<u>ISTANBUL TECHNICAL UNIVERSITY ★ INFORMATICS INSTITUTE</u>

MAPPING DROUGHT HAZARD USING SPI INDEX AND GIS
(CASE STUDY:FARS PROVINCE , IRAN)

M.Sc. THESIS

Fatemeh BAGHERI

Department of Geographical Information Technologies

Geographical Information Technologies Programme

Thesis Advisor: Assoc. Prof. Dr. Himmet KARAMAN

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ BİLİŞİM ENSTİTÜSÜ

KURAKLIK TEHLİKE HARİTALARININ SPI İNDİSİ VE CBS KULLANILARAK OLUŞTURULMASI (PİLOT ÇALIŞMA: FARS VİLAYETİ, İRAN)

YÜKSEK LİSANS TEZİ

Fatemeh BAGHERI
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Coğrafı Bılgı Teknolojılerı Anabilim Dalı

Coğrafı Bılgı Teknolojılerı Programı

Tez Danışmanı: Doç. Dr. Himmet KARAMAN

MAYIS 2015

Fatemeh-BAGHERI, a **M.Sc.** student of ITU **Informatics Institute** student ID 706131011 successfully defended the **thesis** entitled "**MAPPING DROUGHT HAZARD USING SPI INDEX AND GIS (CASE STUDY:FARS PROVINCE,IRAN)** which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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Date of Submission : 4 May 2015
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To my family,

FOREWORD

I would like to express my gratitude to my advisor, Assoc. Prof. Dr. Himmet KARAMAN for his generous support, professional and skillful guidence, patience. It has been a great experience working with him and many thanks goes to my extended family for their neverending support and encouragement not only during this study but also through my life.

May 2015 Fatemeh BAGHERI

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ABBREVIATIONS

GIS : Geographical Information Systems
SPI : Standardized Precipitation Index
IDW : Inverse Distance Weighted Interpolation
PDSI : Palmer Drought Severity Index
CMI : Crop Moisture Index
SWSI : Surface Water Supply Index
APP : Appendix
FIG : Figure

NOMENCLATURE

pi	annual precipitation in each station
$\overline{p}$	average precipitation in each station
sd	standard deviation of precipitation in each station
i	point
z_i	known value
x_i	location
w_i	weights
d_i	distance
$z(s_i)$	the measured value at the *i*th location
λ_i	an unknown weight for the measured value at the *i*th location
s_0	the prediction location
N	the number of measured values
ωi	weights
x*i*	known data

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MAPPING DROUGHT HAZARD USING SPI INDEX AND GIS (CASE STUDY: FARS PROVINCE, IRAN)

SUMMARY

Drought is one of the main natural hazards affecting the economy and the environment of large areas .Semi-arid and arid regions worldwide regularly confront drought. Some of the potentially significant and far reaching consequences of drought include impacts on: poverty rates, health, ecosystem services, land sustainability, and economic development. Unfortunately, recent climate change models predict that over the next 40 years, semi-arid and arid regions worldwide will experience an increase in the severity and intensity of drought as these regions encounter more aridity and less precipitation. Most populated regions, especially in arid and semi-arid environments, are experiencing substantial conflicts over freshwater resources as governments try to meet agricultural and urban water demands and leave flows for the environment. And while the global supply of freshwater resources has been nearly constant for the last 2,000 years recent predictions from climate change models suggest less precipitation and hence further reductions in freshwater supplies in many of the already water-stressed semi-arid and arid regions worldwide, including parts of the Europe, Africa, Australia, and western United States. Important efforts for developing methodologies to quantify different aspects related to droughts have been made, such as the spatial differences in the drought hazard, the prediction of droughts by means of the use of atmospheric circulation indices and the mitigation of drought effects. However, more efforts have been made to develop drought indices, which allow an earlier identification of droughts, their intensity and surface extent. During the twentieth century, several drought indices were developed, based on different variables and parameters.

Drought indices are very important for monitoring droughts continuously in time and space , and drought early warning systems are based primarily on the information that drought indices provideThe majority of drought indices have a fixed time scale. Some of them have many problems related to calibration and spatial comparability. To solve these problems, scientists developed other indices like the Standardized Precipitation Index (SPI),which can be calculated at different time scales to monitor droughts in the different usable water resources.in recent years, Geographic information system (GIS) has played a key role in studying different types of hazards either natural or man-made.

As well as, Iran is a dry land with very low atmospheric precipitation such that rainfall in Iran is less than one third of the average rainfall throughout the world. Meanwhile, the precipitation time and its place do not conform to an agricultural need which is the main consumer of water in the country. Fars province has had remarkable record in crop production especially wheat yield in the country. On the other hand, comprehensive management and decision making in the field of water resources requires reliable prediction of drought area, duration and severity.

To study drought and mapping this thesis Standardized Precipitation Index (SPI) and spatial interpolation in GIS is used. It is practical and simple method. The base of this index is precipitation. To study the drought, Records from10 stations within the same period of 13 years (1994-2006) and 17 stations within the same period of (2007-2011) in scale of annual. For better results three spatial interpolation is compared and Inverse Distance Weighted (IDW) interpolation is more practical for this study area. The result of analysis, is showed that the least SPI and drought magnitude has happened in Sadedorodzan station , in the north of Fars province for 17 stations between 1994-2011 and 10 stations between 2007-2011. For 10 stations during 1994-2006 ,the least SPI is related to the Lamerd station. Figures that produced by interpolation method between 1994-2011 illustrated that drought was generated in the south and it was rapidly extended to north and northeast and northwest. This prediction is used in Fars province to manage the drought .It is the first attempt of its kind in this region and studying such researches by taking into consideration of climate changes may prove to be useful for regional planners, and policy makers for agricultural and environmental strategies, not only in Southern Iran but also in other countries facing similar problem.

TÜRKÇE TEZ BAŞLIĞI BURAYA YAZILIR

ÖZET

Kuraklık, ekonomi ve çevreyi etkileyen ana doğal tehlikelerden biridir. Dünya çapındaki yarı-çorak ve çorak olarak sınıflandırılan bölgeler, kuraklık düzenli olarak kuraklık ile karşılaşmaktadır. Kuraklığın önemli ve etkin sonuçlarından bazıları, yoksulluk oranu, sağlık, ekosistem servisleri, arazi uygunluğu ve ekonomik gelişme üzerinde etkilere sahiptir.

Ne yazık ki, güncel iklim değişim modelleri önümüzdeki 40 yılda dünya çapında yarı-çorak ve çorak bölgelerdeki olası kuraklığın, bu bölgelerde artacak olan çoraklık ve azalacak olan yağış ile, şiddet ve yoğunluğunun artacağını tahmin etmektedir. Yoğun nüfuslu, özellikle çorak ve yarı-çorak çevrelerdeki hükümetler, tarımsal ve şehir kullanımı için su ihtiyaçlarının karşılanmasında ve çevreye yetecek kadar doğada su bırakılması konusunda, mevcut taze su kaynaklarının kullanımı konusunda çelişki yaşamaktadır.

Bunlara ek olarak, Avrupanın bazı bölgeleri, Afrika, avustralya ve batı Amerika'yı da içeren, zaten su stresinde olan dünya çapında yarı-çorak ve çorak bölgelerde taze su kaynaklarında öngörülen azalma ve iklim değişikliği modellerinde tahmin edilen yağışlardaki azalma ve küresel taze su kaynaklarının yaklaşık 200 yıldır neredeyse sabit olarak kalması da bu konudaki küresel önemi ortaya çıkarmaktadır.

Bu sorunlarla başedebilmek ve kuraklık tehlikesi ile ilgili farklı hususları belirlemek için; kuraklık tehlikesinde mekansal farklılıklar, kuraklığın atmosferik dolaşım indisleri kapsamında tahmini ve kuraklık etkilerinin azaltılması gibi önemli çabalar ve metodolojiler geliştirilmiştir.

Buna çalışmalardan yararlanılarak, daha fazla çaba kuraklık indisleri geliştirmek için harcanmıştır. Kuraklık indisleri, kuraklık tehlikesinin daha erken tanımlanması ile yoğunluğunun ve yüzey dağılımının belirlenip tahmin edilmesini sağlamaktadır. Yirminci yüzyıl boyunca, farklı değişkenler ve parametrelere göre birçok kuraklık indisi geliştirilmiştir.

Kuraklık indislerinin kuraklığın zaman ve mekana bağlı olarak izlenmesinde önemi büyüktür. Kuraklık erke uyarı sistemleri temel olarak kuraklık indislerinin sağladığı bilgiye kullanırlar. Kuraklık indislerinin büyük çoğunluğu sabit bir zaman ölçeği kullanır.

Fakat bazı sabit zaman ölçekli kuraklık indisleri, kalibrasyon ve mekansal karşılaştırma konusunda birçok probleme neden olmaktadır. Bu tür karşılaştırma problemlerin çözümü için bilimadamları, farklı zaman ölçeklerinde hesaplanabilen, farklı kullanılabilir su kaynakları için uygulanabilen standartlaştırılmış kuraklık indisi (SPI) olarak tanımlanan farklı indisler geliştirdiler.

Coğrafi Bilgi Sistemleri (CBS) doğal ya da insan kaynaklı farklı tür tehlikelerinçalışılmasında ise büyük rol oynamaktadır. Bu tehlikelerden biri de kuraklıktır.

Kuraklık tehlikesinin izlenmesi ve ileriye dönük öngörüsünün yapılabilmesi için CBS ile birlikte kullanılabilecek ve coğrafi bilgi sistemine entegre edilebilecek algoritmalara ihtiyacı vardır. SPI ise kuraklık tehlikesinin izlenip ileri dönem olası kuraklıkların tahmini için CBS ile kullanılmasında önemli bir algoritma sağlamaktadır.

Çalışma bölgesi olan Iran da çok düşük atmosferik yağış oranına ssahip olan kuru bir bölgedir. Örnek olarak İran'daki ortalama yağış oranı, dünyadaki ortalama yağuş oranının üçte birinden daha azdır. Buunla birlikte, yağış zamanları ve mekanları, suyun ülkedeki ana tüketicisi olan tarım ihtiyaçlarını da karşılayamamaktadır. İran'daki Fars vilayeti, şimdiye kadar mısır üretimde ve özellikle buğday mahsulünde dikkate değer sonuçlara erişmiş bir vilayettir.

Fakat diğer bir yandan, bölgede günümüzde görülmeye başlanan kuraklık, bölgeye ait kapsamlı bir su kaynakları yönetimi ve karar destek sistemi ile güvenilir bir kuraklık bölgesi, kuraklık süresi ve kuraklık şiddeti tahmini çalışmasını gerektirmektedir.

Bu tez çalışmasında kuraklık tehlikesini çalışmak ve haritalandırmak için Standartlaştırılmış Kuraklık İndisi (SPI) ve Coğrafi Bilgi Sistemleri ile mekansal enterpolasyon analizleri kullanılmıştır.

Bu yöntemlerin seçilme nedenleri daha önce de bahsedildiği gibi pratik ve efektif sonuç veren basit yöntemler olmasıdır. Bu çalışmada kullanılan indisleme yönetminin temeli yağış miktarıdır.

Bu tezde kuraklık tehlikesini çalışmak için, Fars vilayetindeki 10 istasyondan elde edilen aynı zaman periyodunda 13 yıllık (1994-2006) ve 17 istasyondan aynı zaman periyodunda elde edilen 5 yıllık (2007-2011) yağış verileri kullanılmıştır.

Tezde yapılan çalışmada daha iyi sonuç elde edebilmek için üç farklı mekansal enterpolasyon modeli kullanılmış ve karşılaştırılmıştır. Bu üç modelden en iyi sonucu veren ağırlıklandırılmış ters uzaklık (Inverse Distance Weighted – IDW) yöntemi çalışma bölgesi için seçilmiştir.

Analizler sonunda en düşük SPI değeri ve kuraklık büyüklüğü Fars vilayetinin kuzey bölgesindeki Sadedorodzan istasyonunda görülmekte olduğu hem 1994-2011 yılları arasında 17 istasyondaki veriler hem de 2007-2011 yılları arasında 10 istasyondaki veriler göz önüne alındığında belirlenmiştir. 1994-2006 yılları arasında veri temin edilen 10 istasyonda ise en düşük SPI değerleri Lamerd istasyonunda görülmektedir. 1994'ten 2011'e kadar yapılan enterpolasyon analizleri sonucunda elde edilen haritalar göstermektedir ki, Fars vilayetinde kuraklık güneyde başlamış ve hızlı bir şekilde önce kuzeye, sonra sırasıyla kuzeydoğu ve kuzeybatıya yayılmıştır. Bu belirlenen hareket Fars vilayetinde kuraklığın tahmini ve yönetimi amacıyla kullanılacaktır.

Bu tez çalışması, Fars bölgesi için kuraklık tehlikesi konusunda yapılan ilk uygulamadır. Çalışma kapsamında elde edilen sonuçlar ve yöntem, iklim değişikliğinin bölgesel şehir planlamacılar, tarımsal ve çevresel stratejiler konusundaki karar vericiler için kullanışlı ve faydalı olduğunu göstermektedir. Bu sonuçlar ve yöntem, sadece Güney İran için değil aynı kuraklık tehlikesi problemini yaşayan diğer ülke ve bölgeler için de kullanışlı olacaktır.

1.INTRODUCTION

Drought is considered by many to be the most complex but least understood of all natural hazards affecting more people than another hazard. However, there remains much confusion within the scientific and policy making community about its characteristics. Drought can be considered to be essentially a climatic phenomenon related to an abnormal decrease in precipitation [35]. Drought is a slow-onset, creeping natural hazard that is a normal part of climate for virtually all regions of the world. It is results in serious economic ,social and environmental impacts. Drought onset and end are often difficult to determine, as its severity . The impacts of drought are largely non-structural and spread over a larger geographical area than are damages from other natural hazards. The non-structural characteristic of drought impacts has a certainly hindered the development of accurate reliable and timely estimate of severity and, ultimately, the formulation of drought preparedness plans by most government [23]. Hence, recent droughts may be one of the factors that causes the problems in water resources but the role of other factors such as lack of proper and appropriate management and also increasing demand for water due to population growth should be taken into serious [54]. It is critical for drought-prone regions to better understand their drought climatology and establish comprehensive and integrated drought information system that incorporate climate, soil and water supply factors such as precipitation, temperature, soil moisture, snowpack, ground water level and stream flow.

Water is the most important limiting factor for agricultural development in Iran. On the other hand comprehensive management and decision making in the field of water resources require reliable prediction of drought area, duration and severity. Drought area variation is one of the subjects that has not been fully considered in Iran despite its importance and effects on human life and environmental management [4].

1.1 Purpose of Thesis

The objective of this study was analyzing spatial pattern of drought by SPI index. According to the data of 10 stations within the same period of 13 years (1994-2006) and 17 stations within the same period of (2007-2011) in scale of annual. Fars Province located in the southern Iran. The pattern of drought hazard are evaluated. Influenced zone of each station was specified by Inverse distance weighted interpolation (IDW) method. It was attempted to make a new model of drought hazard using GIS. The criteria for drought was studied and considered to define areas under vulnerability. Each of the vulnerability indicator map and also final hazard map are classified into nine hazard classes of drought based on SPI value: extrememely humid, very humid,moderately humid, lightly humid, normal, lightly drought, moderate drought, severe drought, extreme drought. The final hazard classes were defined on the basis of hazard scores arrived at by using the geometric mean of the main indicators, deploying the new model. The final vulnerability map shows that extreme hazard areas are much widespread than areas under severe hazard which are observed in the north and south parts of the region.

1.2 Drought As a Natural Hazard

Drought may be considered in general terms a consequence of a reduction over an extended period of time in the amount of precipitation that is received, usually over a season or more in length. It is a temporary aberration, unlike aridity, which is a permanent feature of the climate. Seasonal aridity also needs to be distinguished from drought. It should be noted that drought is a normal, recurrent feature of climate. Most other natural hazards such as cyclones, floods, earthquakes, volcanic eruptions, and tsunamis, are quick onset events that typically result in immediate and structural effects [1]. Further, drought is expected to become more frequent and severe, with increasing water demand due to population growth, limited and uncertain water supplies due to climate change and variability [13,14]. Hydrological extremes (floods and droughts) are natural hazards that are not confined to specific regions, but occur worldwide and, therefore, impact a very large number of people [2]. Drought events, also called ‘the creeping disaster’ [3,4], have a much larger spatial and temporal scale than floods. Droughts can cover extensive areas and can last for months to years, with devastating impacts on many economic sectors [5].

Drought can damage many sectors such as crop production (irrigation), waterborne transportation, nature (forest fires), electricity production (hydropower or cooling water), and recreation (water quality) [5,6]. In other words, Droughts have been a part of our environment since the beginning of recorded history, and humanity's survival may be testimony only to its capacity to endure this climatic phenomenon. [15]. Drought differs from other natural hazards (floods, tropical cyclones, and earthquakes) in several ways. First, since the effects of drought often accumulate slowly over a considerable period of time and may linger for years after the termination of the event, a drought's onset and end are difficult to determine. Because of this, drought is often referred to as a "creeping phenomenon" [17]. Second, the absence of a precise and universally accepted definition of drought adds to the confusion about whether or not a drought exists and, if it does, its degree of severity. Realistically, definitions of drought must be region and application (or impact) specific. This is one explanation for the scores of definitions that have been developed. Unfortunately, many of these definitions have not adequately defined drought in meaningful terms for scientists and policy makers. This is the result, at least in part, of misunderstandings of the concept by those formulating definitions. Third, drought impacts are less obvious and are spread over a larger geographical area than are damages that result from other natural hazards. Drought seldom results in structural damage. For these reasons, the quantification of impacts and the provision of disaster relief are far more difficult tasks for drought than they are for other natural hazards. These characteristics have hindered the development of accurate, reliable, and timely estimates of drought severity and impacts and, ultimately, the formulation of drought contingency plans by most governments. Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length. Although other climatic factors (such as high temperatures, high winds, and low relative humidity) are often associated with it in many regions of the world and can significantly aggravate the severity of the event. Drought is also related to the timing principal season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to principal crop growth stages) and the effectiveness of the rains [16]. In the period 1900–2010, worldwide 2 billion people were affected and more than 10 million people died due to the impacts of drought [7]. Currently, there is increasing awareness of drought and related hazards (heat waves and wildfires), resulting in more research on the topic [3] and increasing efforts to inform the general public via, for example, the European Drought Centre [81] , the European Drought Observatory [82] , and the Global Drought Monitor [83]. In recent years, many severe drought events occurred. In 2012, a drought in central and southern USA and Russia induced an increase in food prices. In spring 2011, Western Europe faced severe water shortage. In 2011, a drought triggered hunger, mass migration, and loss of life in the Horn of Africa [8]. In 2010 and 2011,Russia experienced a drought [9]. In 2010, large parts of China were affected by drought, hampering food production on a large scale [10]. In 2005 and 2010, the Amazon rain forest was affected by a severe lack of precipitation, resulting in a massive dying of vegetation and release of CO_2 into the atmosphere [11]. In 2003 and 2006, Europe was hit by a drought that caused crop failure, navigation problems, cooling water restrictions, and loss of life [12]. Drought severity is dependent not only on the duration, intensity, and geographical extent of a specific drought episode, but also on the demands made by human activities and vegetation on a region's water supplies. The characteristics of drought, along with its far-reaching impacts. Make its effects on society, economy, and environment difficult, though not impossible, to identify and quantify. The significance of drought should not be divorced from its societal context [16]. The impact of a drought depends largely on societal vulnerability at that particular moment. Subsequent droughts in the same region will have different effects, even if they are identical in intensity, duration, and spatial characteristics and the ability to cope with drought also varies from country to country and from one region, community or population group to another [16,1]. Bryant (1991) ranked hazard events based on their characteristics and impacts. Key hazard characteristics used for ranking included the degree of severity, the length of event, total areal extent, total loss of life, total economic loss, social effect, long-term impact, suddenness, and occurrence of associated hazards. It was found that drought stood first based on most of the hazard characteristics. Other natural hazards, which followed droughts in terms of their rank, are tropical cyclones, regional floods, earthquakes, and volcanoes [3]. Design of mitigation strategies to cope with drought is essential to alleviate many economic, social and environmental problems in different parts of the world [28].

1.3 Definitons

As drought definitions are region specific, reflecting differences in climatic characteristics as well as incorporating different physical, biological and socio-economic variables, it is usually difficult to transfer definitions for one region to another. However some of the common definitions of drought can be noted as under:

Drought is a complex phenomenon and is therefore defined in many ways [3]. It is the consequence of a natural reduction in the amount of precipitation over extended period of time, usually a season or more in length, often associated with other climatic factors (such as high temperatures, high winds and low relative humidity) that can aggravate the severity of the event.

It is a normal event that takes place in almost every climate on Earth, even the rainy ones. Drought manifestation varies from region to region and therefore a global definition is a difficult task .

Drought is a recurring extreme climate event over land characterized by below-normal precipitation over a period of months to years. Drought is a temporary dry period, in contrast to the permanent aridity in arid areas. It occurs over most parts of the world, even in wet and humid regions. This is because drought is defined as a dry spell relative to its local normal condition.

On the other hand, arid areas are prone to drought because their rainfall amount critically depends on a few rainfall events [15]. When defining a drought it is important to distinguish between conceptual and operational definitions. Conceptual definitions – those stated in relative terms (drought is a long, dry period), whereas operational definitions, on the other hand, attempt to identify the onset, severity, and termination of drought periods. Generally operationally defined droughts can be used to analyze drought frequency, severity, and duration for a given return period [15,77].

1.4 Types of Droughts

Droughts are generally classified into four categories [3,18,23] :

1.4.1 Meteorological drought

It refers to a precipitation deficit, with respect to a specified threshold, caused by variability of precipitation which is also linked to complex geophysical and oceanographic interactions; further, during latest years, meteorological droughts have been even more recurrent and, as stated "drought is likely to intensify in both duration and severity" due to climate change effects [27].

1.4.2 Soil Moisture drought

It is a deficit of soil moisture, reducing the supply of moisture to vegetation. Soil moisture drought is also called agricultural drought, because it is strongly linked to crop failure [19, 20].

1.4.3 Hydrological drought

Hydrological drought implies deficit of the "normal" water availability in rivers, lakes, groundwater level over large areas. It is characterized by low flows and low levels of surface water (rivers, lakes) and groundwater [3,27]. Although all droughts originate with a deficiency of precipitation, hydrological drought refers to deficiencies in water supply caused by rainfall deficiencies over the watershed or river basin. Hydrological droughts generally lag behind meteorological and agricultural droughts, as it takes longer for precipitation to show up in components of the hydrological system. When precipitation is below average for a long period of time, this is evidenced in declining surface and subsurface water levels, which may vary considerably, based on differing water uses [24].

1.4.4 Socio-economic drought

It is associated with the impacts of the three above-mentioned types. It can refer to a failure of water resources systems to meet water demands and to ecological or health-related impacts of drought [23].

A relationship between the meteorological, agricultural and hydrological droughts can be illustrated from Fig. 1.1 [80].

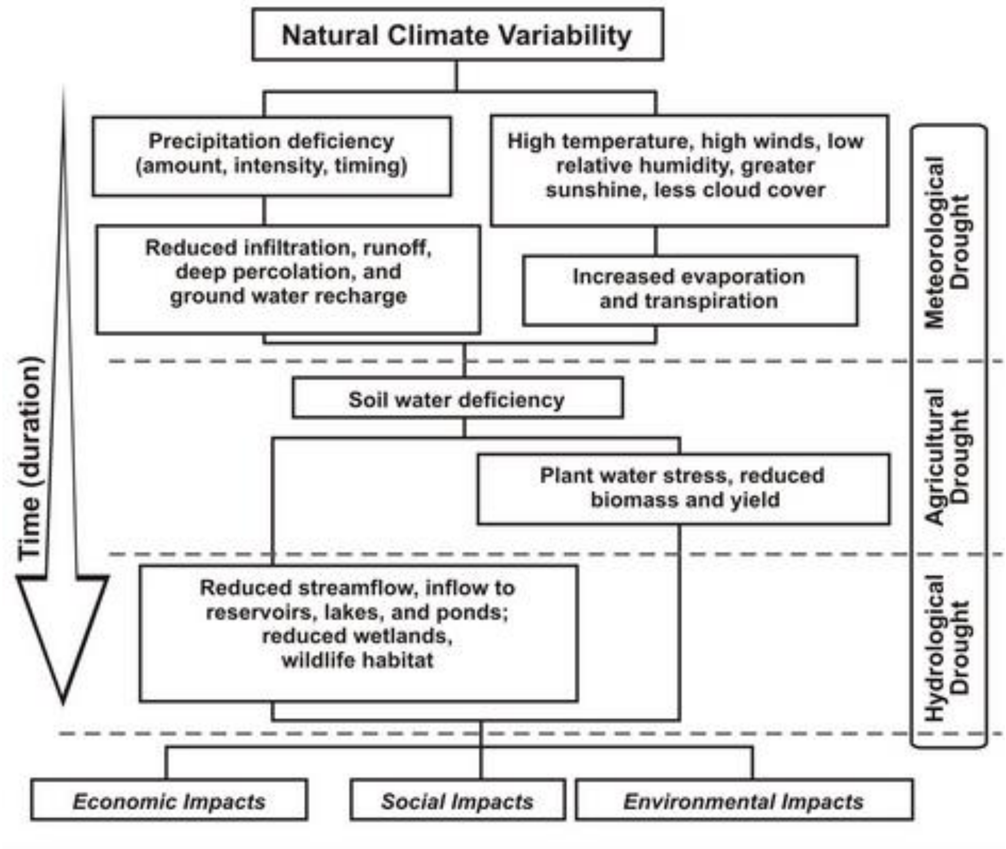


Figure 1.1: Relationship between meteorological, agricultural and hydrological drought [18].

1.5 Drought Propagation

Reasons for the occurrence of hydrological drought are complex, because they are dependentnot only on the atmosphere, but also on the hydrological processes that feed moisture to the mosphere and cause storage of water and runoff to streams [3]. Drought is a period of drier-than-normal conditions that results in water related problems. It is the period when rainfall is less than normal for several weeks, months or years, the flow of streams and rivers declines and water levels in lakes and reservoirs descent and the depth to water in wells increase. If dry weather persists and water-supply problem develops, the dry period can become a drought. The first evidence of drought usually is seen in rainfall records. Within a short period of time, the amount of moisture in soils can begin to decrease. Water levels in wells may or may not reflect a shortage of rainfall for a year or more after a drought begins. That is illustrated in Fig. 1.2 [26]. Light to moderate shower will provide a cosmetic relief and soaking rain alleviate drought and provides some relief to drought areas. Water enters the soil to recharge ground water, which in turn sustains vegetation and feeds streams during periods when it is not raining. Multiple soaking rains break the drought [24]. The depletion of soil moisture storage causes a decreased recharge to the groundwater system, resulting in declining groundwater levels. When pre-event groundwater levels are high, such a decrease has little effect, but when pre-event groundwater levels are low, a hydrological drought can develop. As discharge is strongly linked to storage, low groundwater levels lead to decreased groundwater discharge, which prevents aquifers from further drying, but also causes decreased streamflow [25]. These processes are summarized with the term 'drought propagation', which denotes the change of the drought signal as it moves through the terrestrial part of the hydrological cycle. Famine results from a sequence of processes (natural or man induced) and events that reduces the food availability or food entitlements and causes widespread and substantially increased morbidity and mortality [24].

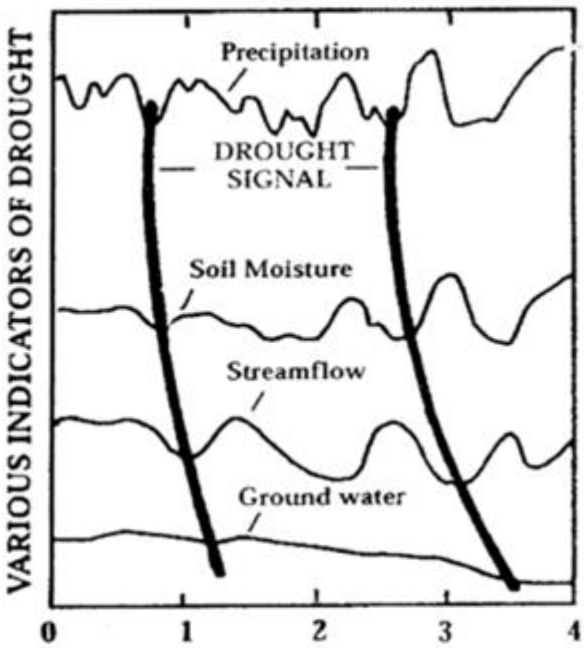


Figure 1.2: Propagation of drought –rainfall to groundwater level [23] .

1.6 Factors Responsible

The factors attributed to drought initiation are: (1) ocean-atmosphere system, sea surface temperature anomalies, high temperature of the soil during drought and the increase in fine particles in the air, the high albedo in dry areas, (2) solar-weather relationship, and (3) monsoon mechanism and impairment of this mechanism [24]. The various factors that are responsible for the drought events are shown in Fig. 1.3.

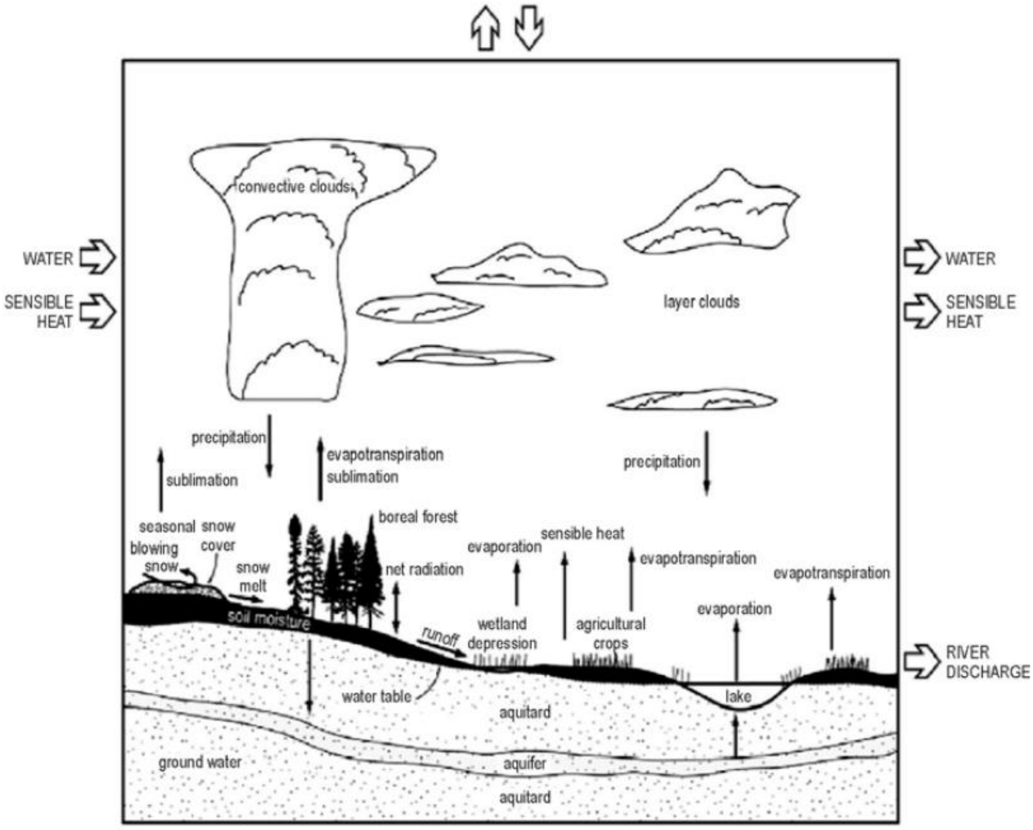


Figure 1.3: Factors responsible for a drought events [24] .

1.6.1 Precipitation

A decreased frequency of precipitation is the climatological factor that causes drought. The strongest drought signals are recognized during the season when the substantial precipitation expected failed to fall .The difference between normal precipitation and deficient precipitation commonly depends on precipitation from few storms. In other words, the lack of few large storms during a season can be sufficient to cause drought [43,34]. The amount of precipitation varies from year to year but over a period of years, the average amount is fairly constant in most of the regions. Normally, the average precipitation in desert is less than three inches per year and coastal areas receive more than 1.50 inches of average yearly rainfall. Even if total amount of rainfall for a year is about average, the rainfall shortages can occur during a period when moisture is critically needed for plant growth. Plants can die when there is no rain or only a very small amount of rainfall [24].

1.6.2 Temperature

Multi-year droughts are generally associated with higher than normal surface air temperatures. In summer, land surface temperatures are linked directly to the availability of moisture [59]. If the soils are wet, then much of the heat from incoming sunlight is used to evaporate water, so temperatures are kept cooler and there is generally more precipitation. But if the soil is dry, then there is little or no water available to evaporate . Consequently, the incoming sunlight can only continue to warm the surface, thereby making conditions hotter and drier, thus beginning the chain of events leading toward drought [44,84].

1.6.3 Wind velocity and evapo-transpiration

The most significant component of the hydrologic budget is evapo-transpiration. It varies regionally and seasonally. It varies according to weather and wind condition. It continues to deplete the limited remaining water supplies in lakes and streams and soil .About 67%, 29%, 2% and 2% is transmitted back through evapo-transpiration, surface water outflow, groundwater outflow and consumptive use of the rainfall respectively. It is not affected by solar radiation, surface area of open bodies of water, wind speed, density and type of vegetative cover, availability of soil moisture, root depth, reflective land-surface characteristics and season of the year [24].

1.6.4 Atmospheric circulation

Heat released from the ocean creates temperature gradients in the atmosphere that cause air currents and because warm water evaporates more readily than cold water, warmer sea surface temperatures contribute to more cloud formation and more rainfall downwind of the general flow of air currents [84].

1.6.5 Hemispheric nature

A climatic perspective on drought is global or at least hemispheric; perspective that includes interactions between the atmosphere and its ocean and land boundaries. The causes of a drought cannot be restricted to the atmosphere above the area affected by a drought only. Day-to-day changes in precipitation, temperature, wind and so forth are defined as weather and not climate. Weather is not predictable even in principle for periods longer than about two weeks [45].

1.7 Impacts of Drought

The impacts of drought can be economic, environmental and social [23,29,32].

It affects several sectors, such as energy production, both in terms of water availability for hydropower and cooling water in electricity generation, river navigation, agriculture, as well as public water supply [22]. Impacts are commonly referred to as direct and indirect. Direct impacts include reduced crop, rangeland, and forest productivity; increased fire hazard; reduced water levels; and increased livestock and wildlife mortality rates, and damage to wildlife and fish habitat. The consequences of these direct impacts illustrate indirect impacts. For example, a reduction in crop, rangeland, and forest productivity may result in reduced income for farmers and agribusiness, increased prices for food and timber, unemployment; and reduced tax revenues because of reduced expenditures, foreclosures on bank loans to farmers and businesses; migration; and disaster relief programs [31].

1.7.1 Economic impacts

Many economic impacts occur in agriculture and related sector, including forestry and fisheries, because of the reliance of these sectors on surface and subsurface water supplies. Droughts also bring increased problems with insects and diseases to forests and reduce growth. The incidence of forest and range fires increases substantially during extended droughts, which in turn places both human and wildlife populations at higher levels of risk [30,23]. Drought also causes significant economic impacts in non-agricultural sectors through its effects on water supplies including stream flows, reservoirs, wetlands, and groundwater. These non-agricultural sectors include, but are not limited to, tourism and recreation, public utilities, horticulture and landscaping services, navigation, and other industries/ businesses that have significant water consumption [32]. An overview of drought economic impacts is supplied in Fig. 1.4.

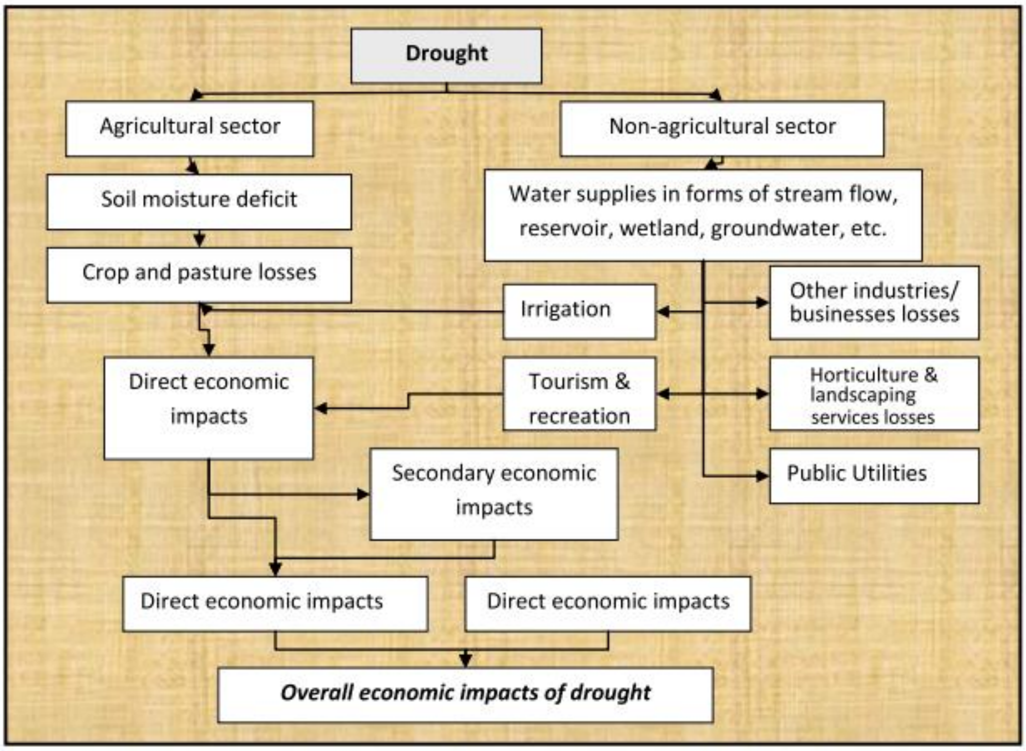


Figure 1.4: An overview of drought economic impacts [23] .

1.7.2 Social impacts

Social Impacts involve public safety, health, conflicts between water users, reduced quality of life, and inequities in the distribution of impacts and disaster relief. Population migration is a significant problem in many countries, often stimulated by a greater supply of food and water elsewhere. Migration is usually to urban area, or to regions outside the drought areas. When the drought has abated , the migrants seldom return home, depriving rural areas of valuable human resources. The drought migrants place increasing pressure on the social infrastructure of the urban areas, leading to increased poverty and social unrest [23,33].

1.7.3 Environmental impacts

Land use is affected by drought. If there is no rainfall at the time of sowing, land may not be sown at all and current fallow land may increase; crop intensity declines; and whatever area is sown may not be harvested because the production is so meager that it cannot be used as fodder. The primary effect of drought on soil is the increased sheet erosion due to loss of plant roots and wind .The erosion of farm soil causes long-term loss in farm production even after the drought is over. Wildfires or man-made-made removal of vegetation enhances the potential for sheet erosion and soil removal. Soil is baked from these fires making them impermeable. Low level of water in rivers and lakes increases turbidity and salinity affecting fish habitat. Groundwater levels drop and spring flow decreases. Deeper aquifers may not be affected immediately. Wet lands may become dry until moisture returns. The decreased pressure on the primary and secondary water systems could create potential cross connection and potential illness. Soil moisture can decrease, killing even the deeper plant root systems. Reservoir draws down and low stream flow affects recreation . Air becomes dry, warm and dusty, further desiccating the soil and increasing evaporation bodies of water. Respiratory ailments increase. Winds enhance sheet erosion from dried soils. Dust storms decrease visibility. Lack of precipitation and humidity increases concentration of dust and pollutants in air. Eco-systems depending on soil moisture or the presence of open water becomes damaged. Wetland and riparian animal and plant life are displaced or die. Dangerous animals may migrate to human settlement areas and become man eaters. Stressed vegetation and wildlife are more vulnerable to disease [24,32].

1.8 What is Geographic Information System (GIS)?

Geographic Information System could be understood in two parts "Geography and Information system". First "Geography"- It is study of relationship between man & environment and key tool to study this spatial relationship is map. Secondly "Information system"- It is a continuous chain of data collection, storage of data, analysis of data, and use the derived information in some decision making [46]. In other words, a GIS or Geographic Information System is a system of computer hardware, software, and data for capturing, storing, checking, integrating, manipulating, analyzing and displaying data related to positions on the Earth's surface or in other words, spatial data. Spatial data is data related to the space around us; data related to a location. Geographic information typically consists of data about time, space, and some attribute. Data are collected about a phenomenon and where it occurs at a particular time or how a phenomenon in a certain location changes over time. The roots of geographic information systems begin with maps. These might be represented as several different layers where each layer holds data about a particular kind of feature. GIS layers can be found in several data structure formats: points, lines, polygons, raster grids, and raster images. Databases offer the ability to amass large quantities of data. GIS offers the ability to integrate many different types of data through the use of common geography. Each feature is linked to a position on the graphical image of a map. Layers of data are organized to be studied and to perform statistical or spatial analysis. Geographic information systems (GISs) allow users to analyze geographic phenomena within areas of interest, thus leading to a better understanding of relationships and to provide a helpful tool in decision-making. Simply put, a GIS combines layers of information about a place to give you a better understanding of that place. What layers of information you combine depends on your purpose [47, 52].

1.8.1 Data and GIS

Data in many different forms can be entered into GIS. Data that are already in map form can be included in GIS. This includes such information as the location of rivers and roads, hills and valleys. Digital, or computerized, data can also be entered into GIS. GIS can also include data in table form, such as population information. GIS technology allows all these different types of information, no matter their source or original format, to be overlaid on top of one another on a single map. Putting information into GIS is called data capture. Data that are already in digital form, such as images taken by satellites and most tables, can simply be uploaded into GIS. Maps must be scanned, or converted into digital information. GIS must make the information from all the various maps and sources align, so they fit together. One reason this is necessary is because maps have different scales. A scale is the relationship between the distance on a map and the actual distance on Earth. GIS combines the information from different sources in such a way that it all has the same scale [48,85].

1.8.2 GIS Maps

Once all of the desired data have been entered into a GIS system, they can be combined to produce a wide variety of individual maps, depending on which data layers are included. Maps can be produced that relate such information as average income, book sales, and voting patterns. Any GIS data layer can be added or subtracted to the same map. GIS maps can be used to show information about number and density. They can also show what is near what, such as which homes and businesses are in areas prone to flooding. With GIS technology, researchers can also look at change over time. They can use satellite data to study topics such as how much of the polar regions is covered in ice. GIS often contains a large variety of data that do not appear in an onscreen or printed map. GIS technology sometimes allows users to access this information. A person can point to a spot on a computerized map to find other information stored in the GIS about that location. GIS systems are often used to produce three-dimensional images. GIS technology makes updating maps much easier. Updated data can simply be added to the existing GIS program. A new map can then be printed or displayed on screen [85,49].

The various components of GIS include the hardware, software, data, people and the method of application; see Fig. 1.5.

The computer system on which the GIS software run is termed as hardware that gets input through the scanner or a digitizer board. Software provides the functions and tools needed to store, analyze and display information. There are several commercial and educational GIS software , to carry out the spatial data analysis (Maplnfo, ERDAS, Intergraph, IDR1SI , GRAM , Arclnfo, GRASS, AutoCAD maps) Table 1.1 summarizes the availability of GIS software platforms and their format. The functional modules that are available in the said commercial software are shown in Fig. 1.6.

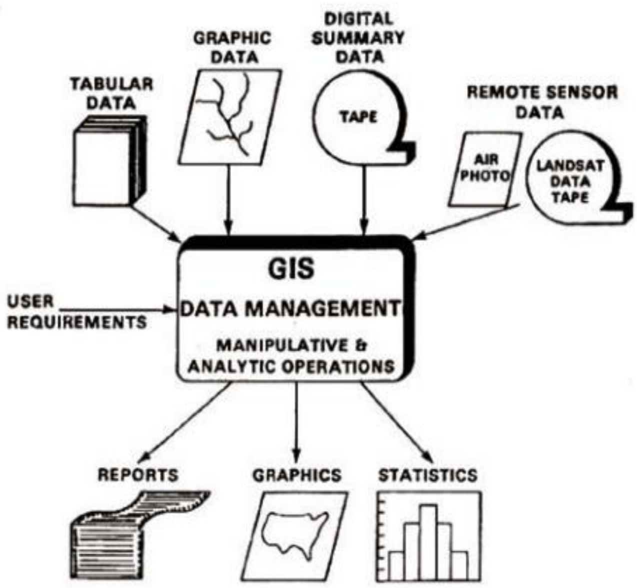


Figure 1.5: Various components of GIS [47] .

Vector format name	*Software platform*	*Raster format name*	*Software platform*
Arc Export	ARC/INFO – ESRI	Arc Digitized Raster Graphics (ADRG)	Common remote sensing standard
ARC/INFO coverage		Band Interleaved by Line (BIL)	
AutoCAD drawing files (DWG)	AutoCAD – AutoDesk	Band Interleaved by Pixels (BIP)	
AutoDesk data Interchange file (DXF)	Many – AutoDesk	Band Sequential (BSQ)	
Digital Line Graphs (DLG)	Many – USGS	Digital Elevation Model (DEM)	Many USGS
HP Geographic Language (HPGL)	Many	PC Paintbrush Exchange (PCX)	PC Paint brush – Zsoft
MapInfo data transfer file (MIF/MID)	MapInfo	Spatial Data Transfer Standard (SDTS)	Many
MapInfo Map files	MapInfo	Tagged Image file format (TIFF)	Page maker Aldus
Microstation Design Files (DGN)	Microstation-Bentley Systems		Internal
Spatial Data Transfer System (SDTS)	Many/US standard		
Topologically Integrated Geographic Encoding and Referencing (TIGER)	Many – US Census Bureau		
Vector Product (VPF)	US Defense Mapping Agency		

Table 1.1: Availability of GIS software platforms and their format [47] .

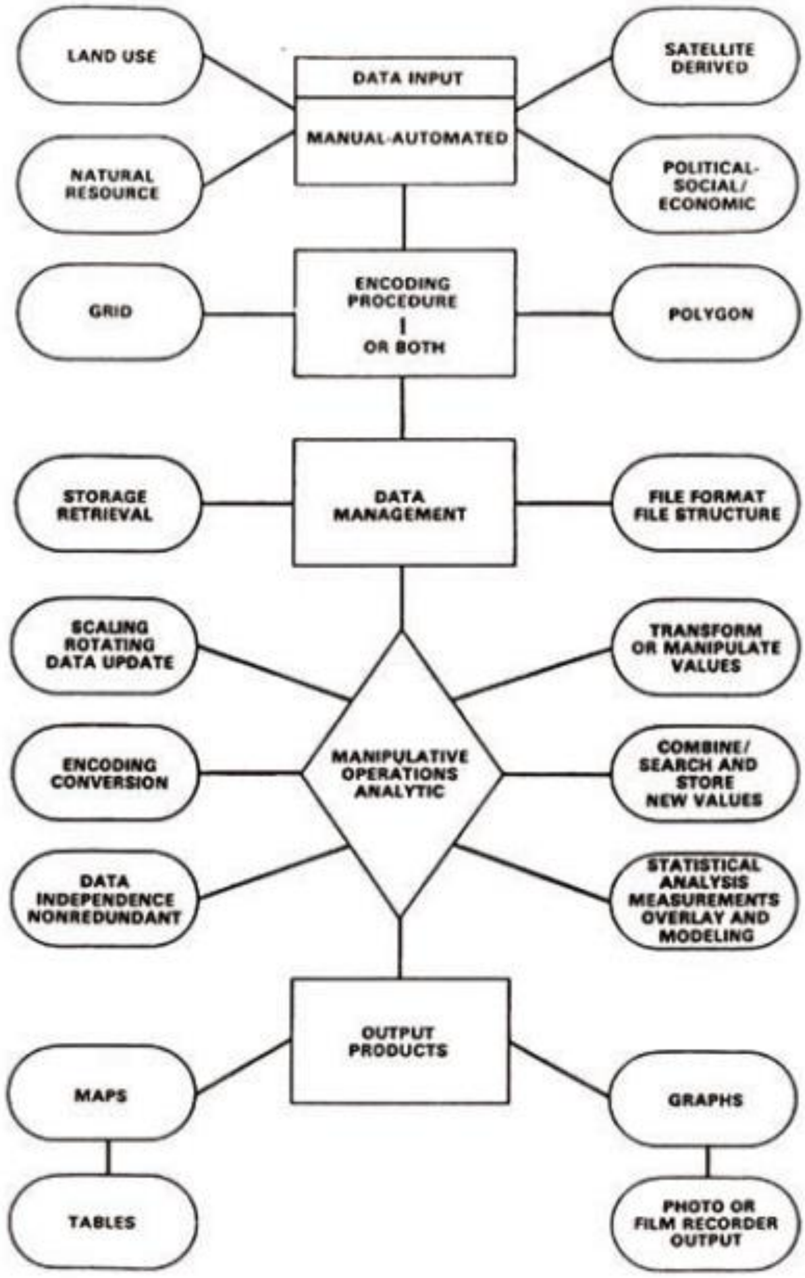


Figure 1.6: Functional module in GIS commercial software [85] .

1.9 Disaster Management With GIS

GIS is incredibly useful and effective tool in disaster management. This technology has been the object of substantial interest for all countries and bodies concerned with space and in exacting emergency services and disaster management. In disaster management, the objectives of the disaster experts are to monitor the situation, simulate the complicated disaster occurrence as accurately as possible so as to come up with better prediction models, suggest appropriate contingency plans and prepare spatial databases [60]. In the past, GIS has emerged as a powerful tool for effective disaster management through mitigation, preparedness, response and recovery phases [61].

In disaster prevention phase, GIS is used in managing the huge levels of data required for vulnerability and hazard assessment [60,61].

In the disaster preparedness phase, GIS is a useful tool for the planning of evacuation routes and resources dispatching, and for the integration of hazard models with other relevant basic data in the design of disaster warning system [62].

In the response phase, GIS can be used to making the detailed pictures of the event tracking, forecast of the affected regions and the evacuation plans. Also GIS, in combination with GPS, is extremely useful in search and rescue operations in areas that have been devastated and where it is difficult to find one's bearings [60,61].

In the disaster recovery phase, GIS is used to organize the damage information and post-disaster census information and in the evaluation of sites for reconstruction [63].

Natural hazard information should be included routinely in developmental planning and investment projects preparation. They should include cost/benefit analysis of investing in hazard mitigation measures and weigh them against the losses that are likely to occur if these measures are not taken. GIS can play a role at the following levels [60]:

- National level
- State level
- District level
- Block level
- Ward or village level
- Site investigation scale

2. LITERATURE REVIEW

2.1 Role of GIS IN Drought Studies

For the last three decades, advancements in the field of GIS has greatly facilitated the operation of drought assessment. Most data required for drought assessment have a spatial component and also change over time. Therefore, the use of GIS has become essential. It is evident that GIS has a great role to play in drought assessment because natural hazards are multi-dimensional. The main advantage of using GIS for drought assessment is that it not only generates a visualization of hazard but also creates potential to further analyze this product to estimate probable damage due to drought hazard [31]. A meteorological station can connect to GIS and keep receiving meteorological information directly entered into GIS, and then these data will managed and analyzed uniformly by the system database. GIS transformed the model to its language and analyzes the data by powerful analysis function, and then adds drought assessment early warning function into drought assessment system [50].

GIS technology offer great promise for natural disaster management with the ability to depict the spatial distribution of the extent and monitoring capability. The capability of GIS is to integrate multi disciplinary data that can be used to analyze drought risk area in time and space [51]. The technical procedure for early warning and drought assessment is shown in Fig. 2.1.

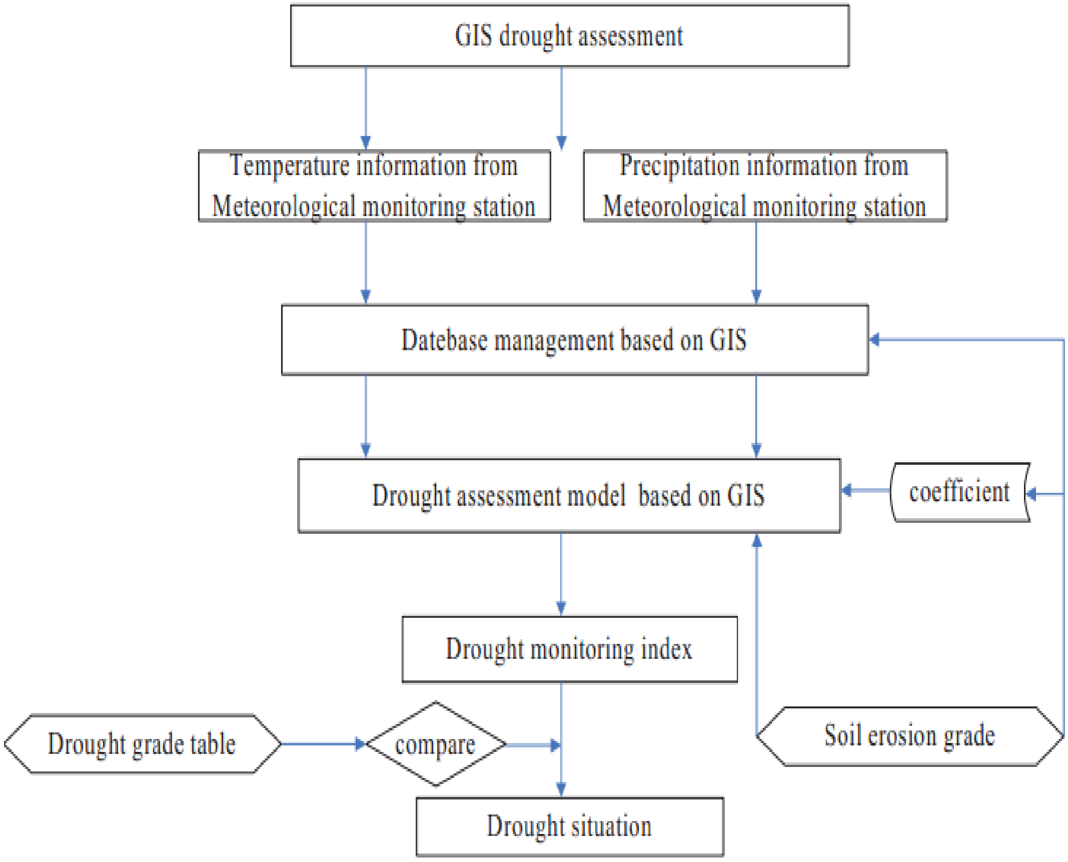


Figure 2.1: Information system implementing procedure for early warning drought Assessment [23] .

2.2 Meteorological Drought Indices and Drought Detection

Drought indices have been developed as a means to measure drought. A drought index assimilates thousands of data on rainfall, snow pack , stream flow and other water-supply indicators into a comprehensible picture. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), Surface Water Supply Index (SWSI).

2.2.1 Palmer drought severity index (PDSI)

In 1965, W.C. Palmer developed an index to measure the departure of the moisture supply. Palmer based his index on the supply and demand concept of the water balance equation, taking into account more than just the precipitation deficit at specific location. The objective of the Palmer Drought Severity Index (PDSI) is to provide standardized measurements of moisture conditions so that comparison could be made between locations and between months. The PDSI is a meteorological drought index that is responsive to abnormal weather conditions either on dry or abnormally wet side. The index was especially designed to treat the drought problem in semiarid and sub humid climates; with palmer himself cautioning that extrapolation beyond these conditions may lead to unrealistic results . PDSI has been used in west –Hungry as soil moisture indicator and has been widely used in United States for drought monitoring. It has been utilized as a tool to trigger actions associated with drought contingency plans. Several researchers have given limitation of PDSI. The Palmer Drought Severity Index (PDSI) has a time scale of about 9 months, which does not allow identification of droughts at shorter time scales. Moreover this index has many other problems related to calibration and spatial comparability. McKee et al. suggested that PDSI is designed for agriculture but does not accurately represent the hydrological impacts resulting from longer drought. Also PDSI is applied within the United States and has less acceptance elsewhere. To solve these problems, McKee et al. developed the Standardized Precipitation Index (SPI), which can be calculated at different time scales to monitor droughts in different usable water resources. Moreover, the SPI is comparable in time and space [23].

2.2.2 Crop moisture index (CMI)

Three years after the introduction of his drought index, palmer introduced a new drought index based on weekly mean temperature and precipitation known as Crop Moisture Index (CMI). It was specifically designed as an agricultural drought index. It depends on the drought severity at the beginning of the week and the evapotranspiration, soil deficit or soil moisture recharge during the week. It measures both evapotranspiration deficit (drought) and excessive wetness (more than enough precipitation to meet evapotranspiration demand and recharge the soil). CMI is designed to monitor short-term moisture conditions affecting a developing crop; therefore CMI is not a good long-term drought monitoring tool. The CMI's rapid response to changing short-term conditions may provide misleading information about long-term conditions. Nemani et al.(1992) used CMI for estimating surface moisture status, because CMI depicts changes in soil moisture situation more rapidly than PDSI. It was found that CMI indicates more favorable moisture conditions over a particularly wet or dry month even in the middle of a serious long-term wet or dry period.

2.2.3 Standardized precipitation index (SPI)

The SPI was formulated by Tom McKee, Nolan Doesken, and John Kleist of the Colorado Climatic Centre in 1993. SPI can be calculated at different time scales and hence can quantify water deficits of different duration. SPI was designed to show that it is possible to simultaneously experience wet conditions on one or more time scales and dry conditions at another time scale. SPI is computed by fitting historical precipitation data to a Gamma probability distribution function for a specific time period and location, and transforming the Gamma distribution to normal distribution with a mean of zero and a standard deviation of 1. SPI for given rainfall amount is then given by the precipitation deviation from the mean of an equivalent normally distributed function with a zero mean and a standard deviation of 1. The main premise of the current effort is that the use of a drought index, such as SPI, may lead to a more appropriate understanding of drought duration, magnitude, and spatial extent in semiarid areas [64]. Table 4.2 shows the classification values for SPI. This following formula **(2.1)** uses for calculation SPI:

$$SPI = p_i - \overline{p} \big/ sd \qquad \textbf{(2.1)}$$

$\overline{p}$:Average precipitation in each station

where pi is the annual precipitation in the each etation, sd is the standarad deviation of precipitation in each station.

This index is negative for drought and positive for wet condition . Fars province has drought when the SPI value less than zero and no drought when SPI is more than zero.

Table 2.1: The classification Values for SPI (McKee et al. 1993) [23].

SPI value	Drought Category
≥ 2	Extremely Humid
1.5 to 1.99	Very Humid
1.0 to 1.49	Moderately Humid
0.5 to 0.99	Lightly Humid
-0.49 to 0.49	Normal
-0.99 to -0.5	Lightly drought
-1.0 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
≤ -2	Extreme drought

2.2.4 Surface water supply index (SWSI)

Shafer and Dezman (1982) to complement the palmer index for moisture conditions across the state of Colorado developed the Surface Water Supply Index (SWSI) [78]. This index compliment the palmer index for moisture condition. It is dependent on the season ; SWSI is a computed with only snowpack, precipitation, and reservoir storage in the winter. During the summer months, stream flow replaces snowpack as a component within the SWSI equation SWSI has been used along with PDSI, to trigger the activation and deactivation of the Colorado drought plan. Though SWSI is easy to calculate yet it has the limitation the values between basins or a regions is difficult to compare [23,79].

2.3 SPI Based Drought Identification

Hayes et al [66] used the standard precipitation index (SPI) to monitor the 1996 drought in the United States of America. Although it is a quite a recent index, the SPI was used in TURKEY [67], Argantina [69],Canada [70], Korea [71],China [72] for real time monitoring or retrospective analysis of drought.The SPI is consistent with regard to the spatial distribution of rainfall that occurs with great variability in South Africa due to geographical location, orography and the influence of the oceans.

Using that index to develop climatology of the spatial extension and intensity of droughts gives also an additional understanding of its characteristics and an indication of the probability of recurrence of drought at various levels of severity. Livada and Assimakopoulos [73] used SPI to detect drought events in spatial and temporal basis in Greece. Using monthly precipitation data from 23 stations well spread over Greece and for a period of 51 years, a classification of drought is performed, based on its intensity and duration. From the estimation of the SPI on 3-, 6-, and 12-month time scales, it is evident that the frequency of mild and moderate drought conditions is approximately of the same order of magnitude over the whole Greek territory. Frequencies present a small reduction moving from north to south and from west to east. The small precipitation amounts over the southern part of Greece during the summer period resulted in the highest frequency of SPI values for severe droughts on the 3-month time scale. From the study of persistence of severe or more drought conditions on 6- and 12-month time scales according to Besson's coefficient of persistence, it was found that, in almost all cases and for both time scales, the persistence is statistically significant. Paltineanu et al [74] characterized droughts in Romania using the approach of both the SPI and climatic water deficit (WD). The values of the main climatic factors (rainfall, temperature, reference evapotranspiration, etc.) were obtained from 192 weather stations in various regions of Romania. Penman–Monteith reference evapotranspiration (ETo-PM) was used to calculate WD as the difference between precipitation (P) and ETo-PM. SPI calculated from precipitation values. There is a clear difference between drought and aridity. Drought occurrence determines higher WD values for plains and plateaus and lower climatic excess water (EW) values for high mountains in Romania, depending on the aridity of the specific region considered and drought severity. WD was calculated as mean values for both normal conditions and for all locations studied, various types of drought correlated with mean annual precipitation and temperature. The combined approach of WD and SPI mainly carried out for periods of 1 year, but such studies could also be done for shorter periods like months, quarters, or growing season. The most arid regions did not necessarily coincide with areas of the most severe drought, as no correlations between WD and SPI and no altitude-based SPI zones around the Carpathian Mountains, as is the case for other climate characteristics, soils and vegetation. Water resource problems arise where both SPI values characterize extremely droughty periods, and WD values are greatly below

−200 mm/year. This combined use of SPI and WD characterizes the dryness of a region better than one factor alone and should be used for better management of water in agriculture in Romania and also other countries with similat climate characteristics.

2.4 Drought Events and Management Profile of Countries

South Africa

Climatically, South Africa is a semi-arid country vulnerable to water stress, particularly drought. Recorded droughts have been experienced since the early 1800 s in both the winter and summer rainfall regions of South Africa and have inflicted major socioeconomic damages. South Africa receives on average about 500 mm of rainfall per year with huge disparities in its spatial distribution, ranging from as little as 2.5 mm on the west coast to more than 1,000 mm on the east coast as shown in Fig. 2.2. It is estimated, however, that about 65 % of the country receives lower than this average amount of rain, and more than 20 % of the country receives less than 200 mm/year of rain [41,42]. Spatial variability in rain seems to follow similar spatial patterns with the low rainfall areas of the east showing the highest variances as Fig. 2.3.

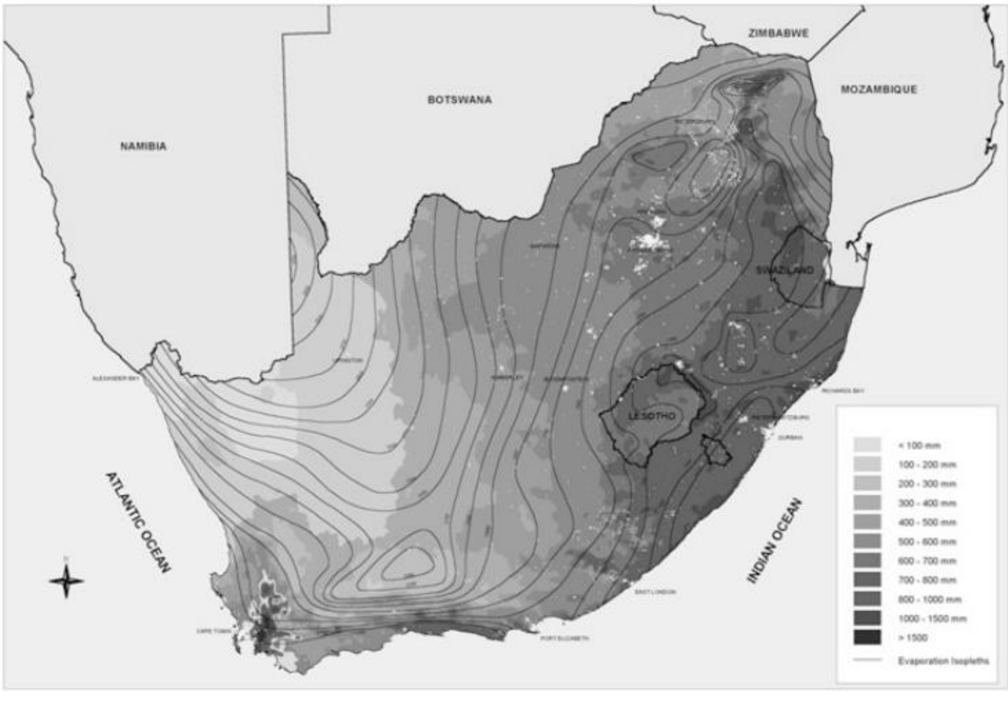


Figure 2.2: Rainfall and evaporation in South Africa [41].

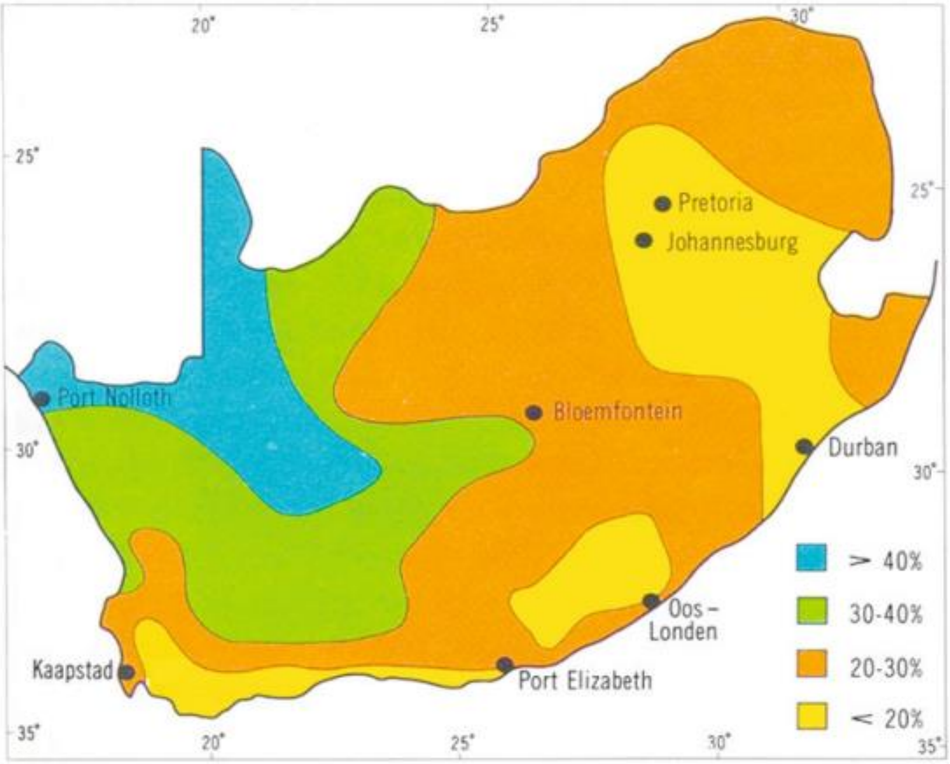


Figure 2.3: Percentage deviation from mean annual rainfall[41].

Mean annual temperature is in 3oC to 5.5oC range for a greater part of the continent with <3oC in the forest belt around the equator. Climate is determined by the wind system, topography, and pressure of large water bodies. The heaviest rainfall occurs near the equator, especially in the region from the Niger Delta to the Zaire River basin and central Zaire. The deserts are dry, and water is deficient throughout the year. The semi-arid region is most affected by droughts. Drought management strategies and policies in the country have also seen important evolutions over the past few decades. The South African water sector in particular has been witnessing radical policy reforms since 1994 that have important implications for drought management. Since different agencies have borne the primary responsibility for managing agricultural drought and hydrological drought, using different approaches and mechanisms, such as managing hydrological drought [58].

Managing Hydrological Drought

The impacts of drought on South Africa are widespread, and include losses in agricultural productivity, farm incomes and food security via reductions in crop yield, and losses in livestock productivity through reductions in grazing quality. Additional impacts include: reductions in power generation capacity through less stream flow, increases in forest and range fires due to less moisture, stresses on vegetation, wildlife and ecosystems, forced migration, less reliable water, and other drought-related health that issues impact general household welfare [40].

Australia

Australia has landmass of 7,617,930 km2 and 34,218 km coastline is on the Indo-Australian Plate and surrounded by the Indian and Pacific oceans. The largest part of Australia is desert or semi-arid lands commonly known as the outback. It is the flattest continent, with the oldest and least fertile soils, and is the driest inhabited continent. Only the southeast and southwest corners of the continent have a temperate climate. Most of the population lives along the temperate southeastern coastline. The landscapes of the northern part of the country, with a tropical climate, consist of rainforest, woodland, grassland, mangrove swamps, and desert. It has a number of distinct climatic zones such as the summer dominant tropics and sub-tropics to the north; the Mediterranean climates to the south; the arid and semi-arid regions in the middle of the continent; and areas of high rainfall on coastal fringes and in the ranges of the east of Australia [24]. Drought has a big impact on the environment, agricultural production and the well-being of Australians - especially those in rural areas. Droughts in Australia can have a very large spatial extent and have, at times, covered most of the continent. They can also last twelve months or more. Australian government policy has focused on drought as a normal part of the agricultural environment, where self-reliance and sustainability are the main objectives. There is, however, allowance made to provide both business and welfare support for events that are rare and severe, beyond what can be dealt with using normal risk management practices. While the principles of self-reliance and sustainability are becoming increasingly accepted there is some debate as to whether or not the current policies are optimally tuned to reaching these objectives, particularly in the use of interest rate subsidies as a mechanism for providing assistance. Delivering sustainability can also be difficult because it can be hard to assess whether or not a specific management practice will be sustainable due to the complexity of the economic, biophysical and social systems in agriculture [57]. Future support could focus on mechanisms that target management skills in rural Australia .The climate observation network will continue to be an important component of the implementation of national policies, whether they be drought support mechanisms, or the long term goal of providing information to improve risk management. Rainfall deficiency is monitored in near real-time using electronically submitted data from numerous sites across the country. Agricultural drought is monitored using a variety of techniques including physically based models of pasture, grass and crop growth in conjunction with satellite data [56].

Iran

Iran is one of the world's most mountainous countries; its landscape is dominated by rugged mountain ranges that separate various basins or plateau from one another. The annual precipitation ranges from 135 to 355 mm. On the northern edge of the country (the Caspian coastal plain) temperatures nearly fall below freezing and it remains humid for the rest of the year. Summer temperatures rarely exceed 29°C. A point far from altitudes can reach up to 60°C during summer. The average temperature during January and May are 22°C and 40°C respectively. It rarely snows there. The annual relative humidity is below 30%. During summer, it decreases, at times, down to 0%. It usually rains during winter and sometimes showers that leads to wash away the earth. It goes without saying that there cannot be proper and enough soil and water for plants to grow. Since these regions are always open to winds and there are not sufficient plants to preserve soil, wind erodes the earth and brings about losses. Therefore, blocking winds by wood made walls and planting shrubs and trees are carried out to confront the destructive natural forces. The wide range of temperature fluctuation in different parts of the country and the multiplicity of climatic zones make it possible to cultivate a diverse variety of crops. Wheat and barley are planted on dry-farmed and irrigated lands and on mountain slopes and plains. Long-grain rice of Iran grows primarily in the wet Caspian lowlands in the northern provinces of Gilan and Mazandaran, where heavy rainfall facilitates paddy cultivation. The major rivers running into the Caspian Sea in Iranian shorelines flowing from the northern Alborz altitudes are: Aras, Sefid Rud, Chalus, Haraz, Se hezar, Babol, Talar, Tajan, Gorgan, Atrak, Qarasu and Neka. Some temporary rivers either run into a body of water or get dried before reaching any watershed. Irrespective of presence of large number of rivers water has always been a vital issue. Many of the rivers contain salty water, and are seasonal that makes fresh drinkable water even more valuable. Drought – It is estimated that 18 of the country's 28 provinces are affected by drought and majority of them are in southern, eastern and central parts. Those hardest hit include Sistan-Baluchestan, Yazd, Fars, Kohkiluyeh Boyerahmad,Bushehr,Hormuzgan,Kerman and Khuzestan. Although limited rainfall in late March brought some relief to crops in west-central parts, it was insufficient to improve overall prospects. The impact of drought is likely to be exacerbated by already low water reserves in dams and reservoirs, following the severe water shortage last year. Most farms in Iran are small.

less than 25 acres (10 hectares) and not economically viable that has contributed to the wide-scale migration to cities. In addition to water scarcity and areas of poor soil, seed is of low quality and farming techniques are antiquated. All these factors have contributed to low crop yields and poverty in rural areas. Vulnerable groups in rural areas have limited alternative sources of income and incurred heavy losses due to crops - wheat and barley. Villagers have begun panic selling of livestock and are reportedly leaving their homes [24].

Canada

Canada occupies a major northern portion of North America, sharing land borders with the continental United States to the south. Northern Canada includes five major physiographic regions such as Canadian Shield, Interior Plains, Arctic Lowlands, Cordillera and Innuitian Region. Annual precipitation in prairie zone ranges from 300 to 550 mm and the driest conditions in the prairies tend to be found in the south and the southwest, while the wettest areas are found in the north and northeastern prairies. Mean annual evaporation decreases from approximately 250 to 400 mm at latitude 60°N to less than 100 mm in the central portions of the Arctic Archipelago. Evaporation is greatest during the summer, especially in areas of low relief characterized by numerous bogs and lakes. Approximately two-thirds of the precipitation falls during the summer months (May to August) and a continuous snow cover lasts 4–5 months [55]. Average winter and summer high temperatures across Canada vary depending on the location. Winters can be harsh in interior and Prairie Provinces which experience a continental climate, where daily average temperatures are near -15°C but can drop below -40°C with severe wind chills. In non-coastal regions, snow covers the ground almost six months of the year. The southern regions of the Canadian Prairies are more susceptible to drought because of their highly variable precipitation. During the past two centuries, at least 40 droughts have occurred in western Canada with multi-year episodes being observed in the 1890s, 1930s, and 1980s. Drought is a major concern in Canada but rarely has it been as serious or extensive as the 1999-2004 episode. This event produced the worst drought in over a hundred years in parts of Canada and in particular, the Canadian Prairies. In more recent past, a major drought was recorded form the region in the 1930s. Local droughts of shorter duration have occurred since the 1930s in parts of Canada, especially in the prairies (1940s, early1960s, late 1970s) and in Ontario (1963). In Canada the effects of droughts have been felt most severely in areas where agricultural activities allow little margin of safety in the water supply. Annual precipitation averages 380 mm, compared to 800 mm at Toronto and 1400 mm at Vancouver and Halifax. The drought of the 1930s is of special importance because of its areal extent and severity, and because of the government policies, programs and farming practices that resulted. The drought began in 1929 and continued, with some respites, until midsummer of 1937. Severe wind erosion of the topsoil compounded the effects of the drought. Drought has a major economic impact on the Canadian prairies owing to the vulnerability of the region’s agricultural sector to weather variability**.** Fig. 2.3 presents extent and severity of long term drought in Canada.

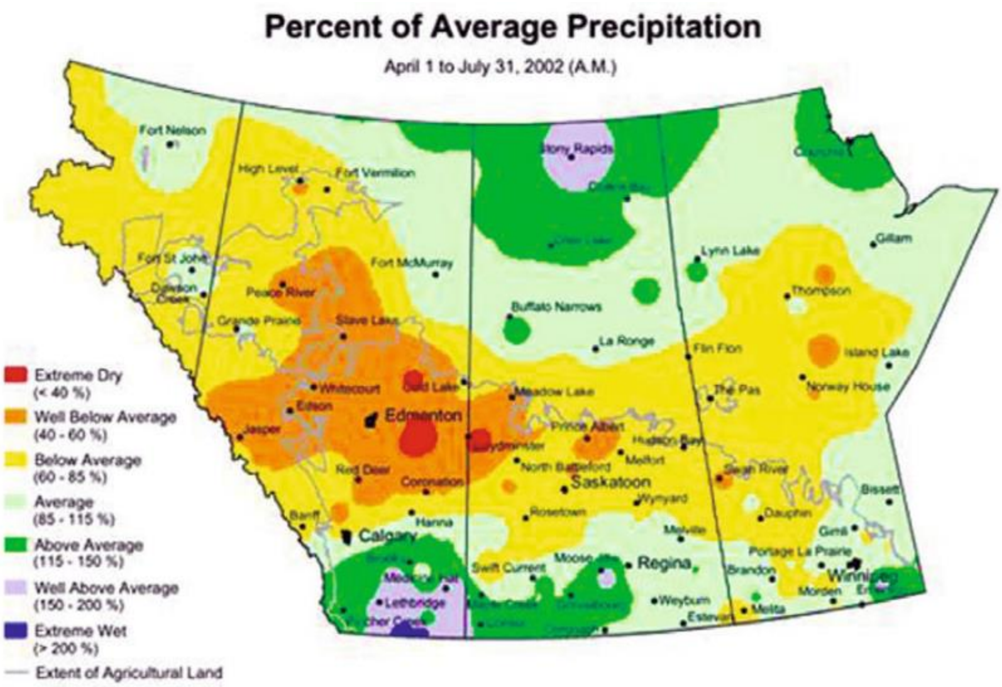


Figure 2.4: Extent and severity of long term drought –Canada [24].

2.5 Drought Management and Forecasting

Gregoric and Sušnik [75] stated that drought is a natural phenomenon which closely connects climate and society. When drought occurs, there is certain risk that the population will suffer social and economic consequences. This risk and depth of such consequences depends on the natural frequency and severity of the drought. As the climate changes, natural hazards are increase, and it would be reasonable to imply that social and economic risks are consequently increasing. However, natural hazards are not the only element determining risk. The other factor is society's capability to overcome difficulties caused by water shortages, vulnerability.Vulnerability determines the risk of drought impact now and in the future. Risk may rise independent of climatic trends, due to increased water demands caused by population or economic growth, or both. And the other way around: Natural hazard trends may be neutralized by reducing a society's vulnerability. Assessment of both natural hazards and societal vulnerability are among the core objectives of the drought management center for southeastern Europe. Historical assessment of drought occurrence and establishment of drought monitoring systems are undertaken to establish a method for regional estimation of climatological and actual natural hazards connected to occurrence of drought. Some aspects of vulnerability (mainly in the agriculture sector) have been described for some southeast European countries. Few extreme events are as economically and ecologically disruptive as drought, which affects millions of people in the world each year. Severe drought conditions can profoundly impact agriculture, water resources, tourism, ecosystems, and basic human welfare. Droughts are of great importance in water resources planning and management [76].

3. Study Area

3.1 Location and Extent of Study Area

Fars province of Iran is in the south of the country and its center is Shiraz as shown in Fig. 3.1. Fars province has an area of about 133,299 km^2 and it is one of the largest provinces in Iran , and covers 8.1 percent of Iran. It is located between 27 030 and 31 420 Northern latitude and 50 300 and 55 360 Eastern longitude. As of 2006, the province was home to 4.34 million people, 62% of which are registered urban dwellers, 38.1% villagers, and 0.7% nomadic tribes. Shiraz is the capital and center of Fars. The province consists of the following counties: Estahban, Abadeh, Eqhlid, Bavanat, Jahrom, Darab, Sepidan, Shiraz, Fasa, Firouzabad, Kazeroon, Lar, Lamerd, Marvdasht, Mamasani, Khonj and Nayriz [34].

3.2 Climate

Three distinct climatic regions exist with the province's 122, 400 km^2 territory: a mountainous area in the north and northwest characterized by moderately cold winters and mild summers; a central region with relatively rainy, mild winters and hot, dry summers; and a southern region with relatively rainy, mild winters and hot, dry summers. Its average annual rainfall varies between 100 mm in the Southern parts and more than 400 mm in the Northern parts of the province. The temperature range from -10 ºC to 45 ºC [38].

3.3 Water Resources

Water consumption in Fars is about 10.1 billion cubic meters that 2.6 billion cubic meters of it is provided by surface reservoirs and 7.5 billion cubic meters is provided by the underground sources. 95% of this consumed water is used in agriculture, and 1% in industries and the rest is used for drinking and hygiene. Ground water resources consist of 69203 wells, 2910 springs, and 1402 quanats. Fars has 5 dams under operation (Doroodzan 1973, Izadkhast 1998, Mollasadra 2006, Ghiir 2007, and Sivand 2007) with the reservoir volume of 2800 million cubic meters, And 17 dams are under study construction.

3.4 Land Use and Agriculture

Fars is one of the most important provinces in agricultural production and its major products include cereal (wheat and barley), citrus fruits, dates, sugar, beets and cotton. For many years, Fars has had remarkable record in crop production especially wheat yield. From an agricultural point of view, Fars is one of the most strategic provinces in Iran, as it is responsible for producing 37% of the country's wheat. Generally, based on aridity index, all regions of Fars province were placed in arid and semi-arid classification [35,37,39].

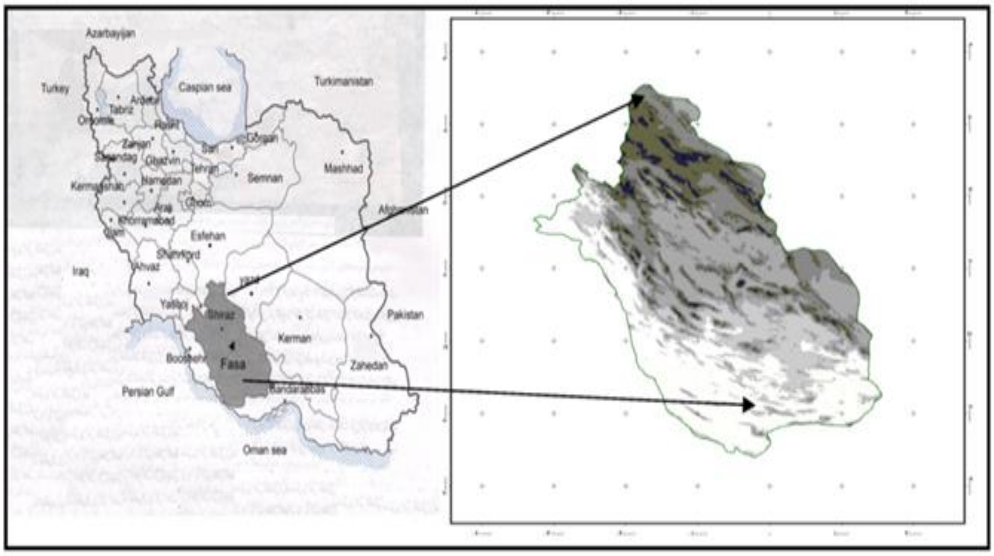


Figure 3.1: Location of Fars Province in Iran [34].

4. Materials and Method

4.1 Data

In drought analysis, availability of long time series of undisturbed, observational data is essential [2,65]. However, observational records are not long enough, some variables are not monitored at all, data quality is too low, or observations are influenced by human activities. However, models also require data. Models need to be forced with observed meteorological data is needed for calibration and validation. Analyzing precipitation data is one of the methods for studying drought, which is considered as one of the most common methods. It can be due to easier access to types of precipitation data in different parts of a region. Iran is a dry land with very low atmospheric precipitation such that rainfall in Iran is less than one third of the average rainfall throughout the world. Meanwhile, the precipitation time and its place do not conform to an agricultural need which is the main consumer of water in the country. Therefore, it shall be accepted that drought in Iran is a climatic reality which we shall adjust ourselves with it. Different drought indices are tools for determining, monitoring and assessing droughts .In this study, Standardized Precipitation Index (SPI) is used [23]. In this section, I describe the meteorological data that is available for the case study area.

4.1.1 Meteorological Data

The meteorological data used in this study, consisting of annual precipitation measurements for 17 meteorological stations distributed fairly evenly in the region as shown in Fig 4.1. , were collected from the Iran Meteorological Organization (IMO) and Regional Water Organization of Fars Province. Due to lack of adequate data, this thesis compared 10 stations from 1994-2006 (Abadeh, Fasa,Larestan,Jahrom, Eghlid, Shiraz, Darab, Lamerd, Sadedorodzan, Zarghan) and 17 stations from 2007-2011(Abadeh , Fasa ,Larestan ,Jahrom , Eghlid , Shiraz, Darab , Lamerd , Sadedorodzan , Zarghan , Arsenjan , Izadkhast , Bavanat , Safashahr ,Kazeroon , Neyriz ,Noorabad). An exhaustive list of the selected stations is given in Table 4.1.

Table 4.1: Name of the selected stations over the study area.

Station Name	Longitude(L)	Latitude(N)	average precipitation (mm)	Elevation
Arsenjan	29.91	53.30	162	1660
Izadkhast	31.32	52.70	94.88	2188
Bavanat	30.28	53.40	130.22	2231
Safashahr	30.16	53.19	139.04	2324
kazaroon	29.62	51.65	234.76	860
Neyriz	2912	54.20	12.25	1632
Noorabad	29.97	51.83	311.25	920
Abade	31.11	52.37	125.36	2030
Fasa	28.55	53.38	276.46	1288
Larestan	27.42	54.17	177.41	792
Jahrom	28.29	53.33	170.21	1082
Eghlid	30.55	52.47	311.42	2300
Shiraz	29.36	52.32	301.45	1488
Darab	28.47	54.17	241.69	1098
Lamerd	27.18	53.07	205.61	411
Sadedorodzan	30.13	52.16	450.56	1620
Zarghan	29.47	52.43	305.75	1590

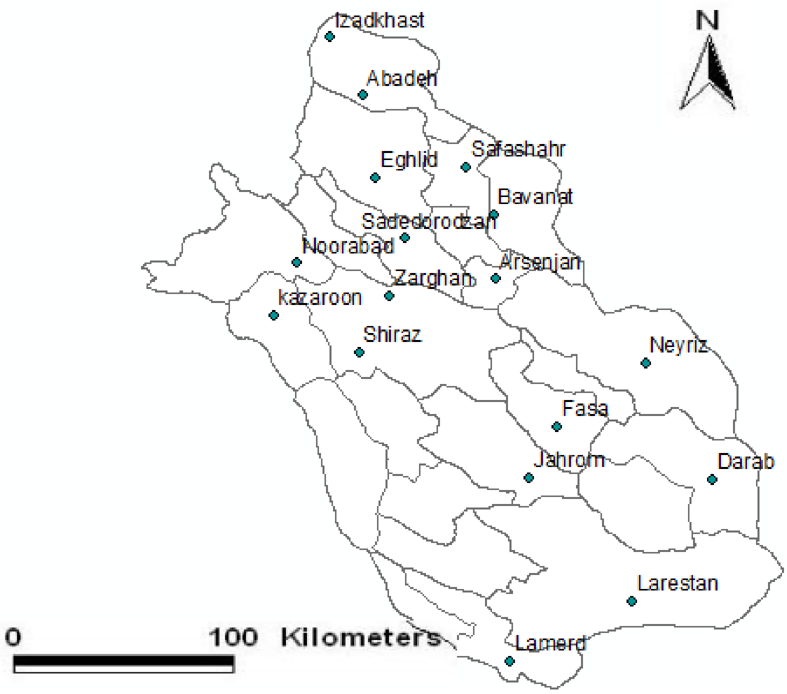


Figure 4.1: Scattering of stations in Fars Province map.

For each station in every year, with DIC (Drought Indicis Calculator 1.0) software, annual precipitation and annual SPI have been calculated, as illustrated in Table 4.2 and Table 4.3.

Table 4.2: Annual Standardized Precipitation Index (SPI) for 10 station from 1994-2011.

Staion Name	Aabdeh	Fasa	Jahrom	Eghlid	Lamerd	Sadedorodzan	Zarghan	Shiraz	Darab	Larestan
1994	0.33	0.32	-0.36	0.36	-0.24	0.44	0.45	0.36	-0.77	-0.35
1995	0.42	0.84	0	-0.17	1.02	0.19	0.63	0.71	1.08	1.41
1996	-1.06	-0.79	0	-1.28	-0.15	-0.1	-0.91	-0.91	-0.26	0.18
1997	-0.24	0.12	0	0.36	0.63	0.52	0.54	0.53	0.36	0.41
1998	-0.19	-0.09	0	-0.57	0.11	-0.01	0.29	0.02	0.11	-0.53
1999	-1.18	-1.11	0	-1.45	-1.71	-1.08	-1.11	-0.96	-1.15	-1.21
2000	-0.77	-0.91	0.21	-0.91	-0.65	-0.74	-0.81	-0.71	-1.15	-0.94
2001	0.28	-0.76	0.31	0.39	-0.48	0.26	0.03	-0.21	-0.58	-0.76
2002	-0.64	-0.35	0.39	-0.16	-0.75	-0.06	-0.42	-0.85	-0.39	-0.55
2003	0.85	0.47	0.78	0.95	-0.05	0.21	0.05	0.14	0.47	-0.3
2004	0.44	0.81	0.91	0.42	0.22	0.21	0.69	0.61	0.31	0.34
2005	-0.91	-1.12	0.11	-0.61	-1.91	-0.34	-0.61	-0.51	-1.32	-1.71
2006	-0.22	0.13	0.61	-0.21	0.27	-0.39	0.45	0.11	0.12	-1.15
2007	-0.85	-0.96	0.21	-0.66	-0.77	-0.74	-1.04	-0.78	-0.96	-0.44
2008	-1.16	-2.03	0.22-	-1.19	-1.66	-1.37	-1.58	-1.65	-1.78	-2.13
2009	-0.21	-0.12	0.63	-0.31	0.21	-0.34	-0.56	-0.47	0.07	0.33
2010	-0.28	-0.41	0.53	-0.32	-0.38	-0.58	-0.91	-0.67	-0.06	-0.31
2011	-3.46	-2.81	-0.58	-3.22	-2.52	-3.61	-3.15	-3.27	-2.48	-1.31

Table 4.3: Annual Standardized Precipitation Index (SPI) for 7 stations from 2007-2011.

Station Name	Arsenjan	Izadkhst	Bavanat	Safashahr	Kazeroon	Noorabad	Neyriz
2007	0.12	0.0089	0.27	0.09	-0.026	0	0.27
2008	-0.57	-0.08	-0.36	-0.61	-0.35	-0.39	-0.84
2009	0.38	0.041	0.18	0.25	0.27	0.41	0.15
2010	-0.09	0.15	-0.19	0.11	0.14	0.15	0.18
2011	-2.22	-2.33	-2.26	-2.23	-2.29	-2.02	-2.14

4.2 Software Used

These software have been used to perform the data processing and analysis.
Microsoft Excel for arrangement of data,

Drought Indices calculator (DIC),

Statistical Package for the Social Sciences (SPSS) and

Arc GIS 9.0.

4.3 What Is Spatial Interpolation?

The estimation of surface values at unsampled points based on known surface values of surrounding points. Interpolation can be used to estimate elevation, rainfall, temperature, chemical dispersion, or other spatially-based phenomena .

Interpolation is commonly a raster operation, but it can also be done in a vector environment using a TIN surface model. There are several well-known interpolation techniques, including inverse distance weighted, kriging and natural neighbor.

4.3.1 Inverse distance weighted interpolation

Inverse Distance Weighting (IDW) is the most common method of spatial interpolation. An interpolation technique that estimates cell values in a raster from a set of sample points that have been weighted so that the further a sampled point is from the cell being evaluated, the less weight it has in the calculation of cell's value. The formula for IDW is shown here **(4.1)** :

$$z(x) = \sum_i w_i z_i \Big/ \sum_i w_i \qquad \textbf{(4.1)}$$

$$w_i = 1 \big/ d_i^2$$

i: point, z_i : known value, x_i : location, w_i : weight, d_i : distance,

4.3.2 Kriging interpolation

An interpolation technique in which the surrounding measured values are weighted to derive a predicated value for an unmeasured location. Weights are based on the distance between the measured points, the prediction locations, and the overall spatial arrangement among the measured points. kriging is unique among the interpolation methods in that it provides an easy method for characterizing the variance, or the precision, of predictions. Kriging is based on regionalized variable theory, which assumes that the spatial variation in the data being modeled is homogeneous across the surface. That is, the same pattern of variation can be observed at all locations on the surface. kriging was named for the South African mining engineer Danie G.Krige(1919). Kriging is similar to IDW in that it weights the surrounding measured values to derive a prediction for an unmeasured location. The general formula for both interpolators is formed as a weighted sum of the data is defined as **(4.2)** :

$$\hat{z}(s_0) = \sum_{i=1}^{N} \lambda_i z(s_i) \qquad \textbf{(4.2)}$$

$z(s_i)$: the measured value at the *i*th location
λ_i : an unknown weight for the measured value at the *i*th location
s_0 : the prediction location
N : the number of measured values

In IDW, the weight, $\boldsymbol{\lambda_i}$, depends solely on the distance to the prediction location. However, with the kriging method, the weights are based not only on the distance between the measured points and the prediction location but also on the overall spatial arrangement of the measured points. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus, in ordinary kriging, the weight, λ_i, depends on a fitted model to the measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.

4.3.3 Natural neighbor interpolation

The Natural Neighbor method is a geometric estimation technique that uses natural neighborhood regions generated around each point in the data set. Natural neighbor interpolation has many positive feature such as: it can be used for both interpolation and extrapolation and it generally works well with clustered scatter points. Like IDW, this interpolation method is a weighted-average interpolation method. However, instead of finding an interpolated point's value using all of the input points weighted by their distance, Natural Neighbors interpolation creates a Delauney Triangulation of the input points and selects the closest nodes that form a convex hull around the interpolation point, then weights their values by proportionate area. Natural Neighbor interpolation finds the closest subset of input samples to a query point and applies weights to them based on proportionate areas to interpolate a value. It is also known as Sibson or "area-stealing". The difference between IDW interpolation and natural neighbor interpolation is the method used to compute the weights and the method used to select the subset of scatter points used for interpolation.

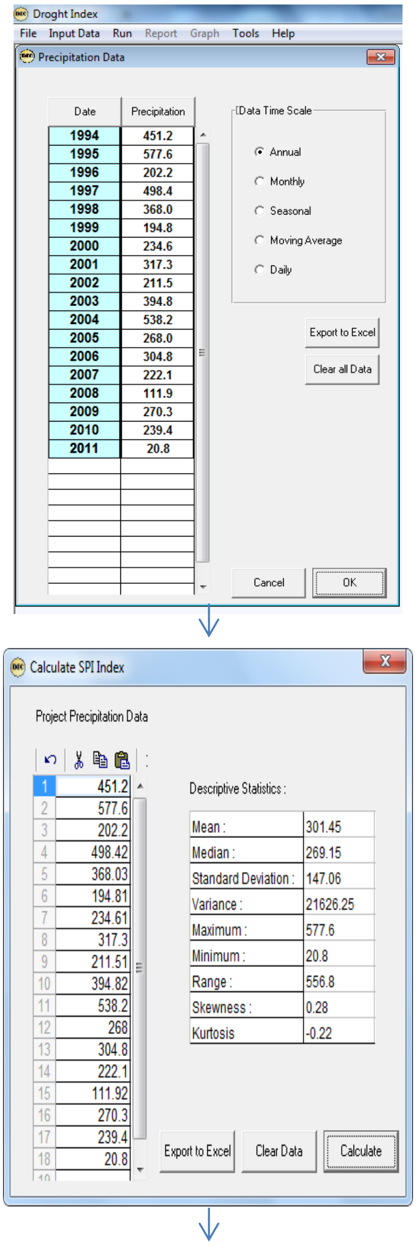
we consider a set X containing the points. $\mathbf{x}\ i = [x\ 1, x\ 2, ..., x\ d]$ for $i = 1, 2, ..., n$.
where $\mathbf{v}$ is the estimate, ωi are the weights and $\mathbf{x}i$ are the known data. The formula is here **(4.3)** :

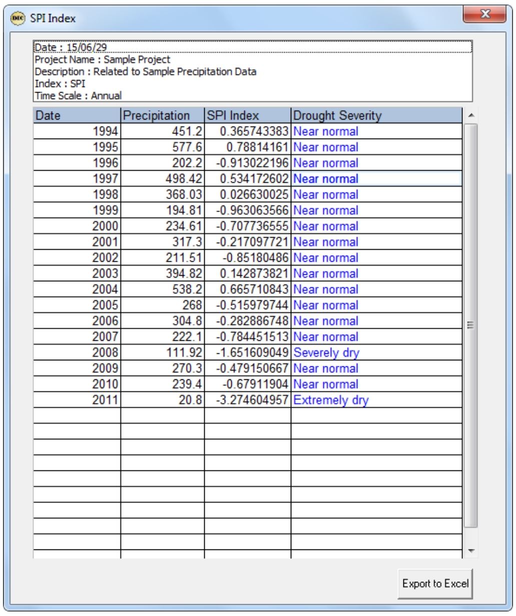
$$\hat{v} = \sum_{i=1}^{K} w_i x_i \qquad \textbf{(4.3)}$$

Note that we always have: $\sum_{i=1}^{N} w_i = 1$ because the sum of the volumes of the Voronoi Cells must remain the same.

4.4 Methodology

This following section outlines the methodology used in the project. As presented earlier, the SPI values were calculated with Drought Indices Calculator (DIC) software, for the period of 1994-2011 using the annual precipitation data from 17 stations. For example for Shiraz station between 1994-2011, DIC software calculated precipitation data to SPI index, as shown in Fig. 4.2.





SPI Index

Date : 15/06/29
Project Name : Sample Project
Description : Related to Sample Precipitation Data
Index : SPI
Time Scale : Annual

Date	Precipitation	SPI Index	Drought Severity
1994	451.2	0.365743383	Near normal
1995	577.6	0.78814161	Near normal
1996	202.2	-0.913022196	Near normal
1997	498.42	0.534172602	Near normal
1998	368.03	0.026630025	Near normal
1999	194.81	-0.963063566	Near normal
2000	234.61	-0.707736555	Near normal
2001	317.3	-0.217097721	Near normal
2002	211.51	-0.85180486	Near normal
2003	394.82	0.142873821	Near normal
2004	538.2	0.665710843	Near normal
2005	268	-0.515979744	Near normal
2006	304.8	-0.282886748	Near normal
2007	222.1	-0.784451513	Near normal
2008	111.92	-1.651609049	Severely dry
2009	270.3	-0.479150667	Near normal
2010	239.4	-0.67911904	Near normal
2011	20.8	-3.274604957	Extremely dry

Export to Excel

Figure 4.2: Calculation of precipitation data to SPI with Drough Indicis Calculator.

To determine and monitor the drought coverage area in different years is used ArcGIS9.0 software. To check normality of the data for each station; the software of "IBM SPSS statistics 22" was used. Data from option of "Normality Test" have been analyzed. Amounts more than 0.05 indicate distribution of data in the period of record is normal while amounts less than this indicate distribution data is not normal. In the assessment 90% of stations have normal data that is acceptable for the assessment. In order to generalize calculated SPI values for 17station to the whole study area, inverse distance weighting (IDW) interpolation, Kriging interpolation and Natural Neighbor interpolation are used. But because of the better results about the study area, inverse distance weighting (IDW) interpolation was selected for this thesis.

4.5 Standardized Precipitation Index (SPI) and Meteorological Drought

SPI as has been mentioned earlier is an index that was developed to quantify precipitation deficit at different time scale. 1-month SPI reflects short term conditions and its application can be related closely to soil moisture; the 3-month SPI provides a seasonal estimation of precipitation; 6 and 9 month SPI indicates medium term trends in precipitation patterns and 12 month SPI shows long-term trend [23]. Therefore 12 month was calculated for 10 rainfall stations using annual data for the period of 1994-2006 and 17 stations for the period of 2007-2011.The threshold for indicating severity of meteorological drought has been adopted from U.S. drought mitigation center . The category column in drought severity classification Table 4.4 has been modified to suit the reclassification of the SPI maps. Initially SPI values had been interpolated using ordinary kriging taking grid size of 8km. Kriging has provided optimal areal estimates in any given situation and is applicable both for drought and flood. But in the present work interpolation by ordinary kriging did not gave good result as the range of SPI (-2 to +2) after interpolation was significantly reduced which could not be used to reclassify the interpolated maps into drought severity classes correctly. Therefore the method of Inverse Distance weighted (IDW) has been used to interpolate the SPI values. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that rare farther apart (ArcGIS 9.0) interpolation has been performed in ArcGIS 9.0. The interpolated maps are thus been reclassified into different drought severity classes. On the analysis of the obtained SPI in annual, for each of the 17 years a threshold -1.5 was chosen to reclassify SPI into binary mask of 1 and 0 where 1 stands for drought and 0for no drought. Two models years for drought years (1994 and 2004) as well as two wet years (2008 and 2011) has been chosen to present the drought severity classes in these two different conditions.

Table 4.4: Drought Severity Classification.
Sources: (U.S. National Drought mitigation Center) [23].

Category	Description	Standardized Precipitation Index (SPI)
D0	No drought	-0.5 and above
D1	Abnormally dry	-0.5 - -0.7
D2	Moderate drought	-0.8 - -1.2
D3	Severe drought	-1.3 - -1.5
D4	Extreme drought	-1.6 - -1.9
D5	Exceptional drought	-2 or less

5. Results and Discussion

The chapter explain about how the analysis has been done taking into consideration index being computed. The results in this chapter presented in two separate sections.

In the first section the results is related to the SPI index and the second section the results is related to the interpolation methods.

5.1 SPI Value and Drought

Some studies so far done in Iran and in the world have based on their estimation on the 'present state' of hazard of drought during a specific year using some indices like SPI. From fig. 5.1 ,SPI for 17 stations in Fars province with the period of 1994-2011 can be analysed which indicate that in 2011 SPI dropped as low as -3.46 is related to Sadedorodzan station in the north of the province and most of the stations in 2011 below -2.20 that they faced extreme drought. Also, 2011 was extreme drought year than 2008 where SPI only up to -2 at two stations of Fasa and Shiraz. This indicates that 1999 was less severe drought affected than 2011. This situation and SPI values are true for a time between 2007- 2011. Another fig. 5.2 is illustrated for a period of 1994-2006, in 1999, Lamerd station in the south of the province with having -1.71 SPI value is faced severe drought . However if we look towards the normal years only few stations experienced SPI below (-1), which is considered to be a normal situation. Investigation showed that dry periods using SPI, continuing drought have increased in recent years. The analysis of very severe dry periods shows that this type of dry periods with calculation of SPI in a annual scale has a repetition and continuity different. Other figures about SPI values for stations are in app.

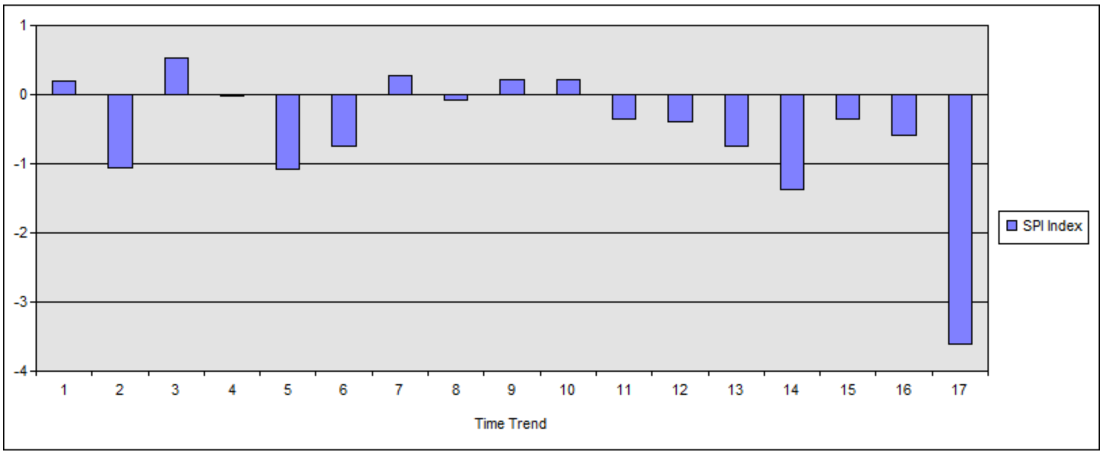


Figure 5.1: 17 years SPI for Sadedorodzan station.

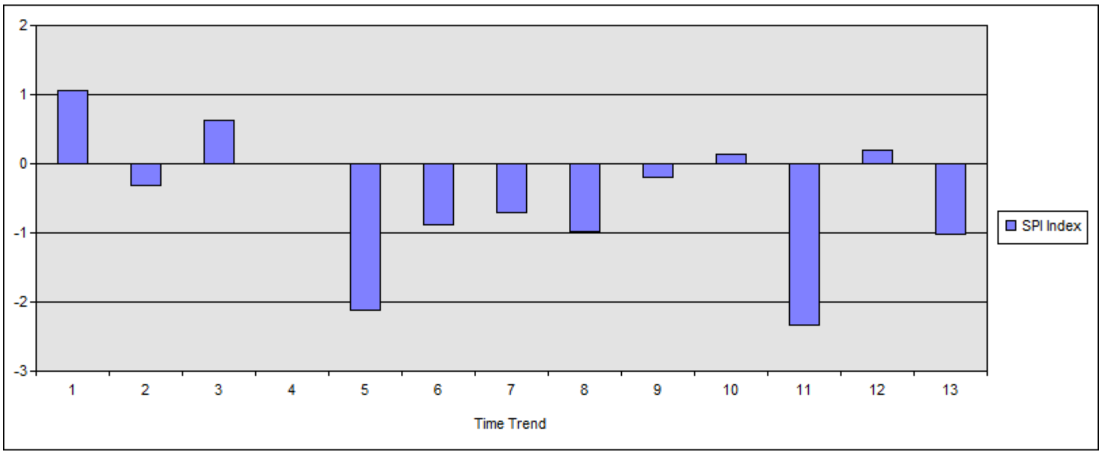


Figure 5.2: 13 years SPI for Lamerd station.

5.2 SPI And Drought Severity

After the interpolation with kriging method, inverse distance weighted method and natural neighbor method, the figures illustared that inverse distance weighted interpolation is the best method for this study . For stations between 1994-2011, kriging interpolatopn and natural neighbor interpolatio can not cover all of the surface of this area and it is not practical for this study.

With inverse distance weighted interpolation and SPI values, selected drought years were reclassified into severity classes. During the period of 17 years in the Fars province, each year has a special feature of drought that this thesis considered the most important events. For 17 station between 1994-2011, From 1994-1998 and 2000-2004 the hazard maps show almost a normal and lightly humid, but in 1999 and 2005 compared with previous years province faced severe drought. Several factors such as amount of precipitation, wind Velocity, evapo-transpiration, atmospheric Circulation, hemispheric nature and temperature have effective in drought. As mentioned in previous part (SPI values and drought) and Fig. 5.3, the most severity drought during 19994-2011 is related to Sadedorodzan station with the number of SPI -3.46 and located in the north of the Fars province in 2011. Fig 5.4 is illustrated that between 1994-2006, in 1999, Lamerd station in the south of the province is faced drought.

Other figures are generated according to inverse distance weighted method are in app. During this year, others stations live in drought conditions. İt is well recognised the usefulness of SPI to quantify different drought types. Since SPI can be calculated at different time scales, it often severes as indicator of different drought types. Many studies have demonstrated that short term and long tem drought are considered as agricultural and hydrological drought indicators. Hence annual SPI during these years was used in the present work to quantify severity of drought for selected drought and wet years. In other words in 2011, 95 percent of the province experinced extreme drought.

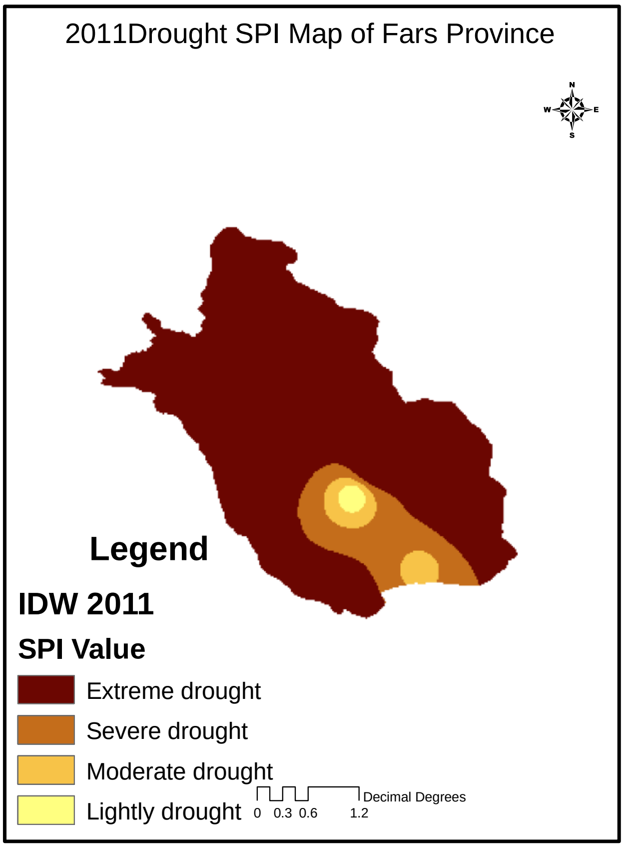


Figure 5.3: Hazard map of drought vulnerability in 2011.

It is worth noting that one of the most problematic issues in the Fars province is the wells' over harvesting that resulted in the recent drop in groundwater levels. Since 75% of water that is used in agricultural sector of the Fars province is provided from regional aquifers, recession in groundwater levels would have direct effects on amount of Fars crop productions in the following decades. Hence, this issue has been subjected to specific consideration in Fars Organization of agriculture. But this study reveals that there is no significant difference between area percentages of the Fars province under severe to extreme drought conditions. So, the recent droughts may be one of the factors that cause expressed problems in water resources but role of other factors such as lack of proper and appropriate management and also increasing demand for water due to population growth should be taken into serious consideration, otherwise the Fars province could experience serious socioeconomic crisis that would challenge natural resources decision makers and executive directors. Also it should be regarded that the clear emergence of drought induced problems in recent years is because of recession in groundwater storages that itself is due to the occurrence of drought events during the past decades. These events cause major degradation in groundwater storages that its rate in some parts of Fars province is too high to restore it. In other words in 1999,75 percent of province experinced moderate drought.

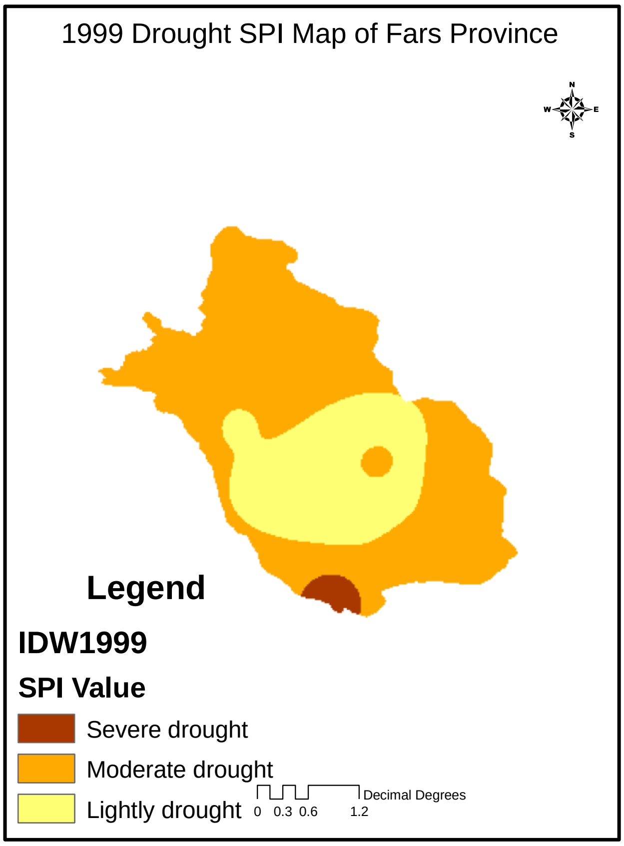


Figure 5.4: Hazard map of drought vulnerability in 1999.

5. CONCLUSIONS AND RECOMMENDATIONS

As among climatic elements, rain has the most fluctuation, observing droughts with different severity and frequency based on rainfall data in climatic studies of each region, especially regions where agricultural center is necessary. This research dealt with the evaluation of time and local changes in drought in Fars province through SPI and inverse distance weighted interpolation (IDW) interpolation method in the environment GIS.

Regarding SPI just uses rainfall parameter to identify severity of drought, so it may have some defect because factors such as temperature, evaporation and transpiration may effect on severity of drought .

In this thesis, for the monitoring and assessment of the drought effective area variations during 17 years in the Fars province, the annual rainfall data from a total of 17 rainfall measuring sites was used. The SPI values in time scales (12 months) were calculated as the surrogate of drought severity for a total of 17 years of data from 1994-2011. Through kriging interpolation and natural neighbor interpolation, inverse distance weighting (IDW) algorithm was applied to spatially expand the SPI data to the whole study area. The results suggest that the nature of utilized data for the drought area assessment has no conflict with the basic assumption of IDW algorithm. Most stations in 2010 to 2011 faced very severity drought. Droughts occurred in the considered stations did not follow a specific order. Obtained results from zoning showed that the most droughts specially severe and very severe occurred in North and Northwest of the study area. In these regions, moderate drought has more frequency in comparison with other values of SPI. This study showed that even wet regions are not safe from natural disaster of drought and also drought and wetness could not be predicted in wet regions, likely damages is more than dry and semi-dry regions.

ArcGIS couple with drought index (SPI) is vital tool for drought monitoring and mitigation. ArcGIS supports visualization of scientific based results important for decision making process. The results showed due to the advancement of computer technology and use it in collection, storage and analysis of data for optimal use of resources, GIS can be used for processing information about the degree, intensity, and spatial distribution of the continuing dry periods and identify better and wider (in terms of location and descriptive information), quick access to the target with cost and less time. Results may prove to be useful for regional planners, and policy makers for agricultural and environmental strategies, not only in Southern Iran but also in other countries facing similar problem.

Totally, province' situation is faced moderate drought and severe drought. Therefore in order to plan and manage the drought or water resources of Fars province, special attention Should be paid to this area since the lack of proper planning in these areas may cause irrecoverable disasters. So, by recognizing sensitive areas, Tension Management Committee of the province should plan how to deal with drought. As a result, some measures are recommended. Proposed proceedings to deal with the consequences of drought:

1- Preparation and implementation of land use plans
2- Public participation in the management of localized drought conditions
3- Cooperation policy makers and experts from differents part of the country
4- International cooperation
5- General and effective training for how to deal with the consequences of the drought and its management
6- Comprehensive risk management rather than crisis management plan to deal with the consequences of the drought
7- Control and proper distribution of population and setteling on water potential

6.1 Problems and limitation

One problem which I could feel have affected the SPI is that since SPI computation requires at least 30 years of time-series rainfall data and more than 20 stations, the data available for this study were only 10 stations for 17 years and 7 stations for 5years which might have affected the SPI derived meteorological drought. The SPI allows monitoring operationally any location with a 30-year time series. This province has just 24 sinoptic station for this research, because of this I had a limitation about time scale for selecting them.

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APPENDICES

APPENDIX A: Figures for SPI index.

APPENDIX B: Droght maps for Fars province**.**

APPENDIX A

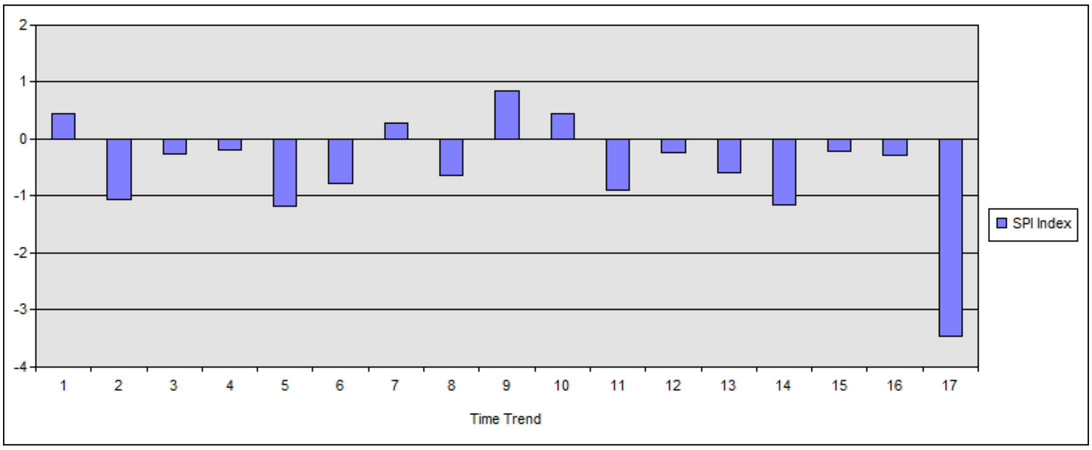

Figure A.1: SPI index for 17 years in, Abadeh station.

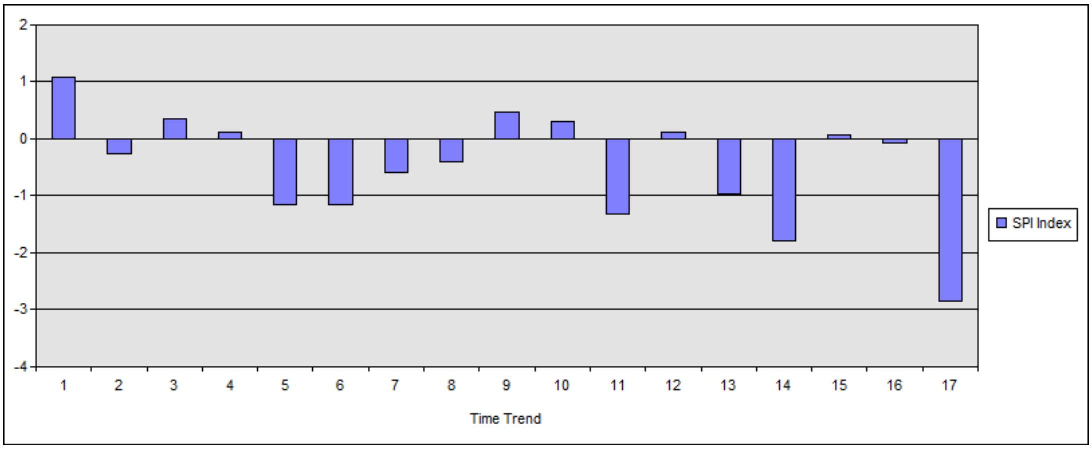

Figure A.2: SPI index for 17 years, Darab station.

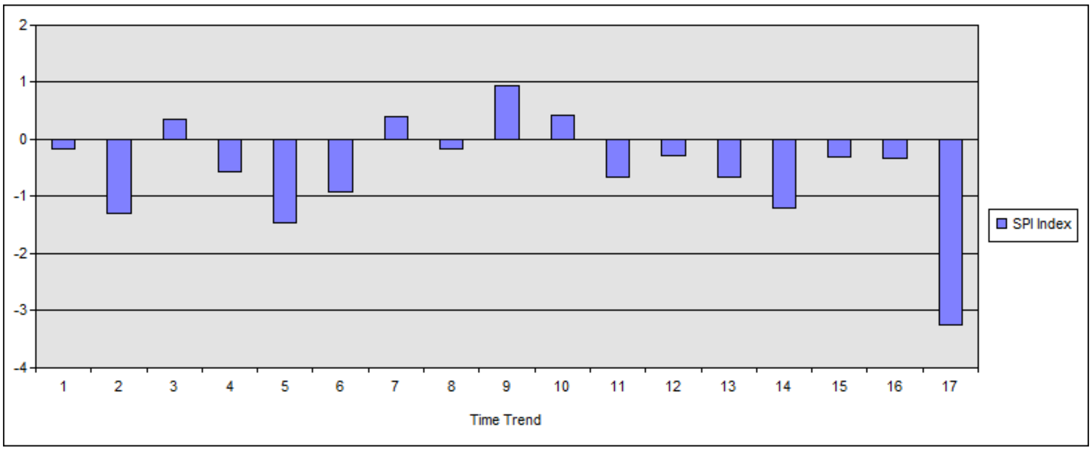

Figure A.3: SPI index for 17 years, Eghlid station.

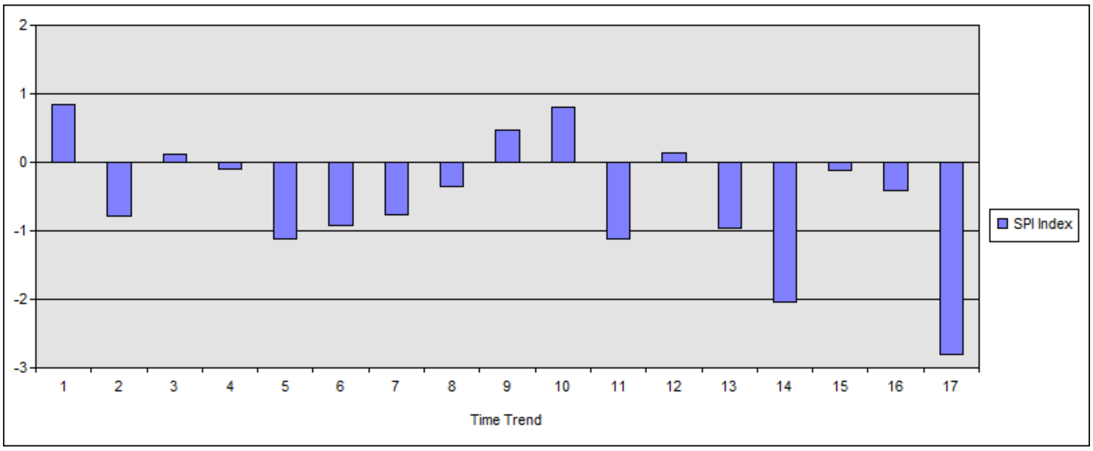

Figure A.4: SPI index for 17 years, Fasa station.

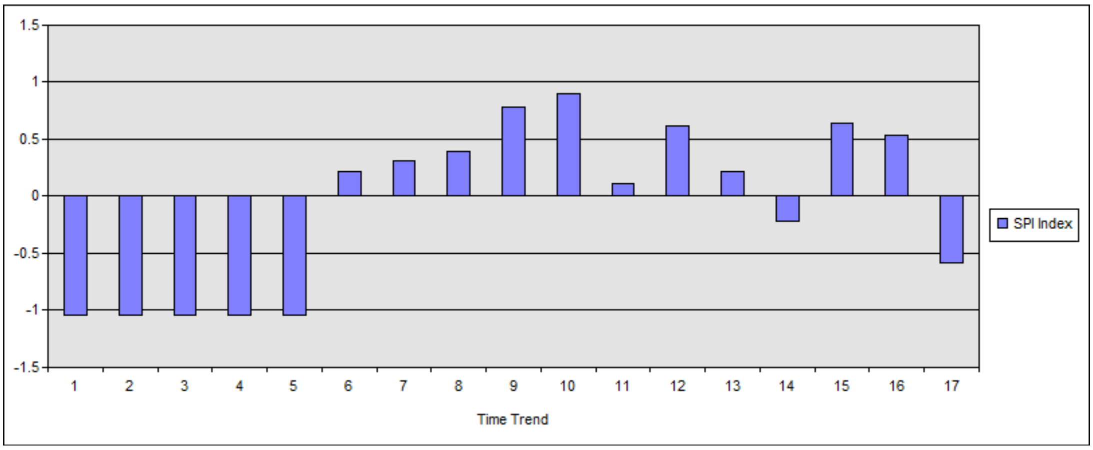

Figure A.5: SPI index for 17 years, Jahrom station.

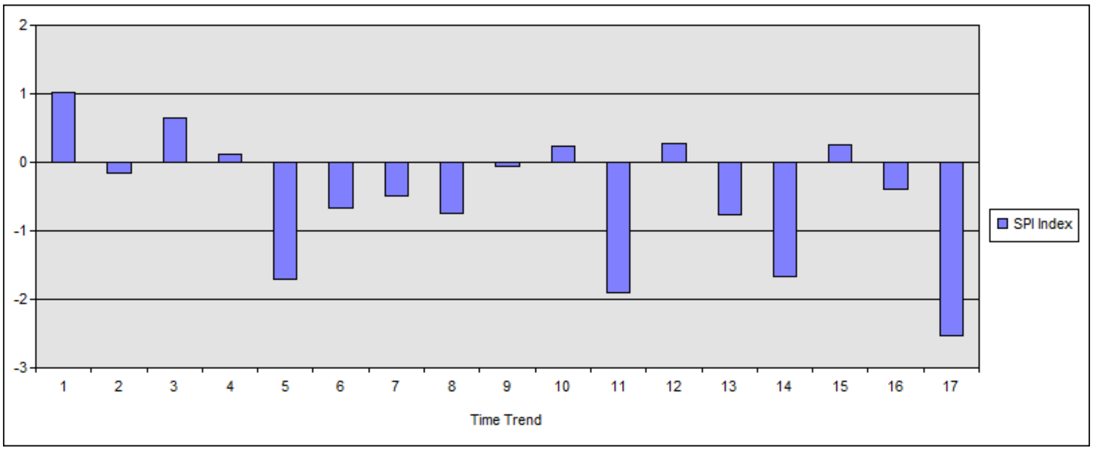

Figure A.6: SPI index for 17 years, Lamerd station.

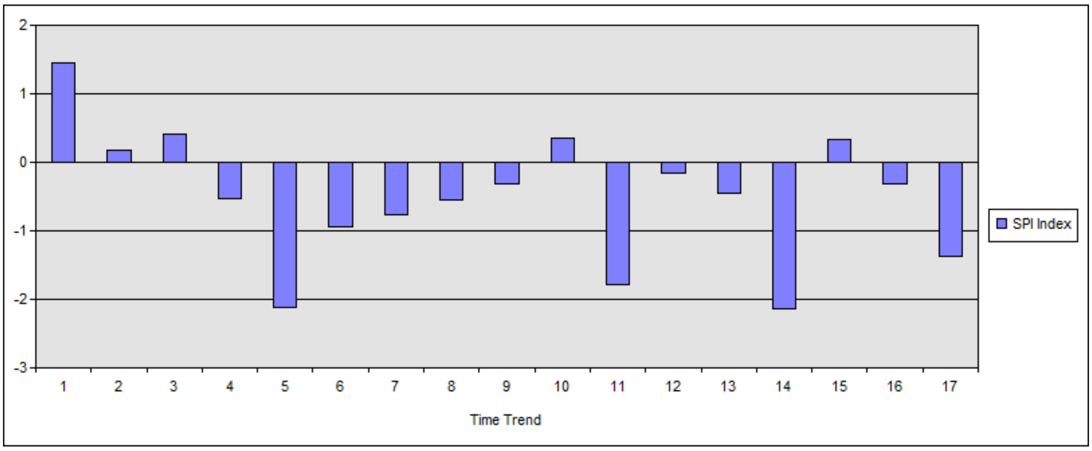

Figure A.7: SPI index for 17 years, Larestan station.

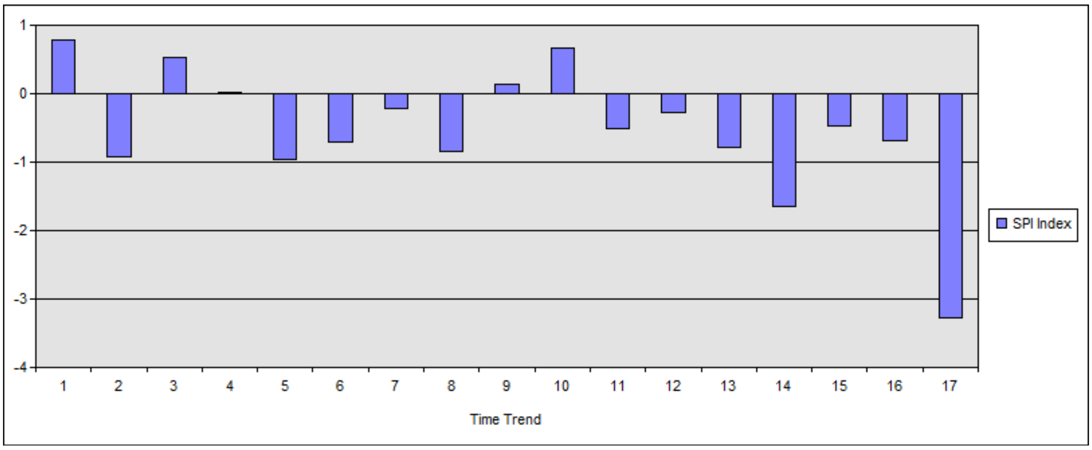

Figure A.8: SPI index for 17 years, Shiraz station.

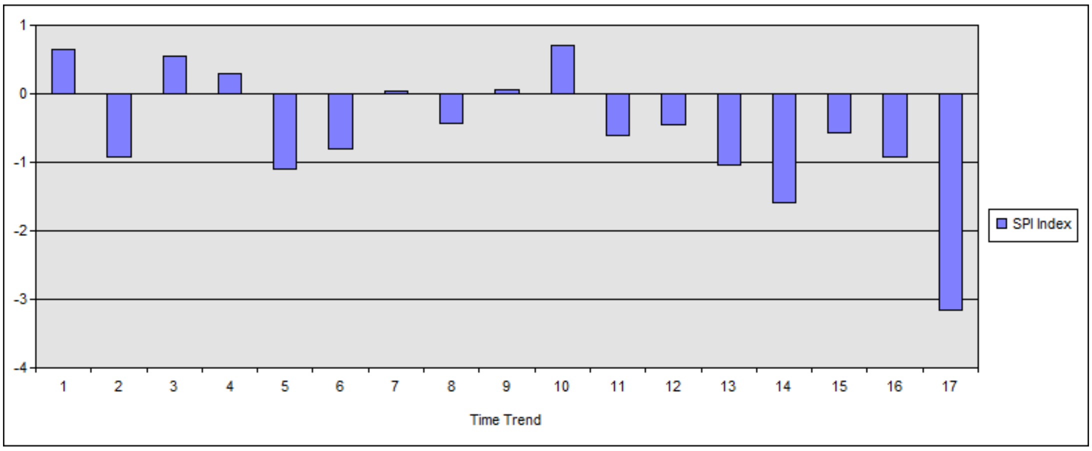

Figure A.9: SPI index for 17 years, Zarghan station.

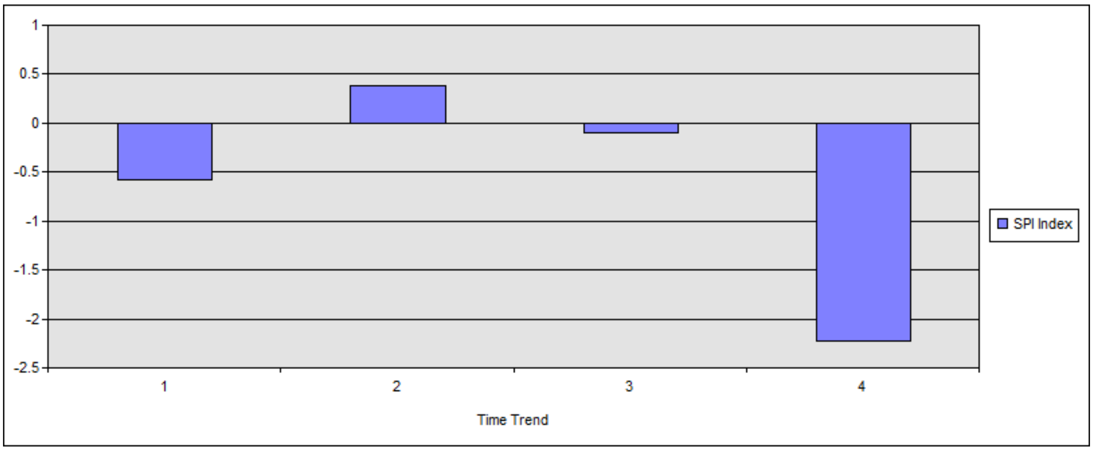

Figure A.10: SPI index for 5 years, Arsenjan station.

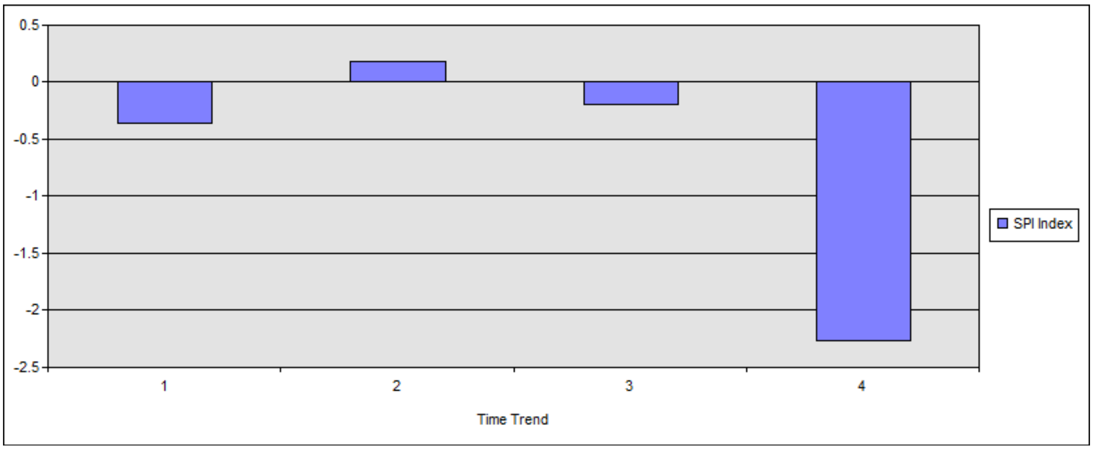

Figure A.11: SPI index for 17 years, Bavanat station.

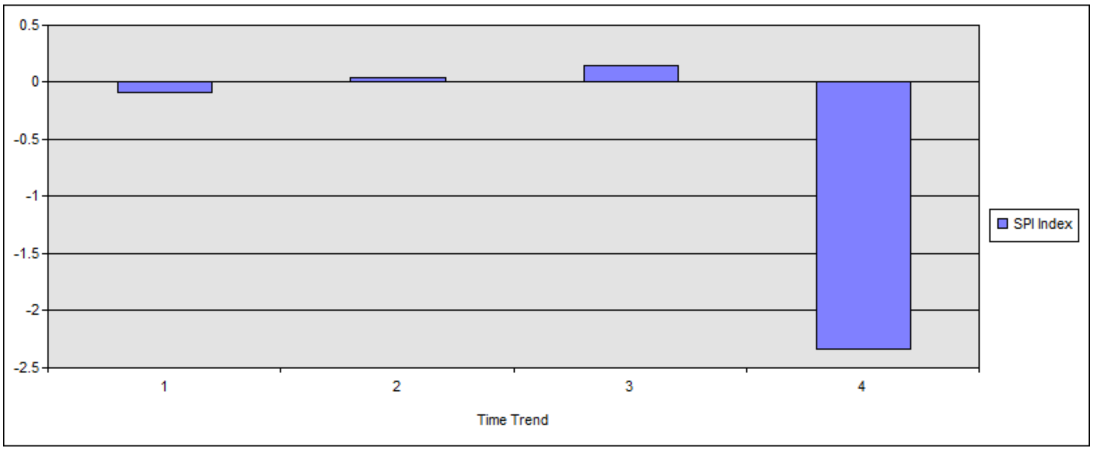

Figure A.12: SPI index for 17 years, Izadkhast station.

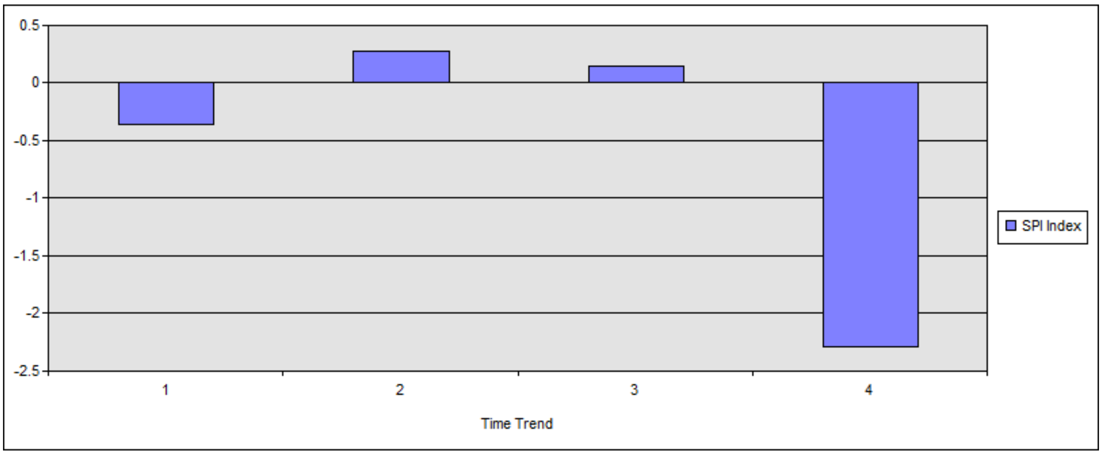

Figure A.13: SPI index for 17 years, Kazeroon station.

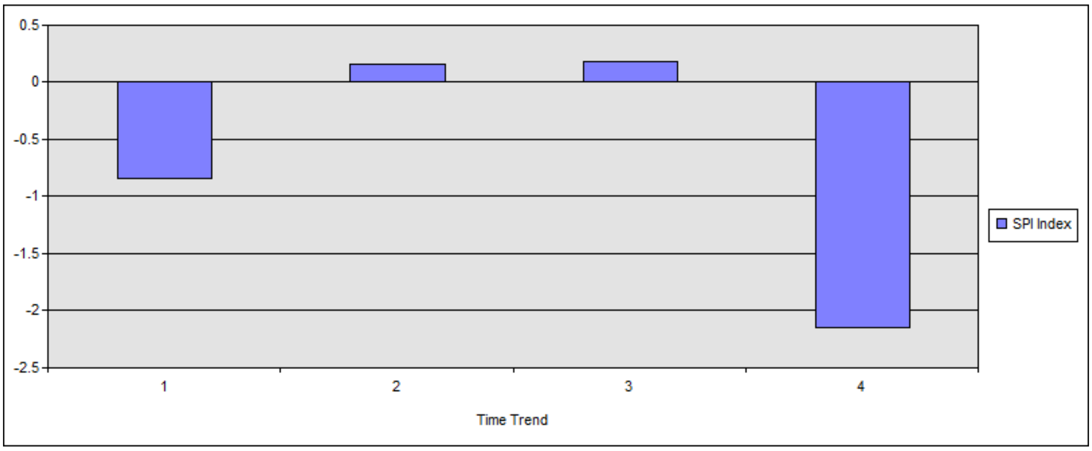

Figure A.14: SPI index for 17 years, Neyriz station.

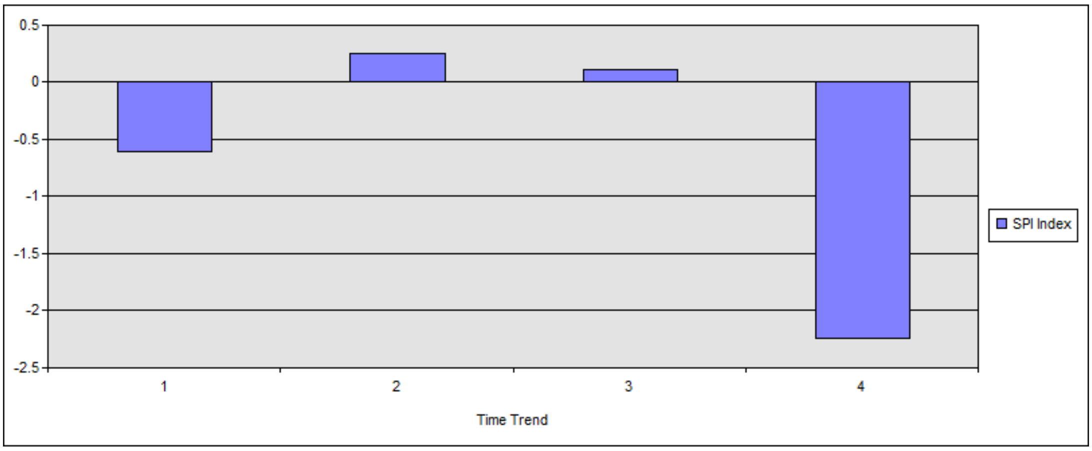

Figure A.15: SPI index for 17 years, Safashahr station.

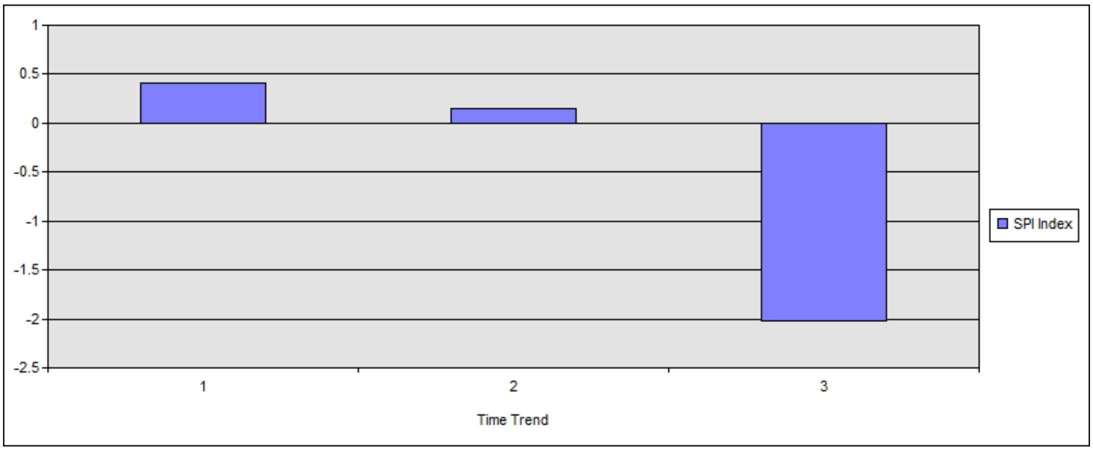

Figure A.16: SPI index for 17 years, Noorabad station.

APPENDIX B

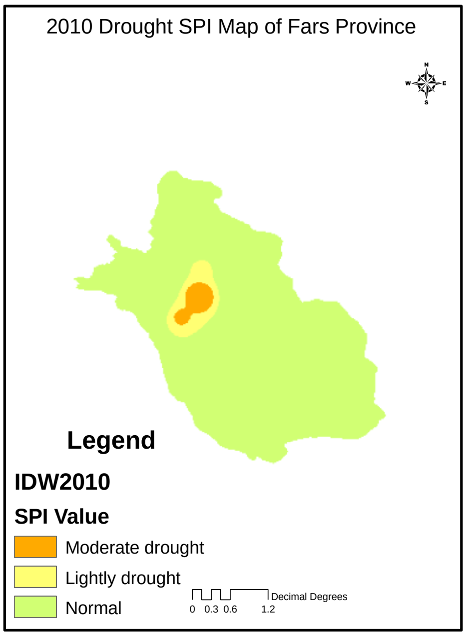

Figure B.1: Hazard map of drought vulnerability in 2010.

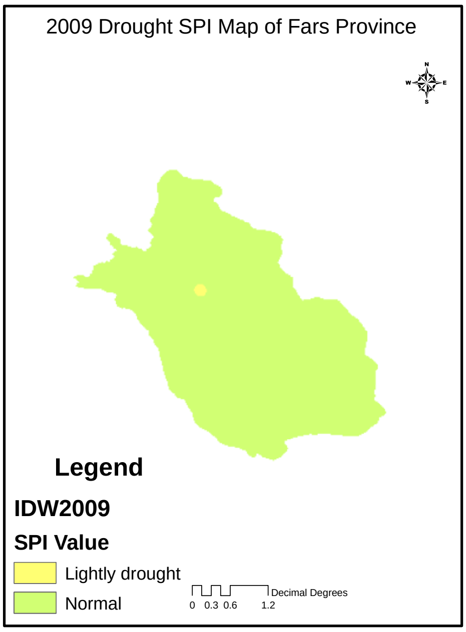

Figure B.2: Hazard map of drought vulnerability in 2009.

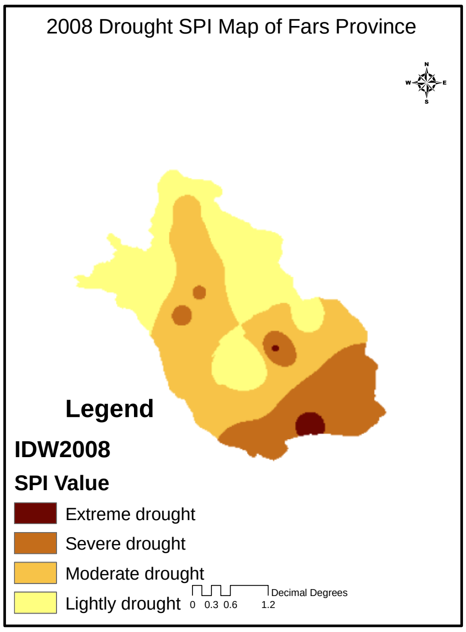

Figure B.3: Hazard map of drought vulnerability in 2008.

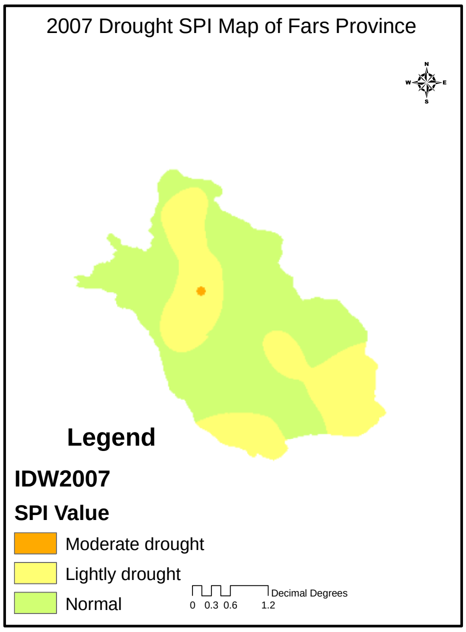

Figure B.4: Hazard map of drought vulnerability in 2007.

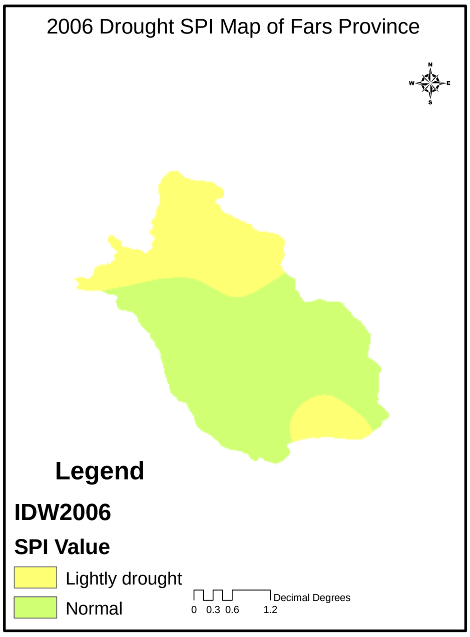

Figure B.5: Hazard map of drought vulnerability in 2006.

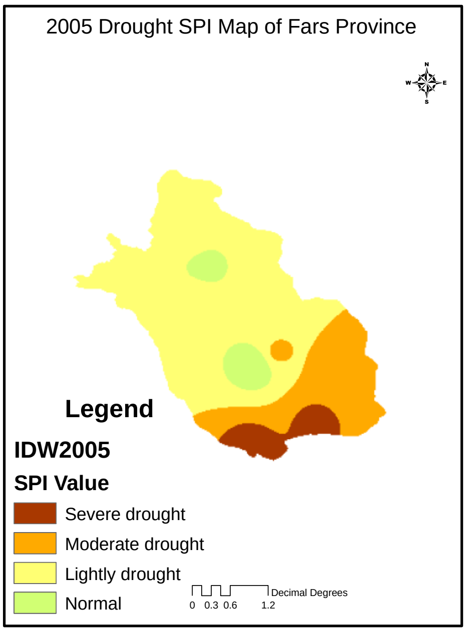

Figure B.6: Hazard map of drought vulnerability in 2005.

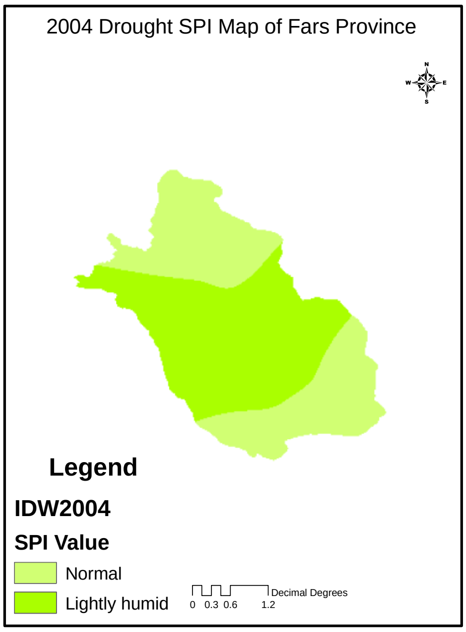

Figure B.7: Hazard map of drought vulnerability in 2004.

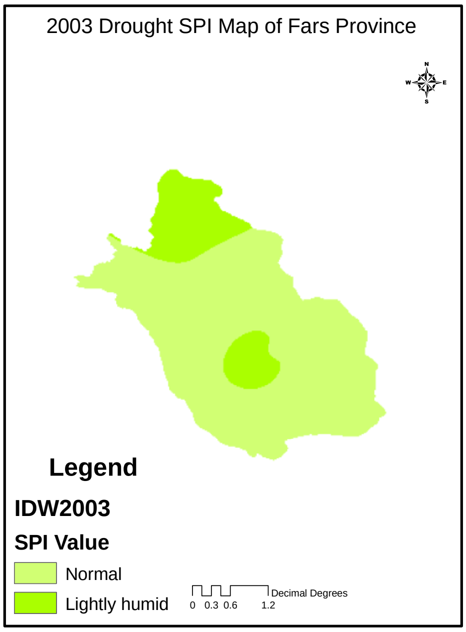

Figure B.8: Hazard map of drought vulnerability in 2003.

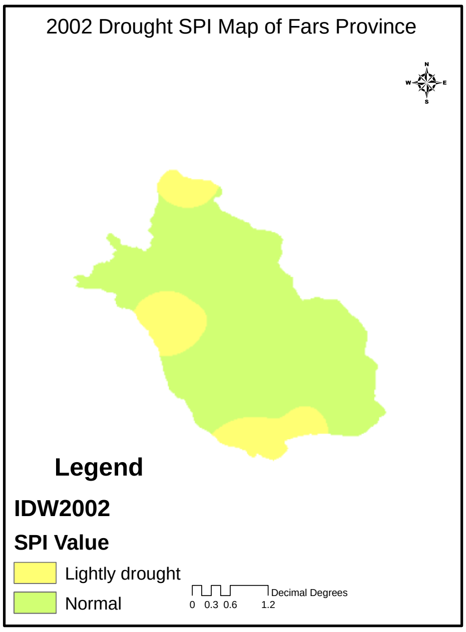

Figure B.9: Hazard map of drought vulnerability in 2002.

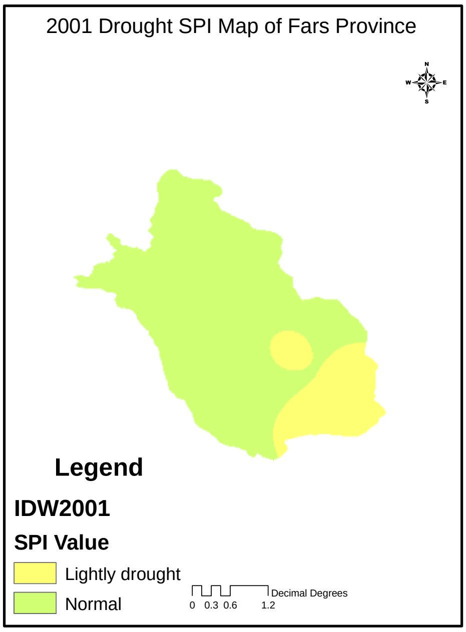

Figure B.10: Hazard map of drought vulnerability in 2001.

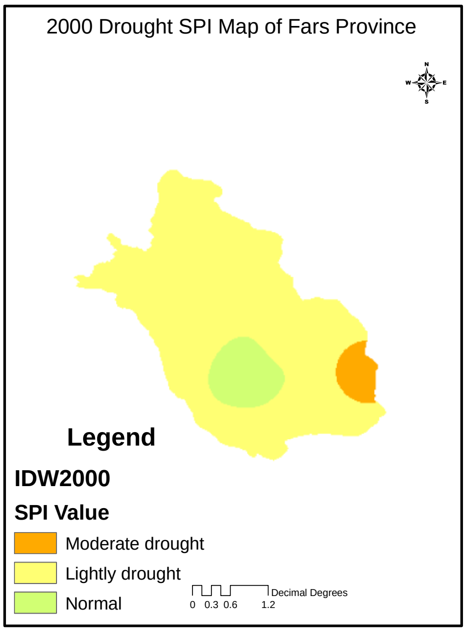

Figure B.11: Hazard map of drought vulnerability in 2000.

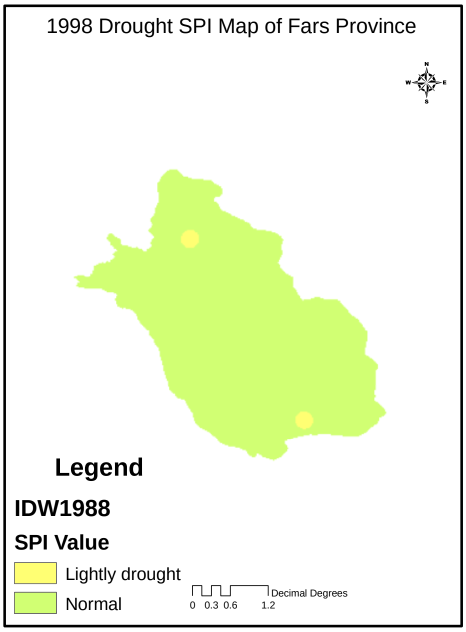

Figure B.12: Hazard map of drought vulnerability in 1998.

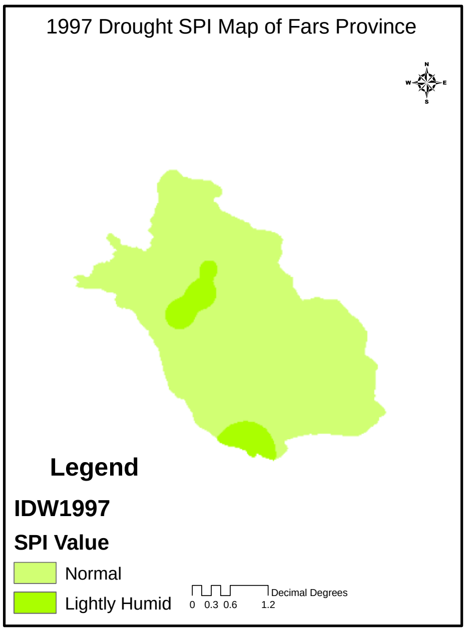

Figure B.13: Hazard map of drought vulnerability in 1997.

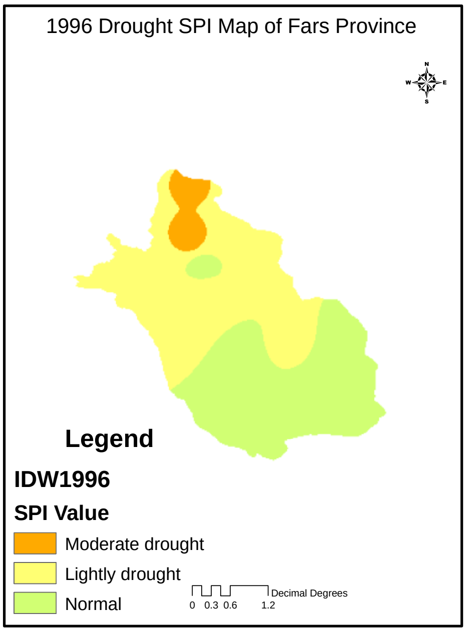

Figure B.14: Hazard map of drought vulnerability in 1996.

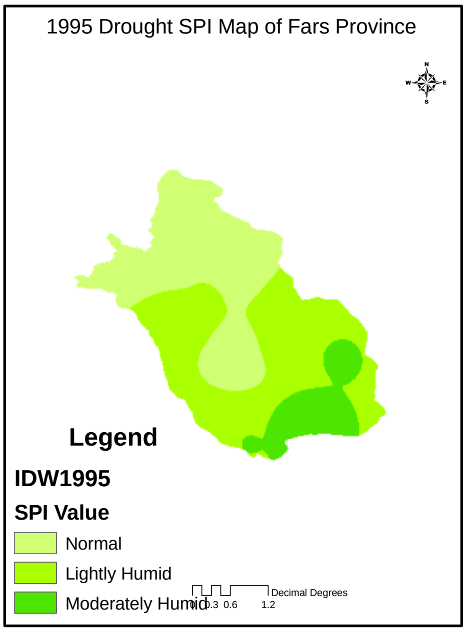

Figure B.15: Hazard map of drought vulnerability in 1995.

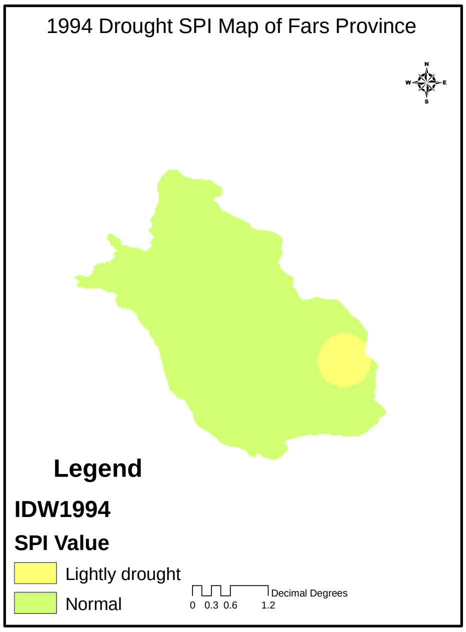

Figure B.16: Hazard map of drought vulnerability in 1994.

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