DROUGHT ASSESSMENT MODELLING USING BIOPHYSICAL PARAMETERS AND REMOTE SENSING DATA

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Dedicated to my beloved family

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ABSTRAK

Kajian ini mengambil kira perkembangan teknikal di dalam beberapa disiplin untuk digunakan sebagai infrastruktur bagi membangunkan model dan kaedah yang sesuai bagi penilaian kemarau bagi pertanian di kawasan separa gersang. Ia mengkaji kemampuan data-data remote sensing bagi pembangunan model penilaian kemarau biofizikal berasaskan raster. Kemampuan untuk menyatakan perubahan spatial dalam pelbagai tahun bagi evapotranspirasi (ET) di kawasan kajian oleh model yang dicadangkan membuat ia lebih berkesan. Model asas, pemetaan ET pada resolusi tinggi dengan kalibrasi dalaman (METRIC) telah dinilai prestasinya untuk menganggarkan ET bagi penanaman pistachio di kawasan separa gersang. Hasil kajian membuktikan model asas ini mampu memberikan kejituan yang baik dan sesuai bagi kawasan kajian, serta ia juga telah dikenalpasti sensitif terhadap beberapa parameter meteorologi. Analisis dua faktor bagi input utama model asas menunjukkan gabungan *albedo* dan suhu permukaan sangat efektif, manakala pasangan lain yang diuji didapati kurang efektif. Kajian ini mencadangkan persamaan bagi pasangan efektif diubah bagi meningkatkan kejituan. Bagi tujuan ini, teknik pelbagai lapisan perceptron jaringan saraf tiruan (ANN) digunakan bagi menganggarkan taburan mengikut masa dan lokasi bagi nilai ET sebenar yang di hitung berasaskan parameter biofizikal yang disari dari data remote sensing. Keputusan menunjukkan ada korelasi yang tinggi diantara nilai ET dari model METRIC dan yang dihasilkan dengan ANN. Analisa kepekaan ANN menunjukkan suhu permukaan, fluks kepanasan tanah dan *albedo* adalah merupakan parameter yang paling ketara. Analisis faktor menggunakan analisis komponen utama (PCA) dijalankan bagi memilih parameter biofizikal yang paling ketara, sebagai input bagi model indeks tekanan air biofizikal (BPWSI) yang baru dibangunkan. BPWSI adalah merupakan model baru bagi mengganggarkan indeks tekanan air menggunakan parameter biofizikal yang terpilih. Keputusan bagi BPWSI adalah sangat ketara dan boleh digunakan untuk menentukan status keperluan air bagi pistachio yang menjadi penanda kepada kemarau pertanian.

ABSTRACT

This study considers the advancement in technical development of a few disciplines as an infrastructure for developing a suitable model and methodology for agricultural drought assessment in semi-arid area. It evaluates capabilities of multi-source remote sensing data in developing raster-based biophysical drought assessment models. The capability for expressing the spatial and inter-annual variation of evapotranspiration (ET) over a study area by the proposed models has made it efficient. The base model, Mapping EvapoTranspiration at high Resolution with Internal Calibration (METRIC) has been evaluated for its performance in estimating ET over the pistachio plantation in a semi-arid region. The result proved that the base model gives good accuracy and is suitable for the selected study area. The base model, METRIC, is found sensitive to a number of meteorological parameters. Two-factor analysis for the primary inputs of the base model shows that the surface albedo and surface temperature pairs is the most effective while other tested pairs are found to be least effective. The study suggests that improving the equations of the effective pair should increase the accuracy. In this case, the multi-layer perceptron Artificial Neural Network (ANN) technique is used for estimating spatial and temporal distribution of actual ET from satellite based biophysical parameters. The result shows that a strong correlation exist between ET values computed using METRIC and those generated using ANN. ANN sensitivity analysis shows that surface temperature, soil heat flux and surface albedo are the most significant parameters. Exploratory factor analysis using Principal Component Analysis (PCA) was performed to select the most significant biophysical parameters to be used as input to a newly developed BioPhysical Water Stress Index (BPWSI). The BPWSI is a new model for estimating water stress index using the selected biophysical parameters. The results of BPWSI are found to be significant and can be used for predicting the pistachio water status which represents the indication of agricultural drought.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ABC - Artificial Bee Colony
AET - Actual Evapotranspiration
ANN - Artificial Neural Network
ASCE - American Society of Civil Engineers
ASTER - Advanced Space borne Thermal Emission and Reflection Radiometer
AVHRR - Advanced Very High Resolution Radiometer
AWC - Available Water Capacity
BPWSI Biophysical water stress index
BMDI - Bhalme And Mooley Drought Index
CIMIS - California Irrigation Management Information System
CMI - Crop Moisture Index
CSDI - Crop-Specific Drought Index
CV - Coefficient Variation
CWSI - Crop Water Stress Index
$C\rho$ - Air Specific Heat At Constant Pressure
D - Displacement Height
DBF - Database Format
dT - Temperature Differences
DV - Dependent Variable
DWT - Discreet Wavelet transformation
EDI - Effective Drought Index
ETDI - Evapotranspiration Deficit Index
EOS - Earth Observation System
EP - Effective Precipitation
ET - Evapotranspiration

ET_{ref} - Reference Evapotranspiration
$ET_{ref}f$ - Reference Evapotranspiration Fraction
ET_{daily} - Daily Evapotranspiration
ET_{ins} - Instantaneous Evapotranspiration
FAO - Food And Agricultural Organization
G - Soil Heat Flux
GCP - Ground Control Point
GDP - Gross Domestic Product
GRI - Ground Water Resources Index
GRNN - Generalized Regression Neural Network
G_{sc} - Solar Constant
H - Sensible Heat Flux
HIS - Hue Saturation Intensity
HPF - High Pass Filter
IDWT - Inverse Discreet Wavelet Transformation
IV - Independent Variable
Kc - Crop Coefficient
LE - Latent Heat Flux
LGP - Linear Genetic Program
$L_{\max}$ - upper limit radiance
$L_{\min}$ - Lower limit radiance
LM - Levenberg-Mardquardt
MAE - Mean Absolute Error
MCI - Moisture Condition Index
MEBES - Surface Energy Balance In Spanish
MES - Mean Square Error
MLP - Multi Layer Perceptron
MODIS - Moderate Resolution Imaging Spectroradiometer
NASA - National Aeronautics And Space Administration
NDVI - Normalized Difference Vegetation Index
PBIM - Pixel Block Intensity Modulation

PCANN - Principal Component Analysis Neural Network
PDIP - Deep Percolation
PDSI - Palmer Drought Severity Index
PM - Penman-Monteith
Rad - Radiance
r_{ah} - Aerodynamic Resistant To Heat Transfer
RAI - Rainfall Anomaly Index
RBNN - Radial Basis Neural Network
RDI - Reclamation Drought Index
RGB - Red Blue Green
R_L - Long Wave Radiation
RMSE - Root Mean Square Error
R_n - Net Radiation
R_S - Shortwave Radiation
SAVI - Soil Adjusted Vegetation Index
SD - Standard Deviation
SDMI - Soil Moisture Deficit Index
SEBS - Surface Energy Balance System
SFI - Stream Flow Index
SFIM - Smoothing Filter Based Intensity
SPI - Standardized Precipitation Index
SR - Simple Ratio
S-SEBI - Simplified Surface Energy Balance Index
STD - Standard Deviation
SVR - Surface Vector Regression
SWAT - Soil And Water Assessment Tool
SWB - Soil Water Balance
SWIR - Shortwave Infrared
SWSI - Surface Water Supply Index
TCI - Temperature Condition Index
TDR - Time Dominant Reflectometry
TIM - Trapezoid Interpolation Model

TIR - Thermal Infrared
TM - Thematic Mapper
T_S - Surface Temperature
T-SEB - Two Surface Energy Balance
U_blend - Wind Speed At Blending Height
U_{200} - Wind Speed Ad 200 Meter Above Ground
VCI - Vegetation Condition Index
VegDRI - Vegetation Drought Response Index
VHI - Vegetation Health Index
VNIR - Visible Near Infrared
Ws - Wind Speed
Z_{om} - Surface Roughness Length For Momentum
$z_{om\,s}$ - Surface Roughness Length For Momentum at Weather Station
σ - Stephan-Boltzmann Constant
θ_{rel} - Solar Incidence
γ - Latent Heat Of Vaporization
θ - solar zenith angle
ρ - Reflectance value
ε_o - Surface Emissivity
ε_a - Atmospheric Emissivity
τ_{sw} - Atmospheric Transmisivity
u^* - Friction Velocity
α - Surface albedo

CHAPTER 1

INTRODUCTION

1.1 Background

Natural hazards such as extreme temperatures, drought, rainfall, flood and sand storm are inevitable events that, damage infrastructures of human society and agricultural lands. It causes reduction in agricultural production and causing socio-economic instability, particularly in rural area.

The driving force for agricultural risk management is to reduce vulnerability of products and increase food production to protect the human population and preserve the health of the earth's environment. Production risk as a primary source of agricultural risk associated with variability in expected yield and uncertainty. The United States Department of Agricultural, (USDA, 1997) reported that weather, pests, disease, interaction of technology with other farm and management characteristics, genetics, machinery efficiency and the quality of input are the major source of agricultural production risk. Among the above mentioned risk sources, drought and heat causes about half of all crop losses (USDA, 1997).

The assessment of natural hazards by means of satellite data began 20 years ago. The use of satellite data has been made it easy and feasible to map and quantities amount of damage on vegetation (NASA, 2009). Recent developments in the field of remote sensing and geo-information system as operational tools increase the information availability and details of earth surface that can be used for agricultural resources management and crop growth modeling particularly in assessing the natural hazards on crop growth and its productivity as this seems to be the bottleneck in agricultural risk management (Sharifi *et al.*, 2008).

High temporal resolution images such as those generated by on-board MODIS and AVHRR Terra and NOAA satellites provide facilities to get daily measurement of green vegetation density and concentration of green leaf using vegetation index calculated from near-infrared and visible light reflected by the earth surface. In addition, many plant parameters such as Photosynthetic absorbed radiation as an important parameter for vegetation productivity assessment, can be quantified by satellite sensors (NASA, 2009). The maps produced from these data type have been used to monitor climatic and environmental changes such as deforestation, desertification as well as drought in previous studies. To assess water deficit and drought condition, remote sensing techniques were identified as an important tool in drought monitoring and impact assessment many researchers (Bastiaanssen, 2005, Donald *et al.*, 2000). Due to the low cost of remote sensing data availability and advances in related software, there has been considerable interest in developing efficient indicators through this technique (Bastiaanssen *et al.,* 2001).

Water is one of the most important components in the existence environment. Huge water consumption in agricultural sector especially in irrigated area and limitation of fresh water resources particularly during the natural hazards such as drought, water resources management becomes more important. Plant water deficit reduces the plant evapotranspiration (ET) rates and consequently its productivity. Efficient water management needs proper tools to quantify the components of hydrologic cycle including ET and its spatial and temporal distribution in detail and accurately. Currently, this information can be retrieved and spatially mapped by remotely sensed data. Nowadays, satellite imagery has become a powerful tool for water consumption determination and crop yield estimation in the hand of managers and planners (Allen and Bastiaanssen, 2005).

Drought as a climatic phenomenon is unpredictable in terms of time and place within the earth's climate systems. It is one of the complex phenomena, which is different from other natural hazards such as flood, earthquake, extreme temperatures, rainfall and sand storm. Although drought is the consequence of reduction in the amount of rainfall, it is difficult to see the impact of drought because of its wide spread impacts over the large geographical area even after extinction of event. On the other hand, drought is distinctly regional and based on its duration, intensity, time of occurrence, effectiveness of the rains and the geographical extent, has different impacts on environment (Redmonds, 2002, Wilhite, 1993). It occurs regularly with no clear warning and the boundaries of drought cannot be delineated. In addition, drought has been defined as a creeping hazard and its impact is said to be cumulative and not immediately observable by ground data (Kogan, 2000). It can be defined as conceptual or operational. Conceptual definition generally defines the boundary of drought concept, but operational definition describes the drought in term of severity, frequency, continuation and termination of drought (Wilhite and Glantz, 1985).

1.2 Description of Drought Problem

Japan Meteorological Agency (1994) reported that, climate abnormality and its frequency are increased and in this condition, protection of food supplies and management of human security becomes more important. So, in order to secure food supply, evaluation of agricultural resources as a main human food supply and assessment of natural hazards effects on this resource quickly and accurately is necessary.

Drought has wide impacts either direct or indirect on natural resources. Drought management and planning, as well as monitoring, risk assessment and mitigation that are the most important parts of drought preparedness plans, reduce the agricultural drought risks (Wilhite, 2009). Although, drought is less in frequent compare to other natural hazards (lowest, 3% in Europe and highest, 30% in Africa continent), but it affects region and people extensively (see Figure 1.2) (CRED-CRUNCH, 2006). It has been reported that about 80, 33, 30, 23 and 42 percent of the persons has been affected by drought in the Africa, Americas, Asia, Europe, and Oceania respectively during the1970-2006 (UN/ISDR, 2007).

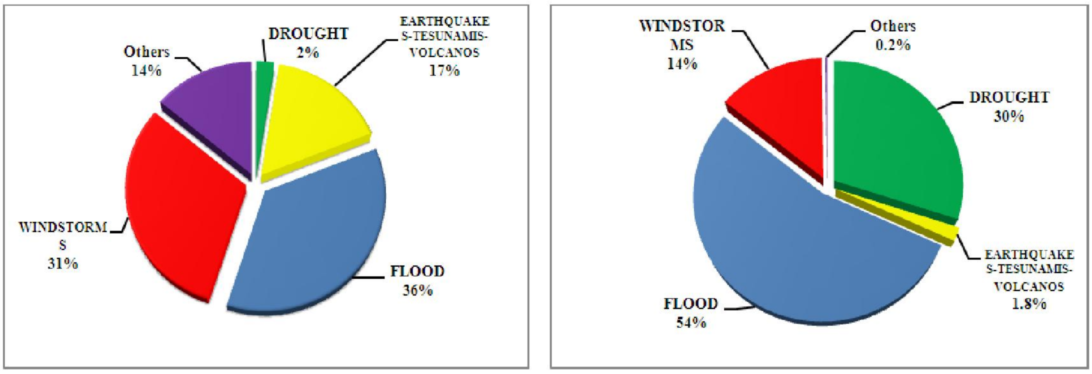

Figure 1.1: Proportion of persons affected by each disaster type (Right) and occurrence of each disaster (Left) in Asia 1970-2006 (UN/ISDR, 2007).

The general problem in drought impact assessment is to identify proper indicators, which can be used to detect and quantify the effect of drought on natural resources. Using reliable indicators as tools in conjunction with real or near real time information might improve drought management and probably will reduce negative effects on environment. Recently, Remote sensing techniques can collect information and estimate damage resulting from natural disaster over large areas or in inaccessible places on the ground (Okamoto *et al.,* 1998).

Agriculture, being a primary economic sector of which large amount of the fresh water is required, will be affected in case of drought. The water deficit is the most limiting factor in crop production. Both long term and short-term drought has severe impacts on agriculture. The short term drought at the critical crop stages has also severe impact on crop yield (Wu and Wilhite, 2004).

1.3 Agricultural Drought in Iran

Iran is located in a semi-arid region where drought occurs periodically as a natural hazard. Agriculture plays an important role in the national economy and development of Iran, although water resources in agricultural sector are insufficient. Without irrigation, agricultural activities are almost impossible in most of the arable lands. Negative changes in the norm of agricultural production resulting from drought occurrence will reduce amount of food and affect socio-economic development in Iran (C.E.A.I, 2003).

Population and urbanization in Iran grows rapidly and consequently environmental degradation and resources depletion are resulted. This pressure on environment has become drastic during the natural disasters incidence and increasing risk to vulnerability of structures and settlements. The history shows that Iran is natural disaster-prone country and during the last decades this country has been affected by several natural disaster including drought, flood and earthquake (Bahrainy, 2003). According to United Nations reports, the cumulative effect of droughts from 1999 to 2001 has seriously affected Iran's agriculture and livestock production. During these years 10 provinces affected severely by drought, 20 provinces has experienced precipitation shortfall, 800,000 livestock were lost and water reservoirs were down by 45% as results of drought (Agrawala *et al.*, 2001). Due to both short and long term drought damage, amount of annual agricultural production dropped down and imports correspondingly rose up. As an example, Iran was third largest wheat importer behind Italy and Brazil during the drought years of 1999-2001. As it can be seen in Figure 1-3 wheat import has been increased during the 1990-2000 that has coincided with drought event (UNDP, 2003). Annual wheat production has been declined 20 percent during these years due to the both long-term and short-term drought. The estimated damages caused by drought during these years, is over the $ 8 billion (Agrawala *et al.*, 2001). The severity of the drought has been increased partly due to improper use of water in agriculture and mismanagement of water resources. It has been verified by United Nations that an effective policy is needed to mitigate disaster risk in this country. Since drought has became more frequent in this country, a new environmental planning and further development are needed to enable the country to reduce the damages (UNDP, 2003).

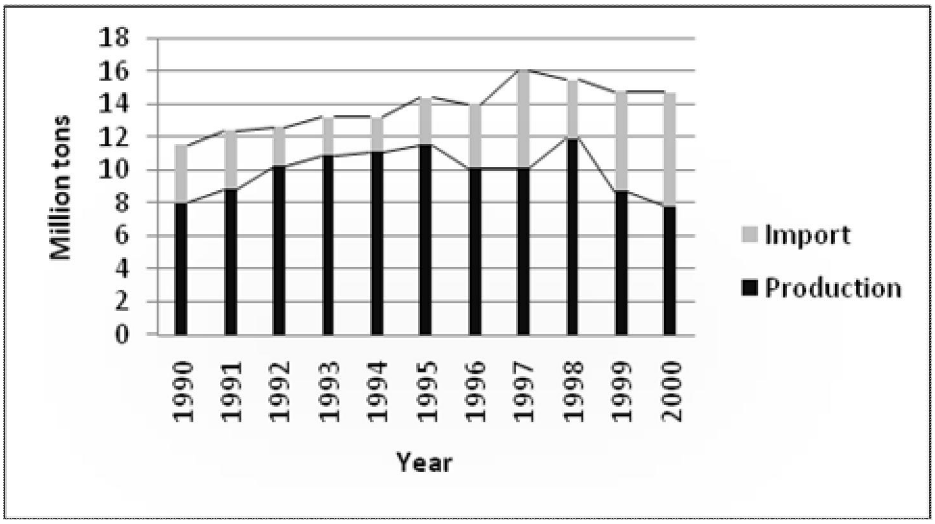

Figure 1.2: Production and imports of wheat in Iran, 1990–2000 (UNDP, 2003).

On the other hand, the Iranian agricultural development Bank pays indemnities for drought losses based on negotiation. Hence, a tool or an appropriate indicator for drought assessment is essential to be better prepared, to limit the effects and to assess impact of drought on agriculture. Identifying reliable indicators, which can be used to measure and quantify drought effects on agricultural fields in semi-arid regions, will help decision-maker to reduce drought impacts. A drought index is typically a single number, far more useful than raw data for decision-making. Reliability of information is a key factor in the decision making process of water allocation and management crop diversification, estimation of damage, estimation of proper rate for insurance, reduction of the environmental impact. Agricultural performance improvement and efficient use of the available water resources are the subjects in management and control of drought impact (Mokhtari, 2006).

Therefore development of an efficient system or tools is essential for natural disaster assessment that is expected to improve conditions and conquer some of the next shortcomings caused by incidence. Long-term monitoring and short-term vegetation condition assessment by means of a proper tool will reduce the vulnerability of agricultural production. The information obtained through this system can be helpful to managers and planers during and after the crisis. Indeed, knowledge of crop growth conditions and final production assessment is vitally important for proper management and planning such as optimization of farming practices, supply and distribution of inputs such as fertilizers, seeds, herbicide, fungicide and the harvest during the drought periods.

1.4 Water Use in Agriculture

In Iran, most of the agricultural lands are groundwater-fed especially in the arid zones that are located in center and east part of the country. Qanat and pumping wells are two ways to extract groundwater. Qanat was the best traditional method for obtaining groundwater but unfortunately it is being replaced by deep pumped wells. Qanats have been considered to be an innovation developed by Iranians about three thousand years ago and it is consist of, a well dug in mountainside, a tunnel that direct the water from aquifer in mountainside to the village and several wells that are located along the tunnel for purpose of cleaning and maintenance of the underground tunnels.

The estimated difference between recharge of groundwater resources (56.5 billion cubic meter) and discharges from them (61.3 billion cubic meter) is about 4.8 billion cubic meter and average drawdown of water table in most of water extraction places is about 1 meter per year. The effects of water table level reduction are soil salinization, land degradation as they are evident in most basins in Iran. The overall irrigation efficiency is about 30 to 35 percent in the country (Alizadeh and Keshavarz, 2005).

Out of 7.8 Million hectare (M ha) irrigated land, 3.0 M ha are allocated to cereal, 2.8 M ha to orchards and 2.8 hectare to different field crops according to published agricultural statistics. For irrigating of these areas, 83 billion cubic meter of water is used. In comparison, it is reported that the average net irrigation requirements in Iran for cereal and field crops are 5,100 and 8,100 cubic meters per hectare (m^3/ha), respectively. Normally, the amount of water supply and demand are being used for determination of the area under cultivation (Alizadeh and Keshavarz, 2005).

It has been considered by Alizadeh and Keshavars (2005) that increasing the water productivity is a key factor for mitigating the problem of water scarcity in Iran and it can be feasible by means of first: a proper water management and improvements in water distribution networks, that increase irrigation efficiency (up to 50 or even 60 %) and as a result the area of irrigated land are increased and second: increase in water productivity by reallocating water from lower to higher value crops or from agriculture to other sectors where the marginal value of water is higher.

Table 1.1 shows amount of the available Iran's freshwater resources. As it can be seen, the average renewable water is 130 billion cubic meters only. Average annual renewable freshwater per person has been decreased from 2,254 m^3 in 1988 to 1,950 in 1994, and it has been estimated to be reduced to 1,300 m^3 for year 2020 (Ghazi, (2002) cited by Alizadeh and Keshavarz (2005)). Whereas agricultural sector consumes more than 94 percent of the renewable water, the productivity of water (ratio of yield per unit of water) is very low and economic value per cubic meter is 0.75 kg/m^3. The economic value of agricultural products in Iran (including rain-fed agriculture) is estimated to be U.S. $4.75 billion, which is about 26 percent of the gross domestic product (GDP).

Table 1.1: Water use and availability in Iran (Alizadeh and Keshavarz, 2005)

Component	Volume (bcm)	Percent of Total
Evaporation	283	70
Renewable water	130	30
Precipitation	413	100
Agriculture	82.0	94.25
Domestic	4.7	4.75
Industry (etc.)	0.8	1
Total water use	87.5	100
Surface water	105	
Groundwater	25	

1.5 Pistachio Production

Iran with 40% of world total production is the largest pistachio producer followed by US, Turkey and China as shown in Figure 1.4 (Rahemi *et al.*, 2005). Pistachio nut as non-oil most important agricultural production, plays important role in Iran's economic programs and exportation. It has been known as largest cash crop. Pistachio was planted originally in Iran and based on the nut shape and size have different name such as; Fandoghi, Ahmad aghaee, Akbari and Kale ghuchi (Amiri Aghdaie, 2009).

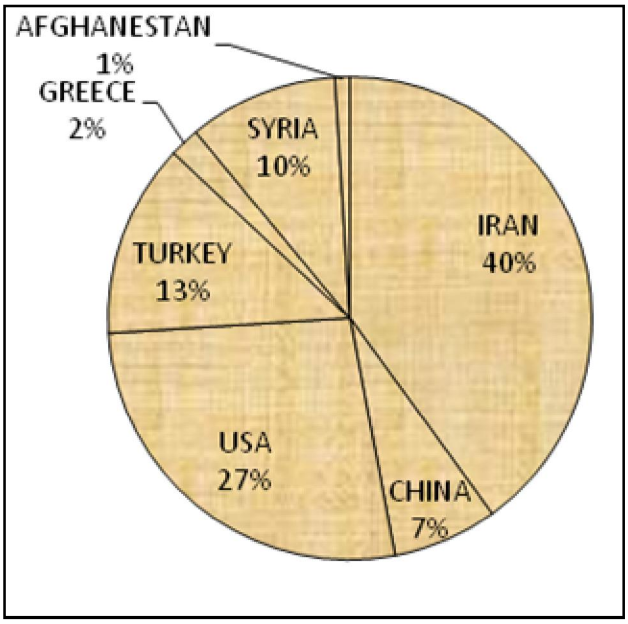

Figure 1.3: World pistachio producer and their allotment (%) (Rahemi *et al.*, 2005).

1.6 Significance of the Study

The consumption of grain food has increased recently due to the increase of population. However, production of grain food such as wheat, barley and rice are hampered by the agricultural drought which recently occurred at quite high frequency as reported and can be seen in the national and international reports and literatures. This affects the water resources and as a result, supply and demand balance for food suddenly. It has been reported by water organization of Iran that groundwater is critically decreased during the last decades and it affects specially most of the summer grain productions which is depends on irrigation by ground water resources. All these related issues imply that agricultural production declines as available water decreases during the drought and thereafter.

In addition, farmers are turning to horticulture recently, and allocating more land and water for pistachio crop. However, regarding to this rotation, water use efficiency has not been investigated and compared with previous farming practices. A few ground-based researches have been done in determination of pistachio water consumption and assessment of drought impact on it. However, it has been shown that pistachio trees are sensitive to extreme conditions such as drought. Pistachio research institute has reported that the productivity of this crop has been declined mainly due to droughts (Sedaghat, 2006). Reduction of leaf water potential of pistachio crop due to soil water deficit, reduces water use efficiency and as result its production (Behboudian *et al.*, 1986, Maldonado, 2009). Although, the remote sensing techniques have been recognized as an efficient tool for quantification of evapotranspiration (ET) and drought assessment in agricultural science (mostly on cereals) by many researches in the last, regarding to the previous studies and available literatures, shown that these tools have been calibrated and applied in determination and quantification of ET as drought indicator in a few researches in horticultural field, where huge volume of water are consumed by trees (Grapes, Peaches and almonds in Spain using SEBAL (Bastiaanssen *et al.*, 2008), vineyard, Mango in Brazil using SEBAL (Teixeira *et al.*, 2009) and Pecan crop in New Mexico, US using REEM model similar to SEBAL (Samani *et al.*, 2009)).

Although, many drought indices and models have been developed during the last couple of years, the effects of the drought are varies from one region to another because of different climatic and environmental conditions and their capacity to respond to the effects of drought. According to literatures which have been reviewed, based on the time and duration of drought occurrence, different crop types have different response to drought in different growth stages. This makes difficult to have a unique model for all regions or all crop types. However, the spatial drought patterns of inter-annual dynamics are not well documented in this area and a proper, efficient and specific drought impact assessment model has yet not been developed for either whole country or specific agricultural area.

Hence, a tool for drought assessment is essential for the quantifying and to limit the effects of drought. Identifying reliable model, which can assess and quantify the drought condition on agricultural fields in the study area, will help managers in agricultural sector, planners and decision-maker to reduce the risk of drought effects.

1.7 Objectives of the Study

In drought assessment studies, especially in a model development there are many issues that have to be addressed. The main approach is to adapt existing resources based on the model requirements to solve the existing problem. The main goal of this study is to develop a drought assessment model for the study area as a representative of semi-arid region. In addition it will also examine the effect of multi-source satellite data used to provide values for parameters in the model. This follows with the validation of the developed model with field observations. In other word, crop response to the soil water in relation to ET will be assessed. In order to achieve the goal of this study the following objectives need to be fulfilled:

i. To evaluate the capability of remote sensing data in estimating ET for pistachio crop using METRIC energy balance model.

ii. To estimate spatial and temporal distribution of ET from remote sensing data using artificial neural network.

iii. To develop a new satellite-based biophysical water stress index using factor analysis.

1.8 Study Area

An agricultural area in a semi-arid region that has been experienced drought during the 1999-2001 and 2006 was selected for this study. This area contains only pistachio orchards and therefore, the error of the mixed pixel of different crop types is avoided where moderate resolution satellite data are utilized.

1.8.1 Location

This site is located in Bahadoran village in south-west part of the Yazd province, Iran. This area expands from longitude of 54° 51′ to 54° 59′ in east and latitude of 31° 29′ to 31° 17′ in north and covers about 7000 ha. The location of study area is shown in Figure 1.5.

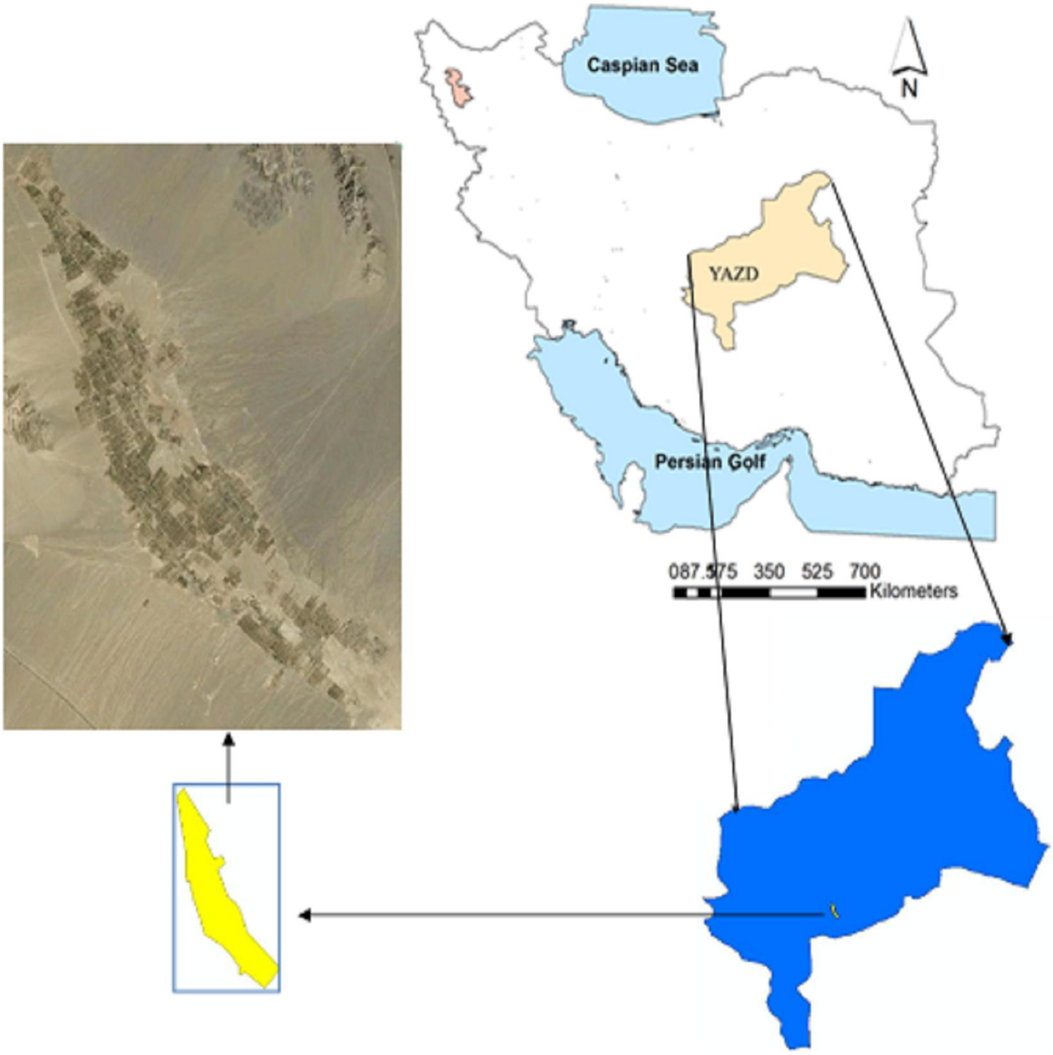

Figure 1.4: Location of study area

1.8.2 Climate

Yazd province is located in the central part of Iran and on the dry belt of the world. This area has a predominantly arid or semi-arid desert climate with rainfall averages only 71.9 mm per year. Most of the rainfall occurring during the winter months from December to April (see Figure 1.6). Monthly evaporation and annual mean relative humidity are about 264 mm and 25% respectively. In this weather condition, it is impossible to have an economical crop production without a reliable irrigation.

The topography of Bahadoran and its farm are almost flat with average altitude of about 1500 m above sea level. The average temperature of the study area is 17.1 °C, whilst the maximum temperature in July is 41° C, and the minimum in January is -10°C. Table (1.2) and Table (1.3) present average temperature and evaporation of the study area respectively.

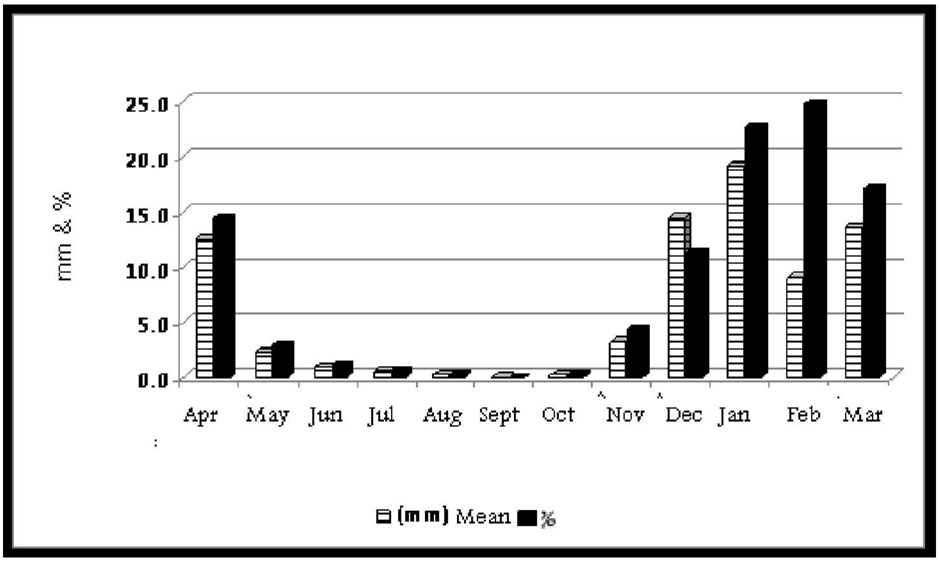

Figure 1.5: Mean and percentage of rain fall in the study area (IRIMO, 2010)

Table 1.2: Mean, lower mean and upper mean air temperature of the study area (IRIMO, 2010).

Month	Lower mean °C	Upper mean °C	Mean °C
Apr	20.5	54.2	37.4
May	14.8	38.0	26.4
Jun	11.1	28.9	20.0
Jul	12.1	25.6	18.8
Aug	11.7	27.9	19.8
Sep	10.3	26.5	18.4
Oct	12.5	32.3	22.4
Nov	18.5	44.6	31.5
Dec	27.2	62.6	44.9
Jan	35.5	73.6	54.5
Feb	22.8	64.7	43.8
Mar	18.7	52.4	35.6
Annual	18.0	44.3	31.1
SD	7.6	16.9	12.1
CV (%)	42.5	38.1	39.0

Table 1.3: Monthly mean evaporation in the study area (IRIMO, 2010)

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Annual
EVP (mm)	265.4	304.9	359.8	322.9	330.1	327.0	298.5	243.3	227.3	213.1	238.7	251.4	3382.4

1.8.3 Water and Irrigation

The main source of water used is groundwater and current irrigation system in the study area is surface irrigation (flood irrigation). In the recent years the area of land for agriculture has been increased and more land allocated for pistachio crop, but with limit amount of water for irrigation. During the water shortage period, farmers are forced to reduce either irrigation frequency or amount of irrigation water. This cause's lower yield per area as amount of water available for irrigation is decreased. Beside lower yield, such condition has increased soil salinity and causing soil degradation. Irrigation period in this area reported to be varying from 30-40 days based on water availability.

1.9 Scope of the Study

The selected study area is the agricultural site in Bahadoran village which is located in the south-west part of Yazd province, Iran. This area was experiencing drought during 1999 to 2001 and 2006, as well as other agricultural area in Iran.

The remote sensing data generated by a number of orbiting sensors are selected as primary data for the study that will take into account spatial variability of land surface for examining the nature of the drought during the growing seasons. Remote sensing data utilized in this study should be able to provide background knowledge that is necessary to understand the drought dynamics in the study area.

Evapotranspiration (ET) and biophysical parameters will be evaluated for the drought assessment modeling. Thus, the study focuses on the assessment of the indices that expressed in term of variation in ET as plant water requirement. These indices will be observed on the image dates of the growing season on a daily basis in order to ensure that pattern or trend in plant water requirement can be accurately studied.

The study will focus only on detection of Pistachio water condition. The pistachio is the major crop in the study area. The following remote sensing data have been considered as major data for this study: MODIS, ASTER, and LANDSAT TM. In the absence of high spatial resolution data high temporal resolution data from MODIS is considered for interpolation of actual ET. Information generated using MODIS data will then be fused with finer resolution data to generate information at a much higher scale as daily basis. This is done using neural network method and result will be validated using ET values generated using high resolution data. In order to reduce the complexity of energy balance model artificial neural network technique will be performed on satellite-based biophysical data to predict spatial distribution of actual ET over the study area. Results for this exercise will be considered as a reference values.

In addition, a biophysical water stress index is developed for pistachio crop using remote sensing-based biophysical parameters and factor analysis. Soil properties, weather, water and crop management's practices and as ground data will be collected during the fieldwork. The weather data of this study are air temperature, relative humidity, dew point, wind speed and radiation that are collected from the station located almost at the middle of the study area. These data are only used for calibration of selected energy balance model (METRIC, Mapping EvapoTranspiration at high Resolution with Internal Calibration) and extrapolation of instantaneous ET estimated at the satellite overpass time. Two consequent soil water balance measurement are subtracted to estimate amount of water losses from plant transpiration and evaporation as *ET*. The result of soil water balance *ET* is used for evaluation of METRIC performance. In addition, LAI as ground data is measured to develop a satellite-based LAI equation for pistachio crop. This equation is used within the METRIC algorithm. Soil properties are also presented as descriptive information in this study.

The selected remote sensing based energy balance model, METRIC will be developed and calibrated for estimating pistachio ET. Sensitivity analysis of algorithm will be performed to identify the most significant parameters in ET calculation using this model. The result will be validated using ground-based measurement. The result of METRIC model will be considered as reference to evaluate the models produced from biophysical parameters.

In general, this study is organized in the following main stages:

i. Data collection including: satellite data (high spatial and high temporal resolution data), ground-based point data from meteorological station, soil data, crop data, farming practice information on irrigation.

ii. Data processing and analysis: satellite data pre and post-processing (ET and LST calculation, sensitivity analysis), importing ground-based data to the GIS environment.

iii. Validation of the models using ground based measurement and presenting the practicable model for the study area.

REFERENCES

Abduljabbar, A., Lugg, D., Sammis, T. and Gay, L. (1985). Relationships between crop water-stress index and alfalfa yield and evapotranspiration. *Trans ASAE,* 28**,** 454-461.

Abrams, M. (2000). The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER): Data products for the high spatial resolution imager on NASA's Terra platform. *International Journal of Remote Sensing,* 21**,** 847-859.

Abudu, S., Bawazir, A. S. and King, J. P. (2010). Infilling Missing Daily Evapotranspiration Data Using Neural Networks. *Journal of Irrigation and Drainage Engineering,* 136**,** 317-325.

Agrawala, S., Barlow, M., Cullen, H. and Lyon, B. (2001). Drought and humanitarian crisis in Central and Southwest Asia: a climate perspective.

Akhtari, R., Morid, S., Mahdian, M. H. and Smakhtin, V. (2009). Assessment of areal interpolation methods for spatial analysis of SPI and EDI drought indices. *International Journal of Climatology,* 29**,** 135-145.

Alizadeh, A. and Keshavarz, A. (2005). Status of Agricultural Water Use in Iran. *Water Conservation, Reuse, and Recycling:Proceedings of an Iranian-American Workshop*, 2005 of Conference Tunis. National Academic Press, 94-105.

Allen, R., Tasumi, M., Morse, A. and Trezza, R. (2005a). A Landsat-based energy balance and evapotranspiration model in Western US water rights regulation and planning. *Irrigation and Drainage Systems,* 19**,** 251-268.

Allen, R. G. and Bastiaanssen, W. G. M. (2005). Special issue on remote sensing of crop evapotranspiration for large regions. *Springer , Irrigation and Drainage Systems,* 19**,** 207-210.

Allen, R. G., Luis, S. P., Raes, D. and Martin, S. (1998). Crop evapotranspiration - Guidelines for computing crop water requirements. *FAO Irrigation and drainage paper 56*.

Allen, R. G., Tasumi, M., Morse, A. and Trezza, R. (2005b). Satellite-Based Evapotranspiration by Energy Balance for Western States Water Management. Anchorage, Alaska, USA. ASCE, 556-556.

Allen, R. G., Tasumi, M., Morse, A., Trezza, R., Wright, J. L., Bastiaanssen, W., Kramber, W., Lorite, I. and Robison, C. W. (2007a). Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)---Applications. *Journal of Irrigation and Drainage Engineering,* 133**,** 395-406.

Allen, R. G., Tasumi, M. and Trezza, R. (2007b). Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC)---Model. *Journal of Irrigation and Drainage Engineering,* 133**,** 380-394.

Amiri Aghdaie, S. f. (2009). Investigating Effective Factors on Iran's Pistachio Exportation. *International Journal of marketing studies,* 1**,** 35-40.

AMS (1997). American Meteorological Society. Meteorological drought - Policy statement. *Bull.Amer. Meteor. Soc. ,* 78**,** 847-849.

Andrews, P., Chalmers, D. and Moremong, M. (1992). Canopy airtemperature differences and soil-water as predictors of waterstress of apple-trees grown in a humid, temperate climate. *American society of horticultural science,* 117**,** 453-458.

Aquastress (2008). Water saving in agriculture, industry and economic instruments, Part A – Agriculture. *Global Change and Ecosystems.*

Araujo, P., Astray, G., Ferrerio-Lage, J. A., Mejuto, J. C., Rodriguez-Suarez, J. A. and Soto, B. (2010). Multilayer perceptron neural network for flow prediction. *Journal of Environmental Monitoring,* 13**,** 35-41.

ASCE-EWRI (2004). The ASCE standardized reference evapotranspiration equation. Environmental and Water Resources Institute of the ASCE, Report by the Task Committee on Standardization of Reference Evapotranspiration.

Bahrainy, H. (2003). Natural Disaster Management in Iran during the 1990s—Need for a New Structure. *Urban Plng. and Devel.,* 129**,** 140-160.

Barreto, A., Arbelo, M., Pedro, A. H., Laia, N.-C., L., Mira, M. and Coll, C. (2010). Evaluation of surface temperature and emissivity derived from ASTER data: A case study using ground-based measurements at a volcanic site. *Journal of Atmospheric and Oceanic Technology,* 27**,** 1677-1688.

Bastiaanssen, W. G. M. (1995). *Regionalization of surface flux densities and moisture indicators in composite terrain. A remote sensing approach under clear skies in Mediterranean climates.* PhD, Agricultural University of Wageningen.

Bastiaanssen, W. G. M. (2000). SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. *Hydrology,* 229**,** 87-100.

Bastiaanssen, W. G. M. (2005). 2nd red river basin sector project part 2. wageningen: water watch,.

Bastiaanssen, W. G. M., Allen, R., Ralf, W., Tasumi, M. and Trezza, R. (2002). SEBAL advance training and user manual. Idaho.

Bastiaanssen, W. G. M., Brito, R. A. L., Bos, M. G., Souza, R. A., Cavalcanti, E. B. and Bakker, M. M. (2001). Low Cost Satellite Data for Monthly Irrigation Performance Monitoring: Benchmarks from Nilo Coelho, Brazil. *Irrigation and Drainage Systems,* 15**,** 53-79.

Bastiaanssen, W. G. M., Menenti, M., Feddes, R. A. and Holtslag, A. A. M. (1998). A remote sensing surface energy balance algorithm for land (SEBAL): 1. Formulation. *Journal of Hydrology,* 212-213**,** 198-212.

Bastiaanssen, W. G. M., Molden, D. J. and Makin, I. W. (2000). Remote sensing for irrigated agriculture: examples from research and possible applications. *Agricultural Water Management,* 46**,** 137-155.

Bastiaanssen, W. G. M., Noordman, E. J. M., Pelgrum, H., Davids, G., Thoreson, B. P. and Allen, R. G. (2005). SEBAL model with remotely sensed data to improve water-resources management under actual field conditions. *Journal of Irrigation and Drainage Engineering,* 131**,** 85-93.

Bastiaanssen, W. G. M., Pelgrum, H., Soppe, R. W. O., Thoreson, B. P., Allen, R. G. and Teixeira, A. H. D. C. (2008). Thermal-infrared technology for local and regional scale irrigation analyses in horticultural systems. *Acta Horticulturae.*

Behboudian, M. H., Walker, R. R. and Törökfalvy, E. (1986). Effects of water stress and salinity on photosynthesis of pistachio. *Scientia Horticulturae,* 29**,** 251-261.

Benson, B. J. and MacKenzie, M. D. (1995). Effects of sensor spatial resolution on landscape structure parameters. *Landscape Ecology,* 10, 113-120.

Berni, J. A. J., Zarco-Tejada, P. J., Sepulcre-Cantó, G., Fereres, E. and Villalobos, F. (2009). Mapping canopy conductance and CWSI in olive orchards using high resolution thermal remote sensing imagery. *Remote Sensing of Environment,* 113, 2380-2388.

Bhuiyan, C., Singh, R. P. and Kogan, F. N. (2006). Monitoring drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. *International Journal of Applied Earth Observation and Geoinformation,* 8, 289-302.

Bordi, I. and Sutera, A. (2007). *Methods and tools for drought analusis and management; Drought Monitoring and forecasting at larg scale*: Springer.

Brown, J., Wardlow, B., Tadesse, T., Hayes, M. and Reed, B. (2008). The Vegetation Drought Response Index (VegDRI): A New Integrated Approach for Monitoring Drought Stress in Vegetation. *GIScience & Remote Sensing,* 45, 16-46.

Bruno, G.-D., Girel, J., Chassery, J.-M. and Pautou, G. (1996). The use of Multiresolution Analysis and Wavelet transform for Merging SPOT Panchromatic and Multispectral Image data. *Photogrammetric Engineering & Remote Sensing,* 62, 1057-1066.

Brutsaert, W. (1982). *Evaporation into the Atmosphere: Theory, History and Applications,* Boston Kluwer Academic

Burrus, C. S., Gopinath, R. A. and Guo, H. (1998). *Introduction to Wavelets and Wavelet Transforms: A Primer,* Newjersy: Prentice Hall.

Byun, H. R. and Wilhite, D. A. (1999). Objective quantification of drought severity and duration. *Journal of Climate,* 12**,** 2747-2756.

C.E.A.I (2003). Borkhar baisin studies. Isfahan: Agricultur and natural resources ministry.

Calcagno, G., Mendicino, G., Monacelli, G., Senatore, A. and Versace, p. (eds.) (2007). *Method and tools for drought analysis and management; Distributed estimation of actual evapotranspiration through remote sensing techniques*: Springer.

Campbell, G. S. and Norman, J. M. (1998). *An Introduction to Environmental Biophysics*: Springer; 2nd edition.

Cerdena, A., Gonzalez, A. and Perez, J. C. (2007). Remote Sensing of Water Cloud Parameters Using Neural Networks. *Journal of Atmospheric and Oceanic Technology,* 24**,** 52-63.

Chattopadhyay, S., Jain, R. and Chattopadhyay, G. (2009). Estimating potential evapotranspiration from limited weather data over Gangetic West Bengal, India: a neurocomputing approach. *Meteorological Applications,* 16**,** 403-411.

Chauhan, S. and Shrivastava, R. (2009a). Performance Evaluation of Reference Evapotranspiration Estimation Using Climate Based Methods and Artificial Neural Networks. *Water Resources Management,* 23**,** 825-837.

Chauhan, S. and Shrivastava, R. (2009b). Reference evapotranspiration forecasting using different artificial neural networks algorithm. *Canadian Journal of Civil engineering,* 36**,** 1491-1505.

Chauhan, S. and Shrivastava, R. K. (2009c). Reference evapotranspiration forecasting using different artificial neural networks algorithms. *Canadian Journal of Civil Engineering,* 36**,** 1491-1505.

Chavez, J. L., Gowda, P. H., Howell, T. A. and Copeland, K. S. (2009). Radiometric surface temperature calibration effects on satellite based evapotranspiration estimation. *International Journal of Remote Sensing,* 30**,** 2337 - 2354.

Chavez, J. L., Gowda, P. H., Howell, T. A., Marek, T. H. and New, L. L. (2007). Evapotranspiration mapping using METRIC for a region with highly advective conditions. *ASABE Annual International Meeting, Technical Papers*.

Chen, B., Ge, Q., Fu, D., Liu, G., Yu, G., Sun, X., Wang, S. and Wang, H. (2009). Upscaling of gross ecosystem production to the landscape scale using multi-temporal Landsat images, eddy covariance measurements and a footprint model. *Biogeosciences Discussions,* 6**,** 11317-11345.

Choi, M., Kustas, W. P., Anderson, M. C., Allen, R. G., Li, F. and Kjaersgaard, J. H. (2009). An intercomparison of three remote sensing-based surface energy balance algorithms over a corn and soybean production region (Iowa, U.S.) during SMACEX. *Agricultural and Forest Meteorology,* 149**,** 2082-2097.

Congalton, R. (2010). Remote Sensing: An Overview. *GIScience & Remote Sensing,* 47**,** 443-459.

Conrad, C., Dech, S., Hafeez, M., Lamers, J., Martius, C. and Strunz, G. (2007). Mapping and assessing water use in a Central Asian irrigation system by utilizing MODIS remote sensing products. *Irrigation and Drainage Systems,* 21**,** 197-218.

Crago, R. and Brutsaert, W. (1996). Daytime evaporation and the self-preservation of the evaporative fraction and the Bowen ratio. *Journal of Hydrology,* 178, 241-255.

CRED-CRUNCH (2006). Disaster Data: A Balanced Perspective. 15.4.2010.

Dai, X., Shi, H., Li, Y., Ouyang, Z. and Huo, Z. (2009). Artificial neural network models for estimating regional reference evapotranspiration based on climate factors. *Hydrological Processes,* 23, 442-450.

DeCoster, J. (1998). *Overview of Factor Analysis, Theoretical Introduction,* Alabama.

Domenikiotis, C., A. Loukas and N. R. Dalezios (2003). The use of NOAA/AVHRR satellite data for monitoring and assessment of forest fires and floods. *Natural Hazards and Earth System Sciences,* 3, 115-128.

Domenikiotis, C., Spiliotopoulos, M., Tsiros, E. and Dalezios, N. R. (2004). Early cotton production assessment in Greece based on a combination of the drought Vegetation Condition Index (VCI) and the Bhalme and Mooley Drought Index (BMDI). *International Journal of Remote Sensing,* 25, 5373-5388.

Donald, A., Wilhite, M. V. K. and Svoboda (2000). Drought early warning system in the Context of Drought Preparedness and Mitigation. Lisbon, Portugal.: World Meteorological Organization.

Doraiswamy, P., Akhmedov, B., Milak, S., Stern, A., : the next generation, J. and 6–11, B., MA, USA. (2008). Remote sensing and modelling methods for crop grain yield assessment. *Proceedings of IEEE on IGARSS, Geosciences and Remote Sensing*, july 6-11 Boston, MA,USA.

Dracup, J. A., Kil Seong, L. and Paulson Jr, E. G. (1980). On the definition of droughts. *Water Resources Research,* 16**,** 297-302.

Duchemin, B., Hadria, R., Erraki, S., Boulet, G., Maisongrande, P., Chehbouni, A., Escadafal, R., Ezzahar, J., Hoedjes, J. C. B., Kharrou, M. H., Khabba, S., Mougenot, B., Olioso, A., Rodriguez, J. C. and Simonneaux, V. (2006). Monitoring wheat phenology and irrigation in Central Morocco: On the use of relationships between evapotranspiration, crops coefficients, leaf area index and remotely-sensed vegetation indices. *Agricultural Water Management,* 79**,** 1-27.

ERSDAC (2010). *Earth Remote Sensing Data Analysis Center* [Online]. Available: http://www.science.aster.ersdac.or.jp/t/en/about_aster/swir_en.pdf.

FAO56 (1998). Crop evapotranspiration, guidline for computing crop water requirement,Chapter 2 - FAO Penman-Monteith equation. 1998 ed.: FAO.

Fisher, S., Kramer, Chin, Mayo and Palmer, R. N. (1997). Managing water supplies during drought: Triggers for operational responses. University of Washington.

Folhes, M. T., Renn', C. D. and Soares, J. V. (2009). Remote sensing for irrigation water management in the semi-arid Northeast of Brazil. *Agricultural Water Management,* 96**,** 1398-1408.

Frank, T. D. and Tweddale, S. A. (2006). The effect of spatial resolution on measurement of vegetation cover in three Mojave Desert shrub communities. *Journal of Arid Environments,* 67**,** 88-99.

Franke, J. and Menz, G. (2007). Multi-temporal wheat disease detection by multi-spectral remote sensing. *Precision Agriculture,* 8**,** 161-172.

Fujisada, H. and Ono, A. (1991). Overview of ASTER design concept. SPIE, 244-268.

Gangkofner, U. G., Pradhan, P. S. and Holcomb, D. W. (2008). Optimizing the high-pass filter addition technique for image fusion. *Photogrammetric Engineering and Remote Sensing,* 74**,** 1107-1118.

Gao, Y. and Long, D. (2008). Intercomparison of remote sensing-based models for estimation of evapotranspiration and accuracy assessment based on SWAT. *Hydrological Processes,* 22**,** 4850-4869.

Garrot, D., Kilby, M., Fangmeier, D., Husman, S. and Ralowicz, A. (1993). Production, growth, and nut quality in pecans under water-stress based on the crop water-stress index. *American society of horticultural science,* 118**,** 694-698.

GLCF (2004). LANDSAT Technical Guide. University of Maryland. www.glcf.umd.edu/library/guide/techguide_landsat.pdf

Glenn, D., Worthington, J., Welker, W. and McFarland, M. (1989). Estimation of peach tree water use using infrared thermometry. *American society of horticultural science,* 114**,** 737-741.

Goetz, S. J., Fiske, G. J. and Bunn, A. G. (2006). Using satellite time-series data sets to analyze fire disturbance and forest recovery across Canada. *Remote Sensing of Environment,* 101**,** 352-365.

Gontia, N. and Tiwari, K. (2009a). Estimation of Crop Coefficient and Evapotranspiration of Wheat (Triticum aestivum) in an Irrigation Command Using Remote Sensing and GIS. *Water Resources Management,* 24**,** 1399-1414.

Gontia, N. K. and Tiwari, K. N. (2009b). Estimation of Crop Coefficient and Evapotranspiration of Wheat (Triticum aestivum) in an Irrigation Command Using Remote Sensing and GIS. *Water Resour Manage,* 24**,** 1399-1414.

Gonzalez, R. C., Woods, R. E. and Eddins, S. L. (2004). *Digital image processing using MATLAB,* New Jersey: Pearson Prentice Hall

Goward, S. N., Markham, B., Dye, D. G., Dulaney, W. and Yang, J. (1991). Normalized difference vegetation index measurements from the advanced very high resolution radiometer. *Remote Sensing of Environment,* 35**,** 257-277.

Gowda, P., Chavez, J., Colaizzi, P., Evett, S., Howell, T. and Tolk, J. (2007a). Remote Sensing Based Energy Balance Algorithms For Mapping ET: Current Status And Future Challenges. *American Society of Agricultural and Biological Engineers,* 50**,** 1639-1644.

Gowda, P., Chavez, J., Howell, T., Marek, T. and New, L. (2008). Surface Energy Balance Based Evapotranspiration Mapping in the Texas High Plains. *Sensors,* 8**,** 5186-5201.

Gowda, P. H., Chavez, J. L., Colaizzi, P. D., Evett, S. R., Howell, T. A. and Tolk, J. A. (2007b). Remote sensing based energy balance algorithms for mapping ET: Current status and future challenges. *Transactions of the ASABE,* 50**,** 1639-1644.

Griffith, J. A., Stehman, S. V., Sohl, T. L. and Loveland, T. R. (2003). Detecting trends in landscape pattern metrics over a 20-year period using a sampling-based monitoring programme. *International Journal of Remote Sensing,* 24**,** 175-181.

Groten, S. M. E. (1993). NDVI - crop monitoring and early yield assessment of Burkina Faso. *International Journal of Remote Sensing,* 14**,** 1495-1515.

Guo, L. J. and Moore, J. M. (1998). Pixel block intensity modulation: Adding spatial detail to TM band 6 thermal imagery. *International Journal of Remote Sensing,* 19**,** 2477-2491.

Gupta, R. K., Prasad, T. S. and Vijayan, D. (2002). Upscaling aspects of multi-resolution satellite data in spatial and frequency domains. *Advances in Space Research,* 29**,** 57-61.

Haydan, R., Dalke, G. W., Henkel, J. and Bare, J. E. (1982). Applications of the IHS colour transform to the processing of multisensor data and image enhancement. *International Symposium on Remote Sensing of Arid and Semi-arid L ands*, 1982 Cairo, Egypt. 599-616.

Hayes, M. (2009). Drought Indices. National Drought Mitigation Center, university of Nebraska.

Hayes, M. J., Svoboda, M. D., Wilhite, D. A. and Vanyarkho, O. V. (1996). Monitoring the 1996 drought using the standardized precipitation index. American Meteorological Society.

Haykin. S (ed.) (1998). *Neural Networks—A Comprehensive Foundation,* NJ: Prentice-Hall: Upper Saddle River.

Hendrickx, J. M. H., Kleissl, J., Velez, J. D. G., Hong, S.-h., Duque, J. R. F., Vega, D., Ramirez, H. A. M. and Ogden, F. L. (2007). Scintillometer networks for calibration and validation of energy balance and soil moisture remote sensing algorithms. *Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XIII*, 2007 Orlando, FL, USA. SPIE, 65650W-16.

Hong, S.-h., Hendrickx, J. M. H. and Borchers, B. (2009). Up-scaling of SEBAL derived evapotranspiration maps from Landsat (30 m) to MODIS (250 m) scale. *Journal of Hydrology,* 370**,** 122-138.

Hou, Y. Y., He, Y. B., Liu, Q. H. and Tian, G. L. (2007). Research progress on drought indices. *Chinese Journal of Ecology,* 26**,** 892-897.

Huang, J., Chen, D. and Cosh, M. H. (2009). Sub-pixel reflectance unmixing in estimating vegetation water content and dry biomass of corn and soybeans cropland using normalized difference water index (NDWI) from satellites. *International Journal of Remote Sensing,* 30**,** 2075-2104.

Huete, A. R. (1988). A soil adjusted vegetation index (SAVI). *Remote Sensing of Environment,* 25**,** 295-309.

Hufkens, K., Bogaert, J., Dong, Q. H., Lu, L., Huang, C. L., Ma, M. G., Che, T., Li, X., Veroustraete, F. and Ceulemans, R. (2008). Impacts and uncertainties of upscaling of remote-sensing data validation for a semi-arid woodland. *Journal of Arid Environments,* 72**,** 1490-1505.

Idso, S., Reginato, R., Clawson, K. and Anderson, M. (1984). On the stability of non-water-stressed baselines. *Agric For Meteorol,* 32**,** 177-182.

IPCC (2007). Climate Change 2007; Synthesis Report. 12-17 November, Published by the Intergovernmental Panel on Climate Change.

IRIMO (2010). Islamic Republic of Iran Meteorological Organization. (www.irimo.org).

Irmak, A. and Kamble, B. (2009). Evapotranspiration data assimilation with genetic algorithms and SWAP model for on-demand irrigation. *Irrigation Science,* 28**,** 101-112.

Izadifar, Z. and Elshorbagy, A. (2010). Prediction of hourly actual evapotranspiration using neural networks, genetic programming, and statistical models. *Hydrological Processes,* 24**,** 3413-3425.

Jahanbani, H. and El-Shafie, A. H. (2010). Application of artificial neural network in estimating monthly time series reference evapotranspiration with minimum and maximum temperatures. *Paddy Water Environment.*

Jain, S. K., Nayak, P. C. and Sudheer, K. P. (2008). Models for estimating evapotranspiration using artificial neural networks, and their physical interpretation. *Hydrological Processes,* 22**,** 2225-2234.

Jayanthi, H., Neale, C. M. U. and Wright, J. L. (2007). Development and validation of canopy reflectance-based crop coefficient for potato. *Agricultural Water Management,* 88**,** 235-246.

Jolliffe, I. T. (2002). *Principal component analysis,* New York: Springer.

Jones, H. G. (1999). Use of infrared thermometry for estimation of stomatal conductance as a possible aid to irrigation scheduling. *Agricultural and Forest Meteorology*, 139−149.

Kaheil, Y. H., Rosero, E., Gill, M. K., McKee, M. and Bastidas, L. A. (2008). Downscaling and Forecasting of Evapotranspiration Using a Synthetic Model of Wavelets and Support Vector Machines. *Geoscience and Remote Sensing, IEEE Transactions on,* 46**,** 2692-2707.

Kamble, B. and Irmak, A. (2008). Assimilating Remote Sensing-Based ET into SWAP Model for Improved Estimation of Hydrological Predictions. *Geoscience and Remote Sensing Symposium, IGARSS. IEEE International*, 7-11 July 2008, 1036- 1039.

Kanda, M., Inagaki, A., Letzel, M. O., Raasch, S. and Watanabe, T. (2004). Les study of the energy imbalance problem with eddy covariance fluxes. *Boundary-Layer Meteorology,* 110**,** 381-404.

Kim, S. and Kim, H. S. (2008). Neural networks and genetic algorithm approach for nonlinear evaporation and evapotranspiration modeling. *Journal of Hydrology,* 351, 299-317.

King, R. L. and Wang, J. (2001). A wavelet based algorithm for pan sharpening Landsat 7 imagery. *Geoscience and Remote Sensing Symposium, IGARSS '01. IEEE 2001 International*, 849-851 vol.2.

Kisi, O. (2006). Evapotranspiration estimation using feed-forward neural networks. *Nordic Hydrology,* 37, 247-260.

Kisi, O. (2007). Evapotranspiration modelling from climatic data using a neural computing technique. *Hydrological Processes,* 21, 1925-1934.

Kisi, O. (2008). The potential of different ANN techniques in evapotranspiration modelling. *Hydrological Processes,* 22, 2449-2460.

Kisi, O. (2010). Fuzzy Genetic Approach for Modeling Reference Evapotranspiration. *Journal of Irrigation and Drainage Engineering,* 136, 175-183.

Kisi, O. and Guven, A. (2010). Evapotranspiration Modeling Using Linear Genetic Programming Technique. *Journal of Irrigation and Drainage Engineering,* 136, 715-723.

Kjaersgaard, J. H., Allen, R. G., Garcia, M., Kramber, W. and Trezza, R. (2009a). Automated Selection of Anchor Pixels for Landsat Based Evapotranspiration Estimation. 2009a of Conference Kansas City, Missouri. ASCE, 342, 442-442.

Kjaersgaard, J. H., Gowda, P. H., Allen, R. G. and Howell, T. A. (2009). Independent Comparisons among Calibration and Output of Energy Balance

Components Estimated by the METRIC Procedure. 2009b Kansas City, Missouri. ASCE, 438-438.

Kogan, F. N. (1990). Remote sensing of weather impacts on vegetation in non-homogeneous areas. *International Journal of Remote Sensing,* 11**,** 1405 - 1419.

Kogan, F. N. (1995). Application of vegetation index and brightness temperature for drought detection. *Advances in Space Research,* 15**,** 91-100.

Kogan, F. N. (2000). Contribution of Remote Sensing to Drought Early Warning, Geneva. World Meteorological Organization, 75-87.

Kojima, N., Laba, M., Velez Liendo, X. M., Bradley, A. V., Millington, A. C. and Baveye, P. (2006). Causes of the apparent scale independence of fractal indices associated with forest fragmentation in Bolivia. *ISPRS Journal of Photogrammetry and Remote Sensing,* 61**,** 84-94.

Krose, B. (ed.) (1996). *An Introduction to Neural Networks,* Amsterdam: The University of Amsterdam.

Kumar, M., Bandyopadhyay, A., Raghuwanshi, N. and Singh, R. (2008). Comparative study of conventional and artificial neural network-based ETo estimation models. *Irrigation Science,* 26**,** 531-545.

Kumar, M., Raghuwanshi, N. and Singh, R. (2010). Artificial neural networks approach in evapotranspiration modeling: a review. *Irrigation Science,* 29**,** 11-25.

Kumar, M., Raghuwanshi, N. S., Singh, R., Wallender, W. W. and Pruitt, W. O. (2002). Estimating Evapotranspiration using Artificial Neural Network. *Journal of Irrigation and Drainage Engineering,* 128**,** 224-233.

Kustas, W. P., Perry, E. M., Doraiswamy, P. C. and Moran, M. S. (1994). Using satellite remote sensing to extrapolate evapotranspiration estimates in time and space over a semiarid Rangeland basin. *Remote Sensing of Environment,* 49**,** 275-286.

Lagouarde, J.-P. (1991). Use of NOAA AVHRR data combined with an agrometeorological model for evaporation mapping. *International Journal of Remote Sensing,* 12**,** 1853 - 1864.

Laine, B. B. (2004). Satellite remote sensing for estimating leaf area index, FPAR and primary production, A literature review. Stockholm: SwedPower AB.

Landeras, G., Ortiz-Barredo, A. and Lopez, J. J. (2009). Forecasting Weekly Evapotranspiration with ARIMA and Artificial Neural Network Models. *Journal of Irrigation and Drainage Engineering,* 135**,** 323-334.

Laux, P., Wagner, S., Wagner, A., Jacobeit, J., Bلrdossy, A. and Kunstmann, H. (2009). Modelling daily precipitation features in the Volta Basin of West Africa. *International Journal of Climatology,* 29**,** 937-954.

Lee, E. J., Kang, M. S., Park, S. W. and Kim, H. K. (2010). Estimation of future reference evapotranspiration using artificial neural network and climate change scenario. *American Society of Agricultural and Biological Engineers Annual International Meeting 2010.* American Society of Agricultural and Biological 5965-5976.

Leszek, Lstrok, ab, eogon and dzki (2007). Estimation of local drought frequency in central Poland using the standardized precipitation index SPI. *Irrigation and Drainage,* 56**,** 67-77.

Liang, S. (ed.) (2004). *Quantitative Remote Sensing of Land Surface*: Wiley.

Liang, S., Shuey, C. J., Russ, A. L., Fang, H., Chen, M., Walthall, C. L., Daughtry, C. S. T. and Hunt, R. (2003). Narrowband to broadband conversions of land surface albedo: II. Validation. *Remote Sensing of Environment,* 84**,** 25-41.

Lin, M. L., Cao, Y., Juan, C. H., Chen, C. W., Hsueh, I. C., Wang, Q. B. and Lee, Y. T. (2008). Monitoring drought dynamics in the ejin oasis using drought indices from modis data. *International Geoscience and Remote Sensing Symposium (IGARSS)*.

Liu, J. G. (2000). Smoothing Filter-based Intensity Modulation: a spectral preserve image fusion technique for improving spatial details. *International Journal of Remote Sensing,* 21**,** 3461-3472.

Liu, W. T. and Kogan, F. N. (1996). Monitoring regional drought using the Vegetation Condition Index. *International Journal of Remote Sensing,* 17**,** 2761-2782.

Liu, Y., Hiyama, T. and Yamaguchi, Y. (2006). Scaling of land surface temperature using satellite data: A case examination on ASTER and MODIS products over a heterogeneous terrain area. *Remote Sensing of Environment,* 105**,** 115-128.

Livada, I. and Assimakopoulos, V. D. (2007). Spatial and temporal analysis of drought in greece using the Standardized Precipitation Index (SPI). *Theoretical and Applied Climatology,* 89**,** 143-153.

Loukas, A., Vasiliades, L. and Dalezios, N. R. (2003). Inter-comparison of meteorological drought indices for drought assessment and monitoring in Greece. *Proceedings of the 8th International Conference on Environmental Science and Technology*, 2003. 484-491.

Maldonado, J. (2009). Syria tree nuts annual. http://photos.state.gov/libraries/syria/328666/trade_commerce/tree-nuts-annual-damascus-syria-09.pdf

Marti, P. and Gasque, M. a. (2010). Ancillary data supply strategies for improvement of temperature-based ETo ANN models. *Agricultural Water Management,* 97**,** 939-955.

Martí, P., Gonza´lez-Altozano, P. and Gasque, M. a. (2010). Reference evapotranspiration estimation without local climatic data. *Irrigation Science*.

Marti, P., Royuela, A., Manzano, J. and Palau-Salvador, G. (2010). Generalization of ETo ANN Models through Data Supplanting. *Journal of Irrigation and Drainage Engineering,* 136**,** 161-174.

Martyniak, L., Dabrowska-Zielinska, K., Szymczyk, R. and Gruszczynska, M. (2007). Validation of satellite-derived soil-vegetation indices for prognosis of spring cereals yield reduction under drought conditions - Case study from central-western Poland. *Advances in Space Research,* 39**,** 67-72.

Matera, A., Fontana, G., Marletto, V., Zinoni, F., Botarelli, L. and Tomei, F. (eds.) (2007). *Use of a new agricultural drought index within a regional drought observatory,* Dordrecht: Springer, , pp. 103–124.

Melesse, A., M. and Nangia, V. (2005). Estimation of spatially distributed surface energy fluxes using remotely-sensed data for agricultural fields. *Hydrological Processes,* 19**,** 2653-2670.

Mendicino, G., Senatore, A. and Versace, P. (2008). A Groundwater Resource Index (GRI) for drought monitoring and forecasting in a mediterranean climate. *Journal of Hydrology,* 357**,** 282-302.

Meneti, M. and Chodhury, B. J. (1993). Parameterization of land surface evaporation by means of location dependent potential evaporation and surface temperature range. *Exchange Processes at the Land Surface for a Range of Space and Time Scales*, July 1993, Yokohama. IAHS Publ.

Michael, J. (2006). What is Drought?: University of Nebraska. http://drought.unl.edu/DroughtBasics/WhatisDrought.aspx

Mishra, U., Clay, D., Trooien, T., Dalsted, K., Malo, D. and Carlson, C. G. (2008). Assessing the value of using a remote sensing-based evapotranspiration map in site-specific management. *Journal of Plant Nutrition,* 31**,** 1188-1202.

Mohandes, M. A., Halawani, T. O., Rehman, S. and Hussain, A. A. (2004). Support vector machines for wind speed prediction. *Renewable Energy,* 29**,** 939-947.

Mokhtari, M. H. (2006). Agricultural drought impact assessment using remote sensing. MSc. ITC, The Netherlands.

Moreira, E. E., Paulo, A. A., Pereira, L. S. and Mexia, J. T. (2006). Analysis of SPI drought class transitions using loglinear models. *Journal of Hydrology,* 331**,** 349-359.

Muukkonen, P. and Heiskanen, J. (2005). Estimating biomass for boreal forests using ASTER satellite data combined with standwise forest inventory data. *Remote Sensing of Environment,* 99**,** 434-447.

Nageswara Rao, E. E., S.V, S., Ramesh, K. S. and Somashekhar, R. K. (2005). Satellite-Based assessment of agricultural drought in Karnataka state. *Journal of the Indian Society of Remote Sensing,,* 33**,** 6.

Nagler, P. L., Glenn, E. P., Kim, H., Emmerich, W., Scott, R. L., Huxman, T. E. and Huete, A. R. (2007). Relationship between evapotranspiration and precipitation pulses in a semiarid rangeland estimated by moisture flux towers and MODIS vegetation indices. *Journal of Arid Environments,* 70**,** 443-462.

Narasimhan, B. and Srinivasan, R. (2005). Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring. *Agricultural and Forest Meteorology,* 133**,** 69-88.

NASA (2009). Measuring Vegetation, NDVI & EVI. http://earthobservatory.nasa.gov/Features/MeasuringVegetation/

NDMC (2009). Undrestanding and Defining Drought. Nebraska, University of Nebraska.

Norman, J. M., Kustas, W. P. and Humes, K. S. (1995). Source approach for estimating soil and vegetation energy fluxes in observations of directional radiometric surface temperature. *Agricultural and Forest Meteorology,* 77**,** 263-293.

Okamoto, K., Yamakawa, S. and Kawashima, H. (1998). Estimation of Flood Damage to Rice Productionin Norh korea in 1995. *International Journal of Remote Sensing,* 19**,** 365 - 371.

Olioso, A., Rivalland, V., Faivre, R., Weiss, M., Demarty, J., Wassenaar, T., Baret, F., Cardot, H., Rossello, P., Jacob, F., Hasager, C. B. and Inoue, Y. (2006). Monitoring Evapotranspiration over the Alpilles Test Site by Introducing

Remote Sensing Data at Various Spatial Resolutions into a Dynamic SVAT Model. *Earth Observation for Vegetation Monitoring And Water Management*, Naples (Italy). AIP, 234-241.

Ozdogan, M. (2009). The spatial distribution of crop types from MODIS data: Temporal unmixing using Independent Component Analysis. *Remote Sensing of Environment,* 114**,** 1190-1204.

Ozkan, C., Kisi, O. and Akay, B. (2010). Neural networks with artificial bee colony algorithm for modeling daily reference evapotranspiration. *Irrigation Science*.

Pallant, J. (2007). *SPSS, Survival Manual, A Step by Step Guide to Data Analysis using SPSS for Windows,* McGraw-Hill.

Parasuraman, A., Grewal, D. and Krishnan, R. (eds.) (2004). *Marketing research,* New York, Boston: Houghton Mifflin Company.

Pardo-Iguzquiza, E. and Atkinson, P. M. (2007). Modelling the semivariograms and cross-semivariograms required in downscaling cokriging by numerical convolution-deconvolution. *Computers & Geosciences,* 33**,** 1273-1284.

Pardo-Iguzquiza, E., Atkinson, P. M. and Chica-Olmo, M. (2009). DSCOKRI: A library of computer programs for downscaling cokriging in support of remote sensing applications. *Computers and Geosciences,* 36**,** 881-894.

Pardo-Iguzquiza, E., Chica-Olmo, M. and Atkinson, P. M. (2006). Downscaling cokriging for image sharpening. *Remote Sensing of Environment,* 102**,** 86-98.

Partal, T. (2009). Modelling evapotranspiration using discrete wavelet transform and neural networks. *Hydrological Processes,* 23**,** 3545-3555.

Qin, Q., Ghulam, A., Zhu, L., Wang, L. and Li, J. (2006). Application of Perpendicular Drought Index in the Drought Assessment: A Case Study in Ningxia Huizu Autonomous Region of China Using MODIS Data. *Geoscience and Remote Sensing Symposium. IGARSS. IEEE International Conference on*, July 31 2006-Aug. 4 2006. 3078-3081.

Rahemi, Majid, Esmailpour, Ali, M., Fatemeh, Esmaili Ranjbar, Ali, P. and Mokhtar (2005). Effects of pistachio different rootstocks on maturity, nut quantitative and storage periods. FAO.

Rahimi Khoob, A. (2008). Comparative study of Hargreaves's and artificial neural network's methodologies in estimating reference evapotranspiration in a semiarid environment. *Irrigation Science,* 26**,** 253-259.

Rahimikhoob, A. (2009a). Estimating daily pan evaporation using artificial neural network in a semi-arid environment. *Theoretical and Applied Climatology,* 98**,** 101-105.

Rahimikhoob, A. (2009b). Estimation of evapotranspiration based on only air temperature data using artificial neural networks for a subtropical climate in Iran. *Theoretical and Applied Climatology,* 101**,** 83-91.

Rahimzadeh, B., Parinaz., Darvishsefat, A. A., Khalili, A. and Makhdoum, M. F. (2008). Using AVHRR-based vegetation indices for drought monitoring in the Northwest of Iran. *Journal of Arid Environments,* 72**,** 1086-1096.

Rahimzadeh Bajgiran, P., Darvishsefat, A. A., Khalili, A. and Makhdoum, M. F. (2008). Using AVHRR-based vegetation indices for drought monitoring in the Northwest of Iran. *Journal of Arid Environments,* 72**,** 1086-1096.

Ramos, J. G., Cratchley, C. R., Kay, J. A., Casterad, M. A., Martnez-Cob, A. and Domnguez, R. (2009a). Evaluation of satellite evapotranspiration estimates using ground-meteorological data available for the Flumen District into the Ebro Valley of N.E. Spain. *Agricultural Water Management,* 96**,** 638-652.

Ramos, J. G., Cratchley, C. R., Kay, J. A., Casterad, M. A., Martيnez-Cob, A. and Domيnguez, R. (2009b). Evaluation of satellite evapotranspiration estimates using ground-meteorological data available for the Flumen District into the Ebro Valley of N.E. Spain. *Agricultural Water Management,* 96**,** 638-652.

Ranchin, T., Aiazzi, B., Alparone, L., Baronti, S. and Wald, L. (2003). Image fusion - The ARSIS concept and some successful implementation schemes. *ISPRS Journal of Photogrammetry and Remote Sensing,* 58**,** 4-18.

Redmonds, K. T. (2002). The depiction of drought: a commentary. *Bull. Amer. Meteor. Soc,* 83**,** 1143-1147.

Ricchiazzi, P., Yang, S., Gautier, C. and Sowle, D. (1998). SBDART: A Research and Teaching Software Tool for Plane-Parallel Radiative Transfer in the Earth's Atmosphere. *Bulletin of the American Meteorological Society,* 79**,** 2101-2114.

Roerink, G. J., Su, Z. and Menenti, M. (2000). S-SEBI: A simple remote sensing algorithm to estimate the surface energy balance. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans and Atmosphere,* 25**,** 147-157.

Rose, C., Stern, W. and Drummond, J. (1965). Determination of hydraulic conductivity as a function of depth and water content for soil in situ. *Soil Research,* 3**,** 1-9.

Rossi, G., Vega, T. and Bonaccorso, B. (2007). *Methods and tools for drought analysis and management*: Springer.

Samani, Z., Bawazir, A., Bleiweiss, M., Skaggs, R., Longworth, J., Tran, V. and Pinon, A. (2009). Using remote sensing to evaluate the spatial variability of evapotranspiration and crop coefficient in the lower Rio Grande Valley, New Mexico. *Irrigation Science,* 28**,** 93-100.

Sarwar, A. and Bill, R. (2007). Mapping evapotranspiration in the Indus Basin using ASTER data. *International Journal of Remote Sensing,* 28**,** 5037 - 5046.

Saura, S. (2004). Effects of remote sensor spatial resolution and data aggregation on selected fragmentation indices. *Landscape Ecology,* 19**,** 197-209.

Saura, S. and Castro, S. (2007). Scaling functions for landscape pattern metrics derived from remotely sensed data: Are their subpixel estimates really accurate? *ISPRS Journal of Photogrammetry and Remote Sensing,* 62**,** 201-216.

Schmugge, T. J., Kustas, W. P., Ritchie, J. C., Jackson, T. J. and Rango, A. (2002). Remote sensing in hydrology. *Advances in Water Resources,* 25**,** 1367-1385.

Sedaghat (2006). Drought hits pistachio output. *Iran Daily*.

Sellers, P. J. (1985). Canopy reflectance, photosynthesis and transpiration. *International Journal of Remote Sensing,* 6**,** 1335 - 1372.

Sepaskhah, A. and Kashefipour, S. (1994). Relationships between leaf water potential, CWSI, yield and fruit-quality of sweet lime under drip irrigation. *Agricultural Water Management,* 25**,** 13-22.

Shafer, B. A. and Dezman, L. E. (1982). Development of a Surface Water Supply Index (SWSI) to Assess the Severity of Drought Conditions in Snowpack Runoff Areas. *Western Snow Conference*, Colorado State University, Fort Collins. Proc.164-175.

Sharifi, M. A., Bastiaanssen, W. G. M. and Zwart, S. J. (2008). Development of a decision suport system for natural damage assessment based on remote sensing and biophysical models. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*, Beijing ISPRS, 509-513.

Shi, W., Zhu, C., Tian, Y. and Nichol, J. (2005). Wavelet-based image fusion and quality assessment. *International Journal of Applied Earth Observation and Geoinformation,* 6**,** 241-251.

Shi, W., Zhu, C. and Yang, X. (2003). Multi-band wavelet for fusing SPOT panchromatic and multispectral images. *Photogrammetric Engineering and Remote Sensing,* 69**,** 513-520.

Shin, Y., Seguchi, M., Koriyama, M. and Isnansetyo, A. (2010). Estimation of LAI in the forested watershed using ASTER data based on Price's model in summer and winter. *European Journal of Forest Research,* 129**,** 1237-1245.

Smith, D. M. S. and McKeon, G. M. (1998). Assessing the historical frequency of drought events on grazing properties in Australian rangelands. *Agricultural Systems,* 57**,** 271-299.

Stathopoulou, M. and Cartalis, C. (2009). Downscaling AVHRR land surface temperatures for improved surface urban heat island intensity estimation. *Remote Sensing of Environment,* 113**,** 2592-2605.

Stefanov, W. L. and Netzband, M. (2005). Assessment of ASTER land cover and MODIS NDVI data at multiple scales for ecological characterization of an arid urban center. *Remote Sensing of Environment,* 99**,** 31-43.

Steyn, M. R., Steyn.D.A and Hana.M (1997). Pasture status from visible and near infrared radiometric measurement. University of Waikato.

Strang, G. and Nguyen, T. (1996). *Wavelets and Filter Banks* Wellesley-Cambridge Press.

Su, Z. (2002). The Surface Energy Balance System (SEBS) for estimation of turbulent heat fluxes. *Hydrology and Earth System Sciences,* 6**,** 85-100.

Sudheer, K. P., Gosain, A. K. and Ramasastri, K. S. (2003). Estimating Actual Evapotranspiration from Limited Climatic Data Using Neural Computing Technique. *Journal of Irrigation and Drainage Engineering,* 129**,** 214-218.

Tabachnick, B. G. and Fidell, L. S. (eds.) (2007). *Using Multivariate Statistics,* Boston: Pearson Education.

Tan, Y. and Van Cauwenberghe, A. (1999). Neural-network-based d-step-ahead predictors for nonlinear systems with time delay. *Engineering Applications of Artificial Intelligence,* 12**,** 21-35.

Tasumi, M. (2003). *Progress in operational estimation of regional evapotranspiration using satellite imagery.* PhD, University of Idaho.

Tasumi, M., Trezza, R., Allen, R. and Wright, J. (2005). Operational aspects of satellite-based energy balance models for irrigated crops in the semi-arid U.S. *Irrigation and Drainage Systems,* 19**,** 355-376.

Teixeira, A. H. d. C., Bastiaanssen, W. G. M., Ahmad, M. D. and Bos, M. G. (2009). Reviewing SEBAL input parameters for assessing evapotranspiration and water productivity for the Low-Middle São Francisco River basin, Brazil: Part A: Calibration and validation. *Agricultural and Forest Meteorology,* 149**,** 462-476.

Thome, K., Palluconi, F., Takashima, T. and Masuda, K. (1998). Atmospheric correction of ASTER. *Geoscience and Remote Sensing, IEEE Transactions on,* 36**,** 1199-1211.

Thoreson, B., Clark, B., Soppe, R., Keller, A., Bastiaanssen, W. and Eckhardt, J. (2009). Comparison of Evapotranspiration Estimates from Remote Sensing (SEBAL), Water Balance, and Crop Coefficient Approaches. Kansas City, Missouri. ASCE, 437-437.

Tolk, J. A., Evett, S. R. and Howell, T. A. (2006). Advection influences on evapotranspiration of alfalfa in a semiarid climate. *Agronomy Journal,* 98**,** 1646-1654.

Toomanian, N., Gieske, A. S. M. and Akbary, M. (2004). Irrigated area determination by NOAA-Landsat upscaling techniques, Zayandeh River Basin, Isfahan, Iran. *International Journal of Remote Sensing,* 25**,** 4945 - 4960.

Tormann, H. (1986). Canopy temperature as a plant water stress indicator for nectarines. *South African Journal of plant soil,* 3**,** 110-114.

Traore, S., Wang, Y.-M., Kan, C.-E., Kerh, T. and Leu, J. (2010a). A mixture neural methodology for computing rice consumptive water requirements in Fada N'Gourma Region, Eastern Burkina Faso. *Paddy and Water Environment,* 8**,** 165-173.

Traore, S., Wang, Y.-M. and Kerh, T. (2010b). Artificial neural network for modeling reference evapotranspiration complex process in Sudano-Sahelian zone. *Agricultural Water Management,* 97**,** 707-714.

Trezza, R. (2006). Estimation Of Evapotranspiration From Satellite-Based Surface Energy Balance Models For Water Management In The Rio Guarico

Irrigation System, Venezuela. *Earth Observation For Vegetation Monitoring and Water Management*, Naples (Italy). AIP, 162-169.

Tsakiris, G. and Pangalou, D. (2009). Drought Characterisation in the Mediterranean. *Coping with Drought Risk in Agriculture and Water Supply Systems.* 69-80.

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation. *Remote Sensing of Environment,* 8**,** 127-150.

UN/ISDR (2007). Drought Risk Reduction Framework and Practices, Contributing to the Implementation of the Hyogo Framework for Action. Geneva.

UNDP (2003). United Nations Common Country Assessment for the Islamic Republic of Iran. Tehran: The United Nations Country Team in Iran.

Unganai, L. S. and Kogan, F. N. (1998). Drought Monitoring and Corn Yield Estimation in Southern Africa from AVHRR Data. *Remote Sensing of Environment,* 63**,** 219-232.

USDA (1997). Introduction to Risk Management Understanding Agricultural Risks: Production, Marketing, Financial, Legal, Human Resources. United States Department of Agriculture, Risk Management Agency.

Van Der Kwast, J., Timmermans, W., Gieske, A., Su, Z., Olioso, A., Jia, L., Elbers, J., Karssenberg, D. and De Jong, S. (2009). Evaluation of the Surface Energy Balance System (SEBS) applied to ASTER imagery with flux-measurements at the SPARC 2004 site (Barrax, Spain). *Hydrology and Earth System Sciences,* 13**,** 1337-1347.

Vogt, J. V. and Soma, F. (2000). *Drought and Drought Mitigation in Europe*: Kluwer Academic Publisher.

Walter, I. A., Allen, R. G., Elliott, I., R. , Brown, M. E., Jensen, D. P., Mecham, B., Howell, T. A., Snyder, R., Eching, S., Spofford, T., Hattendorf, M., Martin, D., Cuenca, R. H. and Wright, J. L. (2002). ASCE, Standardized Reference Evapotranspiration Equation.

Wang, Q., Tenhunen, J., Dinh, N. Q., Reichstein, M., Vesala, T. and Keronen, P. (2004). Similarities in ground- and satellite-based NDVI time series and their relationship to physiological activity of a Scots pine forest in Finland. *Remote Sensing of Environment,* 93**,** 225-237.

Wang, Q., Watanabe, M., Hayashi, S. and Murakami, S. (2003). Using NOAA AVHRR Data to Assess Flood Damage in China. *Environmental Monitoring and Assessment,* 82**,** 119-148.

Wang, W., Sun, L., Liu, G. and Sun, R. (2008). The comparison of regional evapotranspiration estimation with NOAA/AVHRR and MODIS data. *Remote Sensing for Agriculture, Ecosystems, and Hydrology X*, Cardiff, Wales, United Kingdom. SPIE, 71040L-12.

Wilhite, D., Svoboda, M. and Hayes, M. (2007). Understanding the complex impacts of drought: A key to enhancing drought mitigation and preparedness. *Water Resources Management,* 21**,** 763-774.

Wilhite, D. A. (1992). *Preparing for Drought: A Guidebook for Developing Countries.* Climate Unit, United Nation Environment Program. Nairobi, Kenya, Diane.

Wilhite, D. A. (1993). *Drought Assessment, Management and Planning: Theory and case studies.* Boston, keluwer Academic Publisher.

Wilhite, D. A. (2009). Drought Monitoring as a Component of Drought Preparedness Planning. *Coping with Drought Risk in Agriculture and Water Supply Systems.* 3-19.

Wilhite, D. A. and Glantz, M. H. (1985). Undrestanding the drought phenomenon: The role of definitions. *Water International,* 10**,** 111-120.

Wu, H. and Wilhite, D. (2004). An Operational Agricultural Drought Risk Assessment Model for Nebraska, USA. *Natural Hazards,* 33**,** 1-21.

Xiao, J., Zhuang, Q., Law, B. E., Chen, J., Baldocchi, D. D., Cook, D. R., Oren, R., Richardson, A. D., Wharton, S., Ma, S., Martin, T. A., Verma, S. B., Suyker, A. E., Scott, R. L., Monson, R. K., Litvak, M., Hollinger, D. Y., Sun, G., Davis, K. J., Bolstad, P. V., Burns, S. P., Curtis, P. S., Drake, B. G., Falk, M., Fischer, M. L., Foster, D. R., Gu, L., Hadley, J. L., Katul, G. G., Matamala, R., McNulty, S., Meyers, T. P., Munger, J. W., Noormets, A., Oechel, W. C., Paw U, K. T., Schmid, H. P., Starr, G., Torn, M. S. and Wofsy, S. C. (2010). A continuous measure of gross primary production for the conterminous United States derived from MODIS and AmeriFlux data. *Remote Sensing of Environment,* 114**,** 576-591.

Xiaoqin, D., Haibin, S., Yunsheng, L., Zhu, O. and Zailin, H. (2009). Artificial neural network models for estimating regional reference evapotranspiration based on climate factors. *Hydrological Processes,* 23**,** 442-450.

Yazar, A., Howell, T., Dusek, D. and Copeland, K. (1999). Evaluation of crop water stress index for LEPA irrigated corn. *Irrigation Science,* 18**,** 171-180.

Yocky, D. A. (1996). Multiresolution wavelet decomposition image merger of Landsat Thematic Mapper and SPOT panchromatic data. *Photogrammetric Engineering and Remote Sensing,* 62**,** 1067-1074.

Yu, X. and Ng, C. (2006). An integrated evaluation of landscape change using remote sensing and landscape metrics: A case study of Panyu, Guangzhou. *International Journal of Remote Sensing,* 27**,** 1075-1092.

Zaksek, K. and Schroedter-Homscheidt, M. (2009). Parameterization of air temperature in high temporal and spatial resolution from a combination of the SEVIRI and MODIS instruments. *ISPRS Journal of Photogrammetry and Remote Sensing,* 64**,** 414-421.

Zanetti, S. S., Sousa, E. F., Oliveira, V. P. S., Almeida, F. T. and Bernardo, S. (2007). Estimating Evapotranspiration Using Artificial Neural Network and Minimum Climatological Data. *Journal of Irrigation and Drainage Engineering,* 133**,** 83-89.

Zhang, G., Eddy Patuwo, B. and Y. Hu, M. (1998). Forecasting with artificial neural networks:: The state of the art. *International Journal of Forecasting,* 14**,** 35-62.

Zhang, X., Berhane, T. and Seielstad, G. (*2008*). Comparision of Landsat and MODIS Estimates of Heat Fluxes: Effect of Surface Heterogeniety. *Geoscience and Remote Sensing Symposium,. IGARSS. IEEE International*, 7-11 July 2008. III - 759-III - 762.

Zurita-Milla, R., Kaiser, G., Clevers, J. G. P. W., Schneider, W. and Schaepman, M. E. (2009). Downscaling time series of MERIS full resolution data to monitor vegetation seasonal dynamics. *Remote Sensing of Environment,* 113**,** 1874-1885.