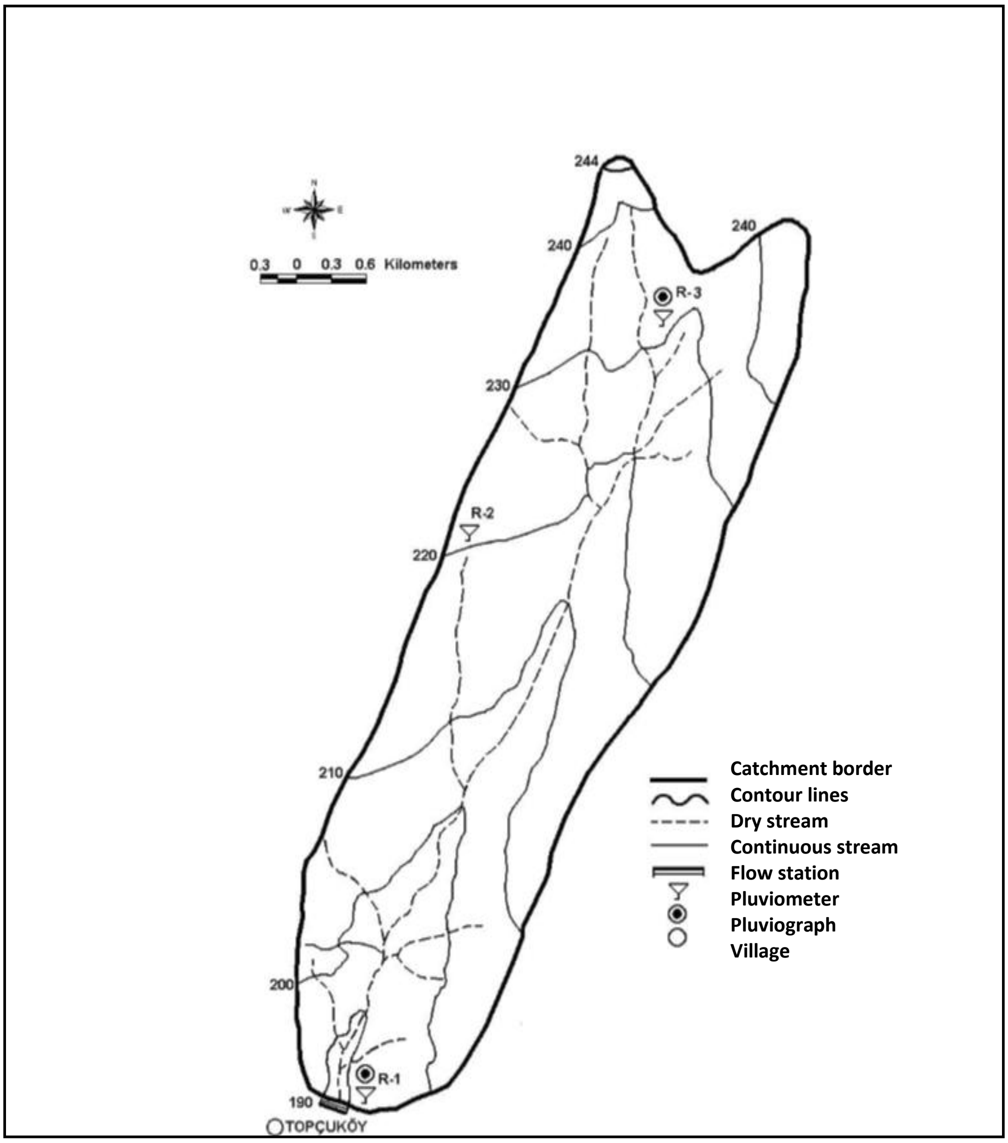

Figure 3.4 Topographic map of the Vize Catchment

Table 3.3 Geomorphologic parameters of Vize Catchment

Parameter	**Symbol**	**Value**
Area	A	4.64 km^2
Catchment perimeter	P	10.55 km
Catchment length	L_H	4.45 km
Catchment width	W_H	1.03 km
Catchment max. elevation	h_{max}	244 m.
Catchment min. elevation	h_{min}	185 m
Catchment relief	r	59 m.
Catchment relative relief	r_n	0.56 %
Catchment Directions		Northeast-Southwest
Catchment average elevations	h_{avr}	215
Catchment median elevation	h_m	212 m
Catchment average slope	S_H	3.0%
Shape Index related to main stream line	S_1	4.32
Shape Index related to catchment length	S_2	4.36
Circularity ratio	S_3	0.52
Congestion index	K_c	1.37
Equivalent rectangular catchment	L_a	4.14 km
Slope index related to equivalent rectangular catchment	L_b	1.12 km
Number of hydrological soil cover	CN	79.2
Main stream line length	L_s	4.5 km
Total stream line lengths	L_u	10.25 km
The distance between projection of catchment's center of gravity to main stream line to outlet of the catchment	L_c	2.475 km
Profile and the slope of the main stream line	S_s	1.3 %
The harmonic slope of main stream line	S	0.587 %

There are 3 rainfall observation stations R1, R2 and R3 which are close to the catchment. R1 rainfall station in the outlet of the catchment at 185 m level, second rainfall station R2 is at level of 222 m, the third one R3 is at a level of 233 m. There is an also one flow observation station at the outlet of the catchment. The climate of the study area varies from humid to semiarid. Statistical Parameters are calculated in Table 3.4.

Table 3.4 Statistical Parameters of Vize Catchment

Date	**SR (mm)**	**F (mm/hr)**	**API**	**t_b (hours)**	**t_p (hours)**	**t_r (hours)**	**q_P ($m^3/s/mm$)**
16.01.1986	2.330	12.06	21.20	20.71	2.00	1.880	0.249
23.01.1986	3.120	7.04	30.60	18.00	3.00	0.750	
07.09.1986	6.230	0.92	15.00	18.00	5.90	3.000	
16.12.1990	0.040	11.52	36.99	11.00	1.56	1.000	0.430
31.01.1995	0.800	19.80	50.65	17.00	5.30	0.100	
31.12.1996	1.410	3.30	13.72	9.00	4.00	1.000	
07.06.1998	3.370	14.40	4.90	13.00	2.00	0.500	0.385
08.02.1999	4.900	3.10	30.68	38.83	5.25	0.580	
20.02.2002	3.770	7.70	51.55	13.06	3.00	0.500	
Mean (μ)	2.886	8.871	28.366	17.622	3.557	1.034	0.355
Variance (σ2)	3.906	37.435	264.244	77.544	2.631	0.789	0.009
Std. Dv. (σ)	1.976	6.118	16.256	8.806	1.622	0.888	0.094
Min.	0.040	0.920	4.900	9.000	1.560	0.100	0.249
Max.	6.230	19.800	51.550	38.830	5.900	3.000	0.430
Range	6.190	18.880	46.650	29.830	4.340	2.900	0.181
Median	3.120	7.700	30.600	17.000	3.000	0.750	0.385

3.1.9 Kumdere Catchment

Kumdere catchment is located on the northwest of Edirne province. The Kumdere catchment is 10 km to Edirne city centre. Area of the catchment is 4.40 km^2 according to topographic map. The topographic map of the Kumdere catchment is given in Figure 3.5.

According to 1/25000 topographic map of the catchment, Kumdere stream is a 3th degree branch that is flows to the Meriç river. Outlet of the catchment is at 41º 40’ 59’’ North latitude, 26 º 40’ 09’’ East longitudes. Elevation above the sea level is 115 m. The geomorphologic parameters of the Kumdere catchment are given in Table 3.5. The catchment shape from Figure 3.5, we can say that, Kumdere is narrow elongated type of catchment. Kumdere Catchment slope is 0.936 %.

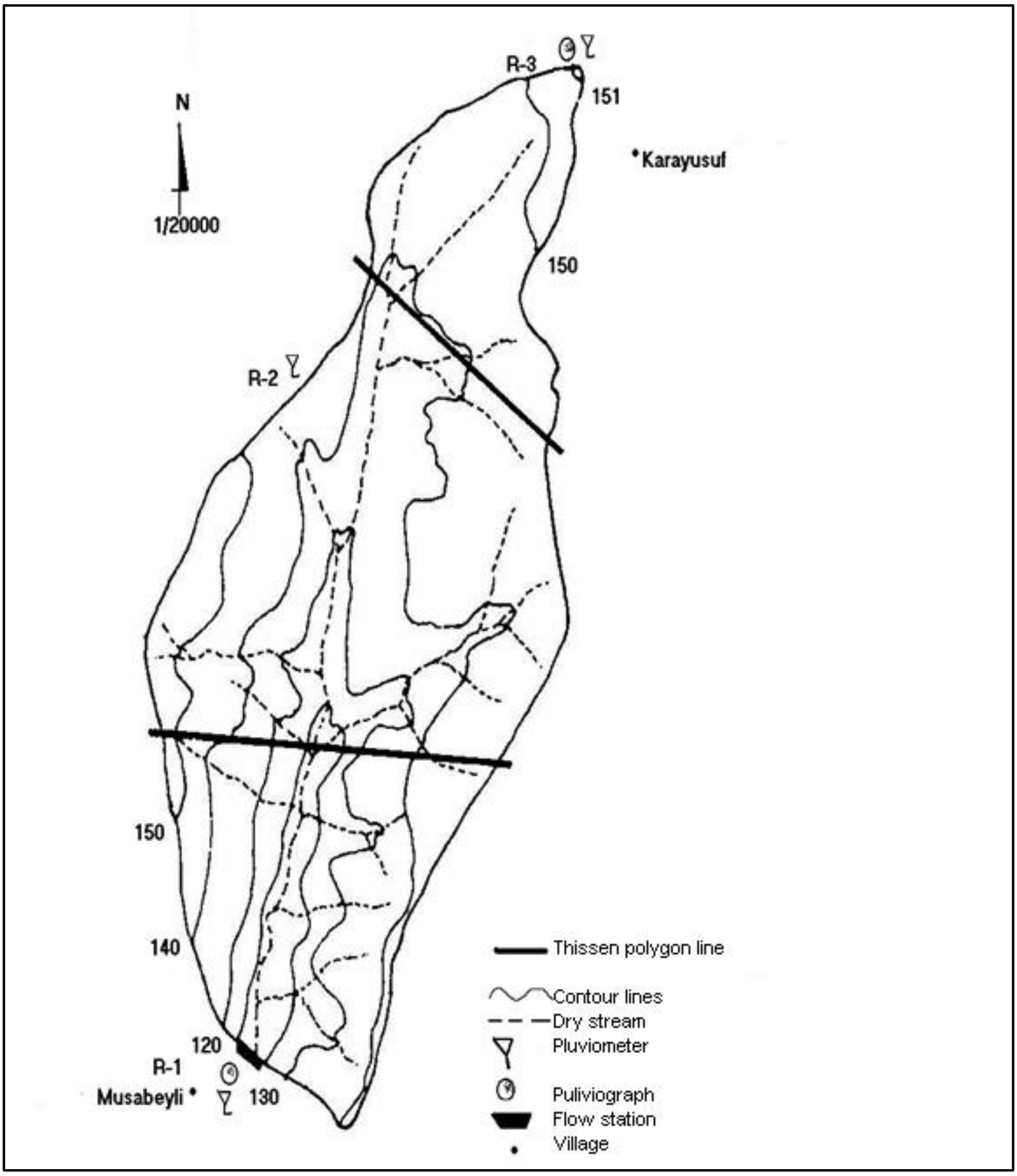

Figure 3.5 Topographic map of Kumdere Catchment

Table 3.5 Geomorphologic parameters of Kumdere Catchment

Parameter	**Symbol**	**Value**
Area	A	4.40 km^2
Catchment perimeter	P	9.50 km
Catchment length	L_H	3.45 km
Catchment width	W_H	1.28 km
Catchment max. elevation	h_{max}	154 m.
Catchment min. elevation	h_{min}	115 m
Catchment relief	r	39 m.
Catchment relative relief	r_n	0.041%
Catchment Directions		North-South
Catchment average elevations	h_{avr}	139.5 m.
Catchment median elevation	h_m	135 m
Catchment average slope	S_H	4.0 %
Shape Index related to main stream line	S_1	2.71
Shape Index related to catchment length	S_2	2.86
Circularity ratio	S_3	0.61
Congestion index	K_c	1.27
Equivalent rectangular catchment	L_a	3.49 km
Slope index related to equivalent rectangular catchment	L_b	1.26
Number of hydrological soil cover	CN	81
Main stream line length	L_s	3.55 km
Total stream line lengths	L_u	12.50 km
The distance between projection of catchment's center of gravity to main stream line to outlet of the catchment	L_c	1.85 km
Profile and the slope of the main stream line	S_s	0.9 %
The harmonic slope of main stream line	S	0.936 %

There are 3 rainfall observation stations R1, R2 and R3 which are close to the catchment. R1 rainfall station in the outlet of the catchment at 115 m level, second rainfall station R2 is at level of 145 m, the third one R3 is at a level of 150 m. There is an also one flow observation station at the outlet of the catchment. The climate of the study area varies from humid to semiarid. Statistical Parameters are calculated in Table 3.6.

Table 3.6 Statistical Parameters of Kumdere Catchment

Date	**SR (mm)**	**F (mm/hr)**	**API**	**t_b (hours)**	**t_p (hours)**	**t_r (hours)**	**q_P (m^3/s/mm)**
20.03.1985	0.040	4.72	0.00	10.00	4.00	1.670	
09.12.1987	0.550	10.00	0.00	10.00	4.00	1.000	
10.12.1987	0.360	9.00	21.92	9.00	3.33	0.170	
15.12.1987	1.950	12.83	0.00	12.83	3.67	1.830	
07.03.1999	2.170	12.00	31.22	12.00	4.00	2.000	
27.12.1989	0.400	3.36	1.10	10.00	1.00	1.000	0.431
06.05.1990	1.110	16.42	27.62	10.00	1.00	1.000	0.546
08.05.1990	0.070	7.39	26.83	8.00	1.00	1.000	
17.10.1991	0.420	25.75	19.26	4.00	0.50	0.500	0.972
18.11.1991	0.670	9.70	22.17	6.03	0.67	0.670	0.715
11.11.1992	0.480	9.60	6.90	6.64	0.83	0.420	0.486
22.06.1994	0.660	81.76	18.70	2.22	0.27	0.250	
11.07.1994	0.320	49.62	10.10	3.75	0.33	0.070	
24.01.1995	0.120	6.20	1.20	10.33	4.10	0.280	
27.01.1995	0.730	12.00	5.60	10.07	1.00	0.170	0.545
19.02.1995	0.040	2.04	11.50	10.17	1.07	0.670	
30.03.1995	1.400	6.80	44.14	9.90	1.33	0.500	
12.04.1995	0.380	2.80	27.55	12.47	0.80	0.420	
02.01.1996	0.580	12.52	28.15	5.82	1.93	0.050	
25.02.1996	1.530	7.68	75.02	7.37	1.92	0.070	
31.03.1996	5.130	3.87	22.48	10.35	1.67	1.000	
25.12.1996	0.690	6.80	22.40	9.00	1.80	0.900	0.540
21.12.1997	1.490	8.20	3.80	13.00	3.00	0.660	
16.11.1998	1.860	12.90	43.30	9.00	1.50	0.330	0.562
07.11.1998	0.680	9.42	19.02	18.00	4.00	0.660	
25.01.2005	0.550	9.50	6.21	9.00	3.50	1.200	
Mean (μ)	0.938	13.572	19.084	9.190	2.008	0.711	0.600
Variance (σ2)	1.098	279.377	296.842	10.775	1.862	0.287	0.029
Std. Dv. (σ)	1.048	16.715	17.229	3.283	1.365	0.536	0.171
Min.	0.040	2.040	0.000	2.220	0.270	0.050	0.431
Max.	5.130	81.760	75.020	18.000	4.100	2.000	0.972
Range	5.090	79.720	75.020	15.780	3.830	1.950	0.541
Median	0.620	9.460	19.140	9.950	1.585	0.660	0.546

3.2. Data Collection

Streamflow and precipitation data are the most important parameters in the hydrological rainfall runoff modeling. Obtaining reliable data over time and space was an essential step before modeling the rainfall-runoff.

In developing relationships for calibration of parameters, for a rainfall-runoff model, collection of rainfall and stream flow data for gauged catchments in the region is very important. The first step in collection of the rainfall and stream flow data was selection of the gauged catchments in the catchment.

In this study, 3 gauged stations R1, R2 and R3 which are close to Damlıca, Vize and Kumdere catchment, were chosen. Rainfall and topographic map values of these three catchments are taken from the reports of General Directorate of Agricultural Research and Policies (TAGEM) (Bakanoğulları 2008, Bakanoğulları and Günay 2010, Bakanoğulları and Günay 2011). The locations of the 3 gauged stations are given in Figure 3.3, 3.4 and 3.5 for the catchments of Damlıca, Vize and Kumdere.

CHAPTER 4

METHODOLOGY

4.1 Derivation of Unit Hydrograph

Hydrograph is a graph that represents the stream discharge versus time. Flow hydrograph is the result of the runoff, which consists of the surface flow, interflow and base flow which is generated from rainfall.

Runoff hydrograph usually consists of a fairly regular lower portion that changes slowly throughout the year and a rapidly fluctuating component that represents the immediate response to rainfall. The lower, slowly changing portion of runoff is termed base flow. The rapidly fluctuating component is called direct runoff. This distinction is made because the unit hydrograph is essentially a tool for determining the direct runoff response to rainfall. Hydrograph components include rising limb, recession limb, peak, direct runoff, and base flow.

1. The unit hydrograph is the direct runoff hydrograph produced by a storm of given duration such that the total volume of excess rainfall is 1 mm (1 cm for large catchments). The total volume of direct runoff is also 1 mm (or 1 cm).

2. The ordinates of UH indicate the direct runoff flow produced by the watershed for every millimeter of excess rainfall; therefore, the units are m^3/sec/mm.

3. A volume of 1 mm is the amount of water in a 1-mm layer uniformly distributed over the entire watershed area. This volume is equal to the area under the UH.

4. Storms of different durations produce different UHs even if the excess rainfall volume is always 1 mm.

5. Longer storms will likely produce smaller peaks and longer duration in the UH.

6. The duration associated with the UH that of originating storm and not the base duration of the UH.

4.1.1 Φ index

Φ index is a constant which is obtained from the histogram of rainfall. The total volume of rainfall above the Φ index line is equal to surface runoff of the same rainfall.

$$d = \frac{\sum q_i \, \Delta t}{A} \qquad (4.1)$$

Where, d is depth of surface runoff (m), q_i is ordinate of surface runoff hydrograph (m^3/s), Δt is time interval (s), A is area of the catchment (m^2).

4.2 Synthetic Unit Hydrograph

4.2.1 Snyder's Synthetic Unit Hydrograph

In order to draw Snyder's Synthetic unit hydrograph of a basin, first of all basin coefficients which are C_t and C_p are to be obtained. All the observed values of each basin are used to find out the C_t and C_p values. For each rainfall for different dates these constants are calculated. Then the averages of all constants are taken. This operation is repeated for all 3 basins. Then by using these C_t and C_p values Snyder's synthetic unit hydrographs are drawn. By replacing observed t_p in Eq. 4.2, t_r is found.

$$t_r = \frac{t_p}{5.5} \qquad (4.2)$$

If $t_r \neq t_R$ (effective rainfall) then by using Eq.4.4 a new corrected t_p value is found. In this equation t_{pR} is given in observed values. The new calculated value of t_p is replaced in Eq.4.3. And after replacing L and L_c values which are basin parameters, C_t is calculated. L is the river length. L_c is the distance from projection of centroid to the outlet of the basin.

$$t_p = 0.75C_t(LL_c)^{0.3} \tag{4.3}$$

By using Eq.4.4, C_p value is found.

$$q_p = \frac{2.75C_p}{t_p} \tag{4.4}$$

$$t_p = t_{pR} + 0.25(t_r - t_R) \tag{4.5}$$

4.2.2 Mockus Unit Hydrograph

By using the observed values q_p, t_p and A (area of the basin) in Eq.4.6, K values are found and replacing that K value in Eq.4.7 H values is found. By repeating these steps for each rainfall all K and H values are found then taking the averages of K and H values, the average values of the basin is found. Then by using Eq.4.10, t_c (time of concentration) value is found. Then using t_c value in Eq.4.11, D is found. By using t_c value in Eq.4.12 AD (unit rainfall time) is found. Unit hydrograph time is considered according to AD. Then t_p value is found by Eq.4.13. t_r is found by Eq. 4.8. t_b is found by using Eq.4.9.

$$\mathrm{K} = \frac{\mathrm{q_p\,t_p}}{\mathrm{Ah}} \tag{4.6}$$

$$H = (2x0.278 - K)/K \tag{4.7}$$

$$t_r = H\ t_p \tag{4.8}$$

$$t_b = t_r + t_p \tag{4.9}$$

$$t_c = 0.00032L^{0.77}/S^{0.385} \tag{4.10}$$

$$D = {t_c}^{0.5} \tag{4.11}$$

$$AD = t_c/5 \tag{4.12}$$

$$t_P = \sqrt{t_C} + 0.6t_C \quad (\text{Özer}, 1990) \tag{4.13}$$

where, q_p is peak discharge unit hydrograph ($m^3/s/mm$), t_p is peak time (hr), A is area (km^2), t_r is time for recession of UH curve from peak point (hr), k and h are constants of basins.

4.2.3 SCS Unit Hydrograph

1. Catchment area (A), longest flow path length (L), slope (S) are obtained both from topographic map and GIS values.

2. Time of concentration (t_c) is found by using Kirpich formula

$$t_c = 0.0078L^{0.77}S^{-0.385} \tag{4.14}$$

where, t_c is in minute, L is in feet and S is feet/feet.

3. Determine the time lag t_L is lag time from centroid of rainfall to q_p (hr).

$$t_L = 0.67t_c \tag{4.15}$$

4. Dertermine time to peak (t_p)

$$t_p = \frac{t_r}{2} + t_L \tag{4.16}$$

where, t_r is effective rainfall duration.

5. Determine the base time (t_b)

$$t_b = 2.67t_p \tag{4.17}$$

6. Determine peak discharge (q_p)

$$q_p = \frac{CA}{t_p} \tag{4.18}$$

where, C=2.08 and A is the catchment area in km^2.

4.2.4. Turkish State of Hydraulic Works (DSI)'s Synthetic Method

DSI hydrograph is a graph showing the temporal change in the flow cross section in a stream. Synthetic unit hydrograph allows the calculation of the flood on the value that can come from long-term observations that are not reliable. This method is used in the drainage areas of about 1000 square kilometers or less. By using basin parameters A, L, L_c and slope in Eq.4.19 q_p is found. Using Eq.4.20 Q_p is found. In Eq.4.21 V is found. In Eq.4.22 replacing V and Q_p, t_b is found. And finally dividing t_b by 5 we obtained t_p.

$$q_p = \frac{414}{\left(A^{0.225}\left(LL_c/\sqrt{S}\right)^{0.16}\right)} \tag{4.19}$$

$$Q_p = Aq_p 10^{-3} \tag{4.20}$$

$$V = Ah_a 10^{-3} \tag{4.21}$$

$$t_b = 3.65(V/Q_p) \tag{4.22}$$

$$t_p = t_b/5 \tag{4.23}$$

where, Q_p is peak discharge unit hydrograph (m^3/s/mm), q_p is peak discharge per unit area (m^3/s/km^2), t_p is peak time (hour), t_r is time for recession of UH curve from peak point (hour), A is the area (km^2), L is the main river length (km), L_c is the length between point where centroid projection of the basin to main canal drops and the outlet of the basin (km), S is harmonic slope, ha is 1.00 mm, V is discharge volume (m^3), t_b is base time (hour).

4.3 Soft Computing Methods

4.3.1 Artificial Neural Network (ANN)

The ANNs technique is a data processing tool that mimics the function of the human brain and nerves, built on the so-called neurons—processing elements—connected to each other. Artificial neurons are organized in such a way that the structure resembles a network. This technique differs from traditional data processing in the relationship between the input and output data (Hecht- Nielsen, 1990; Koutsoyiannis et al., 2008).

Multilayer network models usually consist of three layers, which are the input, hidden and output layers. The input layer constitutes input nodes representing input variables. The output of the input nodes are normalized and transferred to the hidden layer in which they are processed through a transfer function. The output layer consists of the output variables (Aytek et al, 2005).

The basic element of a NN is an artificial neuron, as shown in Figure 4.1, which consists of three main components: weights, bias and an activation function. Each neuron receives inputs x_i (i= 1, 2, …, n) attached with a weight of w_{ij} (j≥1) which shows the connection strength for a particular input for each connection. Every input is then multiplied by the corresponding weight of the neuron connection and summed as:

$$W_i = \sum_{j=1}^{n} w_{ij}\ x_j \tag{4.25}$$

A bias term in a neural network represents the generalization error of the model; in other words, it deals with the ability of a neural network model to fit different particular training sets. In a more explicit way, w_{ij} in equation 4.25 is the weighted sum of the *i*th neuron in the hidden layer and the *j*th neuron in the preceding (input) layer, and x_j is the output of *j*th neuron in the input layer. After being corrected by a bias as in equation 4.26, the summation is transferred using a scalar-to-scalar function, referred to as the 'activation or transfer function', $f(U_i)$, to yield a value of the unit's 'activation', given as:

$$y_i = f(U_i) \qquad (4.26)$$

Activation functions serve to introduce nonlinearity into NNs, which makes them more powerful than linear transformation.

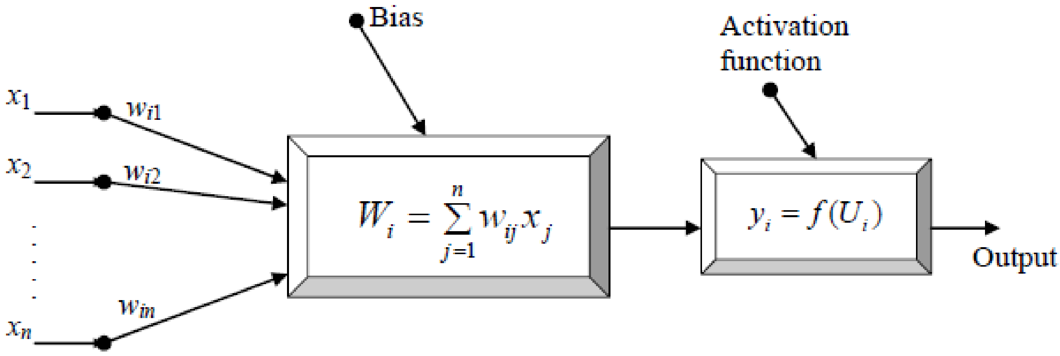

Figure 4.1 Basic elements of an artificial neural network component.

4.3.1.1 Multi Output Neural Network (MONN)

MONN is a type of neural network that requires multiple inputs and generate multiple outputs, as shown schematically in Figure 4.2.

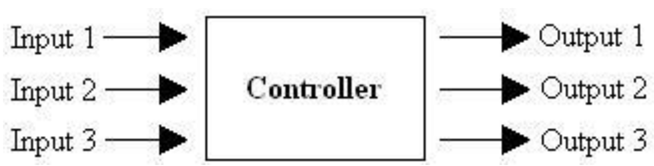

Figure 4.2 Schematic diagram of MONN

As shown in the figure, MONNs are controlled by controllers that combine multiple input readings in an algorithm to generate multiple output signals. Typically, MONNs do not require that the number of inputs and outputs be the same. Instead, any number of input readings could be used to generate any number of output signals.

Once neurons have been programmed to correlate input and output data, they can be connected in a feed forward series to produce a neural network, or neural net (Guven 2011). A schematic diagram of a neural network is shown in Figure 4.3.

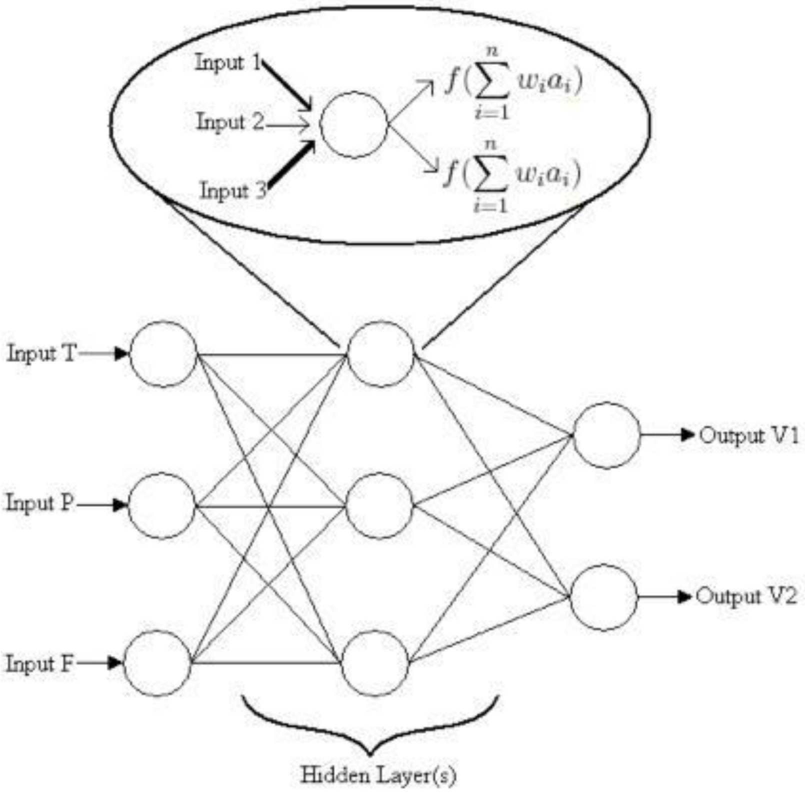

Figure 4.3 Schematic diagram of multi output neural network

Figure 4.3 shows MONN parameters, such as temperature, pressure, and flow readings, are first processed in the first layer of neurons. The outputs of the first layer of neurons then serve as the inputs to the second layer. The outputs of the second layer then become the inputs to the third layer, and so on, until the final output of the network is used to directly affect MONN controls such as valves. The layers of neurons between the initial and final layers are known as hidden layers.

4.3.2 Genetic Programming

As the computer use increased a wide range of mathematical and numerical models have been developed with the intent of predicting or approximating parts of hydrologic cycle. Prior to the advent of conceptual or process based models, physical hydraulic models, which are reduced scale representations of large hydraulic systems, were used commonly in water resources engineering. Fast development in the computational systems and numerical solutions of complex differential equations enabled development of conceptual models to represent physical systems in almost all arenas of life including hydrological and water resources systems.

Statistical / Black box models involve using mathematical and statistical techniques to fit a model to a data set which then relates the dependent variable to the independent variables. This type of modeling includes regression models, response matrix, transfer functions, neural networks, support vector machine etc. The most widely used "black box" type modeling approach in hydrology and water resources literature is neural networks. Genetic Programming is a potential tool to develop simple and efficient functional relationship between hydrological variables. In spite of the wide range of possible applications in hydrology and water resources, GP has not been widely reported in the hydrology and water resources literature. The focus of this chapter is to discuss the potential applicability of genetic programming to develop simple and computationally efficient hydrological models, in light of a few studies reported in the recent years. The key points discussed are as follows;

1. GP's ability to develop simple models with interpretability to overcome the curse of "black box" nature of data intensive models.
2. Lesser number of parameters used in GP models as compared to parallel neural network architectures.
3. GP's ability to parsimoniously identify the significance of the modeling inputs.

4.3.2.1 Genetic programming as a modeling tool

Genetic programming belongs to and is one of the latest members in the family of evolutionary computation. Evolutionary computation refers to the group of computational techniques which are inspired by and emulate the natural process of evolution which resulted in the formation of the entire variety of organisms present on earth (Koza, 1992). Just as the way evolution and natural selection has resulted in the formation of organisms that are competent and best suitable inhabitants to live in any natural environment, the principle has been applied in computational science to evolve solutions to complex engineering problems which are subject to random and chaotic environments similar to the circumstances in which natural evolution has occurred. Evolutionary computation forms the basic principle behind the evolutionary algorithms like genetic algorithm (GA), genetic programming (GP), Evolutionary programming, evolution strategy, differential evolution. Evolutionary algorithms, widely used in mathematical optimization, are in general based on the application of evolutionary principles like selection, cross-over and mutation to a “population” of candidate solutions over a number of generations to find the optimal solutions to an engineering problem. Genetic Algorithm is, for example, a widely used optimization techniques using these principles as the basic “operators” of the algorithm. Genetic programming is similar to genetic algorithm in this aspect that it uses these genetic operators’ selection, cross-over and mutation in its algorithms. However, the uniqueness of genetic programming is that it performs these operators over symbolic expression or formulae or programs rather than over numbers which represent the candidate solutions. Thus, in genetic programming the candidate solutions are symbolic expressions or formulae. In a modeling framework these symbolic expressions or formulae or programs are candidate models to simulate a physical phenomenon. The parse tree notations of two parent and offspring genetic programs are shown in Figure 4.4. Thus the optimal formula that is evolved by genetic programming can be used as a best fit model for predicting the physical phenomenon under consideration.

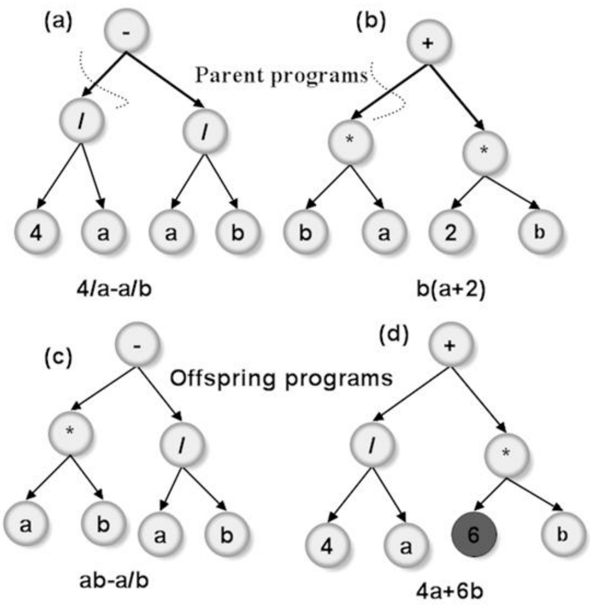

Figure 4.4 Symbolic representations of parent and offspring genetic programs

In Figure 4.4 two parent programs to model a physical phenomenon are shown. After testing these programs for their modeling performance, they are operated by cross-over operator. That is, parts of the programs are crossed over at the dashed locations to generate the offspring programs. Also, mutation is illustrated by arbitrarily changing the parameter 2 to 6. In the last decade a few studies in the broad area of hydrology have utilized genetic programming based models for making hydrological predictions. They combined the use of GP based models with other conceptual models in deriving useful hydro-climatic models. It was concluded that GP was able to develop more robust models in that the functional relationships between different models inputs could be easily identified thus resulting in more transparency of the "black box" type of modeling.

4.3.2.2 Linear Genetic Programming (LGP)

GP technique is an automatic, computerized creation of computer programs in order to solve a selected problem using Darwinian natural selection. LGP, a linear variant of GP, uses a specific linear representation of computer programs. The name 'linear' refers to the structure of the (imperative) program representation, and does not stand for functional genetic programs that are restricted to a linear list of nodes only. On the contrary, genetic programs normally represent highly non-linear solutions in this meaning (Brameier 2004, Guven 2009). The main characteristic of LPG in comparison to conventional tree-based GP is that the expressions of a functional programming language are substituted by programs of an imperative language (like C or C++).

The main characteristics of LGP are the graph-based data flow that results from a multiple usage of indexed variables (registers, r[*i*]) and evolving programs in a low-level language, in which the solutions are directly manipulated as binary machine codes and executed without using an interpreter (Banzhaf et al 1998; Brameier 2004). In this way the computer program can be evolved very quickly (Bhattacharya et al 2001; Brameier and Banzhaf 2001; Foster 2001).

4.3.2.3 Gene Expression Programming (GEP)

The flowchart of a gene expression algorithm (GEA) is shown in Figure 4.5. The process begins with the random generation of the chromosomes of the initial population. Then the chromosomes are expressed and the fitness of each individual is evaluated. The individuals are then selected according to fitness to reproduce with modification, leaving progeny with new traits. The individuals of this new generation are, in their turn, subjected to the same developmental process: expression of the genomes, confrontation of the selection environment, and reproduction with modification. The process is repeated for a certain number of generations or until a solution has been found. Note that reproduction includes not only replication but also the action of genetic operators capable of creating genetic diversity. During replication, the genome is copied and transmitted to the next generation. Obviously, replication alone cannot introduce variation: only with the action of the remaining operators is genetic variation introduced into the population. These operators randomly select the chromosomes to be modified. Thus, in GEP, a chromosome might be modified by one or several operators at a time or not be modified at all (Ferreira, 2001).

In this study, 70 % of data are used for training and 30 % are used for testing.

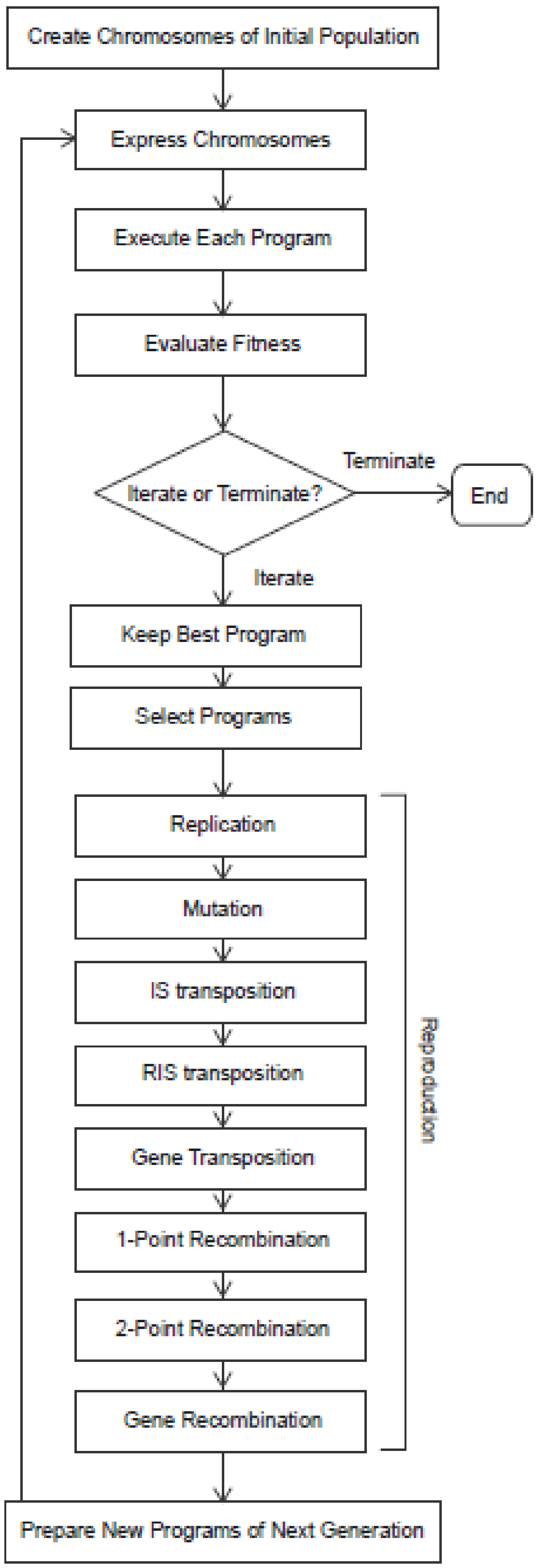

Figure 4.5 Flowchart of a gene expression algorithm (Ferreira, 2001)

CHAPTER 5

CASE STUDY

5.1 Digital Elevation Model of Damlıca Catchment

The Digital Elevation Model (DEM) of Damlıca catchment was downloaded from the Aster Global Digital Elevation Model (Aster GDEM) web site. It is generated from data collected from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), a spaceborne earth observing optical instrument. The ASTER GDEM is in GeoTIFF format with geographic lat/long coordinates and a 1 arc-second (30 m) grid of elevation postings. It is referenced to the WGS84/EGM96 geoid. Pre-production estimated accuracies for this global product were 20 meters at 95 % confidence for vertical data and 30 meters at 95 % confidence for horizontal data. Digital Elevation Model of the north-west part of Turkey where Damlıca catchment is included is shown in Figure 5.1.

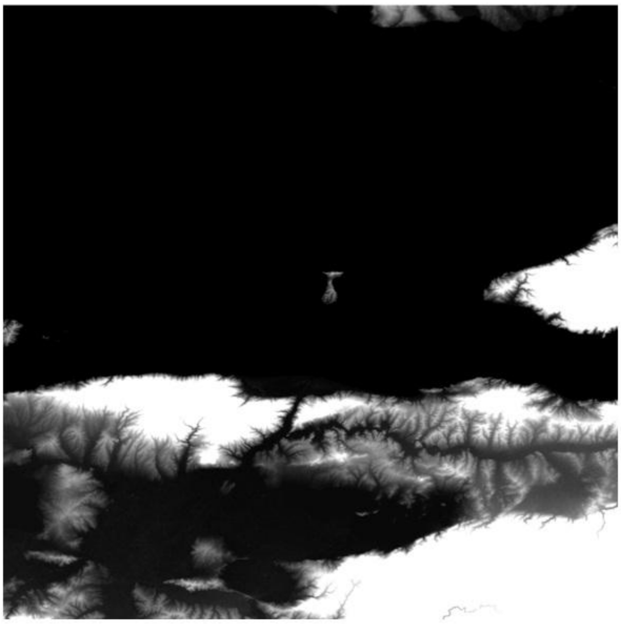

Figure 5.1 Digital Elevation Model (DEM).

This DEM is downloaded to ArcGIS computer program and the Damlıca catchment is extracted from the map. The location of Damlıca catchment is shown in Figure 5.2

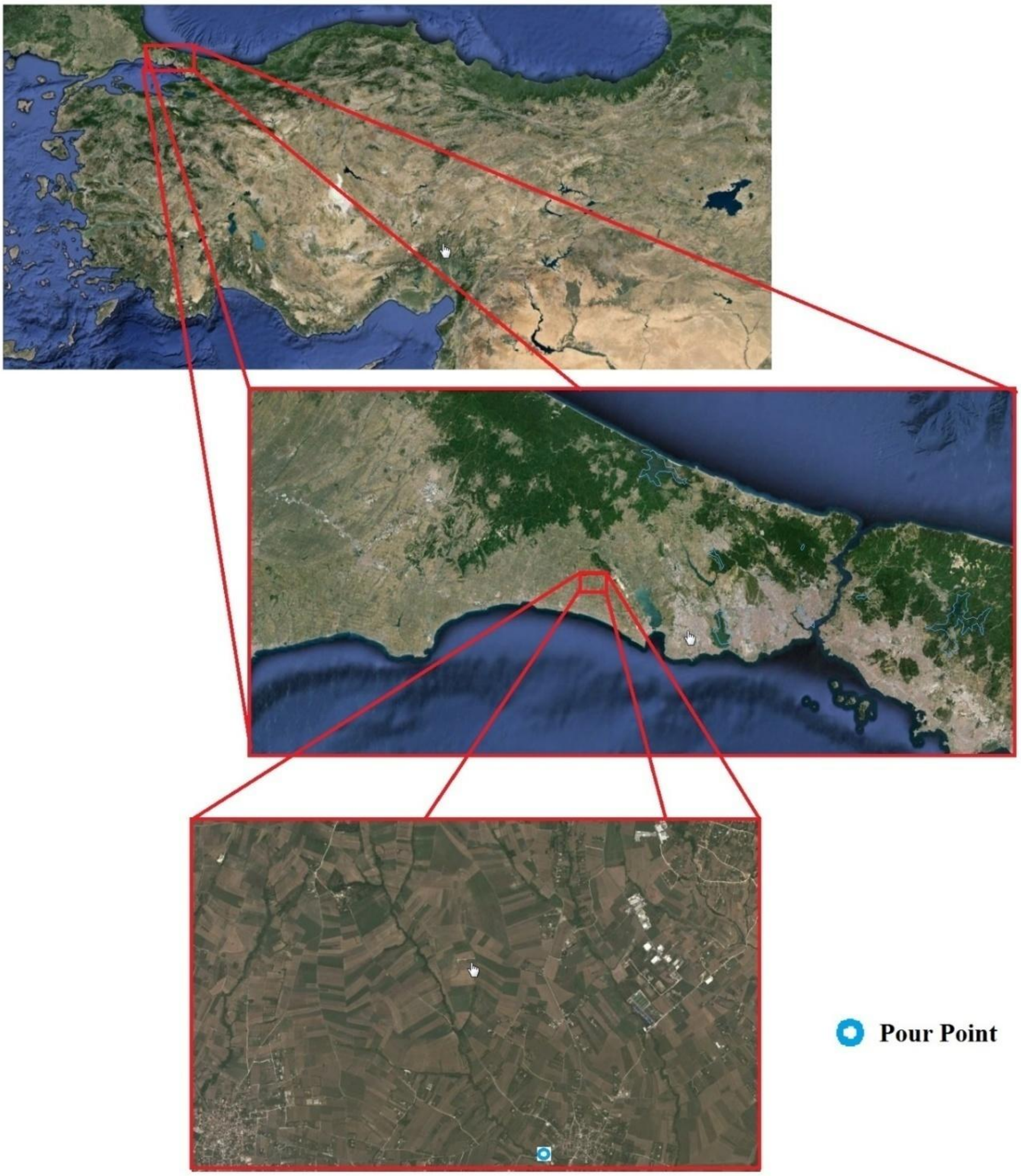

Figure 5.2 Damlıca catchment.

By using ArcGIS program different maps (like elevation map, soil classification map, slope map, land use map etc.) of the catchment can be extracted. Elevation map of the catchment is given in Figure 5.3. The lowest point of the catchment is 120 m and the highest point is 255m.

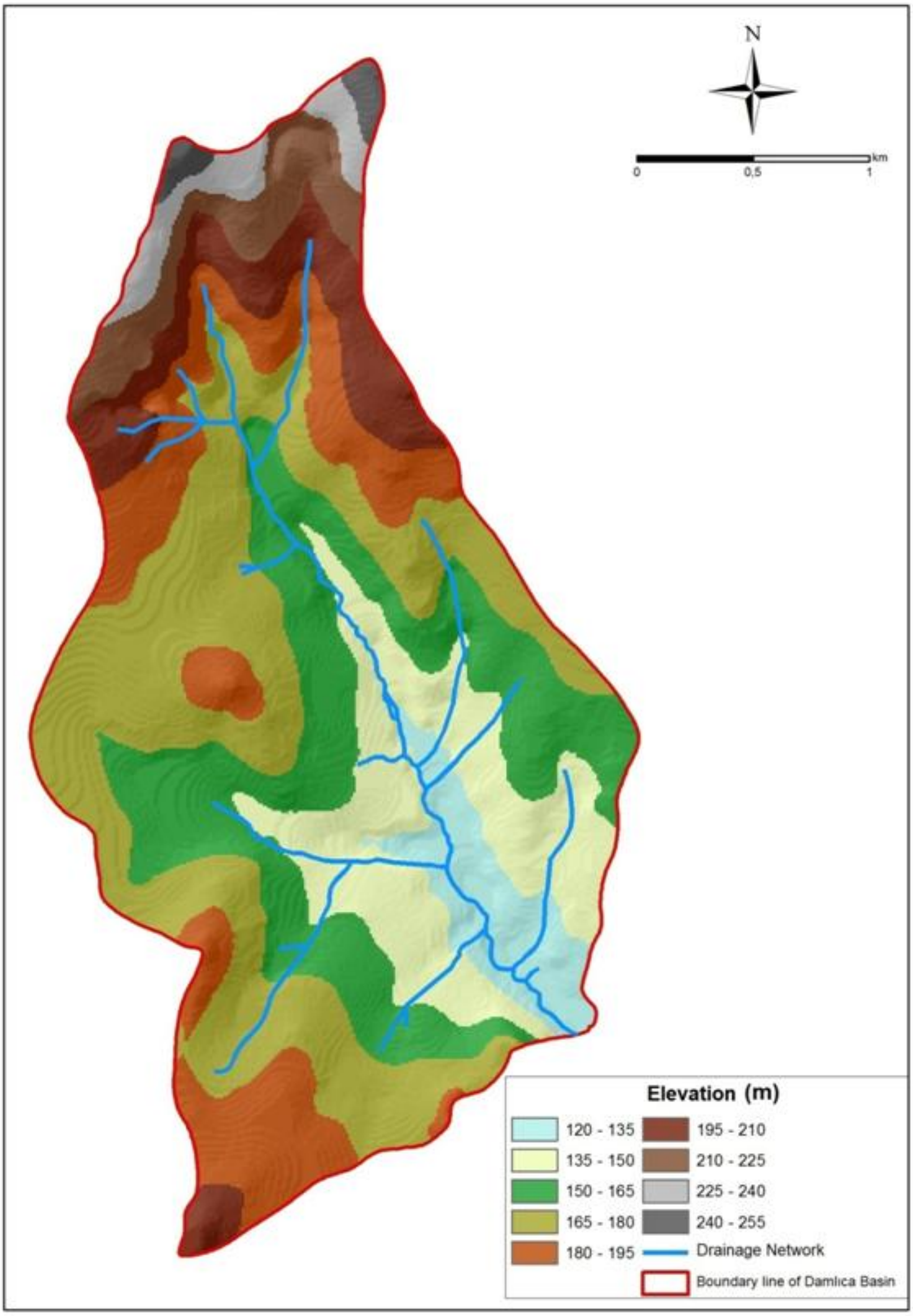

Figure 5.3 Digital map of Damlıca catchment.

The soil classification map is given in Figure 5.4. In the catchment, there are brown forest soil, limeless brown forest soil, limeless brown soil, vertisol soil.

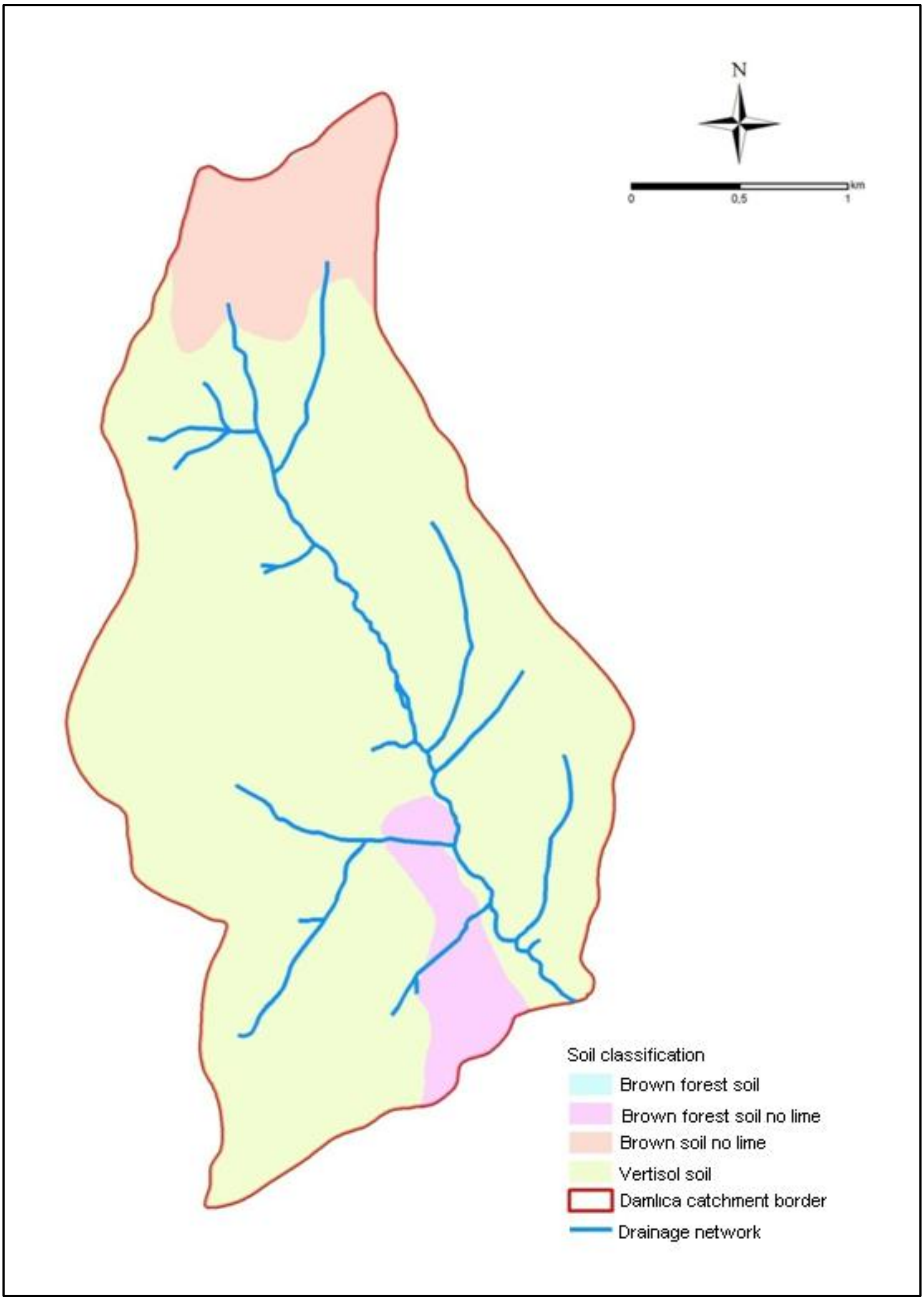

Figure 5.4 Soil Classification Map of Damlıca Catchment.

In Figure 5.5, elevation map of the catchment is given. Isohips are used for different elevations.

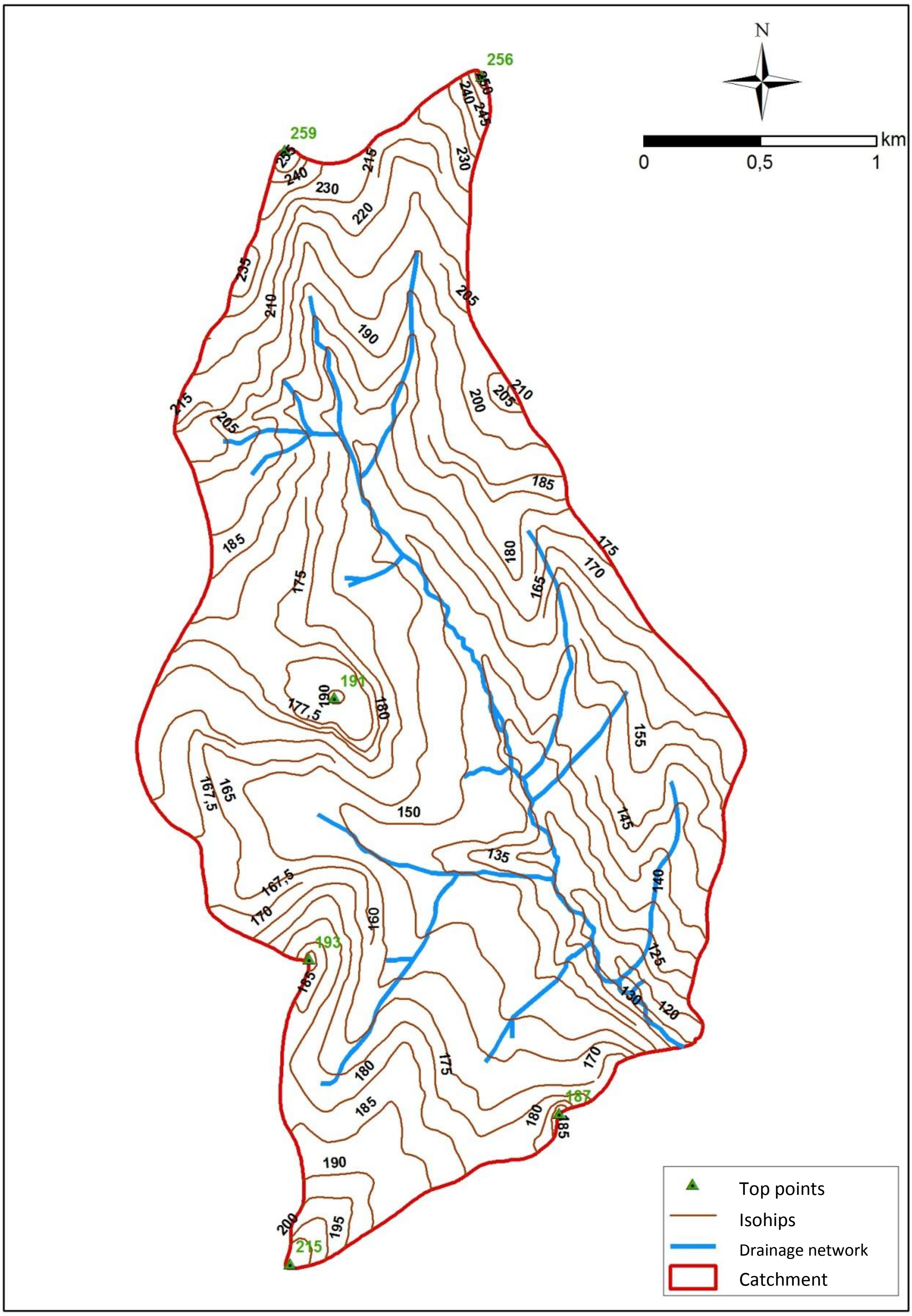

Figure 5.5 Elevation map of Damlıca catchment.

In Figure 5.6, slope map of the Damlıca catchment is given. Slopes and corresponding areas are shown with different colors.

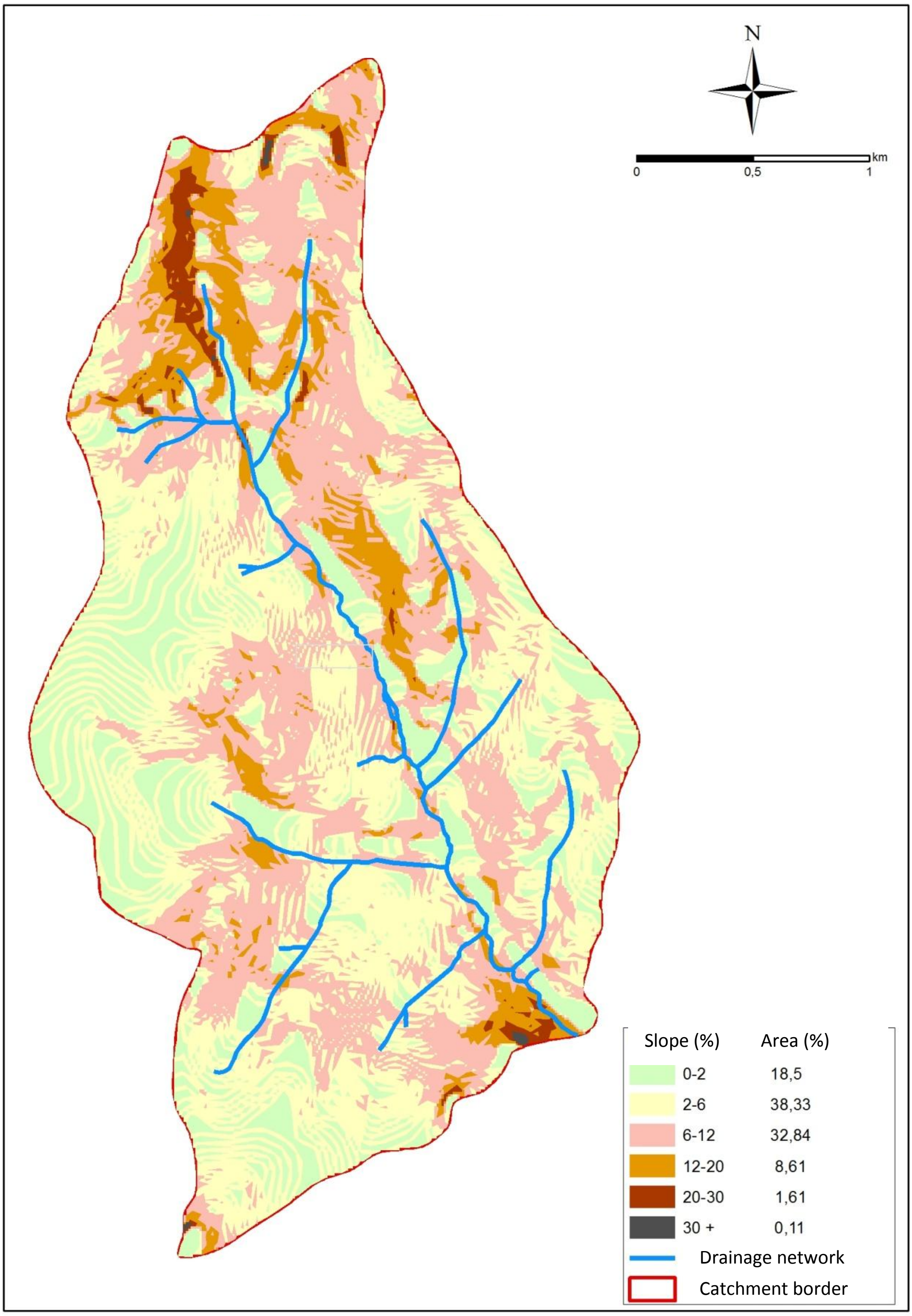

Figure 5.6 Slope Map of Damlıca Catchment.

Finally, in Figure 5.7, land use of the catchment is given. Most of the land is used for dry agriculture. The rest is used for gardening. The 36.28 % (3.00 km^2) of the total area is wheat; 45.21 % (3.74 km^2) of the total area is sunflower; 18.52 % of the total area (1.53 km^2) is garden.

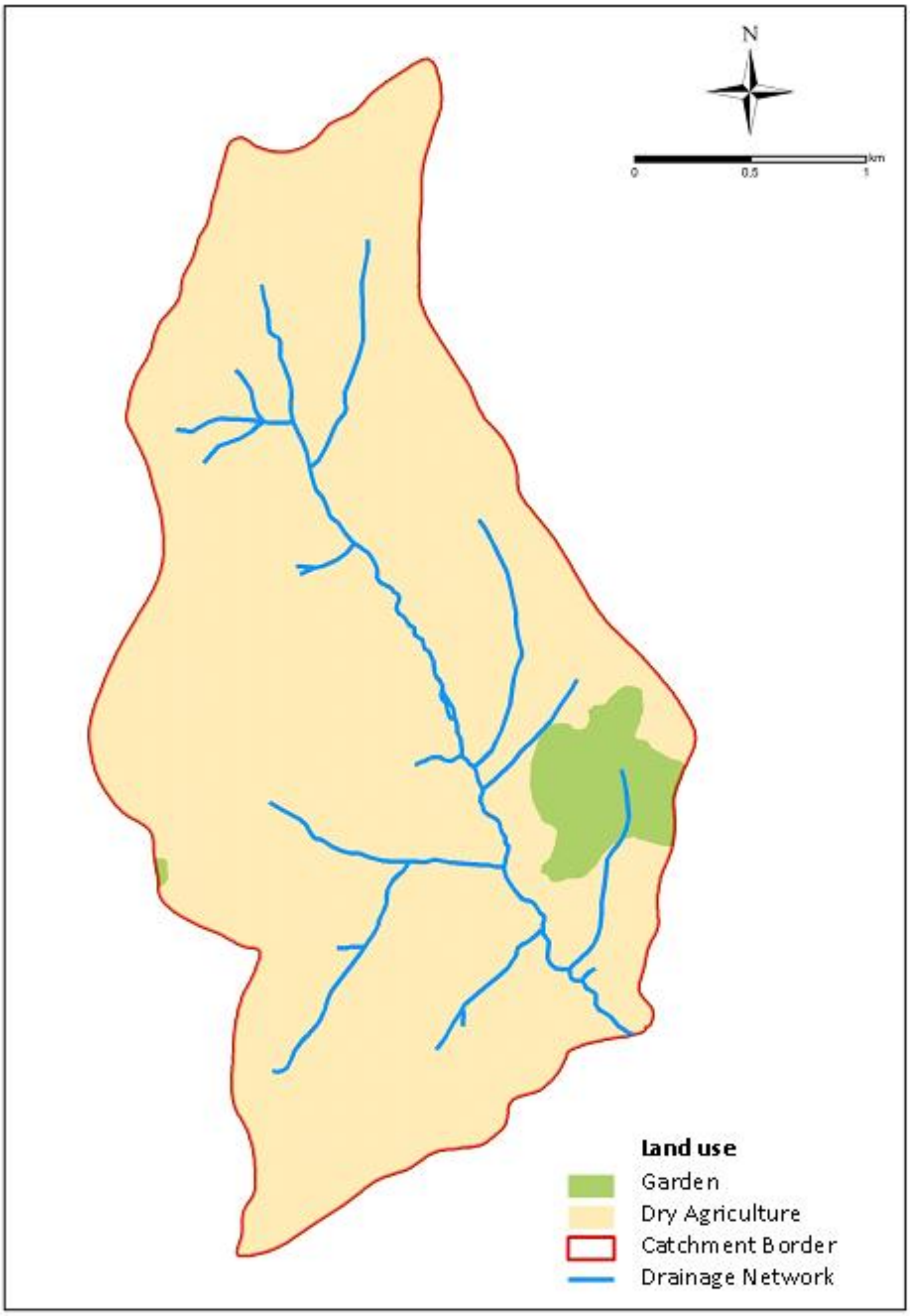

Figure 5.7 Land use map of Damlıca Catchment.

ArcGIS computer program is capable of calculating the geomorphologic parameters of the selected catchment Damlıca. The computer program has found the following parameters of the Damlıca catchment.

Table 5.1 Definitions and Calculations of Geomorphologic Parameters used in this study for Damlıca Catchment

Geomorphologic Parameters	**Symbol**	**Definition**	**Formula**	**Values**
Watershed area	A_w	The total area projected upon a horizontal plane contributing overland flow to the stream segment of the given order and all segments of lower order.	Measured Area	7.63km^2
Catchment perimeter	L_p	The length measured along the divide of the drainage catchment as projected on to the horizontal plane of the map.	Measured distance	13.4 km
Catchment length	L_b	The longest dimension of a catchment parallel to the principal drainage line.	Measured distance	4.2 km
River length	L_r	The length of main channel	Measured distance	4.8 km
Tributary length	L_t	The total length of all streams within the watershed area	Measured distance	12.6 km

Table 5.1 Continued.

L_{ca}	L_{ca}	The length from the catchment outlet to a point adjacent to the centroid.	Measured distance	1.9 km
Form factor	R_{ff}	A dimensionless parameter defined as the ratio of a catchment area A_w to the square of catchment length L_b^2	$R_{ff} = \frac{A_w}{L_b^2} = \frac{7.63}{(4.2)^2}$	0.43
Circularity ratio	R_c	A dimensionless parameter defined as the ratio of the catchment area of a given order w to the area A_p of a circle having a circumference equal to the catchment perimeter L_p	$R_c = \frac{A_w}{A_p}, where$ $L_p = 2\pi \times r \Rightarrow 13.4$ $= 2 \times 3.14 \times r$ $r = 2.13$ $A_p = \pi \times r^2$ $= 3.14 \times (2.13)^2 = 14.25$ $R_c = \frac{A_w}{A_p} = \frac{7.63}{14.25} = 0.54$	0.54
Elongation of watershed	L_l		$L_l = (\frac{L_b \times L_{ca}}{2.58})^{0.3}$ $= (\frac{4.2 \times 1.9}{2.58})^{0.3} = 1.4$	1.4 m
Elongation ratio	R_r	The ratio of diameter of a circle D_c with the same area as that of the catchment to the maximum length.	$R_e = \frac{D_c}{L_b}, where$ $D_c = 2 \times \sqrt{\frac{A_w}{\pi}} = 2 \times \sqrt{\frac{7.63}{\pi}}$ $= 3.12$ $R_e = \frac{D_c}{L_b} = \frac{3.12}{4.2} = 0.74$	0.74

Table 5.1 Continued.

Watershed shape factor	S_b	The square of maximum straight-line length of catchment (from mouth to divide) divided by total area.	$S_b = \frac{L_b^2}{A_w} = \frac{(4.2)^2}{7.63} = 2.31$	2.31
Unity shape factor	R_u	The ratio of the catchment length L_b to the square root of the catchment area A_w	$R_u = \frac{L_b}{\sqrt{A_w}} = \frac{4.2}{\sqrt{7.63}} = 1.52$	1.52
Watershed relief	H	The maximum vertical distance between the lowest (outlet) and the highest (divide) points in the catchment	$H = \max elev - \min elev$ 258-115=143 m	143 m
Relief ratio	R_h	A dimensionless quantity , defined as the ratio of maximum catchment relief H to horizontal distance along the longest dimensions of the catchment parallel to the principal drainage line L_b	$R_h = \frac{H}{L_b} = \frac{0.143}{4.2} = 0.034$	0.034
Relative relief	R_p	The ratio of catchment relief H to the length of the perimeter L_p	$R_p = \frac{H}{L_p} = \frac{0.143}{13.4} = 0.011$	0.011

Table 5.1 Continued.

Drainage density	D	The ratio of the total length of all streams within a watershed to the watershed area	$D = \frac{L_r + L_t}{A_w} = \frac{4.8 + 12.6}{7.63}$	2280.5 m/km^2
Ruggedness number	R_n	Product of relief H and drainage density D	$R_n = H \times D$ $= 0.143 \times 2.2805$	0.326
Constant of channel maintenance	C	The ratio of the drainage catchment area to the total length of all streams in the network.	$C = \frac{A_w}{L_r + L_t} = \frac{7.63}{4.8 + 12.6}$	0.44
Fineness ratio	R_f	The ratio of channel length to the length of catchment perimeter	$R_f = \frac{L_r}{L_p} == \frac{4.8}{13.4} = 0.36$	0.36
Stream frequency	C_f	The total number of streams per unit area	$C_f = \frac{L_t}{A_w} = \frac{12.6}{7.63}$	1.65
Average length of contour	L_{ac}	The total length of contours within the catchment area	$L_{ac} = \frac{L_{co}}{CO_n} = \frac{54.46}{24}$	2.27
Watershed slope %	L_s		$L_s = \frac{H \times L_{ac}}{10 \times A_w} = \frac{143 \times 2.27}{10 \times 7.63}$	4.3
Main channel slope	C_s	Slope of a line L_c is the straight-line drawn from outlet to the inlet of catchment.	$C_s = \frac{\Delta Elev}{L_c} = \frac{H}{L_b} = \frac{0.143}{4.2}$	0.034

5.1.1 Determination of Geomorphologic Parameters of Damlıca Catchment Using GIS

In this study, the geomorphologic parameters of a catchment called Damlıca are determined by using Geographic Information Systems (GIS). The digital elevation model (DEM) of the catchment is downloaded from Aster-GDEM web page and this digital map is downloaded to the GIS computer program to obtain the geomorphologic parameters of the Damlıca catchment. The geomorphologic parameters (area of the catchment, perimeter, river length, slope, etc.) are extracted from GIS computer program. The extracted parameters are compared with the parameters which are obtained by conventional methods. This study shows that the geomorphologic parameters of the Damlıca catchment by GIS are much precisely than conventional methods.

5.2 Derivation of Synthetic Unit Hydrographs of Damlıca Catchment

Geomorphological parameters of Damlıca catchment are obtained by GIS. All the methods which are used in this study (Synder, Mockus, DSI, SCS) are applied to studied catchment. Synthetic Unit Hydrographs (SUH) is derived by using geomorphological parameters by both GIS and topographic map parameters.

5.2.1 Snyder's Method

In Snyder's Method, geomorphological parameters which are area (A), river length (L), and distance from centroid projection to outlet (L_c) are used. By using GIS, these parameters are obtained and in Snyder's Method are used. Below calculations are done for both GIS and topographic values.

5.2.1.1 Snyder's by GIS parameters of Damlıca

In this method GIS parameters are used. In Table 5.2 Snyder's parameters of Damlıca catchment are given.

Table 5.2 Snyder's SUH parameters of Damlıca by GIS

Date	Observed			C_t	C_p	Snyder's		
	q_p	t_p	t_b			q_p	t_p	t_b
04.12.1981	0.480	4.32	16.20	2.674	0.865	0.611	3.893	15.572
15.01.1983	0.607	5.61	15.10	4.070	1.580	0.733	5.924	23.695
16.02.1984	0.607	3.00	17.13	1.587	0.687	0.818	2.310	9.238
06.03.1984	0.662	6.95	19.13	4.685	2.030	0.818	6.820	27.281
01.01.1986	0.460	4.00	18.00	2.476	0.767	0.585	3.605	14.418
02.02.1986	0.619	4.00	13.50	2.747	1.107	0.761	3.998	15.994
24.11.1988	0.440	4.50	19.50	3.124	0.891	0.539	4.547	18.190
08.12.1988	0.530	2.80	11.90	1.733	0.619	0.674	2.523	10.093
09.04.1991	0.436	3.33	9.40	1.132	0.427	0.713	1.648	6.591
01.05.1991	0.475	2.67	8.30	1.922	0.585	0.575	2.798	11.192
17.03.1992	0.418	5.60	9.20	3.532	0.988	0.529	5.141	20.564
19.04.1992	0.419	3.60	7.90	2.445	0.668	0.516	3.559	14.237
25.02.1993	0.419	3.50	8.16	2.489	0.671	0.509	3.623	14.491
01.03.1993	0.650	5.33	18.00	3.902	1.617	0.783	5.679	22.718
29.01.1994	0.490	2.59	8.28	1.683	0.546	0.613	2.450	9.801
25.02.1994	0.540	2.60	13.10	1.691	0.605	0.676	2.461	9.844
27.01.1995	0.451	2.00	6.00	1.103	0.349	0.598	1.605	6.421
30.03.1995	0.435	6.17	15.00	4.400	1.231	0.529	6.405	25.619
05.02.1996	0.467	5.51	20.50	3.843	1.162	0.571	5.593	22.374
25.02.1996	0.566	3.33	17.33	1.430	0.629	0.831	2.081	8.324
17.03.1996	0.660	5.51	17.67	3.751	1.616	0.814	5.460	21.838
28.03.1996	0.418	3.83	4.83	2.077	0.614	0.558	3.024	12.096
17.04.1996	0.425	3.75	10.00	2.109	0.625	0.560	3.070	12.280
22..03.1997	0.500	3.50	10.50	2.548	0.814	0.603	3.709	14.837
20.05.1998	0.450	2.00	6.00	1.465	0.420	0.542	2.133	8.532
24.11.1998	0.650	2.67	19.33	1.922	0.801	0.787	2.798	11.192
18.02.2001	0.429	6.00	28.00	4.120	1.150	0.527	5.998	23.990
28.03.2004	0.430	7.00	16.17	5.188	1.417	0.516	7.553	30.210
29.01.2005	0.435	11.00	23.00	7.935	2.211	0.526	11.551	46.204
Average	0.502	4.368	14.039	2.889	0.955	0.635	4.205	16.822

5.2.1.2 Snyder's by topographic parameters of Damlıca

In this method topographic parameters of Damlıca are used. In Table 5.3 Snyder's parameters of Damlıca catchment are given.

Table 5.3 Snyder's SUH parameters by topographic parameters

Date	Observed			C_t	C_p	Snyder's		
	q_p	t_p	t_b			q_p	t_p	t_b
04.12.1981	0.480	4.32	16.20	2.674	0.799	0.593	3.71	14.825
15.01.1983	0.607	5.61	15.10	4.070	1.459	0.712	5.64	22.560
16.02.1984	0.607	3.00	17.13	1.587	0.635	0.794	2.20	8.795
06.03.1984	0.662	6.95	19.13	4.685	1.875	0.794	6.49	25.974
01.01.1986	0.460	4.00	18.00	2.476	0.709	0.568	3.43	13.727
02.02.1986	0.619	4.00	13.50	2.747	1.023	0.739	3.81	15.227
24.11.1988	0.440	4.50	19.50	3.124	0.823	0.523	4.33	17.318
08.12.1988	0.530	2.80	11.90	1.733	0.572	0.654	2.40	9.609
09.04.1991	0.436	3.33	9.40	1.132	0.395	0.692	1.57	6.275
01.05.1991	0.475	2.67	8.30	1.922	0.540	0.558	2.66	10.655
17.03.1992	0.418	5.60	9.20	3.532	0.913	0.513	4.89	19.578
19.04.1992	0.419	3.60	7.90	2.445	0.617	0.501	3.39	13.555
25.02.1993	0.419	3.50	8.16	2.489	0.620	0.494	3.45	13.796
01.03.1993	0.650	5.33	18.00	3.902	1.494	0.760	5.41	21.629
29.01.1994	0.490	2.59	8.28	1.683	0.505	0.595	2.33	9.331
25.02.1994	0.540	2.60	13.10	1.691	0.559	0.656	2.34	9.373
27.01.1995	0.451	2.00	6.00	1.103	0.323	0.580	1.53	6.114
30.03.1995	0.435	6.17	15.00	4.400	1.137	0.513	6.10	24.392
05.02.1996	0.467	5.51	20.50	3.843	1.073	0.554	5.33	21.302
25.02.1996	0.566	3.33	17.33	1.430	0.581	0.806	1.98	7.925
17.03.1996	0.660	5.51	17.67	3.751	1.493	0.790	5.20	20.792
28.03.1996	0.418	3.83	4.83	2.077	0.567	0.541	2.88	11.516
17.04.1996	0.425	3.75	10.00	2.109	0.577	0.543	2.92	11.692
22..03.1997	0.500	3.50	10.50	2.548	0.752	0.585	3.53	14.126
20.05.1998	0.450	2.00	6.00	1.465	0.388	0.526	2.03	8.124
24.11.1998	0.650	2.67	19.33	1.922	0.740	0.764	2.66	10.655
18.02.2001	0.429	6.00	28.00	4.120	1.062	0.511	5.71	22.841
28.03.2004	0.430	7.00	16.17	5.188	1.309	0.501	7.19	28.763
29.01.2005	0.435	11.00	23.00	7.935	2.042	0.511	11.00	43.990
Average	0.502	4.368	14.039	2.889	0.882	0.616	4.004	16.016

5.2.2 Mockus Method

In this method, GIS and topographic A, L, H_L and S values of Damlıca are used. Below derivation of SUH parameters by using Mockus method are given in Table 5.4.

5.2.2.1 Mockus by GIS parameters

In this method GIS values are used. In Table 5.5 Mockus parameters of Damlıca catchment are given.

Table 5.4 Mockus SUH parameters by GIS parameters

Date	q_p (m³/s/mm)	t_p (hour)	t_r (hour)	t_b (hour)	K	H
04.12.1981	0.480	4.32	4.52	8.84	0.27	1.05
15.01.1983	0.607	5.61	1.38	6.99	0.45	0.25
16.02.1984	0.607	3.00	3.99	6.99	0.24	1.33
06.03.1984	0.662	6.95	11.61	18.56	0.60	0.00
01.01.1986	0.460	4.00	5.22	9.22	0.24	1.31
02.02.1986	0.619	4.00	2.85	6.85	0.32	0.71
24.11.1988	0.440	4.50	5.14	9.64	0.26	1.14
08.12.1988	0.530	2.80	5.20	8.00	0.19	1.86
09.04.1991	0.436	3.33	6.39	9.72	0.19	1.92
01.05.1991	0.475	2.67	6.27	8.94	0.17	2.35
17.03.1992	0.418	5.60	4.55	10.15	0.31	0.81
19.04.1992	0.419	3.60	6.53	10.13	0.20	1.82
25.02.1993	0.419	3.50	6.62	10.12	0.19	1.89
01.03.1993	0.650	5.33	1.20	6.53	0.45	0.22
29.01.1994	0.490	2.59	6.07	8.66	0.17	2.34
25.02.1994	0.540	2.60	5.26	7.86	0.18	2.02
27.01.1995	0.451	2.00	7.41	9.41	0.12	3.70
30.03.1995	0.435	6.17	3.58	9.75	0.35	0.58
05.02.1996	0.467	5.51	3.58	9.09	0.34	0.65
25.02.1996	0.566	3.33	4.16	7.49	0.25	1.25
17.03.1996	0.660	5.51	0.91	6.42	0.48	0.17
28.03.1996	0.418	3.83	6.32	10.15	0.21	1.65
17.04.1996	0.425	3.75	6.23	9.98	0.21	1.66
22,.03.1997	0.500	3.50	4.98	8.48	0.23	1.42
20.05.1998	0.450	2.00	7.43	9.43	0.12	3.71
24.11.1998	0.650	2.67	3.86	6.53	0.23	1.44
18.02.2001	0.429	6.00	3.89	9.89	0.34	0.65
28.03.2004	0.430	7.00	2.87	9.87	0.39	0.41
29.01.2005	0.435	11.00	18.40	29.40	0.63	0.00
Average	0.502	4.368	5.77	10.14	0.287	1.321

5.2.2.2 Mockus by topographic parameters

In this method, topographic values are used. In Table 5.5 Mockus parameters of Damlıca catchment are given.

Table 5.5 Mockus SUH parameters by topographic parameters

Date	q_p (m³/s/mm)	t_p (hour)	t_r (hour)	t_b (hour)	K	H
04.12.1981	0.480	4.32	5.25	9.57	0.25	1.21
15.01.1983	0.607	5.61	1.95	7.56	0.41	0.35
16.02.1984	0.607	3.00	4.57	7.57	0.22	1.52
06.03.1984	0.662	6.95	11.61	18.56	0.56	0.00
01.01.1986	0.460	4.00	5.98	9.98	0.22	1.50
02.02.1986	0.619	4.00	3.41	7.41	0.30	0.85
24.11.1988	0.440	4.50	5.94	10.44	0.24	1.32
08.12.1988	0.530	2.80	5.87	8.67	0.18	2.09
09.04.1991	0.436	3.33	7.19	10.52	0.18	2.16
01.05.1991	0.475	2.67	7.00	9.67	0.15	2.62
17.03.1992	0.418	5.60	5.38	10.98	0.28	0.96
19.04.1992	0.419	3.60	7.37	10.97	0.18	2.05
25.02.1993	0.419	3.50	7.46	10.96	0.18	2.13
01.03.1993	0.650	5.33	1.74	7.07	0.42	0.33
29.01.1994	0.490	2.59	6.78	9.37	0.15	2.62
25.02.1994	0.540	2.60	5.90	8.50	0.17	2.27
27.01.1995	0.451	2.00	8.18	10.18	0.11	4.09
30.03.1995	0.435	6.17	4.38	10.55	0.33	0.71
05.02.1996	0.467	5.51	4.33	9.84	0.31	0.79
25.02.1996	0.566	3.33	4.78	8.11	0.23	1.44
17.03.1996	0.660	5.51	1.44	6.95	0.44	0.26
28.03.1996	0.418	3.83	7.16	10.99	0.19	1.87
17.04.1996	0.425	3.75	7.06	10.81	0.19	1.88
22..03.1997	0.500	3.50	5.69	9.19	0.21	1.62
20.05.1998	0.450	2.00	8.21	10.21	0.11	4.10
24.11.1998	0.650	2.67	4.40	7.07	0.21	1.65
18.02.2001	0.429	6.00	4.71	10.71	0.31	0.78
28.03.2004	0.430	7.00	3.68	10.68	0.36	0.53
29.01.2005	0.435	11.00	18.40	29.40	0.58	0.00
Average	0.502	4.368	6.58	10.95	0.265	1.507

5.2.3 SCS Method

In this method area (A) is used as geomorphologic parameter. Below calculations are done for both GIS and topographic values.

5.2.3.1 SCS by GIS parameters

In this method, GIS values are used. In Table 5.6 SCS parameters of Damlıca catchment are given.

Table 5.6 SCS SUH parameters by GIS parameters

Date	q_p (m³/s/mm)	t_p (hour)	t_r (hour)	q_p (m³/s/mm)	t_b (hour)
04.12.1981	0.480	4.32	7.21	0.93	11.53
15.01.1983	0.607	5.61	9.37	0.71	14.98
16.02.1984	0.607	3.00	5.01	1.33	8.01
06.03.1984	0.662	6.95	11.61	0.58	18.56
01.01.1986	0.460	4.00	6.68	1.00	10.68
02.02.1986	0.619	4.00	6.68	1.00	10.68
24.11.1988	0.440	4.50	7.52	0.89	12.02
08.12.1988	0.530	2.80	4.68	1.43	7.48
09.04.1991	0.436	3.33	5.56	1.20	8.89
01.05.1991	0.475	2.67	4.46	1.50	7.13
17.03.1992	0.418	5.60	9.35	0.71	14.95
19.04.1992	0.419	3.60	6.01	1.11	9.61
25.02.1993	0.419	3.50	5.85	1.14	9.35
01.03.1993	0.650	5.33	8.90	0.75	14.23
29.01.1994	0.490	2.59	4.33	1.54	6.92
25.02.1994	0.540	2.60	4.34	1.54	6.94
27.01.1995	0.451	2.00	3.34	2.00	5.34
30.03.1995	0.435	6.17	10.30	0.65	16.47
05.02.1996	0.467	5.51	9.20	0.73	14.71
25.02.1996	0.566	3.33	5.56	1.20	8.89
17.03.1996	0.660	5.51	9.20	0.73	14.71
28.03.1996	0.418	3.83	6.40	1.04	10.23
17.04.1996	0.425	3.75	6.26	1.07	10.01
22..03.1997	0.500	3.50	5.85	1.14	9.35
20.05.1998	0.450	2.00	3.34	2.00	5.34
24.11.1998	0.650	2.67	4.46	1.50	7.13
18.02.2001	0.429	6.00	10.02	0.67	16.02
28.03.2004	0.430	7.00	11.69	0.57	18.69
29.01.2005	0.435	11.00	18.37	0.36	29.37
Average	0.502	4.368	7.294	1.069	11.662

5.2.3.2 SCS by topographic parameters

In this method topographic values are used. In Table 5.7 SCS parameters of Damlıca catchment are given.

Table 5.7 SCS SUH parameters by topographic parameters

Date	q_p	t_p	t_r	q_p	t_b
04.12.1981	0.480	4.32	7.21	0.85	11.53
15.01.1983	0.607	5.61	9.37	0.66	14.98
16.02.1984	0.607	3.00	5.01	1.23	8.01
06.03.1984	0.662	6.95	11.61	0.53	18.56
01.01.1986	0.460	4.00	6.68	0.92	10.68
02.02.1986	0.619	4.00	6.68	0.92	10.68
24.11.1988	0.440	4.50	7.52	0.82	12.02
08.12.1988	0.530	2.80	4.68	1.32	7.48
09.04.1991	0.436	3.33	5.56	1.11	8.89
01.05.1991	0.475	2.67	4.46	1.38	7.13
17.03.1992	0.418	5.60	9.35	0.66	14.95
19.04.1992	0.419	3.60	6.01	1.03	9.61
25.02.1993	0.419	3.50	5.85	1.06	9.35
01.03.1993	0.650	5.33	8.90	0.69	14.23
29.01.1994	0.490	2.59	4.33	1.43	6.92
25.02.1994	0.540	2.60	4.34	1.42	6.94
27.01.1995	0.451	2.00	3.34	1.85	5.34
30.03.1995	0.435	6.17	10.30	0.60	16.47
05.02.1996	0.467	5.51	9.20	0.67	14.71
25.02.1996	0.566	3.33	5.56	1.11	8.89
17.03.1996	0.660	5.51	9.20	0.67	14.71
28.03.1996	0.418	3.83	6.40	0.96	10.23
17.04.1996	0.425	3.75	6.26	0.98	10.01
22,.03.1997	0.500	3.50	5.85	1.06	9.35
20.05.1998	0.450	2.00	3.34	1.85	5.34
24.11.1998	0.650	2.67	4.46	1.38	7.13
18.02.2001	0.429	6.00	10.02	0.62	16.02
28.03.2004	0.430	7.00	11.69	0.53	18.69
29.01.2005	0.435	11.00	18.37	0.34	29.37
Average	0.502	4.368	7.294	0.85	11.66

5.2.4 Turkish State of Hydraulic Works (DSI)'s Synthetic Method

In this method A, L, L_c, S values are used as geomorphologic parameters. Below calculations are done for both using GIS and topographic values.

5.2.4.1 DSI by GIS parameters

In this method GIS values are used. In Table 5.8 parameters of Damlıca catchment are given.

Table 5.8 DSI SUH parameters by GIS parameters

$A(km^2)$	L(km)	L_c(km)	S	q_p (m^3/s)	V(m^3)	t_b(hour)	t_p(hour)
7.63	4.80	1.90	0.034	0.30	7630	6.22	0.44

5.2.4.2 DSI by topographic parameters

In this method topographic values are used. In Table 5.9 parameters of Damlıca catchment are given.

Table 5.9 DSI SUH parameters by topographic parameters

$A(km^2)$	L(km)	L_c(km)	S	q_p (m^3/s)	V(m^3)	t_b hour)	t_p (hour)
8.26	4.35	1.78	0.019	0.39	8260	6.50	0.50

In Table 5.10 geomorphologic characteristics of Damlıca and other two Vize and Kumdere catchments are given.

Table 5.10 Geomorphologic characteristics of Damlıca, Vize and Kumdere catchments

Parameter	Symbol	Damlıca	Vize	Kumder
Area	A (km^2)	8.26	4.64	4.40
Catchment perimeter	P(km)	13.10	10.55	9.50
Catchment length	L_H(km)	4.10	4.45	3.45
Catchment width	W_H (km)	2.01	1.03	1.28
Catchment max. elevation	h_{max} (m)	258	244	154
Catchment min. elevation	h_{min}(m)	110	185	115
Catchment relief	H_L (m)	148	59	39
Catchment relative relief	$r_{n\,(\%)}$	0.011	0.56	0.041
Catchment Directions		NW-SE	NW-SW	N-S
Catchment average elevations	h_{avr} (m)	184	215	139.5
Catchment median elevation	h_m (m)	207	212	135
Catchment average slope	S_H (%)	5.9	3.0	4.0
Shape Index related to main stream line	S_1	2.29	4.32	2.71
Shape Index related to catchment length	S_2	2.04	4.36	2.86
Circularity ratio	S_3	0.6	0.52	0.61
Congestion index	K_c	1.28	1.37	1.27
Equivalent rectangular catchment	L_a (km)	4.88	4.14	3.49
Slope index related to equivalent rectangular catchment	L_b (km)	1.69	1.12	1.26
Number of hydrological soil cover	CN	86.4	79.2	81
Main stream line length	L_s(km)	4.35	4.5	3.55
Total stream line lengths	L_u (km)	15.90	10.25	12.50
The distance between projection of catchment's center of gravity to main stream line to outlet of the catchment	L_c (km)	1.78	2.475	1.85
Profile and the slope of the main stream line	S_s(%)	2.15	1.3	0.9
The harmonic slope of main stream line	S(%)	1.89	0.587	0.936

5.3 Artificial Intelligence Methods

5.3.1 Genetic Programming Based Synthetic Hydrograph for a Station in Euphrates Catchment

This study presents an alternative method for establishment of synthetic hydrograph of a flow measurement station in Euphrates catchment. Linear genetic programming (LGP) which is an extension to genetic programming (GP) technique is proposed for developing monthly averaged river discharge modeling. The accuracy of LGP is compared to field measurements of monthly averaged discharge values of a station in Murat River on Middle Euphrates Catchment. Flow data from 1999 to 2007 was utilized in developing and validating the LGP model and the data of 2008 is generated by the developed LGP model. It should be noticed that the data of 2008 is not used in both development and validating stages. The generated synthetic hydrograph is compared to real discharge data of the corresponding station. Also a rating curve based on the proposed LGP model is developed and this rating curve is used to fill the gaps in discharge data from 1999 to 2007. The root mean square errors (RMSE) and determination coefficient (R^2) statistics are used for evaluating the accuracy of the models. Based on the comparison of the results it is found that the LGP forecasted the discharge values in strictly good agreement with the measured field data. The overall results of this study encourage the use of LGP in generating synthetic hydrograph of rivers in Turkey.

5.3.2 Multi-output neural networks for estimation of parameters of synthetic unit hydrograph.

For developing unit hydrograph (UH) of catchments detailed information about the rainfall and the resulting flood hydrographs are needed. But such information would be available only at few locations and that for remote locations would be normally very scanty. In this study, Snyder’s based synthetic UHs were developed by using both digitized map and digital elevation model of a case study of a small catchment in Turkey. Multi output neural network (MONN) technique was applied to predict the three UH parameters: peak discharge (q_p), time to peak (t_p) and time base (t_b) of a number of UHs observed in the catchment based on most relevant geomorphologic and meteorological parameters. MONN was observed to outperform the conventional synthetic UH methods. The impact of the proposed MONN is that it predicts the three parameters of the UH based on a single model compared to the conventional NN technique which utilizes a model for each parameter.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 Comparisons of Synthetic Unit Hydrograph Methods

According to observed values for different date unit hydrographs (UH) are drawn. Then by using other synthetic methods (Snyder's, Mockus, SCS, State Hydraulic Works (DSI)) Unit Hydrographs are drawn. The comparison of unit hydrograph and other methods are given. The studied catchments are Damlıca, Vize and Kumdere.

6.1.1 Damlıca Catchment

For Damlıca catchment observed UH_{60} parameters and Snyder's, Mockus, DSI, SCS parameters are studied. The comparison of the UH graphs are given in Figure 6.1.

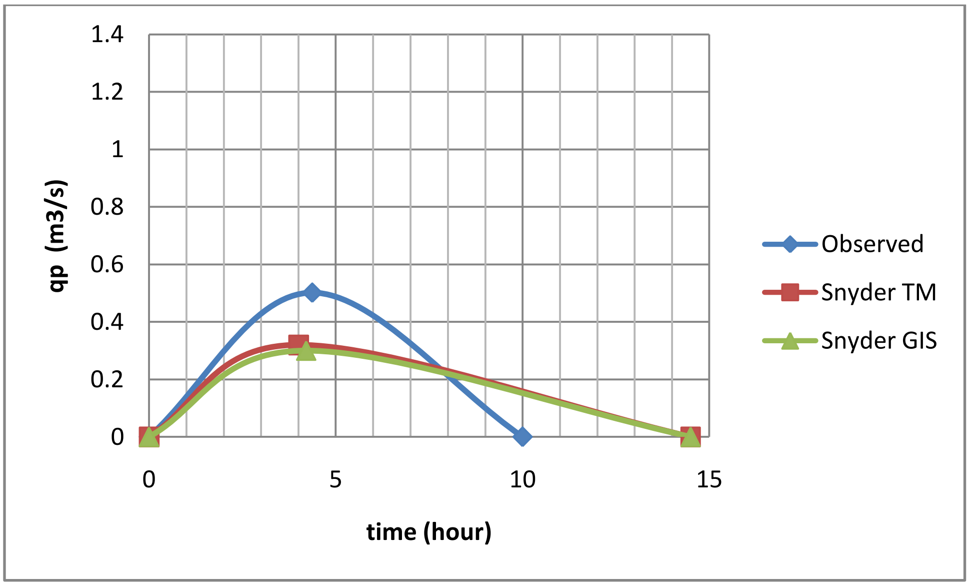

Figure 6.1 Comparisons of Observed Unit Hydrograph and Snyder's GIS, Snyder's TM for Damlıca Catchment.

6.1.1.1 Results of observed and Snyder's UH_{60}

According to the observed values, observed UH_{60} is drawn for Damlıca catchment. Also UH_{60} graphs by using all synthetic methods which are Snyder's, Mockus, SCS, DSI are drawn. In Figure 6.1 comparisons are given for observed and other used synthetic methods by using topographic map values. The percentage errors are calculated for all synthetic methods. The calculated values are given in Table 6.1. The observed q_p, t_p, t_b values are 0.502 m^3/s, 4.368 hour, 10.0 hour respectively.

In Damlıca catchment is studied for both by using topographic and GIS values. By using topographic map values all methods (Snyder's, Mockus, SCS, DSI) are studied. In Snyder's method; A = 8.26 km^2, L=4.35 km, L_c = 1.78 km, values are used. The C_t=2.889 and C_p=0.882 coefficients of Snyder's method are found for Damlıca catchment. q_p, t_p and t_b values are calculated as 0.32m^3/s, 4.00 hours and 14.5 hours respectively.

From GIS values in Snyder's method; A = 7.63 km^2, L = 4.80 km, L_c = 1.90 km, values are used. The C_t=2.889 and C_p=0.995 coefficients of Snyder's method are found for Damlıca catchment. q_p, t_p and t_b values are calculated as 0.3 m^3/s, 4.21 hours and 14.5 hours respectively.

6.1.1.2 Results of Mockus Method

In Mockus method from topographic map, A= 8.26 km^2, L=4.35 km, h_L = 148 m, S=0.0189 are used. The Mockus coefficients K and H are calculated as 0.265 and 1.507 respectively for Damlıca catchment. q_p, t_p and t_b values are calculated as 1.28 m^3/s, 1.78 hours and 3.71 hours respectively.

In Mockus method from GIS values, A= 7.63 km^2, L=4.80 km, h_L = 143 m, S = 0.034 are used. The Mockus coefficients K and H are calculated as 0.287 and 1.321 respectively for Damlıca catchment. q_p, t_p and t_b values are calculated as 1.20 m^3/s, 1.88 hours and 3.60 hours respectively.

In Figure 6.2 comparisons of Unit Hydrograph and Mockus-GIS, Mockus-TM for Damlıca catchment are given.

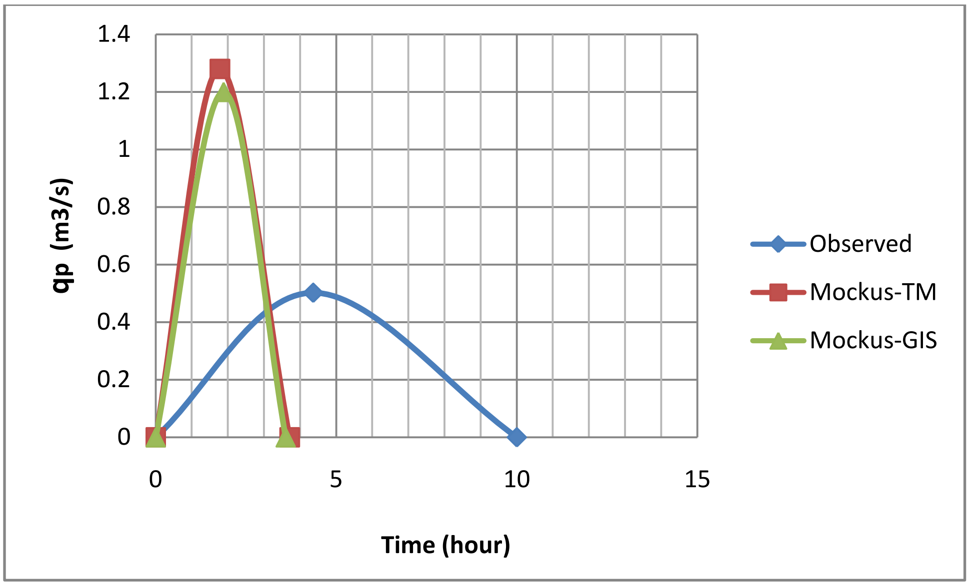

Figure 6.2 Comparisons of Observed Unit Hydrograph and Mockus-GIS, Mockus-TM for Damlıca catchment

6.1.1.3 Results of SCS Method

In SCS method by using topographic map values for Damlıca L= 4350 m, S=0.0189 are used. q_p, t_p and t_b values are calculated as 0.494 m^3/s, 4.20 hours and 11.24 hours respectively. In SCS method by using GIS values for Damlıca L= 4800 m, S=0.034 are used. q_p, t_p and t_b values are calculated as 0.43 m^3/s, 4.13 hours and 11.0 hours respectively. In Figure 6.3 comparisons of Unit Hydrograph and SCS for Damlıca catchment are given.

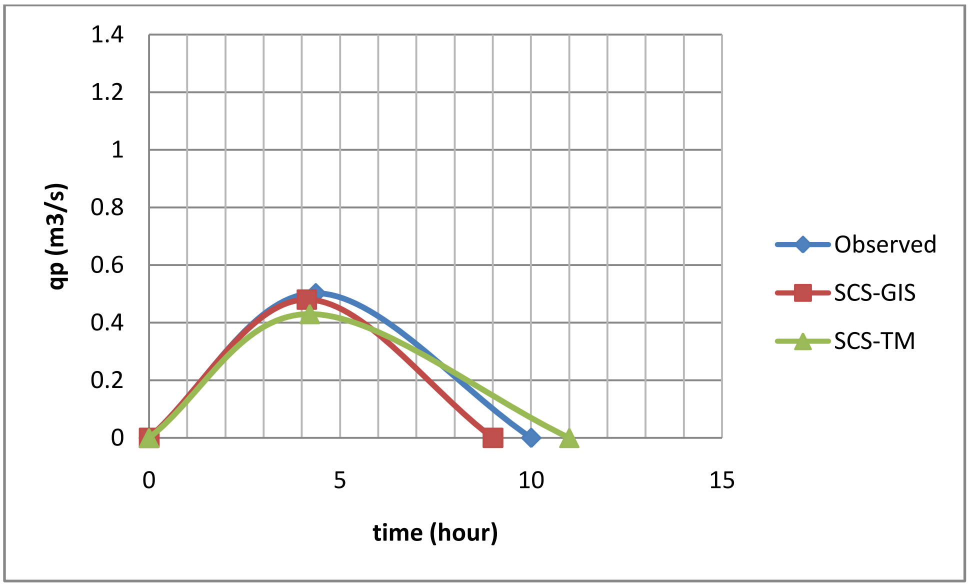

Figure 6.3 Comparisons of Unit Hydrograph and SCS-GIS, SCS-TM for Damlıca catchment.

6.1.1.4 Results of DSI Method

In DSI method from topographic map values for Damlıca A= 8.26 km^2, L=4.35 km, L_c=1.78, S = 0.019 are used. q_p, t_p and t_b values are calculated as 0.7 m^3/s, 0.5 hours and 6.56 hours respectively.

In DSI method from GIS values for Damlıca A= 7.63 km^2, L=4.8 km, L_c=1.9, S = 0.034 are used. q_p, t_p and t_b values are calculated as 0.66 m^3/s, 0.44 hours and 6.5 hours respectively. Comparisons of Observed Unit Hydrograph and DSI-GIS, DSI-TM for Damlıca catchment are given in Figure 6.4.

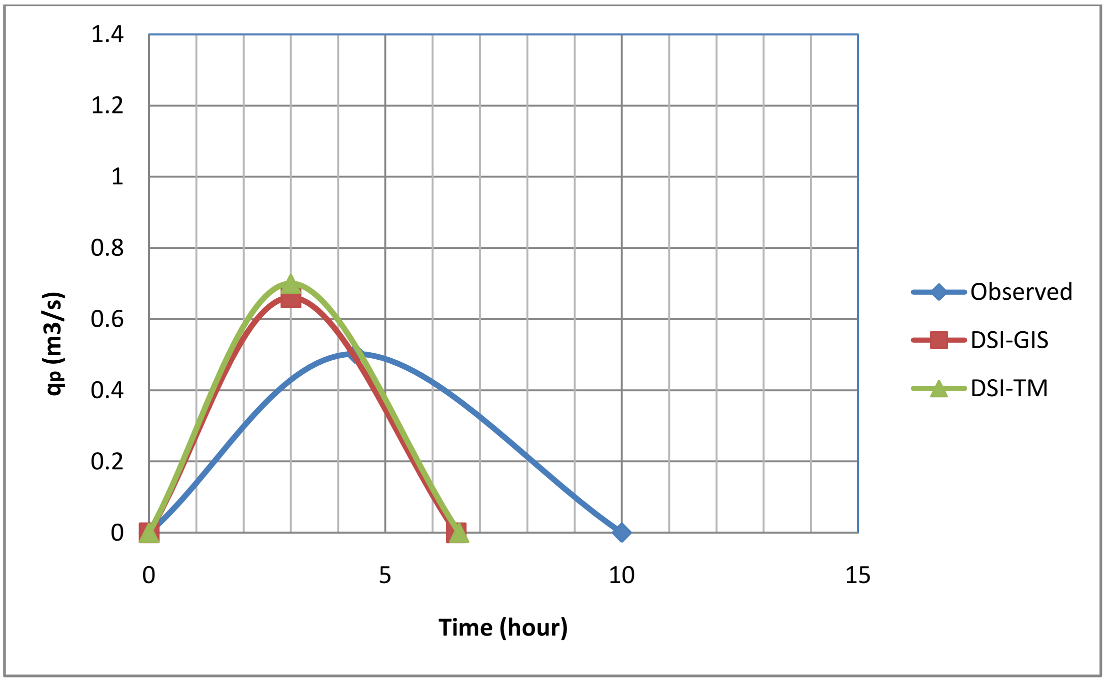

Figure 6.4 Comparisons of Observed Unit Hydrograph and DSI-GIS, DSI-TM for Damlıca catchment.

6.1.2 Kumdere Catchment

For Kumdere catchment observed UH_{60} parameters and Snyder's, Mockus, DSI, SCS parameters are studied. The comparison of the UH graphs are given in Figures 6.5, 6.6, 6.7 and 6.8.

6.1.2.1 Results of observed and Snyder's UH_{60}

According to the observed values, observed UH_{60} is drawn for Kumdere catchment. Also UH_{60} graphs by using all synthetic methods which are Snyder's, Mockus, SCS, DSI are drawn. The observed q_p, t_p, t_b values are 0.6 m^3/s, 1.29 hour, 4.4 hour respectively. In Figure 6.5 comparisons of Unit Hydrograph and Snyder's TM for Kumdere catchment is given.

Kumdere catchment is studied by using topographic values. From topographic map values all methods are studied. In Snyder's method; A = 4.40 km^2, L=3.55 km, L_c = 1.85 km, values are used. The C_t=2.926 and C_p=1.019 coefficients of Snyder's method are found for Kumdere catchment. q_p, t_p and t_b values are calculated as 0.28 m^3/s, 3.85 hours and 8.9 hours respectively.

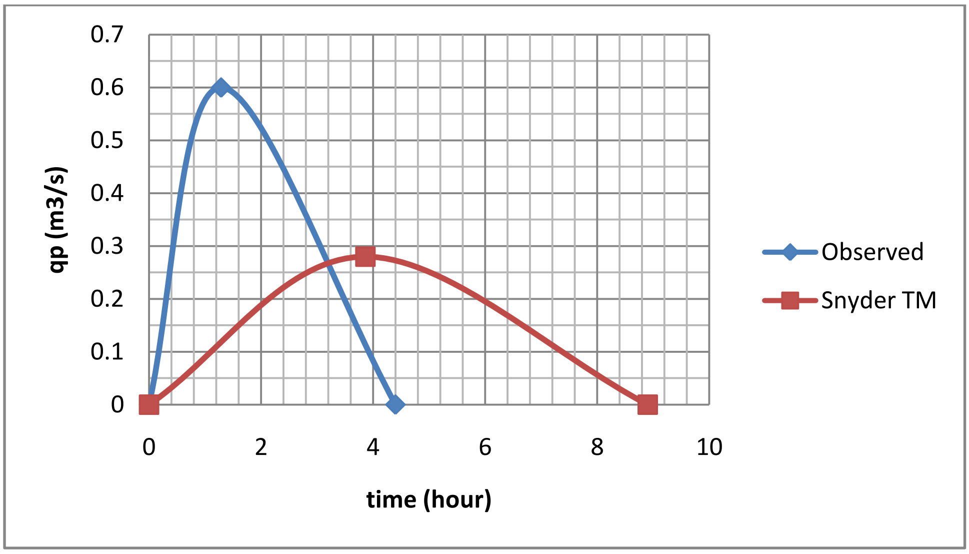

Figure 6.5 Comparisons of Observed Unit Hydrograph and Snyder's for Kumdere Catchment.

6.1.2.2 Results of Mockus Method

In Mockus method, from topographic map, A= 4.40 km^2, L=3.55 km, h_L = 39 m, S = 0.00936 are used. The Mockus coefficients K and H are calculated as 0.09 and 4.95 respectively for Kumdere catchment. q_p, t_p and t_b values are calculated as 0.31 m^3/s, 2.05 hours and 8.0 hours respectively. In Figure 6.6 comparison of Unit Hydrograph and, Mockus-TM for Kumdere catchment is given.

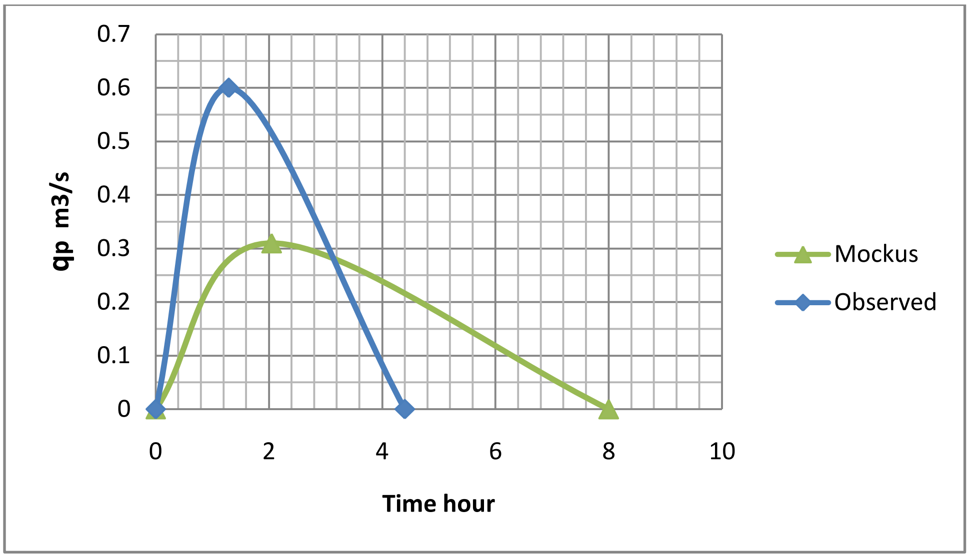

Figure 6.6 Comparisons of Observed Unit Hydrograph and Mockus for Kumdere catchment.

6.1.2.3 Results of SCS Method

In SCS method by using topographic map values for Kumdere L= 3550 m, S=0.00936 are used. q_p, t_p and t_b values are calculated as 0.62 m^3/s, 3.85 hours and 4.0 hours respectively. In Figure 6.7 comparisons of Unit Hydrograph and SCS for Kumdere catchment is given.

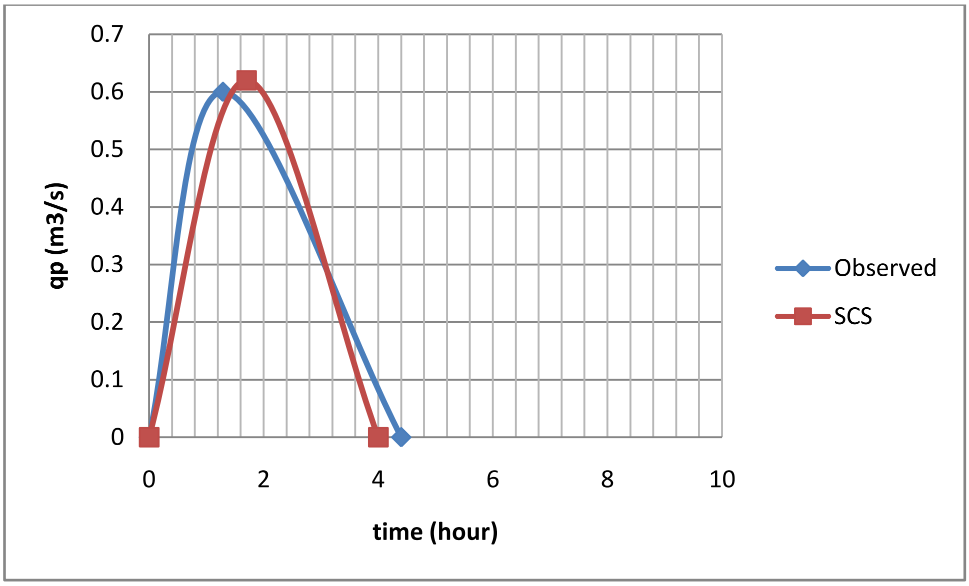

Figure 6.7 Comparisons of Unit Hydrograph and SCS for Kumdere catchment.

6.1.2.4 Results of DSI Method

In DSI method from topographic map values for Kumdere A= 4.40 km^2, L=3.55 km, L_c=1.85, S = 0.00936 are used. q_p, t_p and t_b values are calculated as 0.41 m^3/s, 0.34 hours and 6.0 hours respectively. Comparisons of Observed Unit Hydrograph and DSI for Kumdere catchment is given in Figure 6.8.

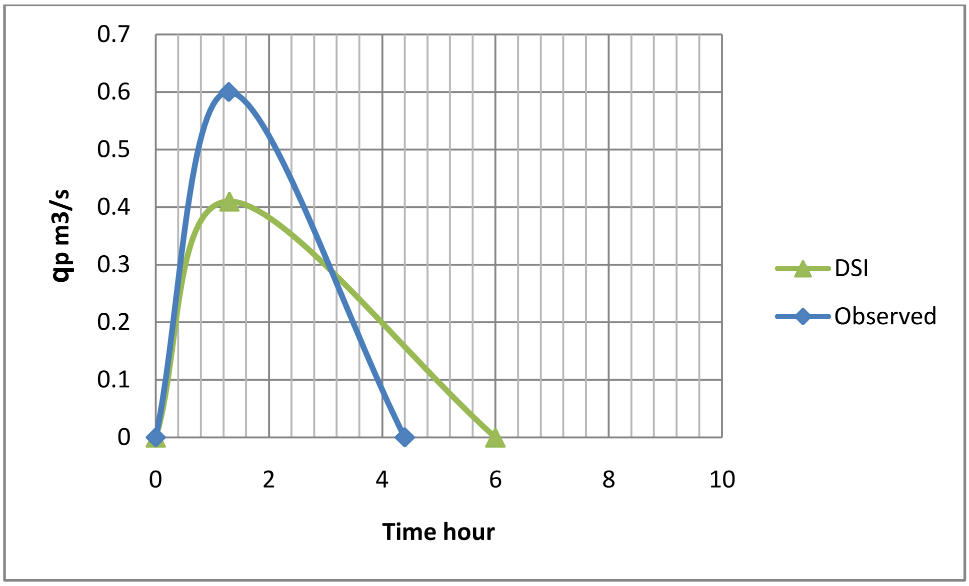

Figure 6.8 Comparisons of observed unit hydrograph and DSI-TM for Kumdere catchment.

6.1.3 Vize Catchment

For Vize catchment observed UH_{60} parameters and Snyder's, Mockus, DSI, SCS parameters are studied. The comparison of the UH graphs are given in Figures 6.9, 6.10, 6.11 and 6.12.

6.1.3.1 Results of observed and Snyder's UH_{60}

According to the observed values, observed UH_{60} is drawn for Vize catchment. Also UH_{60} graphs by using all synthetic methods which are Snyder's, Mockus, SCS, DSI are drawn. The observed q_p, t_p, t_b values are 0.35 m^3/s, 1.63 hour, 7.5 hour respectively. In Figure 6.9 comparisons of Unit Hydrograph and Snyder's TM for Vize catchment is given.

Vize catchment is studied by using topographic values. Snyder's, Mockus, SCS, DSI methods are studied. In Snyder's method; A = 4.64 km^2, L=4.5 km, L_c = 2.475 km, values are used. The C_t=0,554 and C_p=0.296 coefficients of Snyder's method are found for Vize catchment. q_p, t_p and t_b values are calculated as 0.18 m^3/s, 1.85 hours and 14.6 hours respectively.

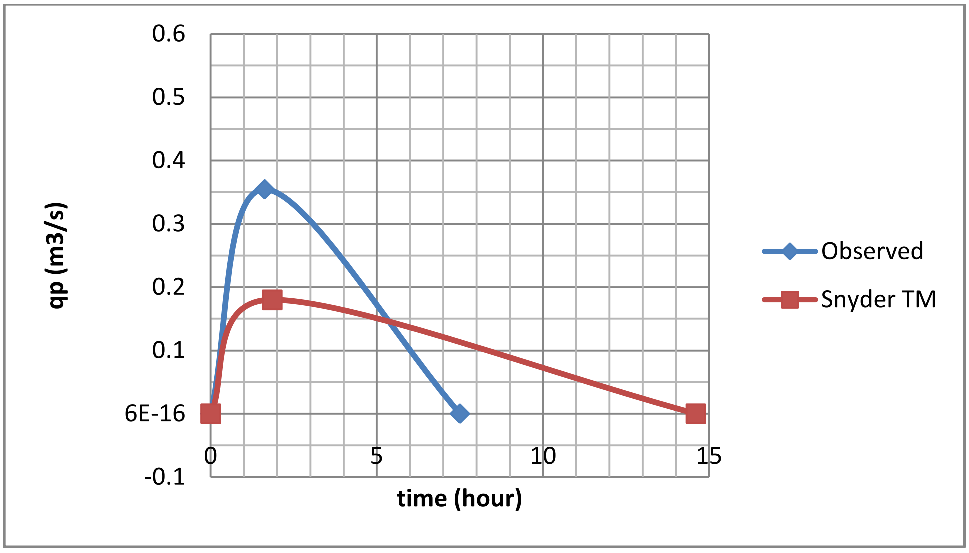

Figure 6.9 Comparisons of observed unit hydrograph and Snyder's TM for Vize catchment.

6.1.3.2 Results of Mockus Method

In Mockus method from topographic map, A= 4.40 km^2, L=3.55 km, h_L = 39 m, S = 0.00936 are used. The Mockus coefficients K and H are calculated as 0.09 and 4.95 respectively for Vize catchment. q_p, t_p and t_b values are calculated as 0.32 m^3/s, 2.05 hours and 8.29 hours respectively. In Figure 6.10 comparison of Unit Hydrograph and, Mockus for Vize catchment is given.

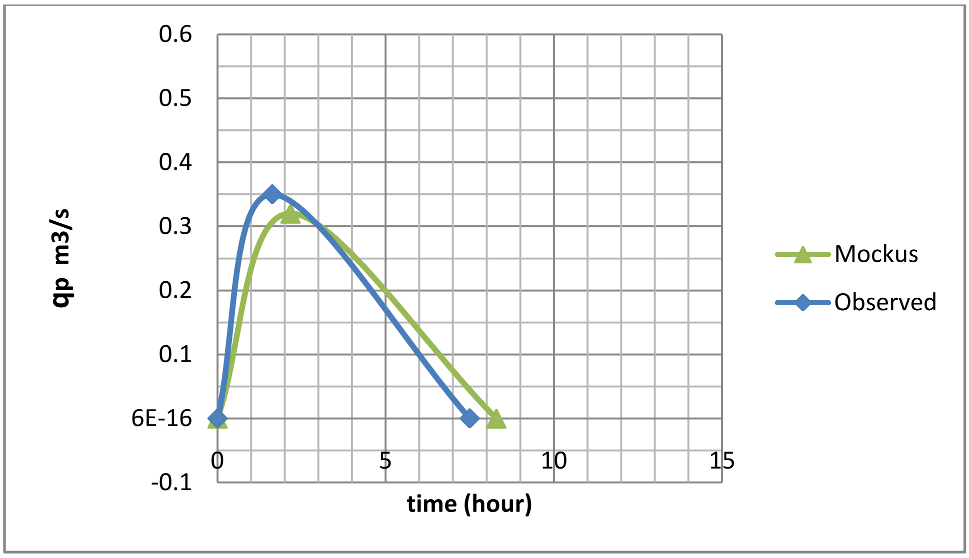

Figure 6.10 Comparisons of observed unit hydrograph and Mockus for Vize catchment.

6.1.3.3 Results of SCS Method

In SCS method by using topographic map values for Vize L= 4500 m, S=0.00587 are used. q_p, t_p and t_b values are calculated as 0.53 m^3/s, 3.85 hours and 5.0 hours respectively. In Figure 6.11 comparisons of Unit Hydrograph and SCS for Vize catchment is given.

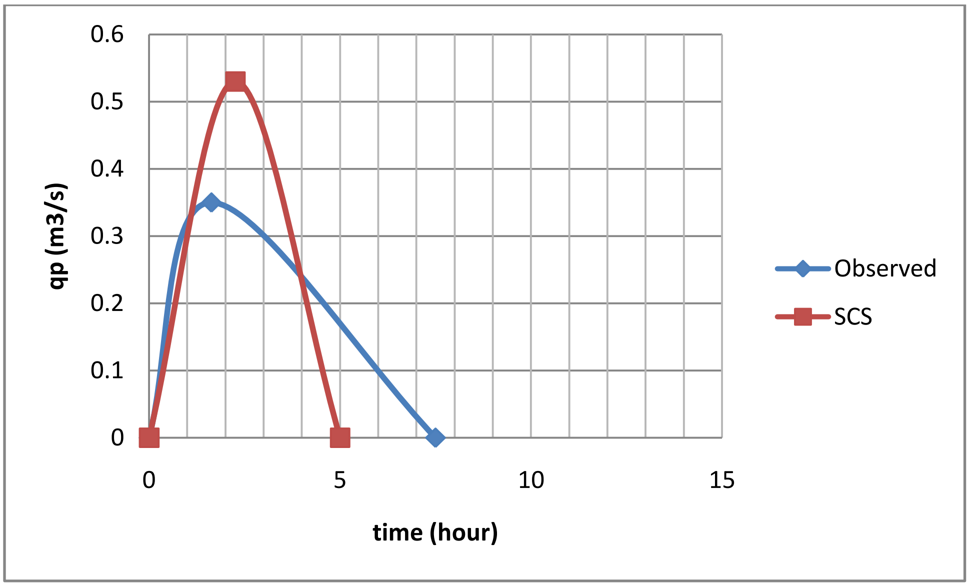

Figure 6.11 Comparisons of unit hydrograph and SCS for Vize catchment.

6.1.3.4 Results of DSI Method

In DSI method from topographic map values for Vize A= 4.64 km^2, L=4.50 km, L_c=2.475 km, S = 0.05087 are used. q_p, t_p and t_b values are calculated as 0.185 m^3/s, 0.5 hours and 14.0 hours respectively. Comparisons of Observed Unit Hydrograph and DSI-TM for Vize catchment is given in Figure 6.12.

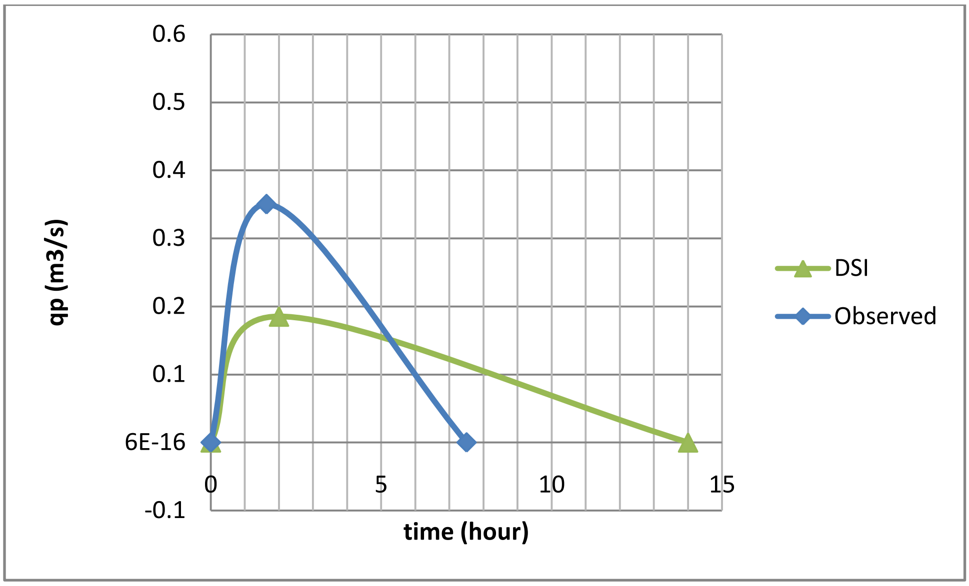

Figure 6.12 Comparisons of observed unit hydrograph and DSI-TM for Vize catchment.

6.2 Comparison of Observed and Synthetic Methods for Catchments

Comparison of UH_{60} graphs by using observed values and synthetic methods are given for each catchment (Damlıca, Vize, and Kumdere) which are studied in this study. Comparison of UH_{60} for Damlıca by using topographic map values is given in Figure 6.13. Comparison of UH_{60} for Damlıca by using GIS values is given in Figure 6.14.

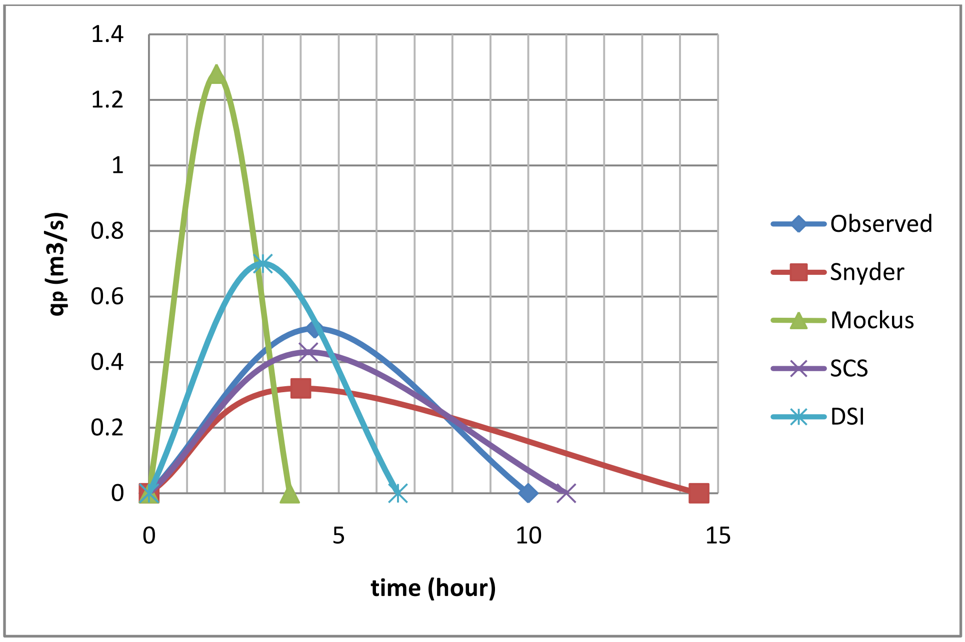

Figure 6.13 Comparison of UH_{60} for Damlıca by using topographic map values.

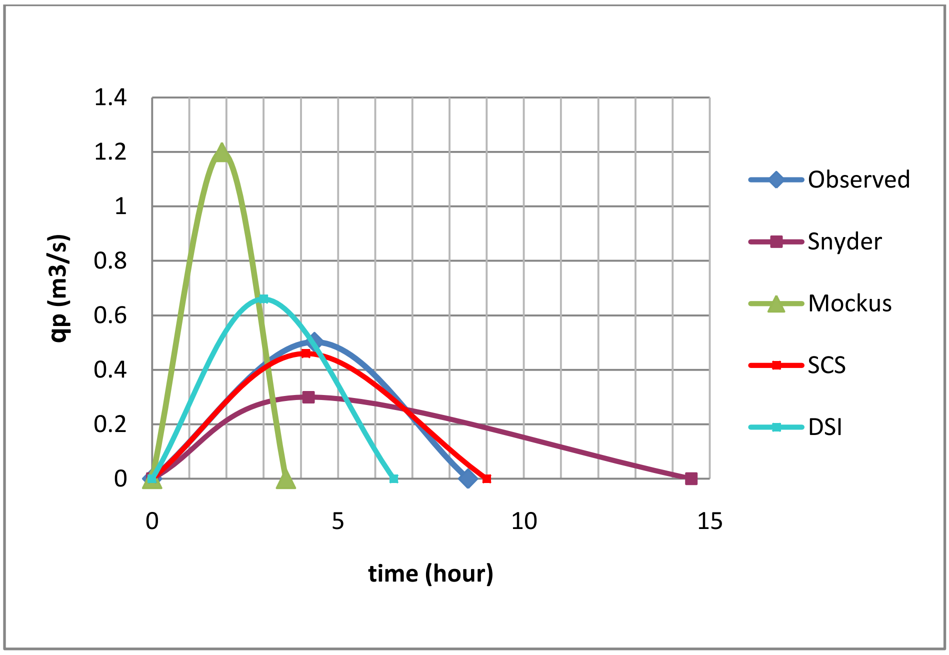

Figure 6.14 Comparison of UH_{60} for Damlıca by using GIS values.

Comparison of UH_{60} graphs by using observed values and synthetic methods are given for Vize in Figure 6.15.

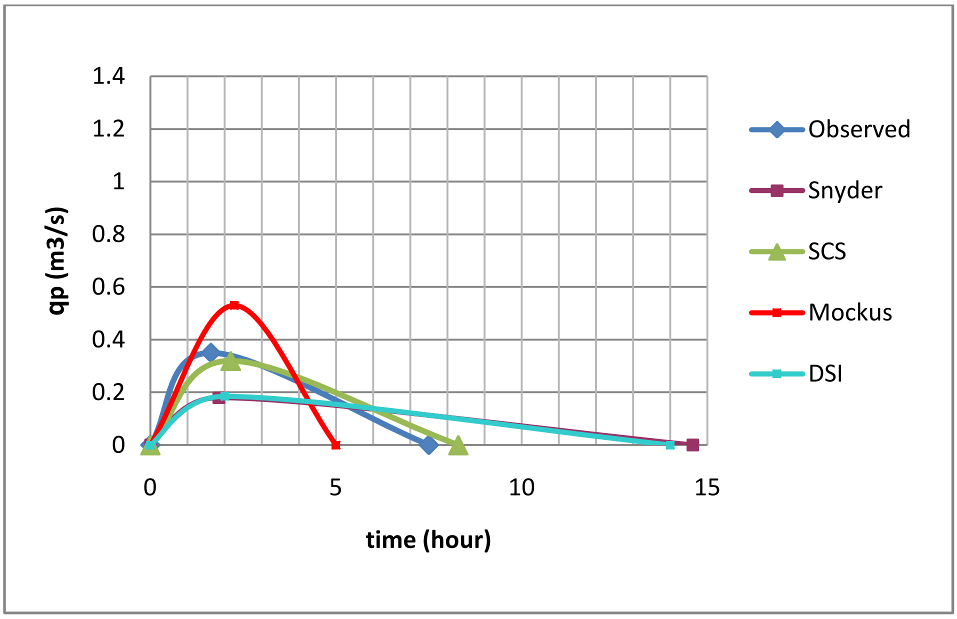

Figure 6.15 Comparison of UH_{60} for Vize by using topographic map values.

Comparison of UH_{60} graphs by using observed values and synthetic methods are given for Kumdere in Figure 6.16.

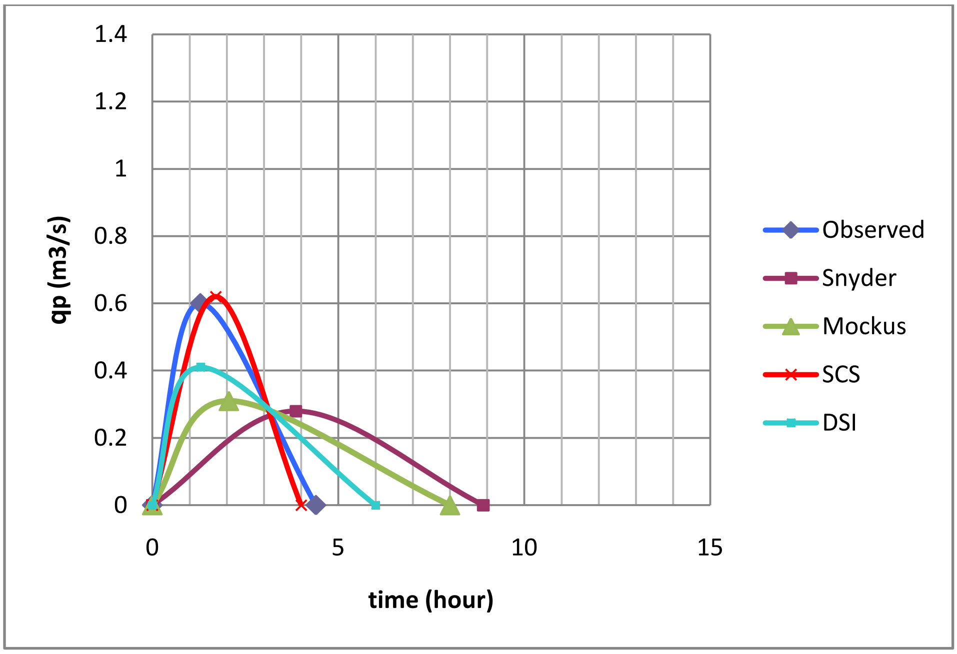

Figure 6.16 Comparison of UH_{60} for Kumdere by using topographic map values.

All UH values (q_p, t_p, t_b) for observed and synthetic methods values are given in Table 6.1.

Table 6.1 Comparison of observed and Synthetic UH parameters for Catchments

	Kumdere			**Vize**			**Damlıca**		
	q_p	t_p	t_b	q_p	t_p	t_b	q_p	t_p	t_b
Observed	0.6	1.29	4.40	0.35	1.63	7.53	0.502	4.368	10.00
Snyder's	0.28	3.85	8.90	0.18	0.86	14.60	0.32	4	14.50
Mockus	0.31	2.05	8.00	0.53	2.17	8.29	1.28	1.78	3.71
SCS	0.62	1.7	4.00	0.32	2.26	5.03	0.43	4.2	11.00
DSI	0.41	1.34	6.0	0.185	2.00	14.00	0.70	3.0	6.56

6.3 Genetic Programming Based Synthetic Hydrograph: Case Study of a Stream Gauge Station in Euphrates Basin.

Information regarding rates and volumes of flow at any point of interest along a stream is necessary in the analysis and design of many types of water projects. Although many streams have been gauged to provide continuous records of streamflow, planners and engineers are sometimes faced with little or no available streamflow information and must rely on synthesis and simulation as tools to generate artificial flow sequences for use in rationalizing decisions regarding structure sizes, the effects of land use, flood control measures, water supplies, water quality, and the effects of natural or induced watershed or climatic changes. It is generally accepted that river flow processes, especially daily discharges, are seasonal and nonlinear, since the processes generally pronounce seasonal means, variances, and the underlying mechanisms of streamflow generation are likely to be different during low, medium, and high flow periods, especially when extreme events occur (Wang et al. 2006).

Several linear and nonlinear methods have been applied in the prediction of discharge in rivers and successful results have been reported. These studies have focused on the prediction of the discharge based on stage-discharge, rainfall-discharge or time-series of discharge relationships, using either conventional methods (Wang et al. 2006; Baiamonte and Ferro, 2007) or new so-called ‘soft computing techniques’ such as neural networks, genetic programming, fuzzy logic and machine learning (Maier and Dandy, 2000; Kisi, 2004; Guven and Gunal, 2008; Guven and Talu, 2010). In this study, Linear Genetic Programming (LGP), which is an extension of GP, is used. Only limited number of studies of LGP application on hydrological data is available (Guven, 2009).

The time-series modeling of daily discharge can be formulated as:

$$Q(t) = f\{Q(t-n), Q(t-n).n), \ldots, Q(t-(d-1).n)\} \tag{6.1}$$

where, n is the constant time delay between samples, d is the embedded dimension, and f is a function. The objective is to find an optimal input set that can explain the behavior of dynamical river flow system. There are several conventional statistical methods to cope with this type of problem, most of them being based on ARMA-derived (Auto-Regressive Moving Average) methods. Alternatively, several heuristic models have been proposed (Guven, 2009).

Evolutionary computational methods have been successfully applied in time-series modeling of flow discharge problems, with limited number of examples. Tayfur and Moramarco (2008) predicted hourly-based flow discharge hydrographs from level data by using GAs; Preis and Otsfeld (2008) presented a coupled model tree-genetic algorithm scheme for predicting flow and water quality constituents in watersheds.

In this study, to employ an emerging strong evolutionary computational technique, LGP is proposed in predicting daily time series of river flow data. Auto regressive (AR) technique is also presented as conventional time-series model of the same discharge data. The performance of each model was compared based on the well-known statistical performance measures. The results of each model were tabulated and illustrated in time-series diagrams.

6.3.1 Linear Genetic Programming

Each individual program in LGP is represented by a variable-length sequence of simple C language instructions. These instructions operate on one or more registers ($r[i]$) or constants (c) from predefined sets (Oltean and Grosan, 2003; Bramier, 2004). An example of LGP program can be as:

```
Void LGP
double v[2];
{
r[0]+ = v[0];
r[1]- = r[0];
r[0]* = v[1];
r[1] / = r[0];
r[0]* = v[2];
}
```

where $v[i]$ represents the input and output variables, and r[1] is a temporary computation variable in the programs LGP creates. The output of these programs is the value remaining in r[0] after the program executes.

The *function set* of the system can be composed of arithmetic operations (+,-,/,*), conditional branches (if $v[i]<=v[k]$), and function calls ($f \in \{e^x, x, \sin, \cos, \tan, \log, \text{sqrt}, \ln\}$. Each function implicitly includes an assignment to a variable $v[i]$, which facilitates the use of multiple program outputs in LGP, whereas in tree-based GP those side effects need to be incorporated explicitly (Bramier and Banzhaf, 2001). After several trials, the functional set and operational parameters given in Table 6.2 have been found to be optimal in the present LGP modeling.

LGP utilizes two-point string crossover. A segment of random position and random length is selected in both parents and exchanged between them. If one of the resulting children would exceed the maximum length, crossover is abandoned and restarted by exchanging equalized segments (Bramier and Banzhaf, 2001).

An operand or an operator of an instruction is changed by mutation into another symbol over the same set. LGP also employs a special kind of mutation (called *macro mutation*) which deletes or inserts an entire instruction.

The fitness of a LGP individual may be computed by using the equation:

$$f = \sum_{j=1}^{N} (|O_j - E_j|) \qquad (6.2)$$

where, O_j is the value returned by a chromosome for the fitness case j, and E_j is the expected value for the fitness case j.

In LGP, the maximum size of the program is usually restricted to avoid over-growing programs without bound (Brameier and Banzhaf, 2001). In this study, the maximum size of each program has been set to 256, starting with 80 instructions per program.

This configuration has been tested for each LGP model and has been experienced to be sufficient. The best individual (program) of a trained LGP can be converted into a functional representation by successive replacements of $v[i]$ starting with the last effective instruction (Oltean and Grosan, 2003). The further details on LGP can be found in Brameier and Banzhaf (2001) and Bramier (2004).

6.3.2 Auto-regressive (AR) Model

AR model is the most widely used traditional technique for time-series analysis. The model is usually referred to as the AR(p) model where p is the order of model. The AR(p) model for time-series of daily flow rate can be represented as:

$$Q(t) = c + \sum_{i=1}^{p} \alpha_i \, Q(t - i) + \varepsilon(t) \tag{6.3}$$

where α_i is the model parameter, c is a constant, and $\varepsilon(t)$ is random error.

In the present study, AR model with 2 input (AR(2)) was developed based on the same training data set used in LGP modeling. The model parameters of the proposed AR model were optimized using Levenberg&Marquardt algorithm.

Table 6.2 Parameters of the LGP model

Parameter	Description of parameter	Setting of parameter
p_1	Function set	+, -, *, /, √, power
p_2	Population size	250
p_3	Mutation frequency %	95
p_4	Crossover frequency %	50
p_5	Number of replication	10
p_6	Block mutation rate %	30
p_7	Instruction mutation rate %	30
p_8	Instruction data mutation rate %	40
p_9	Homologous crossover %	95
p_{10}	Program size	initial 80, maximum 256

6.3.3 Case Study: A flow gauge in Euphrates Basin

The data set used in this study was obtained from Turkish Electrical Power Resources Survey and Development (EİEİ). The time series of monthly averaged daily streamflow and suspended sediment data from a station on Murat River in Middle Euphrates Region is used: the station Palu (station no: 2102) at Elazığ City. The drainage area at the site is 25.516 km^2 for the station Palu. Information on the monthly time series for the stations in Euphrates Basin can be acquired from the EİEİ web server (http://www.eie.gov.tr/turkce/YEK/HES/hidroloji/sedim.html).

The data of October 01, 1999–September 30, 2007 were chosen for training and cross-validation. 20% of the training data was used for cross-validation (C.V.) purpose in order to avoid over-generalization. The data of October 01, 2008–September 30, 2008 were chosen for forecasting. Thus, the forecasted period will be presented as a synthetic hydrograph, which is developed unseen in training and cross-validation stages. In the station 2102, the discharge values of 1693.58 m^3/s and 1529.68 m^3/s are observed while the other discharge values are below 200 m^3/s. These values give an additional difficulty to the models in estimation periods. The models trained using such outliers generally give overestimations of the low discharge values.

The monthly averaged statistical parameters of the discharge data for the station are given in Table 6.3. In this table, $\overline{X}$, S_x, C_v, C_{sx}, X_{max} and X_{min} denote the mean, standard deviation, coefficient of variation, skewness, maximum and minimum, respectively. The skewness and coefficient of variation of discharge are high, for both the training and forecasting data. In the training discharge data, X_{min} and X_{max} values fall in the ranges 14.33–1693.58 m^3/s. However, the forecasting discharge data set extremes are x_{min} = 19.72 m^3/s, X_{max} = 652.65 m^3/s. The data range of the training discharge data covers that of the forecasting set, which avoids possible extrapolation difficulties in estimation of extreme discharge values (Guven, 2009).

Table 6.3 The statistical parameters of data set for station 2102

Data Set	Data Type	$\overline{X}$	S_x	C_{sx}	C_v	X_{max}	X_{min}
Training	Q	271.28	348.82	1.87	1.29	1439.01	33.06
Forecasting	Q	178.25	216.92	1.62	1.22	652.65	19.72

Note: Q in m^3/s; $C_v = (S_x/\overline{X})$

6.3.4 Results and Discussion

An important issue in model development studies is to find the optimal input set which best represents the considered problem. In present study, the same issue is to find to what degree of time-lagged Q (Q_{t-1}, Q_{t-2},…., Q_{t-n}) will be used in prediction of Q_t. The most common way is to investigate the correlation between each time-lagged input parameter and the output, Q_t. Hence, the auto correlation between Q_t and time-lagged discharges (Q_{t-1}, Q_{t-2},…., Q_{t-n}) was evaluated in Table 6.4. As it seen in the table, R value is equal or higher than 0.1 only for inputs Q_{t-1} and Q_{t-2}. Therefore it was decided to select Q_{t-1} and Q_{t-2} as input parameters in prediction of Q_t. Hence, the relationship given in Eqn. 6.4 was used for both LGP and AR(p) model development.

$$Q_t = f(Q_{t-1}, Q_{t-2}) \tag{6.4}$$

Table 6.4 Correlation matrix (Q_t output)

Input	R
Q_{t-1}	0.1
Q_{t-2}	0.1
Q_{t-3}	-0.1
Q_{t-4}	-0.1
Q_{t-5}	-0.1

Table 6.5 lists the statistical performance of each model in prediction of Q_t in training and validation periods in terms of R^2 and RMSE. From the table, it is obvious that LGP model approximates the corresponding observed discharge values

much better (R^2=0.799, RMSE=158.13 m^3/s) than AR (R^2=0.630, RMSE=349.44 m^3/s) The training results show that LGP model predicted much better the non-linear relationship given in Equation 6.4, compared to AR. The validation results are in parallel with those for the training (see Table 6.5), which proves the generalization capacity much better than that of AR model.

Table 6.5 Training &Validation and Forecasting results of LGP and AR models.

Model	Training		Validation		Forecasting	
	RMSE (m^3/s)	R^2	RMSE (m^3/s)	R^2	RMSE (m^3/s)	R^2
LGP	158.13	0.799	212.22	0.754	135.68	0.663
AR(2)	260.37	0.630	349.44	0.654	190.24	0.410

Figure 6.17 shows the observed discharge values and LGP estimations in training period. From the figure, LGP estimations are observed to be in quite good agreement (R^2=0.799) with the observed ones. Figure 6.18 also shows the observed and the forecasted (synthetic) discharge hydrographs for the forecasting period (01.10.2007-01.10-2008). As seen in Figure 6.17 and 6.18, LGP (R^2=0.663, RMSE=135.68 m^3/s) outperform AR (R^2=410, RMSE=190.24 m^3/s) (see also Table 6.5). In Figure 6.18, negative estimations of AR model to both training and forecasting periods are observed, which are not physically acceptable. It can be deduced from the overall results that LGP model is more generalized and robust compared to AR model.

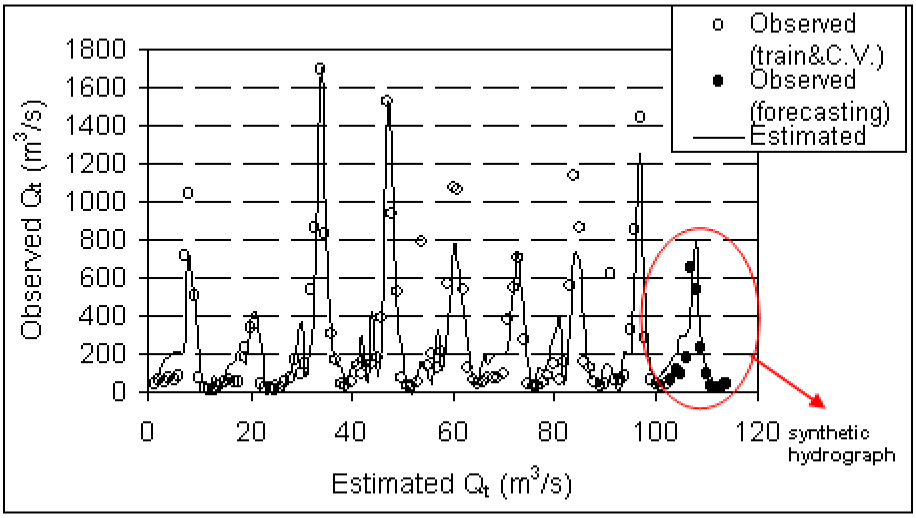

Figure 6.17 Observed Q_t and LGP estimations for training & C.V. and forecasting (synthetic) periods.

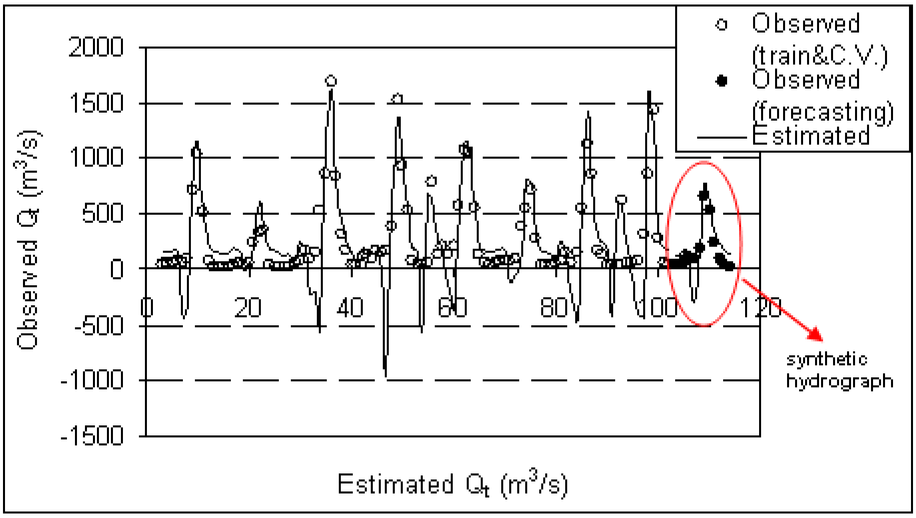

Figure 6.18 Observed Q_t and AR estimations for training & C.V. and forecasting (synthetic) periods.

6.4 Multi-Output Neural Networks (MONN) for estimation of parameters of synthetic unit hydrograph: A case study of Damlıca catchment

This study directly aims to derive the knowledge from a well trained and tested NN model. The selected catchment is Damlıca. Statistical values of input and output variables of Damlıca catchment are given in Table 6.6.

6.4.1 Results of training and testing of NNs model

The data of Damlıca catchment were randomly split in to Training and Testing sets. Namely, 8 sets of the total 29 data sets were reserved for testing (30%), and 21

(70%) sets were used for model training. Statistical values of data sets are given in Table 6.6. Firstly different NN models were developed and their performance was evaluated based on estimations to these data sets. The MONN modeling is described in the next section.

The model parameters of the multi-layer feed forward neural networks with back-propagation learning algorithm were optimized by Levenberg and Marquardt algorithm, which is one of the most common and successful back-propagation algorithm. Another important issue is to find the optimal architecture of the NNs model. Most studies in the literature used a trial approach, which generally leads to local maxima or minima. In this study, this issue is eliminated by using a Genetic Algorithm in order to find the optimal architecture of the proposed NNs model. Namely, a fitness function was chosen based on MSE of the Testing Set and the program searched for optimal architecture with least MSE for Testing Set. The optimal architecture of the proposed NNs was found to be 4-9-3 (no. of inputs, no. of hidden neurons, and no. of outputs), as shown in Figure 6.19. The correlation matrix among the inputs and the outputs are shown in Table 6.7. From Table 6.7, it is obvious that the interrelationship among the input set is quite poor.

Table 6.6 Statistical values of input and output variables of Damlıca catchment (29 data).

Variable	**Min. value**		**Max. value**		**Mean**		**Variance**		**Std. Dev.**	
	Train	Test	Train	Test	Train	Test	Train	Test	Train	Test
SR	0.05	0.14	9.36	3.13	1.09	0.76	3.10	0.92	1.762	0.90
F	1.27	1.84	127.68	35.40	11.57	8.88	547.427	112.16	23.397	9.98
t_r	0.08	0.17	2.55	2.55	0.75	1.09	0.336	0.59	0.58	0.73
API	0.00	6.78	57.94	57.94	15.61	20.16	165.463	235.55	12.863	14.47
t_b	4.83	7.90	28.00	23.00	14.04	14.92	32.46	26.12	5.697	4.82
t_p	2.00	2.60	11.00	7.00	4.37	4.29	3.68	6.65	1.917	2.43
q_p	0.42	0.42	0.66	0.65	0.502	0.49	0.007	0.01	0.084	0.07

Table 6.7 Correlation matrix for the field data (29 data).

	SR	*f*	t_r	*API*	t_b	t_p	q_p
SR	1						
F	-0.003	1					
t_r	0.168	-0.312	1				
API	-0.234	-0.049	-0.090	1			
t_b	0.124	-0.241	-0.051	0.180	1		
t_p	0.160	-0.283	-0.048	0.203	0.603	1	
q_p	-0.172	-0.028	-0.115	-0.004	0.326	-0.032	1

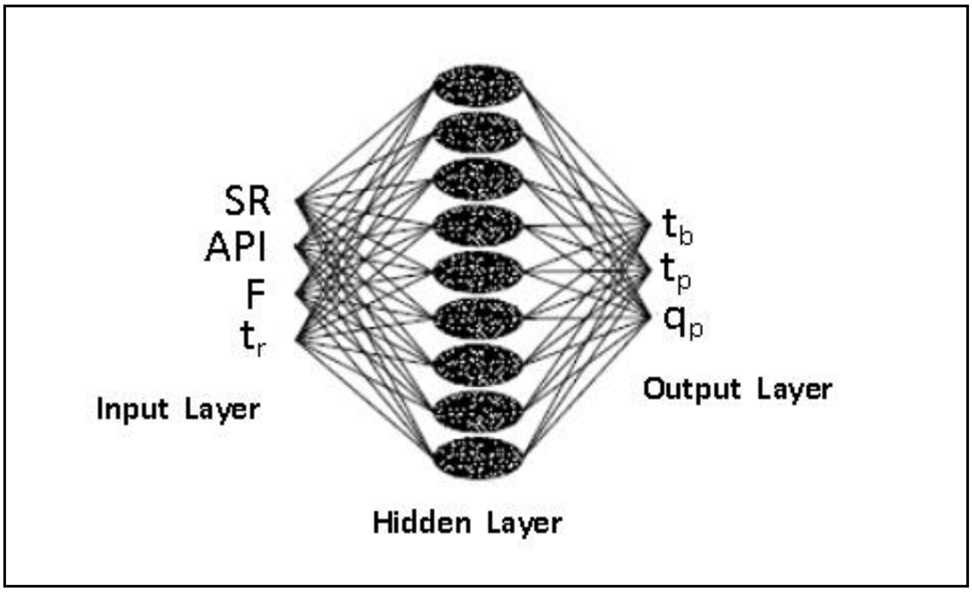

Figure 6.19 Architecture of the proposed NNs

The overall performance of the training and testing sets were evaluated by MSE and the R^2. The training results of the proposed models showed that the NNs learned the highly non-linear relationship between the input parameters and the UH parameters with high correlations (R^2=0.990, 0.991, 0.989 for q_p, t_p, and t_b, respectively) and low errors (MSE=0.990, 0.991, 0.989 for q_p, t_p, and t_b, respectively). Validation of the trained model proved the high generalization capacity of the proposed model with a high correlation and low error (R^2=0.990, 0.991, 0.989 for q_p, t_p, and t_b, respectively). It is seen in Figure 6.20, almost all estimations of the NNs fall on the line of perfect agreement, which shows strictly good agreement with the observed ones. The overall results show that the proposed NN architecture is well applicable for the next steps of the MONN methodology.

6.4.2 Comparison of the MONN with Snyder's Technique

6.4.3 Performance Criteria

It is important to define the criteria by which the performance of a model and its estimation accuracy will be evaluated in the model-development process. Various statistical measures have been developed and used to assess a model's performance. In our case we considered a number of error measures that would evaluate the performance of the compared models with respect to model size. The coefficient of determination (R^2), the mean square error (MSE), the variance (VAR), and the standard deviation (S.Dev.) in comparison of the proposed MONN with TM-based- and the GIS-based-Snyder's methods using the Testing Set.

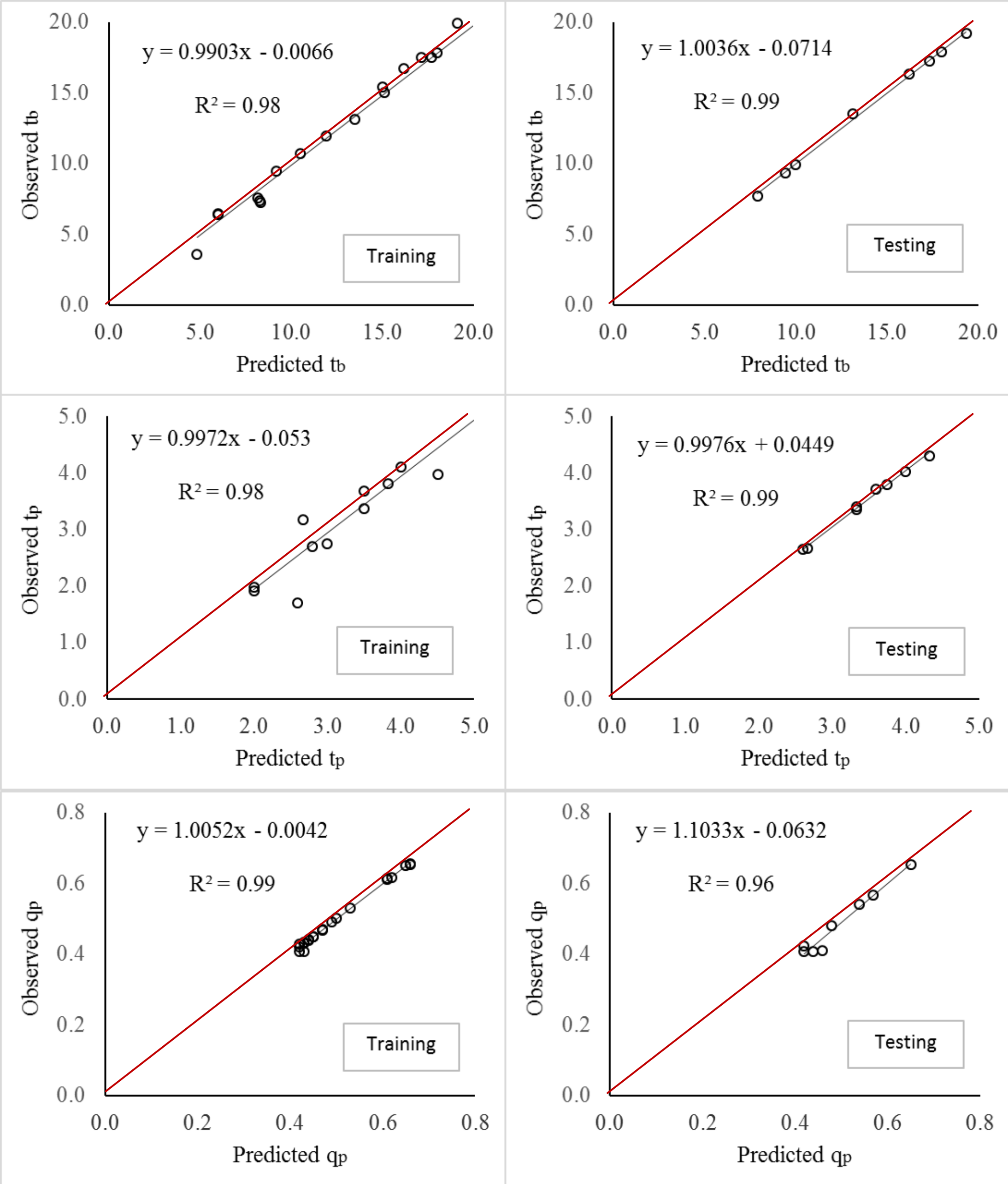

Figure 6.20 Observed and predicted t_b, t_p and q_p for the Training and Testing sets.

6.4.4 Peak discharge estimation, q_p

In this section, the performance of MONN and the other methods are compared based on the Testing data set, as shown in Table 6.8. Table 6.8 shows the overall best performance of MONN with the lowest values of error measures (MSE=0.077, VAR=0.00, S.Dev. = 0.012) and highest correlation (R^2=0.99). On the other hand, TM-based Snyder estimated q_p better than the GIS-based-Snyder based on R^2 and MSE criteria.

Table 6.8 Observed and predicted UH parameters for the Testing Set.

Measure	Models								
	MONN			TM-Snyder			GIS-Snyder		
	t_b	t_p	q_p	t_b	t_p	q_p	t_b	t_p	q_p
R^2	0.989	0.975	0.986	0.352	0.956	0.846	0.352	0.956	0.846
MSE	0.254	0.462	0.077	47.355	0.325	0.014	55.304	0.270	0.020
VAR	24.702	5.539	0.000	68.618	4.288	0.011	75.699	4.731	0.012
S.Dev.	4.830	2.287	0.012	8.700	2.175	0.111	8.283	2.070	0.108

6.4.5 Time to peak estimation, t_p

Table 6.8 indicates the performance of MONN in estimation of t_p compared to the two Snyder's methods. MONN estimated t_p values with the lowest errors (MSE=0.462, VAR=5.539, S.Dev. =2.287) and the highest correlation (R^2=0.975). The TM-based-Snyder's model showed overall better performance compared to and the GIS-based Snyder's. It should be noted that the TM-based-Snyder's model over predicted q_p while the GIS-based-Snyder generally under predicted. The predictions of the MONN are observed to be the closest ones to observed values.

6.4.6 Time base of unit hydrograph estimation, t_b

Table 6.8 indicates the same performance of MONN in estimation of t_b. Namely, MONN estimated t_b values with the lowest errors (MSE=0.254, VAR=24.702, S.Dev. = 4.83) and the highest correlation (R^2=0.989). It should be noted that GIS-based-Snyder's model underestimated all t_b values with considerable deviation, while those of TM-based-Snyder's are relatively closer to experimental values compared to those of TM-based-Snyder's.

CHAPTER 7

CONCLUSIONS

In this study, precipitation and runoff characteristics of Damlıca, Vize, Kumdere catchments were studied. Snyder's, Mockus, SCS, and DSI Synthetic Unit Hydrograph and Multi Output Neural Network (MONN) methods are used for calculating the parameters peak discharge (q_p), base time(t_b), peak time (t_p).

Using selected unit hydrograph data, the catchments average unit hydrograph were examined. Different methods which are Snyder's synthetic unit hydrograph based on topographic map, GIS, observed, MONN are used. All the unit hydrograph parameters (q_p, t_p, t_b) were calculated for each method. Also the coefficients of Snyder's C_p and C_t values were established. For the similar catchments these coefficients can be used.

7.1 Synthetic Unit Hydrographs Methods

Peak discharge, q_p values in Snyder's method are lower predicted for all catchments. Base time, t_b values in Snyder's method are over predicted in all catchments.

Peak discharge, q_p values in Mockus method are under-predicted in Vize and Kumdere catchment but over predicted in Damlıca catchment because of shape factor of catchments. Base time, t_b values in Mockus method accept Kumdere are lower predicted in catchments comparison with respect to observed values.

Peak discharge, q_p values in SCS method are reasonably well predicted in Damlıca catchment for both by using topographic map and GIS values but over predicted in Kumdere and Vize catchment. Base time, t_b values in SCS method are under-predicted in all catchments.

Peak discharge, q_p values in DSI method are under-predicted in Vize and Kumdere catchments but over predicted in Damlıca catchment because of shape factor. Base time, t_b values in DSI method are under predicted for only Damlıca comparison with respect to observed values.

As an overall conclusion SCS method gave the closest predictions to the observed hydrographs .

7.2 Multi Output Neural Networks (MONN)

The three parameters of a synthetic unit hydrograph were estimated by a multi-output neural network model (MONN). MONN estimated the time base and the peak discharge of the corresponding unit hydrographs with very good agreement with the field data obtained from Damlıca Basin in Turkey. MONN is observed to perform superior to Snyder's synthetic unit hydrograph technique, which is most widely used in its subject area.

The significance of this study is in that, the proposed MONN model estimates the three unit hydrograph parameters q_p, t_p, and t_b in a single NN model, as opposed to developing three separate NN models as used in conventional NN technique. By this, the proposed MONN model can be refined/improved by using more experimental or field observations, and also it can be used in comparison with conventional methods.

The robustness of the proposed MONN is validated in estimation of field data and the results are very promising. MONN estimated the observed q_p, t_p and t_b with quite accuracy that R^2 values are 0.989, 0.975, 0.986 respectively.

The results of this study showed that conventional synthetic unit hydrograph techniques could better be replaced by MONN.

7.3 Genetic Programming Based Synthetic Hydrograph

The use of LGP (Linear Genetic Programming) technique in development of synthetic hydrograph for a station on Murat River in Euphrates basin has been investigated in the present study. The performance of LGP is compared with that of conventional auto regressive (AR) technique. The synthetic hydrograph generated by LGP is quite similar to the observed one (R^2=0.663, RMSE=135.68 m^3/s). The comparison results indicate that the LGP model is superior to AR (R^2=0.799 in training and R^2=0.663 in forecasting). Compared with AR, the LGP model was found to reduce the root mean square errors by 60% in training and 15% in forecasting periods, and increase the determination coefficient by 25 and 10% for the training and forecasting periods, respectively. According to the comparison of models' peak discharge estimations, the LGP was found to estimate more accurately in all periods.

7.4 Suggestions for further study

- In this study, only small sized catchments were studied. The robustness of the proposed methodologies may also be applied for large size catchments.
- The number of geomorphologic parameters related to catchments may be increased to improve the accuracy of the proposed models.
- The effect of global climate change only hydrologic parameters of the catchments must be investigated using relevant climate change scenarios.

REFERENCES

Asaad Y.S., O'Connor, Kieran M., Liang, G.C., (1997). Methods for combining the outputs of different rainfall–runoff models. *Journal of Hydrology*, 197, 203–229.

Asaad, Y.S. (1997). Application of a neural network technique to rainfall-runoff Modeling. *Journal of Hydrology*, 199, 272-294.

Asadi, S., Shahrabi, J., Abbaszadeh, P., Tabanmehr, S. (2013). A new hybridartificial neural networks for rainfall–runoff process modeling. *Neurocomputing*, 121, 470–480.

Aytek, A., Guven, M., Yuce, I., Aksoy, H. (2008). An explicit neural network formulation for evapotranspiration. *Hydrological Sciences Journal*, 53(4), 893-904.

Aytek, A., Asce M. and Alp M. (2008). An application of artificial intelligence for rainfall-runoff modeling. *Journal of Earth System Science*, 117(2), 145-155.

Baiamonte, G. and Ferro, V. (2007). Simple Flume for Flow Measurement in Sloping Open Channel. *Journal of Irrigation and Drainage Engineering*, 133(1), 71-78.

Bakanoğulları, F. (2008). Damlıca deresi havzası yağış ve akım karakteristikleri. Tarım ve Köy İşleri Bakanlığı Tarımsal Araştırmalar Genel Müdürlüğü, Yayın no: TAGEM-BB-TOPRAKSU-2008/64.

Bakanoğulları, F., Günay S. (2010). Kırklareli – Vize Deresi havzası yağış ve akım karakteristikleri. Tarım ve Köy İşleri Bakanlığı Tarımsal Araştırmalar Genel Müdürlüğü, Yayın no: TAGEM-BB-TOPRAKSU-2010/83.

Bakanoğulları, F., Günay S. (2011). Edirne – Merkez Kumdere havzası yağış ve akım karakteristikleri. Tarım ve Köy İşleri Bakanlığı Tarımsal Araştırmalar Genel Müdürlüğü, Yayın no: TAGEM-BB-TOPRAKSU-2011/126.

Bakanoğulları, F., Günay, S. (2011). Determination of the Unit Hydrograph Elements of Vize Creek Watershed in Kırklareli, Tarım Bilimleri Araştırma Dergisi 4(2), 7-13.

Balçın, M., Oğuz, İ. (1998). Tokat-Zile Akdoğan havzası yağış ve akım karekteristikleri. KHGM, APK Dairesi Başkanlığı Toprak ve Su Kaynakları Araştırma Şube Müdürlüğü, Yayın No:108, Ankara.

Banzhaf, W., Nordin, P., Keller, R.E., Francone, F.D. (1998). Genetic Programming: An Introduction: On the automatic evouation of computer programs and its applications. Morgan Kaufmann Dpunkt-verlag.

Berry, J.K., Sailor, J.K. (1987). Use of geographic information system for storm runoff prediction for small urban watersheads. *Environmental Management*, 11, 21-27.

Bhattacharya, M., Abraham, A., Nath, B. (2001). A linear genetic programming approach for modeling electricity demand prediction in Victoria. Proceedings of the Hybrid Information Systems, *First International Workshop on Hybrid Intelligent Systems*. Adelaide, Australia, 379–393.

Bhunya, P.K., Panda, S.N., Goel, M.K. (2011). Synthetic Unit Hydrograph Methods: A Critical Review. *The Open Hydrology Journal*, 5, 1-8.

Brameier, M. (2004). On linear genetic programming, PhD Disertation, University of Dortmund.

Brameier, M., Banzhaf, W. (2001). A comparison of linear genetic programming and neural networks in medical data mining. *IEEE Trans. Evol. Comput.* 5 (1) 17-26.

Bruce N.W., William J.B. (2007). Development and evaluation of a dimensionless unit hydrograph. JAWRA *Journal of the American Water Resources Association* 28(2), 397–408.

Chow, V.T., Maidment, D.R., Mays, L.W. (1988). Applied Hydrology: McGraw-Hill Publishing Company, New York, 572 p.

Dune, T. (1982). Relation of field studies and modeling in the prediction of storm runoff. *Journal of Hydrology*, 65, 25-28.

El-Hames, A.S. (2012). An empirical method for peak discharge prediction in ungauged arid and semi-arid region catchments based on morphological parameters and SCS curve number. *Journal of Hydrology*, 456–457.

Ferreira, C. (2001). Gene expression pogramming: A new adaptive algorithm for solving problems. *Complex Systems*, 13(2), 87-129.

Fleurant, C., Kartiwa, B., Roland, B. (2005). Analytical model for a geomorphological instantaneous unit hydrograph. *Hydrological Processes*, 20(18), 3879-3895.

Foster, J.A. (2001). Discipulus: a commercial genetic programming system. *Genetic Programming and Evolvable Machines* 2, 201–203.

Gibbs, M.S., Dandy, G.C., Maier, H.R. (2010). Evaluation of parameter setting for two GIS based unit hydrograph models. *Journal of Hydrology*. 393, 197–205.

Gunal A. Y., Guven A. (2015). Derivation of synthetic unit hydrograph of a small catchment by using GIS. *International Conference on Computational and Experimental Science and Engineering*, October 19-24, Kemer, Antalya, Turkey.

Gunal A. Y., Guven A. (2014). Determination of geomorphological parameters of Damlıca basin using GIS. *International Conference on Computational and Experimental Science and Engineering*, October 25-29, Kemer , Antalya, Turkey.

Gunal A. Y., Guven A. (2010). Genetic programming based synthetic hydrograph for a station in Euphrates basin. A case study of a catchment in Turkey. *9 th International Congress on Advances in Civil Engineering*, September 27-30, Karadeniz Technical University, Trabzon, Turkey.

Gunal, A.Y., Guven, A. (2015). Determination of Geomorphological Parameters of Damlica Basin Using GIS. *ACTA Polonica A*, 128(2B), B222-224.

Guven, A. (2009). Linear genetic programming for time series modelling of daily flow rate. *Earth System Science*, 118(2), 137-146.

Guven, A. (2011). A multi-output descriptive neural network for estimation of scour geometry downstream from hydraulic structures. *Advanced in Engineering Software*, 42(3), 85-93.

Guven, A., Gunal, M. (2008). Genetic expression programming approach for prediction of local scour downstream of hydraulic structures. *Journal of Irrigation Drainage Engineering*, 134(2), 241-249.

Guven, A., Talu, N.E. (2010). Gene expression programming for estimating suspended sediment yield in Middle Euphrates Basin, Turkey. *Clean-Soil, Air, Water* 38(2), 1159-1168.

Guven, A., Kisi, O. (2011). Estimation of Suspended Sediment Yield in Natural Rivers Using Machine-coded Linear Genetic Programming. *Water resources management*, 25(2), 691-704.

Han, D., Yang, Z. (2006). Derivation of unit hydrograph using a transfer function approach. *Water Resources Research*, 42(W01501).

Hecht-Nielsen, R. (1990). Neurocomputing, Addison-Wesley Publishing Company, 433 pages.

Himanshu S.K., FISCA, Garg N., Rautela S., Anuja K.M. and Tiwari M. (2013). Remote Sensing and GIS Applications in Determination of Geomorphological

Parameters and Design Flood for a Himalyan River Basin, India. *International Research Journal of Earth Sciences*. Vol. 1(3), 11-15.

Huggins, L.F., Burney, J.R. (1982). Surface runoff, storage and routing. In:Haan CT (Editors). Hydrologic Modeling of Small Watershead, *ASAE Monograph* 5, 209-214.

Jain, A., Srinivasulu, S. (2006). Integrated approach to model decomposed flow hydrograph using artificial neural network and conceptual techniques. *Journal of Hydrology*, 317, 291–306.

Jakeman, A.J., Littlewood I.G., Whitehead P.G. (1990). Computation of the instantaneous unit hydrograph and identifiable component flows with application to two small upland catchments. *Journal of Hydrology*, 117, 275-300.

Jena S. K., Tiwari K.N. (2006). Modeling synthetic unit hydrograph parameters with geomorphologic parameters of watersheds. *Journal of Hydrology*,139, 1–14.

Kasiviswanathan, K.S., Cibin, R., Sudheer, K.P., Chaubey, I. (2013). Constructing prediction interval for artificial neural network rainfall runoff models based on ensemble simulations. *Journal of Hydrology*. 499, 275–288.

Kaya, S. (2000). Adıyaman-Kahta Harabe deresi havzası yağış ve akım karekteristikleri (ara rapor 1985-1999). Toprak ve Su Kaynakları Araştırma Sonuç Raporları. KGHM, APK Dairesi başkanlığı, Toprak ve Su Kaynakları Araştırma Şube Müdürlüğü, Yayın No:117.

Khaleghi, M.R., Gholami, V., Ghodusi, J., Hosseini, H. (2011). Efficiency of the geomorphologic instantaneous unit hydrograph method in flood hydrograph simulation. *Catena*, 87, 163–171.

Kirby, M.J., (Editor), (1978). Hillslope Hydrology, Landscape systems, a series in geomorphology. John Wiley and sons, 389 p.

Kisi, O. (2005). Suspended sediment estimation using neuro-fuzzy and neural network approaches. *Hydrological Science Journal*, 50(4), 693-696.

Kisi, O., Cigizoglu, H. K. (2007). Comparison of different ANN techniques in river flow prediction. *Civil Engineering and Environmental Systems*,Vol.24(3), 211-231.

Koutsoyiannis, D. Efstratiadis, A., Mamassis, N., Christofides, A. (2008). On the credibility of climate predictions, *Hydrological Sciences Journal*, 53(4), 671-684.

Koza, J.R. (1992). Genetik Programming:On the Programming of Computers by Means of Neural Selection, Cambridge, MA: The MIT Press.

Linsley, R.K., Kohler, M.A., Paulhus, J.L.H. (1988). Hydrology for Engineers. SI edition. McGraw-Hill, Singapore.

Maathuis, B. (2006). DEM Based Hydro-Processing-Introduction to the tools developed, tutorial with exercise (version 1). International Institute for Geo-Information science and earth observation, Enschede, 71.

Maidment, D.R. (1996). GIS and Hydrologic Modeling. An Assessment of Progress. *Third International Conference on GIS Environmental Modeling*, Santa Fe, New Mexico, 22-26.

Maier, R.M., Dandy, C.D. (2000). Neural Networks for the prediction and forecasting of water resources variables: a review of modelling issues and applications. *Environmental Modelling and Software*, 15(1), 101-124.

Manoj, K.J., Umesh C.K., Kittur, G.R.R. (2004). A GIS based distributed rainfall-runoff model. *Journal of Hydrology*, 299(1-2), 107-135.

Narayan, K., Dikshit, P.K.S., Dwivedi, S.B. (2013). Spatially Distributed Unit Hydrograph for Varuna River Basin of India. *International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development*, 3(4), 27-34.

Oğuz, İ., Balçın, M. (2000). Yozgat-Sorgun İkikara havzası yağış ve akım karekteristikleri (ara rapor 1990-1999). Toprak ve Su Kaynakları Araştırma Sonuç Raporları. KGHM, APK Dairesi başkanlığı, Toprak ve Su Kaynakları Araştırma Şube Müdürlüğü, Yayın No:117.

Oltean, M., Grosan, C. (2003). A comparison of several linear genetic programming techniques. *Complex Systems Engineering*, ASCE 134 (2), 241–249.

Pan, Tsung-yi, Wang, Ru-yih (2004). State space neural networks for short term rainfall-runoff forecasting. *Journal of Hydrology*, 297, 34–50.

Ponce, V.M., (1989). Engineering Hydrology: Principles and Practices. Prentice Hall.

Preis, A., Ostfeld, A. (2008). Multiobjective contaminant sensor network design for water distribution systems. *Journal of Water Resources Planning and Management* 134(4), 366-377.

Rabunal, J.R., Puertas, J., Suarez, J., Rivero, D. (2007). Determination of the unit hydrograph of a typical urban basin using genetic programming and artificial neural networks. *Hydrological Process*, 21, 476–485.

Raghunath, H.M. (1985). Hydrology, Principles, Analysis, Design. New Age International Publishers.

Rajurkar, M.P., Kothyari, U.C., Chaube, U.C. (2004). Modeling of the daily rainfall-runoff relationship with artificial neural network. *Journal of Hydrology*, 285, 96–113.

Rodriguez-Iturbeet, I., Valdes, J.B. (1979). The geomorphologic structure of hydrologic response, *Water Resources Research*, 15(6), 1409-1420.

Saghafian, B. (2006). Nonlinear transformation of unit hydrograph. *Journal of Hydrology*, 330, 596– 603.

Salajegheh, D.S., Mahdavi, M.B.A., Afzali, A. (2010). Determining the effect of physical characteristics on flood hydrograph (Case study: Western section of Jazmurian Basin). Desertation. 15, 33-43.

Salami A.W., Solomon, Bilewu O., Ayanshola A.M., Sikiru Folahan Oritola, (2009). Evaluation of synthetic unit hydrograph methods for the development of design storm hydrographs for Rivers in South-West. Nigeria, *Journal of American Science*, 5(4), 23-32.

Sarangi A., Madramootoo, C.A., Enright, P., Prasher, S.O. and Patel, R.M. (2005). Performance evaluation of ANN and geomorphology-based models for runoff and sediment yield prediction for a Canadian watershed. *Current Science*, 89(12), 2022-2033.

Sarangi, A., Madramootoo, Enright, C.A.P., Prasher, S.O. (2007). Evaluation of three unit hydrograph models to predict the surface runoff from a Canadian watershed. *Water Resource Management*, 21, 1127–1143.

Sarangi, A., Bhattacharya, A.K. (2005). Comparison of Artificial Neural Network and regression models for sediment loss prediction from Banha watershed in India. *Agricultural Water Management*, 78, 195–208.

Seaedrashed,Y., Guven, A. (2013). Estimation of Geomorphological Parameters of Lower Zab River-Basin by Using GIS-Based Remotely Sensed Image. *Water Resource Manage*, 27, 209-219.

Sherman, L.K. (1932). The relation of runoff to size and character of drainage basins. *Trans. Amer. Geophys. Union.*, 13, 332-339.

Skaugen, T., Onof, C. (2013). A rainfall-runoff model parameterized from GIS and runoff data. *Hydrological Processes*, 28(15), 4529-4542.

Snyder, W.M. (1938). Synthetic unit hydrographs. *Trans. Amer. Geophys. Union.*, 19, 447-454.

Sule, B.F., Alabi, S.A. (2013). Application of synthetic unit hydrograph methods to construct storm hydrographs. *Academic Journals*, 5(11), 639-647.

Tarboton, D.G., Brass, R.L., Rodrigues-Iturbe, I. (1991). On the extraction of channel networks from digital elevation data. *Hydrological Processes*, 5, 81-100.

Tayfur, G., Moramarco, T. (2008). Predicting hourly-based flow discharge hydrographs from level data using genetic algorithms. *Journal of Hydrology*, 352(1-2), 77-93.

Todini, E. (1988). Rainfall-runoff modeling-Past, present and future, *Journal of Hydrology*, 100(1-3), 341-352.

Usul, N. (2008). Mühendislik Hidrolojisi, ODTÜ Yayıncılık, Ankara.

Wang, W., van Gelder P.H.A.J.M., Vrijling J. K., Ma J. (2006). Forecasting Daily Streamflow Using Hybrid ANN Models. *Journal of Hydrology*, 383-399.

Yang, Y., Rosenbaum, M.S. (2001). Artificial neural networks linked to GIS for determining sedimentology in harbors. *Journal of Petroleum Science and Engineering*, 29, 213–220.

Yılmaz, A. (1987). Konya-Çiçek deresi havzası yağış ve akım karekteristikleri, Köy Hizmetleri Genel Müdürlüğü Yayınları, Genel Yayın No:119, Rapor Seri No:92, Konya.

Zhang, B., Govindaraju, R.S. (2003). Geomorphology-based artificial neural networks (GANNs) for estimation of direct runoff over watersheds. *Journal of Hydrology*, 273, 18–34.

CURRICULUM VITAE

PERSONAL INFORMATION

Name and Surname: Ayşe Yeter GÜNAL

Nationality: Turkish

Birth place and date: Gaziantep, 1967

Marital status: Married

Phone number: +90 342 3172412

Fax: +90 342 3601107

Email: agunal@gantep.edu.tr

EDUCATION

	Graduate school	Year
Master	Kahramanmaraş Sütçü İmam University	1999-2001
Bachelor	Middle East Technical University	1987-1991
High School	Diyarbakır Anadolu High School	1980-1987

Work experience

	Place	Enrollment
2000-Present	Gaziantep University	Instructor
1995-2000	Kahramanmaraş Sütçü İmam University	Instructor
1991-1992	Shell Drilling Company, Diyarbakır	Civil Engineer

PUBLICATIONS

Technical Papers in International Journals (SCI)

1. Temiz H., Gunal, A.Y. (2002). An Investigation on Microstructure of cement paste containing fly ash and silica fume, *Cement Concrete Research*, ASCE, 32(7),1131-1132.
2. Gunal, A.Y., Guven A. (2015). Determination of geomorphological parameters of Damlıca basin using GIS. *ACTA Polonica A*, 128(2B), B222-224.

Technical papers in national congresses

1. Gunal A.Y., Guven A. (2015). Derivation of synthetic unit hydrograph of a small catchment by using GIS. *International Conference on Computational and Experimental Science and Engineering*, October 19-24, Kemer, Antalya, Turkey.
2. Gunal A.Y., Guven A. (2014). Determination of geomorphological parameters of Damlıca basin using GIS. *International Conference on Computational and Experimental Science and Engineering*, October 25-29, Kemer , Antalya, Turkey.
3. Gunal A.Y., Guven A. (2010). Genetic programming based synthetic hydrograph for a station in Euphrates basin. A case study of a catchment in Turkey. *9 th International Congress on Advances in Civil Engineering*, September 27-30, Karadeniz Technical University, Trabzon, Turkey.
4. Gunal M., Bulut S., Gunal A.Y. (2005). İçme suyu şebekelerinde Hardy-Cross ve ölü Nokta Metotlarının Karşılaştırılması. *Antalya yöresinin inşaat Mühendisliği Sorunları Kongresi*, Bildiriler Kitabı, Cilt 2, 100-106, Antalya, Türkiye
5. Gunal M, Gunal A.Y. (2001). Ters eğimli kanallarda dalga kırılması sırasında enerji kaybının modellenmesi. *Turkiye İnşaat Mühendisliği, XVI. Teknik Kongre ve Sergisi*, 1-3 Kasım, ODTU Kongre ve Kültür Merkezi, Ankara, Türkiye

FOREIGN LANGUAGE

Turkish (native)

English (fluently)

German (intermediate)

HOBBIES

Table tennis, Voleyball, Basketball, Listening piano classics, Painting.