ANALYSIS OF DROUGHT EVENTS IN NORTH CYPRUS

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ABSTRACT

ANALYSIS OF DROUGHT EVENTS IN NORTH CYPRUS

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Drought is a temporary climatic condition which arises due to lack of precipitation. It has become an important natural phenomenon for North Cyprus due to its semi-arid climate and with vulnerabilities culminating as a result of climate change there is a dire need to keep a good track of such extreme climate events for sustainable water resource management. The island is facing serious water shortages, and for Mediterranean region climate change impacts on water resources has become a pressing issue, hence, there is a need to understand these relationships which will aid in planning of hydroclimatic and agroclimatic designs. To achieve this objective, the study aims to analyze spatial-temporal characteristics of drought events for period 1978-2015 using monthly rainfall data from 33 stations across North Cyprus. In this study, number of commonly used drought indices such as Standard Precipitation Index (SPI), Z-Score Index (ZSI), Rainfall Departure from Mean (RD), China Z- Index (CZI), and Rainfall Deciles based Drought Index (RDDI) are calculated. The comparison of these indices at multiple time steps is achieved which showed CZI, SPI and ZSI are highly interchangeable and rain months (November, December, January, February and March) alone can best describe annual droughts for this region. SPI being the widely accepted drought index and giving similar results to other indices is selected to compute the drought characteristics indicating severity, magnitude, duration, intensity, and frequency of historical droughts in the region. Results showed that the region is mostly characterized by droughts of mild severity and short duration. Severity-Duration-Frequency (SDF) relationships are studied and isoseverity maps are developed for North Cyprus which indicated increasing drought severities with decreasing frequencies and also observed increasing severity trends towards north coast, north western peninsula and central Meseoria plain region of the country. In addition, teleconnections between drought indices and Ocean Atmosphere Circulations, such as El Nino Sothern Oscillation (ENSO), North Atlantic Oscillations (NAO), Arctic Oscillations (AO), North Sea Caspian Pattern (NCP) and Western Mediterranean Oscillation (WeMO), is analyzed to evaluate and predict impact of large scale climate variabilities on the drought occurrence. The correlations based on lag times showed ENSO at lag of three years is linked to drought occurrence in North Cyprus. The results of this study are beneficial for decision makers for planning and design of hydrological structures and will ultimately help in the mitigation of such extreme events.

Keywords: drought, climate change, North Cyprus, drought indices, severity, magnitude, duration, intensity, frequency, teleconnections, Ocean Atmosphere Circulations, lag time

ÖZ

Kuraklık, yetersiz yağışdan dolayı ortaya çıkan geçici bir iklim koşuludur. Yarı kurak ikliminden dolayı kuraklık Kuzey Kıbrıs için önemli bir doğal fenomen haline gelmiştir. Diğer taraftan değişen iklim koşulları altında sürdürülebilir su kaynakları yönetimi için bu tür ekstrem iklim olaylarının yakından takip edilmesi gerekmektedir. Adada ciddi su sıkıntısı bulunmaktadır. Akdeniz bölgesinde meydana gelen iklim değişikliğinin su kaynakları üzerindeki etkisi önemli bir sorun haline gelmiştir. Dolayısıyle kuraklık analizi sonuçları hidro-klimatik ve tarımsal tasarımların planlanmasında önemli bir rol almaktadır. Bu çalışma, 1978-2015 yıllarına ait yaşanmış kuraklık olayalarının mekansal ve zamansal dağılımlarını Kuzey Kıbrıs'taki 33 yağış istasyonuna ait aylık yağış verilerini kullanarak analiz etmeyi amaçlamaktadır. Bu çalışmada literatürde sıkça görülen birçok kuraklık indisi kullanılmıştır [Standard Precipitation Index (SPI), Z-Score Index (ZSI), Rainfall Departure from Mean (RD), China Z- Index (CZI), and Rainfall Deciles based Drought Index (RDDI)]. Kuzey Kıbrıs genelinde farklı zaman adımları kullanılarak elde edilen indislerden CZI, SPI ve ZSI yöntelerinin bir birine benzer sonuçlar verdiği ve yağışlı aylarda (Kasım, Aralık, Ocak, Şubat, ve Mart) meydana gelen kuraklıkların bölgedeki yıllık kuraklıkları temsil ettiği görülmektedir. SPI yönteminin birçok ülkede kabul gören bir indis olmasından ve bu indisin Kuzey Kıbrıs'ta kullanılan diğer indislerle benzer sonuçlar vermesinden dolayı bölgenin kuraklık karakteristiklerini gösteren kuraklığın şiddeti, değeri, süresi, yoğunluğu ve frekansı SPI sonuçlarına göre yapılmıştır. Sonuçlar bölgede hafif şiddetli ve kısa süren kuraklıklar yaşandığını göstermektedir. Bu çalışmada ayrıca Şiddet-Zaman-Frekans ilişkisi çalışılmış ve bölgenin eş-şiddet eğrilerini gösteren haritalar elde edilmiştir. Bu haritalara bakıldığında kuraklık şiddetinin arttığı kuraklık freakansının ise sıklaştığı görülmektedir. Çalışma sonuçlarında ayrıca zaman içerisinde kuraklıkların şiddetinde artış olduğu görülmektedir. Bu çalışmada ayrıca adanın Kuzey Kıyı Şeridinde, Karpaz Yarımadasında ve Orta Mesarya Ovasında kuraklıkların şiddetinde artışlar görülmektedir. Bu çalışmada kuraklık indisleriyle Okyanus-Atmosfer salınımları [El Nino Sothern Oscillation (ENSO), North Atlantic Oscillations (NAO), Arctic

Oscillations (AO), North Sea Caspian Pattern (NCP) and Western Mediterranean Oscillation (WeMO)], arasındaki ilişkiye de bakılmıştır. Yapılan korelasyon çalışmadında ENSO ile Kuzey Kıbrıs'ın kuraklık olayları arasında bir ilişki olduğu görülmektedir. Bu çalışmanın sonuçları, su kaynaklarının sürdürülebilir bir şekilde planlanması ve kuraklığın etkisinin daha az hissedilmesine katkı sağlayacaktır.

Anahtar Kelimeler: Kuraklık, İklim Değişikliği, Kuzey Kıbrıs, Kuraklık İndisi, Kuraklık Şiddeti, Değeri, Yoğunluğu ve Frekansı, Tele-bağlantı, Okyanus-Atmosfer Salınımı.

DEDICATION

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ACRONYMS AND ABBREVIATIONS

AMIP	Atmospheric General Circulation Model
AO	Arctic Oscillations
AVHRR	Advanced Very High Resolution Radiometer
BMI	Bhalme-Mooley Index
CMIP3	Coupled Ocean-Atmosphere General Circulation Model
CZI	China Z- Index
DAI	Drought Area Index
DWRAM	Daily Water Resources Assessment Modeling
DI	Drought Index
EDI	Effective Drought Index
ENSO	El Nino Southern Oscillation
EOF	Empirical Orthogonal Function
GCM	Global Circulation Models
GIS	Graphical Information Systems
hPa	hectopascal
IDF	Intensity-Duration-Frequency
IDW	Inverse Distance Weighted
ITCZ	Intertropical convergence zone
mb	millibars
MEI	Multivariate El Nino Southern Oscillations
NAO	North Atlantic Oscillation
NCP	North Sea Caspian Pattern
NCPI	North Sea Caspian Pattern Index
NDI	NOAA Drought Index
NOAA	National Ocean and Atmospheric Administration
OWDA	Old World Drought Atlas
PCA	Principal Component Analysis
PDO	Pacific Decadal Oscillation
PDSI	Palmer Drought Severity Index

RD	Rainfall Departure from mean
RDI	Reconnaissance Drought Index
RDDI	Rainfall Deciles based Drought Index
-Rm	Rain months
RPCA	Rotated Principal Component Analysis (RPCA)
SAI	Standardized Anomaly Index
scPDSI	Self-Calibrating Palmer Drought Severity Index
SDF	Severity-Duration-Frequency
SOI	Southern Oscillation Index
SPATSIM	Spatial and Time Series Information Modeling
SPI	Standard Precipitation Index
SST	Sea surface temperature
SWSI	Surface Water Supply Index
VCI	Vegetation Condition Index
WeMO	Western Mediterranean Oscillation
WeMOi	Western Mediterranean Oscillation Index
-Wm	Winter months
ZSI	Z-Score Index

CHAPTER 1

INTRODUCTION

Drought is a natural occurring phenomenon which is generally categorized into four types, agricultural, meteorological, hydrological, and socio-economic drought (Wilhite & Glantz, 1985). Agricultural drought tends to link characteristics of both meteorological and hydrological drought and determines the impact on agriculture with focus on soil water deficit, changes in evapotranspiration and precipitation shortages. Meteorological drought uses the threshold or normal value and estimates the degree of dryness in comparison to that threshold, as well as, the duration of this dry period. Hydrological droughts are linked with shortage of surface or sub-surface water supplies such as groundwater levels, stream flow, reservoir storage etc. Lastly, socio-economic drought links elements of the three above mentioned drought types to supply and demand of economic good and services.

There is not a single specific definition of a drought (Tannehill, 1947; Tate & Gustard, 2000). In general it is defined as reduction in precipitation amount that is received over time, a season or more in length, however, other factors such as temperature, wind and humidity can also play a role. Drought can occur in any climate, whether it is a low or heavy rainfall region. However, it should not be confused with aridity which is a permanent feature of climate (Wilhite, 1992). Generally the latitude between 15 and 35 are considered as regions with low rainfall, and occurrence of drought in those regions is a norm. Since drought is most commonly defined as severe water shortage, this water shortage will differ with amount of water needed, as different type of communities have different water needs (Gibbs & Maher, 1967). It differs from other natural disasters such as floods, earthquake etc. in four ways, firstly it develops slowly overtime and then lingers on for years even when the event has terminated, and also, it is hard to determine the start and termination of a drought, secondly, as mentioned, lack of a universally accepted drought definition makes it hard to understand the occurrence as well as the severity of drought, thirdly, drought impacts are not structural as is the case with other natural disasters, and lastly, human activities such as deforestation, excessive irrigation and over-farming tends to trigger droughts more than any other natural hazard (Wilhite, 1992).

Drought is the most complex natural disaster which is difficult to define and detect, since it is usually spread over multiple sectors and timespans, absence of a single definition in these conditions makes it difficult to have a single drought index. These indices are single numbers that assimilate raw data and make use of the individual factors that can have impact on the phenomenon under consideration (Hayes, 2006). This drought index defines different drought parameters such as drought intensity, severity, duration and spatial extent. Drought indices can be measured on various timescale such as monthly and yearly. Yearly timescale is most commonly used and gives information on regional drought behavior while monthly time scale is more useful for agriculture, water supply and groundwater withdrawal related studies (Mishra & Singh, 2010).

Indices based on rainfall data are easier to compute and are considered accurate. Rainfall is the main parameter affecting water availability, however, evaporative losses and reservoir storage can also impact the availability of water. This makes rainfall the most important indicator for drought and, in most of the cases, rainfall totals are considered sufficient for drought monitoring (Gibbs & Maher, 1967). Therefore, the drought indices chosen for this study also use single parameter i.e. rainfall. There is no single drought index that is more superior to the others in all circumstances, however, one index can be better suited for a particular region than the other (Ntale & Gan, 2003), therefore use of multiple index is considered in this study to have a better picture of drought events. Some of the indices that require only rainfall for computation include Standard Precipitation Index (SPI; Mckee et al., 1993), Rainfall Deciles based Drought Index (RDDI; Gibbs &Maher, 1967), Rainfall Anomaly Index (RAI; van Rooy, 1965), Drought Area Index (DAI; Bhalme & Mooley, 1980), Effective Drought Index (EDI; Byun & Wilhite, 1996), NOAA Drought Index (NDI; Strommen & Motha, 1987), Standardized Anomaly Index (SAI; Kraus, 1977; Katz & Glantz, 1986), China Z- Index (CZI), Z- Score Index (ZSI).

The island of Cyprus is facing serious and chronic water shortages, where droughts have become a recurrent phenomenon (Nachmani, 2000). The water shortage in North

Cyprus is reported to begin in 1960 and this situation is still increasing (Elkiran & Ergil, 2006). This water shortage is often linked to climate change, however, over-extraction of water due to old and poorly managed irrigation techniques and inefficient conveyance installations are also important factors. Agriculture, which is very important for the country's economy, demands water for efficient crop production and citrus fruits, being the key export, require more water than other fruit crops (Elkiran & Ergil, 2006). According to Mediterranean water scarcity and drought report, (2011) Cyprus is a water stressed country, while, water scarcity is also becoming a reality for the country. Water stress is experienced when the volume of per person water availability falls below 1700 cubic meters (60000 cubic feet) per year, while water scarcity is experienced when the per person water availability is less than 1000 cubic meter (35000 cubic feet) per year (ICID.CIID, 2017). This water scarcity can be attributed to a number of reasons such as dry climate, desiccation, drought, and water stress. Out of these reasons, drought is a very important natural disaster to predict climate change impacts that are linked to changing temperature and precipitation (Spinoni et al., 2014). The impacts of climate change on water resources in Mediterranean region has become a pressing issue (Cook et al., 2016). A decreasing trend in precipitation and increasing trend in extreme climates is observed for Mediterranean region, while climate models suggest increase in future drought events (Vicente-Serrano et al., 2004). Climate change can contribute to droughts in different ways, 1) increase in temperature will cause increased evaporation and ultimately causing water stress condition 2) change in precipitation patterns, and 3) reduced snowpack impacting the river flows. A drought can have a wide range of threats to the community and environment including disruption of water quality which can make it unfit for drinking purposes; effects on agriculture and crop production; effecting the reliability of energy production that will have a direct impact on daily life and routine work; wild-fires which will not only further contribute to climate change with increased greenhouse gas emissions but will also destroy habitat of many organisms etc. (C2ES; Center for drought and climate change, 2017; Yusa et al., 2015).

The oceans have a very key role in determining and effecting the climate of the world because of their high heat capacity and large spatial extent. Similarly atmosphere can impact the climate through atmospheric circulations caused by differential heating of the ocean and the continent. (Kantha & Clayson, 2000). The climate cycles are recurrent and persistent patterns of these ocean and atmosphere circulations that can have large scale impacts on climate even in the remote geographic areas (Mishra & Singh, 2010). Teleconnection is a term that is used in literature to understand the links between the large scale climate variability and any geographic region (Nigam & Baxter, 2015). These teleconnections are possible using indices which define the complicated phenomenon of ocean atmospheric variability using a single value that can be tracked over time (Mishra & Singh, 2010). Some of these indices include Pacific Decadal Oscillation (PDO; Bond & Harrison, 2000; Mantua et al, 1997), North Atlantic Oscillations (NAO; Hurrell, 1995), Southern Oscillation Index (SOI) and the multivariate El Nino Southern Oscillations (MEI; Wolter & Timlin, 1993) etc. The analysis of these large scale climate oscillations together with drought indices can help to predict significant indicators of drought occurrence (Ozger et al., 2009).

1.2. Motivation

Water is very essential for all life forms and, at present, the availability of freshwater is the biggest threat being faced all over the world. The water demand is exceeding the supply, especially, in the arid and semi-arid regions, such as Cyprus, which have limited renewable water resources and receive less annual rainfall. These arid and semi-arid regions are facing periodic droughts, and in the recent decades drought is the most frequently occurring natural hazard faced by them which directly affects the water resources. Drought is a natural phenomenon that is not easily detectable unless some damages are observed associated with it, and usually, it’s late when these damages are realized and it gets difficult to counteract those consequences. The main motivation towards this study is to analyze patterns of drought events in North Cyprus, which is already becoming a water scarce country. With changing climate, climate extremes such as droughts are becoming a recurrent phenomenon in semi-arid regions. These droughts, if unchecked, have a huge tendency to affect the three pillars of sustainability, i.e., economy, society and environment. The economy of North Cyprus will be affected to due low agricultural yield as a consequence of drought impacts on water supplies. Food security and water quality are two important social impacts of drought. While environmental impacts of droughts will include loss of biodiversity.

The results of this study will be beneficial in any decision regarding water management and drought mitigation in North Cyprus. The three main components of a drought management and mitigation plan include 1) monitoring and early warning, 2) risk assessment, and 3) mitigation and response (ICID.CIID, 2017). This study will cover the first component of drought risk management plan through calculation of a number of drought indices and will help to describe the characteristics of droughts such as its start, end, severity, duration, intensity and frequency, which will aid to use the appropriate management tools.

1.3. Objective of Study

This study aims to analyze historical drought events in North Cyprus using various drought indices such as Standard Precipitation Index (SPI), Rainfall Departure from mean (RD), China Z- Index (CZI), Z- Score Index (ZSI), and Rainfall Deciles based Drought Index (RDDI). Most appropriate drought index for the region will be identified based on correlation analysis at different time steps. The drought characteristics will be evaluated for the most suitable time step using drought parameters such as severity, duration, magnitude, intensity, and frequency of drought events. Teleconnections will be made with Ocean Atmospheric Circulations to predict any relation of large scale climate variabilities to droughts in North Cyprus.

The next section in this study includes the literature survey. In Chapter 3, study area and data are discussed, and Chapter 4 incorporates the research methodology followed. The Chapter 5 incorporates the results and discussion part and Chapter 6 concludes the study.

CHAPTER 2

LITERATURE REVIEW

There is a wide extent and nature of drought studies in literature, for example, some focus on drought identification with respect to its severity, duration, frequency and magnitude; some focus on analyzing the spatial and temporal extent of droughts; some focus on determining relationships between drought occurrence in two or more locations; some focus on analyzing workability of a particular drought index or its modification; some studies compare various drought indices; while some studies focus on to look for linkages with climate change. The literature survey in this chapter will focus on these above mentioned topics.

2.1. Drought Studies Based on Drought Identification and Drought Characteristics

This section has those studies which are focusing on different methods of drought calculation. Some of these studies are defining and comparing droughts using their characteristics. Selected studies are summarized in the following paragraphs.

Drought characteristics such as severity, frequency, area and duration are determined for China, for 1980-2015 period, using Self-Calibrating Palmer Drought Severity Index (scPDSI). Drying trends are observed all over China, while, drought area increased by 1.16% per decade and drought severity decreased by 0.015% per decade. The clustering algorithm for drought identification showed that drought frequency is increasing. Drought duration, frequency and severity all showed increasing trend in past 36 years. The 2005-2015 is observed as most prominent event (Shao et al., 2018).

In order to assess the extent and impacts of drought on households in Nigeria, Normalized Rainfall Index (NRI) is used. The aim is to provide policy solutions to tackle droughts in the region. The study also utilized questionnaires to learn about income of the community and one way analysis of variance (ANOVA) test is applied. This test on economic activities, that provide high income opportunities, showed that agriculture is the main contributor to high economic activities but high frequency of drought is constraining agriculture. Drought events of mild to severe nature are characterized for the region. The 1986-1995 and 2006-2017 periods showed high occurrence of droughts, while, 1996-2005 period faced fewer droughts. The study proposed that household should have the capacity in future to adapt to drought through developmental plans (Eze, 2018).

A study by Hanel et al., (2018) aimed at re-defining the droughts observed in Europe. Principal component regression is used to up-scale the station data to reconstruct the climate data. Standardized Deficit Index (SDI) is used for drought characterization. Soil moisture showed drying trends while increasing trends of drought frequency is observed which showed that high temperature periods have been recurring in the past. The study is able to combine the occurrence of extreme drought with decreased soil moisture and how they can have major impact in future.

Spinoni et al., (2014) did an extensive study in order to observe the drought hotspots in the world for three different periods (1951-1970, 1971-1990, and 1991-2010). SPI is used for the analysis and assessment is done using drought frequency, drought duration and drought severity. Drought frequency is defined as number of drought events, drought duration is defined as number of months that faced drought, and drought severity is the area below the zero line for each event. The assessment found that all three components of drought, i.e. frequency, duration and severity, increased in Eastern Asia, Africa, Mediterranean Region and Southern Australia and they showed a decreasing trend for Russia and America.

Assessment of spatial and temporal variability in Ethiopia is done by Gebrehiwot et al., (2011) using precipitation data and remote sensing images. Vegetation Condition Index (VCI) and SPI is used for this purpose. The spatial and temporal extent of droughts are based on the critical values of VCI and SPI. Recurrent drought cycles are observed in southern and eastern regions of the country. VCI and rainfall data showed significant correlations at each station making it ideal to detect drought conditions. The intensity of drought is found to be more accurate by VCI images from remote sensing, hence, giving timely detection of drought onset in time and space.

A study by Min et al., (2003) used SPI index in order to compare drought occurrence and its intensity, both spatially and temporally, between two countries (East Asia and

Korea). The time span used is 1951 to 1996. They also used dry-wet index of China in order to correlate the droughts events at Korea and China. They observed that intensity of droughts increased in Korea since 1980, while, three regions of East Asia, Manchuria, Central Eastern China, and north coast of Japan, showed good relation with droughts in Korea.

The study by Patel et al., (2007) utilized SPI at 3-month time scale and it is interpolated to determine the spatial trends of drought events as well their severity during wet and dry years. They also aimed to establish relationship of droughts to food grain production through correlation analysis and, lastly, drought risk is quantified for the study region, Gujrat, India.

Tsakiris et al., (2007) proposed a new index, Reconnaissance Drought Index (RDI), and carried on regional drought assessment using this index together with SPI and deciles index. RDI has advantage over the two as it uses evapotranspiration as an additional parameter apart from precipitation. The study is made for two river basins in Greece. It is found that RDI is a better meteorological drought indicator as compared to other indices, since, it is more sensitive and does comprehensive analysis. Therefore, it is deemed best to compare drought conditions in different regions of the world. Although it has similar response to SPI and deciles, but its ability to encompass evapotranspiration into calculation makes it better indicator for Eastern Mediterranean regions that are observing decrease in precipitation and increase in evapotranspiration.

For drought identification in United States, annual tree-ring chronologies are used for drought reconstructions for period 1700-1978. These reconstructions are validated with Palmer Drought Severity Index (PDSI). The results showed high degree of association of reconstructions with PDSI and they are able to record all inherent spatial variability of droughts in the study region (Cook et al., 1999).

An attempt is made to reconstruct drought intensity and frequency over past 2,300 years for Northern Great Plains located in USA. These reconstructions are based on fossil diatom assemblages that had lake salinity fluctuations. The results showed that there have been more intense extreme events than that of 1930 and, also, they are more common before AD 1200. The study suggested that the atmospheric circulation anomalies that contribute to drought at present are more persistent and frequent in past (Laird et al., 1996).

Three types of Palmer drought Indices are used to determine drought frequency and duration in USA. These indices are, PDSI, Monthly Moisture Anomaly Index, and Hydrologic Drought Index. Inverse relationship is found between the spatial patterns for drought frequency of monthly moisture anomaly with that of the other two indices. In case of spatial patterns for duration, as well, all indices showed varying patterns. (Soulé, 1992).

2.2. Comparative Studies on Drought Indices

There are number of papers that have worked on comparison of drought indices such as Wang et al., (2017), Jain et al., (2015), Kumar et al., (2009), Pandey et al., (2008), Morid et al., (2006), Wu et al., (2001), Ntale and Gan, (2003), and Guttman (1998) to name a few. These studies in addition to some other are mentioned in the following paragraphs.

Wang et al., (2017) worked on three drought indices namely precipitation anomaly percent (Pa) or rainfall departure, China Z- index (CZI) and soil moisture index (M) or Z index. They worked on 18 stations in one province and data is of 59 years from 1953 to 2012. The main aim is to study the drought characteristics and identify optimum index for this province. Results indicated that Pa has low sensitivity while M has high sensitivity to drought conditions, and Pa tends to under-exaggerate while M tends to over-exaggerate droughts. China Z- index which considers rainfall to follow Pearson type III distribution uses normalization method in order to avoid any error and it is found to depict most realistic drought conditions for the province under study.

Work by Jain et al., (2015) aimed at studying six drought indices to identify suitable drought index as well as suitable time step for river basin (Ken River Basin), in India, for period 1901-2002 in 13 districts. The drought indices studied included Standard Precipitation Index (SPI), China Z- Index (CZI), statistical Z-Score, Rainfall Departure from mean (RD), Effective Drought Index (EDI), and Rainfall Decile based Drought Index (RDDI). In the study, 1-, 3-, 6-, 9-, and 12-month time steps are utilized, but for EDI, only 1-month time step is used. The 9-month time step proved to be the best, while 1-month time step showed more imprecise results. Correlation results showed that at similar time steps, the drought indices can be interchanged. RD and RDDI are not found to be suitable for this region. EDI showed results more realistically and is deemed as best choice for assessing drought characteristics and also for drought monitoring because of timely information on drought onset.

Another study (Morid et al., 2006) compared similar drought indices (as the study mentioned above) with addition of modified CZI (MCZI) in which median of precipitation data is used in computation instead of mean. This study utilized 32 years of data (1970-2001) and is done for Tehran province in Iran using six meteorological stations. In first part of the study, SPI is correlated with CZI, MCZI, and Z-Score using Pearson correlation coefficient (R^2) and, in the second part, SPI is correlated with EDI (after averaging the daily values for monthly values), RDDI and RD. SPI, CZI and Z-Score showed similar results, and RD and MCZI are found to show extreme drought conditions too frequently as contrary to actual situation. RDDI showed unrealistic high temporal and spatial variation due to its sensitivity. For emerging drought conditions, EDI proved to be the best indicator and, also, it described the spatial and temporal drought conditions better as compared to the other indices.

Suitability of SPI as a drought indicator is assessed by Kumar et al., (2009) by comparing it with rainfall deviations. SPI is found to underestimate the impacts of rainfall intensity, be it high or low, and it is less sensitive to low rainfall as depicted by scatter plots with rainfall deviations. So SPI is not deemed suitable for low rainfall regions and required certain modifications to be used under such conditions.

Pandey et al., (2008) utilized two softwares namely Spatial and Time Series Information Modeling (SPATSIM) and Daily Water Resources Assessment Modeling (DWRAM). The first software investigates SPI, EDI, RDDI and Rainfall Departure from mean and median, while, the later only determined EDI. Again EDI showed best results for drought severity at both daily and monthly time steps. Drought severity trends are same for SPI, EDI and rainfall departure from mean. RDDI is not suitable for the region. The drought frequency in the region showed to vary once in every 3 to 4 years. The study is done for two districts in India

Two drought indices, RDDI and Soil-Moisture Decile based Drought Index are used to compute future droughts in Australia under different greenhouse gas scenarios using climate models. Apart from the western part of the country, rest of the regions showed increase in the frequency of droughts by both indices. This increase in frequency is suggested to have implications on water resource management, water security, natural resource management and drought relief payments (Mpelasoka et al., 2008).

Three indices, Palmer Drought Severity Index (PDSI), Bhalme-Mooley Index (BMI) and SPI are modified in a study and compared in terms of eight assessment criteria to choose most appropriate index for the region. The results found that index values of BMI, which only uses precipitation data, is strongly correlated with PDSI which led to conclusion that precipitation, only, can help to access drought conditions in a region. SPI gave most consistent spectral patterns for East African region and is deemed most suitable index for this region (Ntale & Gan, 2003).

Ryu et al., (2002) used PDSI, SPI and Surface Water Supply Index (SWSI) for finding the degree of association between them using correlation coefficient and also applied comparative study in order to evaluate most severe drought by comparing the relative severities of drought observed in the river basin under study.

A study by Wu et al., (2001) compared SPI, CZI and Z-score indices at 1-, 3-, 6-, 9- and 12-month time steps. The study is done for four locations in China for period 1951-1998. The results indicated that CZI and Z-score despite being easier to evaluate showed similar results to SPI in all time steps. Further, these three drought indices are easier to calculate in comparison with PDSI. In extremely dry conditions, CZI is most responsive to precipitation deficits, while Z-score has tendency to miss out serious drought conditions.

Guttman (1998) utilized spectral analysis to compare two drought indices, PDSI and SPI. The results showed that PDSI has no consistency in results from location to location while SPI has, therefore, SPI is better suited to compare conditions in different locations. Unlike SPI, PDSI has a very complex structure which makes it hard to interpret its results.

2.3. Teleconnections with Ocean Atmosphere Circulations

This section is focusing on the literature that is linking drought conditions to climate change. Most of these studies focus on linking Ocean Atmosphere Circulations to droughts in order to predict impacts of large scale climatic phenomenon on drought occurrence.

In order to study the impact of dominant Ocean Atmospheric Oscillations on drought occurrence, Ozger et al., (2009) utilized continuous wavelet transform and cross correlation method to predict the impact of El Nino Southern Oscillation (ENSO) and Pacific Decadal Oscillations (PDO) on Texas. For analysis, PDSI is used. They used lag times, correlation coefficients and kriging maps to investigate the spatial variations. The results of the study showed stronger correlation to arid regions, and between the two oscillations, ENSO gave better correlations. Another finding is that results of continuous wavelet transform and cross correlation are consistent with correlation results.

Another study that utilized teleconnection with Ocean Atmospheric Circulations made correlations between Southern Oscillation Index (SOI) and Southern African Rainfall Index (SARI). The study divided 1950-1988 period into two sub-periods, and found that both sub-periods are associated with different patterns. The first sub-period is linked to regional ocean atmospheric anomalies, while, the second sub-period is found to be linked with ENSO. Another finding is that drought are more intense and long when there is high variability between SOI and SARI. However, the study suggested further work to be done for in-depth study in order to understand why not all ENSO events lead to droughts over Southern Africa (Richard et al., 2001).

Coats et al., (2016) made an attempt to establish a relationship between mega droughts experienced in Western North America to ocean atmospheric variability. They used tree ring reconstructions to deduce any associations, between these mega droughts and ocean atmosphere dynamics, with main focus to link the droughts with the four oscillations namely El Nino Southern Oscillations (ENSO), North Atlantic Oscillations (NAO), Atlantic Oscillation Multidecadal (AMO) and Pacific Decadal Oscillation (PDO). These tree ring reconstructions incorporated data of the hydroclimate variability in Northern Hemisphere. The result of the study suggested that these variabilities have been a driving force for these drought.

Quinn et al., (1978) did an extensive study on Southern Oscillations and El Nino events for a period of 116 years. One of the objective is to link these events to droughts over Indonesia. They found that when the value SOI is low and ENSO activity is observed, the country also observed drought in those years and drought are more dominant during east monsoon season, May to October.

In another study, climatic teleconnections found that wet years are linked with northward displacement of Intertropical convergence zone (ITCZ). The drought years in West Africa are linked with less intense rainfall which did not depend on ITCZ. However, Hadley circulation is suggested to have some link with rainfall fluctuations that are observed in the region (Nicholson, 1981).

A relationship with spatially remote teleconnections is found for Europe. The study utilized SPI for computations and applied Principal Component Analysis (PCA) to understand the time variability and spatial patterns of drought. The results showed a decreasing trend for precipitation and found spatially remote teleconnections that linked European area and Tropical Pacific. However, this study did not establish any specific oscillation that is contributing to these droughts (Bordi & Sutera, 2001).

To find teleconnections between NAO and droughts, observed in northwestern China, Lee & Zhang, (2011) conducted a correlation study using historical records of drought. Statistical analysis showed a negative relation between the NAO and drought, which meant positive phase of NAO is linked with reduced frequency and intensity of droughts due to emerging Westerlies in the mid latitudes.

Rajagopalan et al., (2000) investigated teleconnections of PDSI with both ENSO and global sea surface temperature (SSTs) for period 1985-1995. In southwestern USA, robust teleconnections are observed between drought index and ENSO. The first three decades found the teleconnections to be very strong, while, the recent three decades showed weaker teleconnections with the winter SSTs and summer drought over southern Arizona and Texas.

2.4. Drought Studies in Mediterranean Region

Since Cyprus is a part of Mediterranean region, it is essential to look into the variety of literature present for this region since the results of these studies will have high level of associations with results of studies in Cyprus due to the same climate. Selected studies are mentioned in the following paragraphs.

A recent study in Turkey by Cavus & Aksoy, (2019) aimed at spatially characterizing drought at Seyhan River Basin. SPI is used for analysis of monthly rainfall data at 19 stations. Drought severity, duration, intensity and frequency are calculated. Frequency analysis is done using critical drought severity value (derived from drought with largest severity in the year). The spatial distribution of precipitation deficit is interpolated using Inverse Distance Weighted (IDW) technique. Mild and severe droughts are observed for the basin from spatial and temporal characteristics of drought. There is high drought vulnerability at coastal regions at all return periods and durations, while, northern parts are less effected.

Another study in Turkey is based on Seyhan-Ceyhan River Basin. The study utilized SPI (meteorological index) and Streamflow Drought Index (hydrological index) for detailed spatial and temporal analysis of droughts. The correlation between the two indices showed that there is one year lag time between the two indices, where hydrological drought precedes the meteorological drought. The study revealed that for efficient use of water and management of hydroelectricity and agriculture production, better planning can be done using the predicted hydrological period (Gumus & Algin, 2017).

To fully understand natural climate variability in Mediterranean region that affects drought occurrence, a 900 period from 1100 to 2012 is used. Old World Drought Atlas (OWDA), which is a spatiotemporal tree-ring reconstruction, is used for analysis. A high correlation is found between OWDA and spring precipitation, also OWDA gave high correlations with each of the Scandinavian pattern (NAO and East Atlantic pattern). Recent droughts are mainly observed for western part of Mediterranean, Greece and Levant. The study also concluded that OWDA aids in understanding of present drought events as well as in the future climate change contributions to drought (Cook et al., 2016).

Drought analysis using SPI for the period 1916-2006 is done in Calabria which is located in southern Italy. Geostatistical approach is used for spatially mapping the worst drought events, mapping also included the ungauged locations which showed that severe drought episodes have been hitting this region. The most severe drought as shown by short term SPI is observed in 1945, while, the drought from December 2001 to April 2002 is recorded as the worst one. Trend analysis using Mann-Kendall test showed that there is a shift towards drier conditions as depicted by falling SPI values (Buttafuoco et al., 2015).

In order to predict the factors behind increased drying of the areas surrounding the Mediterranean region since 1902, a study is done using two models namely Atmospheric General Circulation Model (AMIP) and Coupled Ocean-Atmosphere General Circulation Model (CMIP3). It is observed that Mediterranean precipitation has reduced during the period 1902-2010. The simulations are able to give meaningful causes of climate change leading to increased drought frequency in the region (Hoerling et al., 2011).

A study by Tigkas, (2008) utilized RDI for analyzing historical drought in four drought prone areas in Greece for period 1955-2002. Future drought events are predicted using Global Circulation Models (GCM) and statistical extrapolation of time series data. The results from the first scenario showed that percentage of drought events will increase, while, second scenario based on trend analysis of RDI data is not able to show significant changes. Drought monitoring system is established using calculated series of RDI.

Another study in Greece aimed at studying spatial and temporal behavior of droughts based of intensity and duration of droughts calculated using SPI. The study period is 51 years and data is taken from 23 stations. From the study, it is observed that at 3- and 6-month time step, a decrease in mild and moderate droughts is observed from west to east and north to south. The southern part of the country showed higher frequency of severe droughts at 3-month time step. At 12-month time scale, frequency of occurrence is very low for extreme and severe droughts. Finally, the study also found a significant correlation between SPI and “de Martonne aridity index (I)”, and the correlation is stronger in south since monthly precipitation variability is higher in southern part of the country (Livada & Assimakopoulos, 2007).

The impact of drought on vegetation in a semi-arid island is studied by Vicente-Serrano, (2007) for Ilberian Peninsula for period 1987-2000. The evaluation is done using Advanced Very High Resolution Radiometer (AVHRR), Graphical Information Systems (GIS), and SPI. The results showed spatial variation in drought occurrence which depends on land cover type and vegetation characteristics, in addition to this, they found that droughts also varied with seasons (more in spring and summer).

Drought vulnerability is studied for Turkey using SPI by Sönmez et al., (2005). The method involved evaluating the severity and frequency of drought events and the critical rainfall value at each station at various time steps. These critical values are the amount of rainfall needed to avoid drought occurrence. At short time periods, southeastern and eastern Anatolia observed moderate droughts while non-coastal regions observed severe droughts. The critical rainfall amounts, at higher time steps, are observed to decrease as we move from the coastal regions towards the central regions.

Vicente-Serrano et al., (2004) used SPI to study drought patterns in Valencia (Spain) for period 1951-2000. Principal Component Analysis (PCA) is used for temporal analysis. The drought frequency, duration and intensity is found to vary from location to location. There is an increase in number of drought events from mid towards north regions, while, overall the spatial patterns are complex for the remaining region. A general increase in drought affected areas is observed in the study region.

2.5. Drought Studies in Cyprus

This section focuses on drought studies done for the whole island of Cyprus. These studies helped to identify the gaps in literature by analyzing the variety of studies that have been done in this region. The gaps identified are mentioned in the next section.

Griggs et al., (2014), conducted drought assessment by reconstructing precipitation records for period 1860 to 2006 (250 years) from *Pinus brutia* Ten. Tree-rings. The study revealed that the country faces annual droughts once in every five years, while, the sustained droughts which are usually of length 2 to 6 years occurred in small time periods when there is a positive phase of winter North Atlantic Oscillations.

In Cyprus, drought assessment is done using SPI and RDI which focused on determining the drought duration, intensity and areal extent. The results indicated nine drought events faced by the country during the periods 1971-1974, 1981-1984, 1989-1991, 1993-1994, 1995-2000 and 2004-2008. The last two droughts events showed an exceptional duration of five years as compared to normal behavior in which droughts last only for one to three years. A high correlation of 0.95 is observed between the two indices and both indices showed that the last 15 years experienced more severe and frequent drought events. 27% of the years are recorded as wet years while 16% as dry years. The study further emphasized on establishing relationship of drought indices with Ocean Atmospheric Circulations such as NAO which is likely to impact the climate in Mediterranean region (Pashiardis & Michaelides, 2008).

Drought characterization during the hydrometeorological year 2007- 2008 using SPI values is done by Michaelides & Pashiardis, (2008). This is an extensive study which calculated the SPI values for all the stations in the south of the country for a period of more than 30 years. The results of the study indicated a severe drought during the period 2007-2008, in addition, severe drought conditions depicted by SPI values below -3.0 are seen in the southern and eastern part of the country. These droughts conditions had severe implication on crop production which faced a reduction as compared to normal season. In addition, forest trees such as pines and cypress trees, which are considered to be resistant towards drought conditions, also experienced decline in their number.

A study in North Cyprus for analyzing drought characteristics utilized SPI at different time steps (3-, 6- and 12-months). The analysis is done for 36 years using precipitation data of nine stations. The main aim of the study involved analyzing how drought propagates from one timescale to the other one. The study also estimated critical values of rainfall during different drought severity i.e. moderate, severe and extreme droughts. The results of the study depicted that 78-79% of the droughts at 3- month timescale propagated into the 6-month and 12-month timescale drought, while, about

90% propagated from 6-month to 12-month droughts. The highest value of critical rainfall is found to be less than 255 mm/year (Payab & Turker, 2018).

2.6. Gaps in Literature

From the literature survey the following gaps have been identified in the literature:

- Drought characterization in North Cyprus using various drought indices
- Comparison of indices and identification of most suitable drought index and time step for this region
- Analyzing historical droughts based on drought severity, magnitude, duration, intensity, and frequency
- Teleconnections of drought indices with large scale climate variabilities

CHAPTER 3

STUDY AREA AND DATA

3.1. Study Area

The present study is a case study of North Cyprus, which makes up one-third part of Cyprus. Cyprus is an Eastern Mediterranean Island and it is the third largest island in Mediterranean Sea and has Turkey, Lebanon, Syria, Greece, Egypt and Israel as its surrounding neighboring countries. Turkey is located 75 km to the north, Lebanon and Syria are located 120 km to the east, Greece is located 800 km to the northwest, Egypt is located 380 km on south and Israel (200 km) is located to the southeast. The coordinates of the island are 35.1264° N, 33.4299° E and altitude is 136 m. The island has total area of 9,251 km^2, however, North Cyprus which is considered in this study has an area of 3,355 km^2. The Island comprises of vast terrains and rich topography including peninsula, mountains, plains and coastal regions. A study by Zaifoglu et al., (2018) has worked on dividing North Cyprus into five homogenous sub-regions. The sub-region one includes Kyrenia Mountain range and North Coast, sub-region two includes East Mesaoria Plain and East Coast, sub-region three consists of Karpass Peninsula, sub-region four consists of West Mesaoria Plains and sub-region five consists of Middle Mesaoria Plain. The details on geographical location of the 33 meteorological stations (Figure 3.1), included in this study, and the sub-region in which they fall are given in Table 3.1.

The country has a subtropical climate, along the coasts it has a Mediterranean climate with mild and rainy winters and hot summers, in the inland plains the summers are even hotter. Most of the rainfall is concentrated between the winter months of December, January and February, while, main rainfall months throughout the year include November, December, January, February and March. The Kyrenia mountain range which makes up the northern range receives about 473 mm rainfall per year while the Mesaoria plain can receive up to 300-400 mm of annual rainfall.

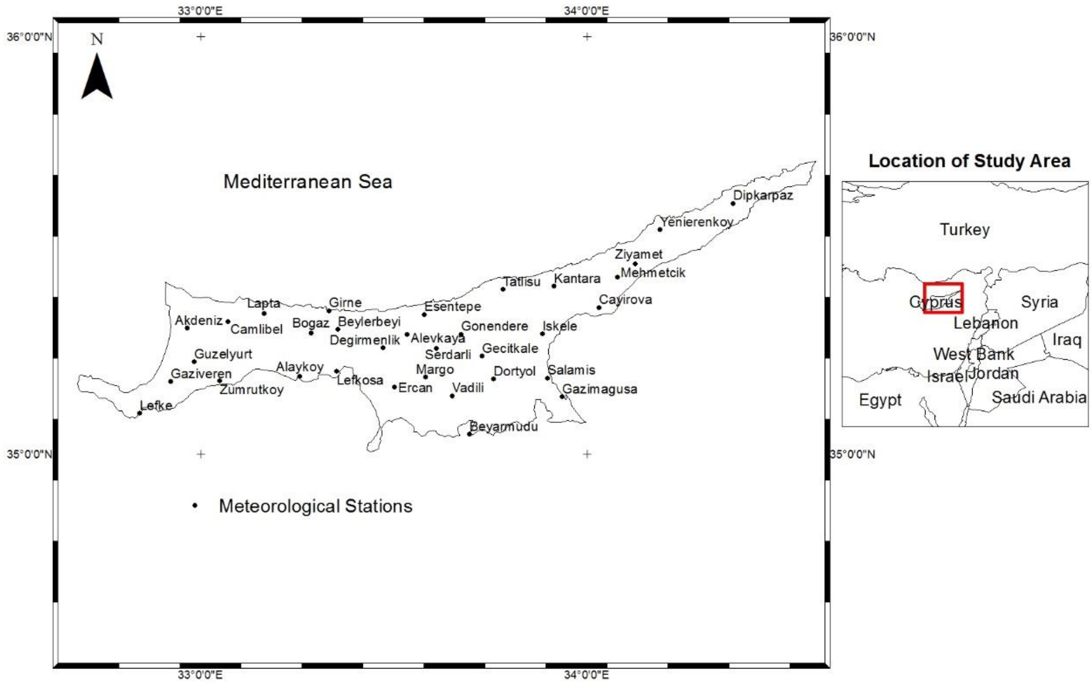


Figure 3.1 Location of meteorological stations in study area

3.2. Data

The drought indices selected in this study require input of precipitation data only. The monthly precipitation data is derived from daily precipitation data for North Cyprus which has been taken from Meteorological Department of North Cyprus. The 37 years long term precipitation data is used for period 1978-2015. The data used is tested for quality and homogeneity using four homogeneity tests by Zaifoglu et al., (2017) thereby working on any missing values and outliers.

The data on Ocean Atmosphere Oscillation indices has been taken from two sources namely National Weather Service, National Ocean and Atmospheric Administration (NOAA) (https://www.cpc.ncep.noaa.gov/data/) and Climate Research Unit, University of East Anglia (https://crudata.uea.ac.uk/cru/data/pci.htm).

Table 3.1 Geographical characteristics of selected meteorological stations in North Cyprus

Sub-regions	Stations	Latitude (°)	Longitude (°)	Elevation (m)
1	Lapta	35.33575	33.16336	168
	Girne	35.34194	33.33139	10
	Beylerbeyi	35.29729	33.35404	225
	Bogaz	35.28825	33.28484	300
	Esentepe	35.33273	33.57852	183
2	Gecitkale	35.23333	33.72861	45
	Vadili	35.13869	33.65161	54
	Beyarmudu	35.04716	33.69582	87
	Gazimagusa	35.13639	33.93556	10
	Salamis	35.18080	33.89734	6
	Dortyol	35.17889	33.75861	54
	Gonendere	35.26983	33.65660	75
	Iskele	35.28611	33.88444	39
3	Cayirova	35.34949	34.03129	67
	Mehmetcik	35.42222	34.07833	99
	Ziyamet	35.4535	34.12451	82
	Dipkarpaz	35.59889	34.37917	136
	Yenierenkoy	35.53556	34.18944	123
	Tatlisu	35.22470	33.45060	168
	Kantara	35.40056	33.91361	480
4	Akdeniz	35.29972	32.96500	89
	Camlibel	35.31611	33.07056	277
	Guzelyurt	35.18889	32.98194	52
	Gaziveren	35.17306	32.92194	19
	Lefke	35.09664	32.84091	129
	Zumrutkoy	35.17444	33.04917	129
5	Ercan	35.15917	33.50194	119
	Serdarli	35.25183	33.61024	111
	Degirmenlik	35.25276	33.47218	168
	Alevkaya	35.28583	33.53472	623
	Alaykoy	35.18472	33.25667	166
	Lefkosa	35.19639	33.35194	134
	Margo	35.16701	33.54525	110

The selected oscillations are North Atlantic Oscillations (NAO), Arctic Oscillations (AO), El Nino Southern Oscillations (ENSO), North Sea Caspian Pattern (NCP) and Western Mediterranean Oscillations (WeMO). The data for the first two indices i.e. NAO and AO is taken from (https://www.cpc.ncep.noaa.gov/data/), while for the rest of the oscillations, data is taken from (https://crudata.uea.ac.uk/cru/data/pci.htm).The data for each of the oscillation is organized from September 1978 till August 2015. A brief discussion of the selected oscillations are given in the following sub-sections.

3.2.1 North Atlantic Oscillations (NAO)

North Atlantic Oscillations (NAO) is a prominent pattern of every season and every month of the year (Barnston & Livezey, 1987). This low frequency oscillation is linked to large decadal climate variability in North Atlantic as revealed by Greenland ice-core data. This pattern is a dipole anomaly of north and south with Greenland having one center while the central latitudes (35°N and 40°N) of North Atlantic having the other opposite center. The below-normal height and pressure over the high latitudes of North Atlantic and above-normal height and pressure over central latitudes of North Atlantic, eastern United States and western Europe are characterized by positive phase of NAO. The opposite of this pattern depicts negative phase of NAO. Its extreme phase during winter time over past decades have shown Europe regions to experience warmer winter while northwest Atlantic region to observe colder conditions (Hurrell, 1995). Rotated Principal Component Analysis (RPCA) is used to calculate North Hemisphere oscillation patterns and indices which includes North Atlantic oscillations (Barnston & Livezey, 1987).

3.2.2 Arctic Oscillations (AO)

This oscillation is also referred to as Northern Hemisphere annular mode. This climatic pattern is observed around Arctic (50°N latitude) and is characterized by strong counterclockwise winds. The positive phase of AO causes strong cold winds to circulate in North Pole region, while, negative phase causes the winds to become weaker and move southwards towards mid latitudes. The calculation involves projecting the daily 1000 mb height anomalies (poleward of 20°N) onto the loading pattern of AO which is defined as Empirical Orthogonal Function (EOF) analysis of monthly mean 1000 mb height during 1979-2000 period (NOAA).

3.2.3 El Nino Southern Oscillations (ENSO)

El Nino Southern Oscillation or ENSO are fluctuations that occur periodically in the sea surface temperature (El Nino) and overlying air pressure (Southern Oscillation) across equatorial Pacific Ocean. Number of indices are used to calculate ENSO, however, this study is utilizing Southern Oscillation Index (SOI) which measures the difference of atmospheric pressure at sea levels between Tahiti and Darwin. These changes in pressure are first discovered by Walker and Bliss (1932). During El Nino phase, SOI is negative and pressure is below average in Tahiti, while, above average in Darwin. During La Nina, SOI is positive and pressure is above average in Tahiti, while, below average in Darwin. The negative phase is linked with abnormally warm waters in east tropical Pacific Ocean, while, positive phase causes ocean water to become cold. The data used in this study is calculated using method by (Ropelewski & Jones, 1987).

3.2.4 North Sea Caspian Pattern (NCP)

The North Sea Caspian Pattern (NCP) is an atmospheric circulation which is stronger during the winter and transitional seasons. North Sea Caspian Pattern Index (NCPI) is used for calculation that utilizes normalized 500 hPa pressure difference between averages of North Caspian (50°E, 45°N and 60°E, 45°N) and North Sea (0°E, 55°N and 10°E, 55°N) centers. Kutiel and Benaroch (2002) used same method and selected these locations using linear correlation between pressure grid points and a GIS approach.

3.2.5 Western Mediterranean Oscillations (WeMO)

Western Mediterranean Oscillation (WeMO) is a climatic variability that allows detection of cyclogenesis next to the Western Mediterranean Basin and in its positive phase it's as a dipole composed of anticyclone in Azores and depression in Liguria. In its negative phase, it has anticyclone in central Europe, north of Italian Peninsula, and has low-pressure center in southwest Ilberia. Western Mediterranean Oscillation Index (WeMOi) is used to calculate WeMO and, in its calculation, each dipole series is standardized separately (Martin-Vide & Lopez-Bustins, 2006).

CHAPTER 4

METHODOLOGY

The present study is conducting drought characterization of North Cyprus using different drought indices and comparing them based on different time steps. The drought characteristics such as severity, duration, magnitude, intensity and frequency, are evaluated for the most suitable time step. The flow chart of the methodology is given in Figure 4.1. The following steps are taken to achieve the goals of study:

4.1. Calculation of Drought Indices

For long term rainfall data of 37 years available from 1978-2015, five drought indices, that use only rainfall data as input for calculation, have been selected. These indices are: Standard Precipitation Index (SPI), Rainfall Departure from mean (RD), China Z- Index (CZI), Z- Score Index (ZSI), and Rainfall Deciles based Drought Index (RDDI). The methodology for calculation of these indices is shown in following sub-sections. In this study water year is used which starts from September and ends in August for North Cyprus. Water year is commonly used in hydrological studies when precipitation totals are measured for consecutive 12 months period unlike normal calendar year that divides the precipitation driven water cycle into two years. The use of water year will help to compare drought conditions in one year to another year since droughts are directly related to precipitation deficit.

For calculation of these indices multiple time steps are used, which are 1-, 3-, 6-, 9-, 12-months, winter season (-Wm) (December, January and February) and rain months (-Rm) (November, December, January, February and March). Time step 1-month means that drought indices for every month, during the period September 1978 to August 2015, are calculated. Rest of the time steps are single yearly values obtained by taking sum of precipitation totals in that time step and calculating drought index using the summed value. Time step 3-months includes months of September, October and November from period 1978 to 2015. Time step 6-months (September, October, November, December, January and February) and 9-months (September, October, November, December, January, February, March, April and May) are calculated in the similar manner. Time step 12-month includes all months in the year. The reason for choosing these time steps is that since majority of the rainfall in the country is concentrated in winter period, hence, the time steps chosen have at least one or more than one significant rainfall month (Jain et al., 2015). These selected time steps will allow to study impacts of water deficit on various components of water such as water storage, groundwater, streamflow and soil moisture (Morid et al., 2006). The 1-month time step will help to identify meteorological drought, anywhere from 1-month to 6- month based time steps are useful for agricultural droughts and time steps from 6- months onwards up to 24-months are useful for hydrological drought analysis (Svoboda et al., 2012).

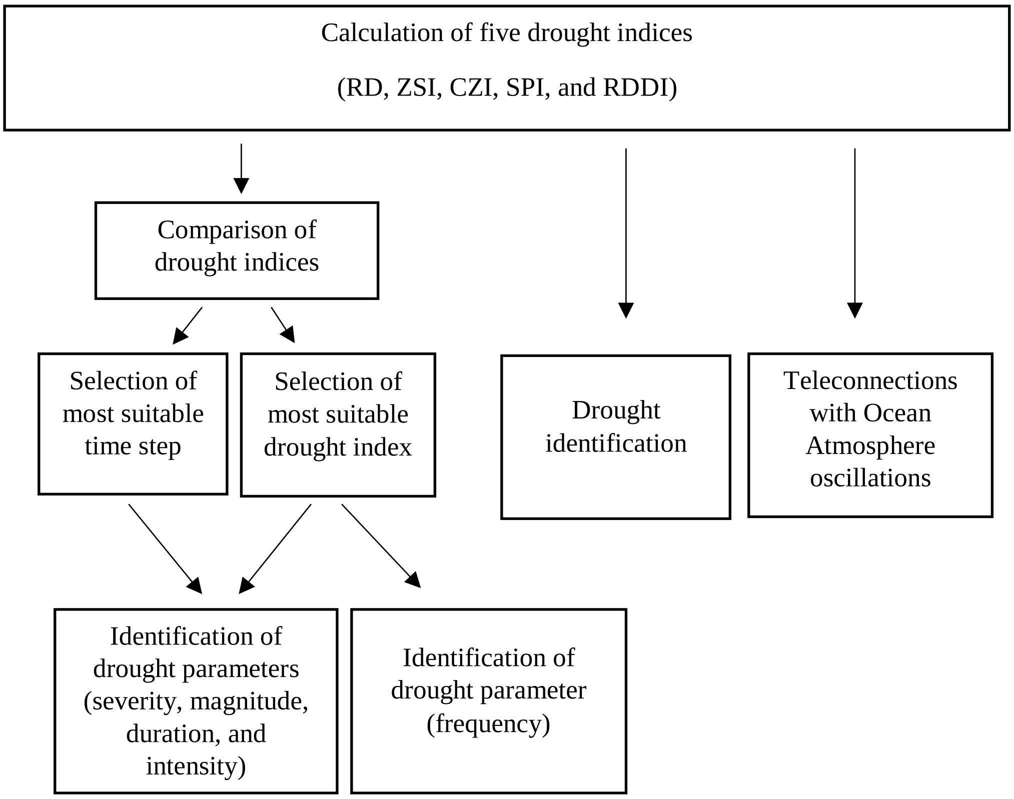


Figure 4.1 Flow chart of the methodology

4.1.1 Standard Precipitation Index (SPI)

This method of drought calculation is given by Mckee et al. (1993). It mainly uses monthly rainfall data and can be used for drought monitoring at multiple time steps. It requires continuous long term data of about 30 years for its calculation, hence, it does not allow missing values. Details on calculation of SPI is given by Edwards and Mckee (1997).

For calculation, the long term rainfall data is fitted to gamma distribution and this is then transformed to normal distribution, hence, the mean SPI for the desired period and location becomes zero. The resulting transformed probability gives the SPI value which can range from +2.0 to –2.0, indicating wet and dry conditions along with the severity of droughts, while extremes occur outside the range 5% of the time (Edwards & Mckee, 1997).

The gamma distribution is defined by its frequency or probability distribution function.

$$G\ (x) = \int_0^x g(x)\, dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} * e^{-x/\beta} \tag{4.1}$$

For $\alpha > 0$ the gamma function $\Gamma\ (\alpha)$ is defined as:

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x}\, dx \tag{4.2}$$

where α is shape parameter and β is scale parameter given as:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{\frac{4A}{3}}\right) \tag{4.3}$$

$$\beta = \frac{\bar{x}}{\alpha} \tag{4.4}$$

For n observations A is given by:

$$A = ln(\bar{x}) - \frac{\sum ln(\bar{x})}{n} \tag{4.5}$$

The cumulative probability distribution function w.r.t x, shape and scale parameters is given as:

$$G\ (x) = \int_0^x g(x)\, dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha}\, e^{-x/\beta} \tag{4.6}$$

The gamma distribution for $x = 0$ and $q = P(x = 0) > 0$ is undefined, where $P(x = 0)$ is the probability of zero precipitation. The cumulative probability function thus is given as:

$$H\ (x) = q + (1 - q) * G\ (x) \tag{4.7}$$

4.1.2 Rainfall Departure from Mean (RD)

This is a simple drought indicator which helps to specify wet and/or dry conditions in a given time over a specific area. It can be calculated for month, season, year or multiple time steps as required. It involves calculating the deviation of rainfall from its long term mean, hence, it is also called percent of normal (PN). In this index, long term average precipitation is subtracted from monthly rainfall data (in case of different time steps, long term average rainfall of that time step is used) and the result is divided by long term average rainfall. The result is negative and positive values with negative values indicating rainfall deficit condition, while, the positive values indicate wet conditions. It is calculated with the help of formula shown by Equation 4.8.

$$RD_{ij} = \frac{x_{ij} - \bar{x}_i}{\bar{x}_i} \times 100 \tag{4.8}$$

where RD_{ij} is rainfall departure from mean, x_j is rainfall amount in time step j and $\bar{x}$ is average long-term rainfall in that time step calculated as:

$$\bar{x}_i = \frac{1}{n} \sum_{j=1}^{n} x_{ij} \tag{4.9}$$

4.1.3 China Z- Index (CZI)

National Climate Centre (NCC) of China uses China Z- Index (CZI) for drought monitoring throughout the country (Wu et al., 2001; Jain et al., 2015.) This index is based on Wilson-Hilferty cube-root transformation (Kendall & Stuart, 1977) and assumes that the rainfall data follows Pearson type III distribution. The calculation is done using the Equations 4.10-4.13.

$$CZI_{ij} = \frac{6}{Cs_i}\left(\frac{Cs_i}{2}\varphi_{ij} + 1\right)^{1/3} - \frac{6}{Cs_i} + \frac{Cs_i}{6} \tag{4.10}$$

where CZI_j is China Z- Index, i is the time scale of interest and j is the current month (sum of multiple months). In order to expand CZI to include multiple time steps Equation 4.11 is used:

$$Cs_i = \frac{\sum_{j=1}^{n} (x_{ij} - \bar{x}_i)^3}{n * \sigma_i^3} \tag{4.11}$$

where Cs_i is coefficient of skewness and n is total number of months in the record

Calculation of σ_i is shown in next section (Equation 4.13). CZI allows missing data in the record by excluding missing values.

4.1.4 Z- Score Index (ZSI)

This index also called as statistical Z- Score or standard variate (φ) is another simple drought index that can be used for calculations at multiple time steps. The calculation involves subtracting the long term rainfall mean from the individual value (any time step) and then dividing the result with the standard deviation. The data does not require adjustment to Gamma or Pearson type III distribution. It also allows for missing values like SPI and CZI. The Equation 4.12 shows formula for its calculation.

$$\varphi_{ij} = \frac{x_{ij} - \bar{x}_i}{\sigma_i} \tag{4.12}$$

where φ_{ij} is Z- Score and x_{ij} is precipitation of month j in period i, $\bar{x}_i$ is average long term rainfall in period i (Equation 4.9) and σ_i is standard deviation in period i given as:

$$\sigma_i = \sqrt{\frac{1}{n} \sum_{j=1}^{n} (x_{ij} - \bar{x}_i)^2} \tag{4.13}$$

4.1.5 Rainfall Deciles based Drought Index (RDDI)

This approach is suggested by Gibbs and Maher (1967). The calculation uses long-term data and involves ranking the monthly rainfall totals from highest to lowest so that a cumulative frequency distribution is constructed. This distribution is split into deciles or, in other words, into 10 parts. The first decile will represent the rainfall values that are not exceeded by lowest 10% of all rainfall in record, while second decile represents values between lowest 10 and 20%. The severity of the droughts will be assessed by comparing these monthly (or other time steps) rainfall amounts with a cumulative frequency distribution of long term rainfall data. The two lowest deciles (0-10 and 10-20) will represent dry periods, the wet events are represented by highest two deciles (80-90 and 90-100) and deciles in between indicate below normal (20-40), normal (40-60) and above normal rainfall (60-80). Weibull plotting position (i/m+1) (Equation 4.17) is used to give values to the years divided based on calculated deciles.

4.2. Comparison of Drought Indices

The comparison of all the drought indices is done based on the index values and the severity category given by each index. The comparison is done to identify the most suitable index for the region together with the most suitable time step for identifying droughts in North Cyprus.

4.2.1 Comparison of Drought Indices at Multiple Time Steps

For comparison of calculated indices at multiple time steps and identifying best time step for drought analysis, Pearson Product-Moment Correlation Coefficient, commonly known as correlation coefficient, is used. This method is the most widely used statistical test and allows for the calculation of strength of linear relationship between two arrays of data. A correlation coefficient of either 1 or -1 indicate that there is a perfect linear relationship between the two variables, while 0 coefficient value indicate there is no linear relationship between the two variables. The positive sign indicates that they are directly related to one another, while, the negative sign indicates they are inversely related to one another. Each index is paired with itself at different time steps and with other indices again at all selected time steps. For example, SP1-1 is correlated with SPI 1-, 3-, 6-, 9-, 12-months, SPI-Wm, SPI-Rm, and then with RD 1-, 3-, 6-, 9- , 12-months, RD-Wm and RD-Rm, and then correlated so on with all the remaining indices at all time steps. This will create a cross correlation matrix of 35 column and 35 rows as five indices have seven time steps. These correlation matrices are developed for all 33 stations.

Correlation coefficient ‘r’ is calculated using Equation 4.14.

$$r = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{x_i-\bar{x}}{\sigma_x}\right)\left(\frac{y_i-\bar{y}}{\sigma_y}\right) \tag{4.14}$$

where x_i and y_i are array values, n is the number of values that are compared, $\bar{x}$ and $\bar{y}$ are mean and σ_x and σ_y are standard deviations of two arrays x_i and y_i respectively

4.2.2 Comparison of Drought Indices Based on Drought Severity

In order to define level of severity of a drought event, each drought index has a range of values falling into moderate, severe or extreme categories, but the range of every index varies. Hence, in order to allow for inter-comparison seven categories are used namely *Extremely Dry*, *Severely Dry*, *Moderately Dry*, *Normal*, *Moderately Wet*, *Very Wet* and *Extremely Wet*. The value of each of the index falling into these categories is shown in Table 4.1. The drought indices are also compared based on the severity category for each dry, normal or wet period identified. The comparison is done based on the correlation coefficient ‘r’ calculated using Equation 4.14. Since these indices are divided into seven categories, as given in Table 4.1, for ease of calculation they are given numeric values for correlation analysis. For instance, a drought event falling into extremely dry category is given a numeric value of ‘-9’. The severely dry and moderately dry events are given numeric value of ‘-6’ and ‘-3’ respectively. The normal periods are given zero value. The extremely wet, very wet, and moderately wet events are given numeric values ‘9’, ‘6’ and ‘3’ respectively. After organizing the data, correlation coefficient is calculated between the indices at all time steps for each station.

Table 4.1 Dry and wet categories of drought indices based on index value (Jain et al., 2015)

Category	SPI	ZSI	CZI	RD (%)	RDDI
Extremely Dry	≤ -2.0	≤ -2.0	≤ -2.0	< -60	≤ 10
Severely Dry	-1.99 to -1.5	-1.99 to -1.5	-1.99 to -1.5	-60 to < -40	10 – 20
Moderately Dry	-1.49 to -1.0	-1.49 to -1.0	-1.49 to -1.0	-40 to < -30	20 – 30
Normal	-0.99 to 0.99	-0.99 to 0.99	-0.99 to 0.99	-30 to 30	30 – 70
Moderately Wet	1.0 to 1.49	1.0 to 1.49	1.0 to 1.49	> 30 to 40	70 – 80
Very Wet	1.5 to 1.9	1.5 to 1.9	1.5 to 1.9	> 40 to 60	80 – 90
Extremely Wet	≥ 2.0	≥ 2.0	≥ 2.0	> 60	≥ 90

4.3. Identification of Drought Events

The drought events identified by various indices will be selected based on criteria that at least three indices out of the five indices describe a month and/or year as a drought month and/ or year. Table 4.1 indicates drought thresholds for each index.

4.4. Drought Characteristics

The drought characteristics, such as *severity*, *duration*, *magnitude* and *intensity* of drought events will be evaluated using one index based on the result of comparison of indices highlighting the most suitable index and most suitable time step for the region. However, for *frequency* analysis, monthly values of the selected drought index will be used. The following sub-sections explain method of calculation of each of these drought parameters.

4.4.1 Severity

Drought severity defines certain threshold limits, in simple words, it is the cumulative deficiency below the defined critical level. Each calculated drought index gives a severity value of the drought event and helps to determine number of months/ years falling under different drought severity categories. The severity of the drought event will be given according to the range of values in Table 4.1.

4.4.2 Duration

Duration of drought event is defined as a period of continuous drought months/ years. For each of the drought event that is defined by its beginning and end, its duration will be calculated.

4.4.3 Magnitude

The drought magnitude is calculated using method given by Mckee et al., (1993). Since negative value of indices indicate drought event, so it is calculated as positive sum of the negative values of drought indices over consecutive months and/or years. Magnitude for a drought event will be calculated using the formula:

$$Drought\ Magnitude\ (M) = -\left(\sum_{j=1}^{x} DI_j\right) \tag{4.15}$$

where DI is drought index value for j month

4.4.4 Intensity

The intensity of a drought event of a particular magnitude and duration will be evaluated as follows:

$$Drought\ Intensity\ (I) = \frac{M}{D} \tag{4.16}$$

where M is drought magnitude given by Equation 4.15 and D is drought duration

4.4.5 Frequency

The frequency analysis of drought episodes relates magnitude of a drought event to its probability of occurrence. In this study, it is calculated based on monthly computed values of drought index. However, the index to be used will depend on the previous stage of drought indices comparison, the selected most suitable drought index will be used for frequency analysis. This is done for every station. Drought episodes are identified by using sum of consecutive negative values (magnitude of drought event) for a corresponding duration in months. This will give multiple drought episodes per year having different durations. The frequency analysis will then be applied to each duration of every station separately. The probability tables of cumulative severities of drought for each duration (at each station) includes arranging the magnitudes in descending order and ranks are given, like rank 1 is given to drought episode with highest magnitude. After this probability of occurrence (p) which is also called exceedance probability of the corresponding event is calculated using Weibull plotting position, the Equation 4.17 shows the formula. After this, the return period (average recurrence interval) for a drought event of particular duration, magnitude and probability of occurrence is calculated as given by Equation 4.18.

$$p = \frac{m}{n+1} \tag{4.17}$$

where m is the rank number and n is the total data points

$$T = \frac{1}{p} \tag{4.18}$$

where p is the probability of occurrence given by Equation 4.17

After this, the data is fitted to a statistical probability distribution, however, there are several probability distribution families, such as Normal family (Normal, Log-Normal, Log-Normal III), Generalized extreme value family (EVIII-Weibull, EV1-Gumbel, GEV), and Pearson/Exponential type family (Pearson type III, Log- Pearson type III, exponential). In this study, EV1 distribution (Gumbel, 1958) is selected as this distribution is best for predicting chance of an extreme event. It has been used in literature for drought frequency analysis by Dalezios et al., (2000). However, to support this, Chi Square goodness of fit test is applied, and also visual representation is used to inspect the fitting of frequency distributions to cumulative drought severity values. The cumulative distribution function (cdf) of EV1 distribution is given as:

$$F(x) = exp\left[-exp\left(\frac{x-u}{\alpha}\right)\right] \quad (4.19)$$

where α is scale parameter and u is location parameter given as:

$$\alpha = \frac{\sqrt{6}\,\sigma}{\tau} \quad (4.20)$$

$$u = \bar{x} - 0.5772\alpha \quad (4.21)$$

where $\bar{x}$ and σ are mean and standard deviation of the data

4.5. Teleconnections with Ocean Atmospheric Circulations

Atmospheric teleconnections is defined as effect of large scale changes in atmospheric circulation patterns on distant regions (Mishra & Singh, 2010). This sections aim to identify impacts of some of the prominent oscillations in the region on the drought occurrence in North Cyprus.

The Ocean Atmospheric Circulations data is also grouped so as to have multiple time steps 1-, 3-, 6-, 9-, 12-months, -Wm and -Rm just like drought indices. To compute the teleconnections between oscillations and drought indices, Equation 4.14 is used. A cross correlation matrix of 5 columns and 5 rows for each time step is obtained. The teleconnections are done at lag time of zero, 1, 2, 3, and 4 years to seek for delayed impacts of these oscillations and to get maximum correlations. Since, this is a correlation between two different parameters, Ocean Atmosphere indices and drought indices, statistical significance is also calculated. For this purpose, a two-tailed t-test is carried out at 5% significance level. The null hypothesis assumes that there is no significant relation or nothing has changed and an alternative hypothesis assumes there is a significant relation. Rejection of null hypothesis would mean we accept alternative hypothesis and state that a statistically significant result is obtained. The p-value is used to determine the significance of result, a p-value < 0.05 would mean that the observed time series have a significant trend (Bothale & Katpatal, 2016).

CHAPTER 5

RESULTS AND DISCUSSION

5.1. Comparison of Drought Indices

After calculation of each of the five drought indices, RD, ZSI, CZI, SPI, and RDDI, they are compared with one another in terms of the index values and the severity categories given by each. This is done using Pearson correlations to identify the most suitable index for the region, as well as, the most suitable time step for drought identification in North Cyprus. The results of the two types of comparisons are given in the sub-sections below.

5.1.1 Comparison of Drought Indices Based on the Index Values

The methodology followed here is same as given by Jain et al., (2015), in which they correlated the calculated values of each of the indices with each other at all time steps. In this study, however, two different correlation matrix are prepared, one only for the 1-month time step, since, it has monthly data and the other for averaged 1-month time step together with the other time steps. The averaged value for 1-month time step is taken in order to have equal number of data sets in all time steps. The first averaged 1-month time step value is the average of drought index values from September 1978 to August 1979, the next averaged index value for 1-month time step is average of all the months from September 1979 to August 1980, and so on, till the average of monthly values from September 2014 to August 2015. The first matrix with only 1-month correlations is a 5 x 5 matrix as correlations are made between five indices. With seven time steps and five indices, another matrix of 35 x 35 is calculated for every station and average correlation value of each index at each station is also determined. The purpose of these calculations is to determine the best index which determines the onset of a drought, as well as, the most appropriate time step that can best inform about the drought characteristics. For 35 x 35 index average value of all the correlations is calculated for each index and also average value of correlations at similar time steps is also determined to identify which indices give the most similar results.

5.1.1.1 Monthly indices correlations

The 1-month time step drought evaluation is best to determine agricultural droughts. The correlation results between the indices at 1-month time step will help to establish the best index that will determine the drought onset and these results will be valuable for agricultural sector. Out of the 33 stations, fifteen stations showed correlations greater than 0.95, and of these strong correlations, fourteen are between CZI and SPI. The maximum correlation of 0.98 is observed, at Lefke, between CZI and SPI. The Table 5.1 shows the correlation matrix at Lefke. It can be seen that the first cell of the matrix is formed by correlation between RD with RD, the next on right is formed by correlations between RD and ZSI, the third cell has correlation of RD with CZI, the fourth cell has RD and SPI correlation, and finally fifth cell has RD correlated with RDDI. The second row has ZSI correlated with each of the indices and, similarly, the subsequent rows have CZI, SPI and RDDI correlated with all the indices respectively.

Table 5.1 Correlation matrix of 1-month time step at Lefke station

Indices	RD-1	ZSI-1	CZI-1	SPI-1	RDDI-1
RD-1	1.00	0.79	0.54	0.48	0.46
ZSI-1	0.79	1.00	0.88	0.82	0.70
CZI-1	0.54	0.88	1.00	0.98	0.76
SPI-1	0.48	0.82	**0.98**	1.00	0.71
RDDI-1	0.46	0.70	0.76	0.71	1.00
Average	0.65	0.84	0.83	0.80	0.72

Other stations that showed correlation coefficient greater than 0.95 include Girne (0.96), Esentepe (0.95), Gecitkale (0.97), Vadili (0.96), Iskele (0.95), Cayirova (0.95), Dipkarpaz (0.96), Kantara (0.97), Ercan (0.98), Serdarli (0.96), Alevkaya (0.96), Alaykoy (0.96), Lefkosa (0.97) and Margo (0.96). All these strong correlations are found between CZI and SPI in all stations, except, Alaykoy which showed strongest correlation between ZSI and CZI. Apart from Alaykoy, other stations that have strongest correlations between ZSI and CZI include Gaziveren, Bogaz and Beylerbeyi. All the remaining stations have their strongest correlations between CZI and SPI. If we look at the maximum average correlation coefficient value for the entire region, the maximum averaged coefficient value is given by CZI, followed by ZSI (with negligible difference from CZI) and then SPI. The lowest correlation value among the stations is in the range of 0.34 and 0.70, where 0.34 is observed in Camlibel between RD and SPI, while 0.70 is observed in Ercan between RD and RDDI.

Table 5.2 Average correlation coefficient of 1-month time step in all stations

	RD-1	**ZSI-1**	**CZI-1**	**SPI-1**	**RDDI-1**
Lapta	0.63	0.83	0.83	0.75	0.75
Girne	0.69	0.87	0.86	0.82	0.80
Beylerbeyi	0.72	0.88	0.88	0.80	0.80
Bogaz	0.73	0.87	0.88	0.79	0.80
Esentepe	0.70	0.86	0.86	0.80	0.79
Gecitkale	0.75	0.89	0.89	0.85	0.83
Vadili	0.74	0.88	0.89	0.84	0.82
Beyarmudu	0.71	0.86	0.86	0.80	0.78
Gazimagusa	0.62	0.82	0.82	0.75	0.75
Salamis	0.71	0.86	0.87	0.78	0.79
Dortyol	0.72	0.87	0.88	0.79	0.80
Gonendere	0.74	0.87	0.88	0.82	0.81
Iskele	0.69	0.85	0.86	0.80	0.78
Cayirova	0.67	0.85	0.85	0.80	0.77
Mehmetcik	0.69	0.86	0.86	0.79	0.79
Ziyamet	0.66	0.84	0.84	0.79	0.77
Dipkarpaz	0.66	0.85	0.85	0.80	0.78
Yenierenkoy	0.61	0.83	0.83	0.74	0.76
Tatlisu	0.70	0.86	0.86	0.80	0.79
Kantara	0.71	0.88	0.88	0.84	0.81
Akdeniz	0.59	0.82	0.83	0.74	0.73
Camlibel	0.59	0.82	0.82	0.74	0.74
Guzelyurt	0.63	0.83	0.83	0.75	0.75
Gaziveren	0.63	0.83	0.84	0.73	0.75
Lefke	0.65	0.84	0.83	0.80	0.72
Zumrutkoy	0.62	0.83	0.83	0.76	0.75
Ercan	0.82	0.92	0.93	0.90	0.87
Serdarli	0.82	0.91	0.92	0.87	0.85
Degirmenlik	0.76	0.89	0.89	0.83	0.82
Alevkaya	0.78	0.89	0.90	0.86	0.79
Alaykoy	0.76	0.89	0.90	0.82	0.83
Lefkosa	0.75	0.89	0.89	0.87	0.83
Margo	0.75	0.88	0.88	0.85	0.82
Average	0.70	**0.86**	**0.86**	0.80	0.79

The result from all the stations show RD has lowest average coefficient value, with lowest average of 0.59 observed in Camlibel. Overall, the average for the entire region showed CZI and SPI have highest correlation (0.94) while RD and SPI have lowest correlations (0.50). The average correlation value of each indices at 1-month time step are shown in Table 5.2.

5.1.1.2 Correlations at higher time steps

The 35 x 35 matrix followed the same methodology. The first cell of the matrix is a correlation between averaged RD 1-month with itself, the next cell in the same row has correlation of averaged RD 1-month with RD-3 and, so on, with all the time steps of all indices, with the last cell in the row having correlation between averaged RD-1 month with RDDI-Rm. The next row is correlation of RD-3 with all the indices at all time steps. The last row of the matrix is correlations of RDDI-Rm with all indices at all time steps. The results of all the stations showed a similar trend of strongest correlation coefficient (r = 1) observed between RD and ZSI at similar time steps, except for averaged 1-month values. This means that RD-3 and ZSI-3 showed r = 1, similarly, RD-6 and ZSI-6, RD-9 and ZSI-9, RD-12 and ZSI-12, RD-Wm and ZSI-Wm, and RD-Rm and ZSI-Rm also gave correlation coefficient of 1. Only in the case of Dortyol station, RD-Wm and ZSI-Wm did not give a correlation coefficient 1 as a whole number. Apart from this, Yenierenkoy is the only station that exhibited a very strong correlation of 1 of CZI with both RD and ZSI at 9-month time step. An example of correlation matrix at Yenierenkoy station in given in Appendix A.

The average value of correlation results of each index at each time step for all stations are given in Table 5.3 (a-c). The maximum average value of correlation coefficient is observed for RD-12 at Tatlisu station. While the lowest is observed for Akdeniz for RD at averaged 1-month time step. The best overall correlation in all the stations is shown by RD-12 and ZSI-12. The correlation coefficient in this case is reported as 0.82. CZI also showed a good overall correlations at 9- and 12-month time steps, where “r” is equal to 0.82. Correlation coefficient of 0.82 is also shown by SPI-9 and SPI-12, however, similar correlation coefficient is also observed for RD-9 and ZSI-9. This is in accordance with the results of Jain et al., (2015) which also revealed higher correlations at higher time steps. The 3-month time step for all the indices gave the lowest averaged correlation coefficient, with RD-3 and ZSI-3 having the lowest value amongst them.

Table 5.3 a) Average correlation coefficient at higher time step in all stations

Stations	RD 3	RD 6	RD 9	RD 12	RD Wm	RD Rm	ZSI 3	ZSI 6	ZSI 9	ZSI 12
Lapta	0.44	0.84	0.84	0.85	0.74	0.82	0.44	0.84	0.84	0.85
Girne	0.43	0.83	0.84	0.84	0.74	0.81	0.43	0.83	0.84	0.84
Beylerbeyi	0.35	0.82	0.82	0.82	0.71	0.79	0.35	0.82	0.82	0.82
Bogaz	0.52	0.81	0.82	0.82	0.74	0.79	0.52	0.81	0.82	0.82
Esentepe	0.53	0.82	0.84	0.84	0.66	0.80	0.53	0.82	0.84	0.84
Gecitkale	0.49	0.82	0.84	0.84	0.72	0.79	0.49	0.82	0.84	0.84
Vadili	0.38	0.82	0.83	0.83	0.71	0.77	0.38	0.82	0.83	0.83
Beyarmudu	0.38	0.82	0.83	0.83	0.70	0.78	0.38	0.82	0.83	0.83
Gazimagusa	0.42	0.80	0.82	0.82	0.69	0.79	0.42	0.80	0.82	0.82
Salamis	0.37	0.82	0.82	0.82	0.71	0.80	0.37	0.82	0.82	0.82
Dortyol	0.41	0.81	0.83	0.83	0.68	0.79	0.41	0.81	0.83	0.83
Gonendere	0.28	0.79	0.79	0.79	0.68	0.75	0.28	0.79	0.79	0.79
Iskele	0.43	0.80	0.81	0.82	0.68	0.77	0.43	0.80	0.81	0.82
Cayirova	0.33	0.78	0.80	0.80	0.61	0.75	0.33	0.78	0.80	0.80
Mehmetcik	0.40	0.79	0.81	0.81	0.59	0.74	0.40	0.79	0.81	0.81
Ziyamet	0.36	0.76	0.78	0.78	0.59	0.72	0.36	0.76	0.78	0.78
Dipkarpaz	0.38	0.81	0.82	0.82	0.70	0.77	0.38	0.81	0.82	0.82
Yenierenkoy	0.31	0.78	0.79	0.80	0.61	0.72	0.31	0.78	0.79	0.80
Tatlisu	0.56	0.86	0.87	0.88	0.73	0.83	0.56	0.86	0.87	0.88
Kantara	0.39	0.79	0.80	0.80	0.62	0.73	0.39	0.79	0.80	0.80
Akdeniz	0.52	0.84	0.85	0.85	0.71	0.82	0.52	0.84	0.85	0.85
Camlibel	0.44	0.83	0.84	0.84	0.72	0.81	0.44	0.83	0.84	0.84
Guzelyurt	0.45	0.82	0.84	0.84	0.69	0.80	0.45	0.82	0.84	0.84
Gaziveren	0.41	0.81	0.83	0.83	0.66	0.77	0.41	0.81	0.83	0.83
Lefke	0.33	0.78	0.79	0.79	0.69	0.78	0.33	0.78	0.79	0.79
Zumrutkoy	0.43	0.81	0.82	0.82	0.68	0.80	0.43	0.81	0.82	0.82
Ercan	0.38	0.79	0.79	0.80	0.63	0.76	0.38	0.79	0.79	0.80
Serdarli	0.39	0.79	0.79	0.79	0.62	0.74	0.39	0.79	0.79	0.79
Degirmenlik	0.49	0.83	0.83	0.84	0.68	0.79	0.49	0.83	0.83	0.84
Alevkaya	0.37	0.79	0.79	0.79	0.68	0.76	0.37	0.79	0.79	0.79
Alaykoy	0.35	0.78	0.80	0.80	0.64	0.76	0.35	0.78	0.80	0.80
Lefkosa	0.35	0.77	0.77	0.78	0.61	0.68	0.35	0.77	0.77	0.78
Margo	0.35	0.77	0.78	0.77	0.61	0.73	0.35	0.77	0.78	0.77
Average	0.41	**0.81**	**0.82**	**0.82**	0.67	0.77	0.41	**0.81**	**0.82**	**0.82**

Table 5.3 b) Average correlation coefficient at higher time step in all stations

Stations	ZSI Wm	ZSI Rm	CZI 3	CZI 6	CZI 9	CZI 12	CZI Wm	CZI Rm	SPI 3	SPI 6
Lapta	0.74	0.82	0.42	0.84	0.85	0.85	0.75	0.82	0.42	0.84
Girne	0.74	0.81	0.43	0.84	0.84	0.84	0.75	0.81	0.40	0.84
Beylerbeyi	0.71	0.79	0.37	0.82	0.82	0.83	0.71	0.79	0.37	0.83
Bogaz	0.74	0.79	0.48	0.77	0.79	0.78	0.66	0.76	0.49	0.82
Esentepe	0.66	0.80	0.53	0.84	0.84	0.84	0.66	0.80	0.51	0.84
Gecitkale	0.72	0.79	0.49	0.83	0.83	0.84	0.72	0.79	0.47	0.82
Vadili	0.71	0.77	0.44	0.82	0.83	0.83	0.70	0.77	0.43	0.81
Beyarmudu	0.70	0.78	0.39	0.82	0.83	0.83	0.71	0.78	0.39	0.81
Gazimagusa	0.69	0.79	0.43	0.80	0.82	0.82	0.70	0.78	0.43	0.80
Salamis	0.71	0.80	0.38	0.82	0.83	0.83	0.73	0.80	0.40	0.82
Dortyol	0.68	0.79	0.42	0.82	0.83	0.83	0.68	0.79	0.43	0.82
Gonendere	0.68	0.75	0.33	0.79	0.79	0.78	0.68	0.76	0.32	0.80
Iskele	0.68	0.77	0.45	0.80	0.82	0.82	0.68	0.78	0.46	0.80
Cayirova	0.61	0.75	0.34	0.78	0.80	0.80	0.61	0.75	0.35	0.78
Mehmetcik	0.59	0.74	0.41	0.80	0.81	0.81	0.60	0.76	0.42	0.80
Ziyamet	0.59	0.72	0.37	0.77	0.79	0.79	0.55	0.73	0.39	0.77
Dipkarpaz	0.70	0.77	0.42	0.82	0.83	0.83	0.71	0.78	0.45	0.81
Yenierenkoy	0.61	0.72	0.33	0.78	0.79	0.80	0.63	0.74	0.35	0.78
Tatlisu	0.73	0.83	0.59	0.87	0.87	0.88	0.74	0.83	0.63	0.87
Kantara	0.62	0.73	0.39	0.79	0.80	0.80	0.62	0.73	0.33	0.79
Akdeniz	0.71	0.82	0.52	0.84	0.85	0.85	0.71	0.82	0.50	0.83
Camlibel	0.72	0.81	0.48	0.83	0.85	0.85	0.72	0.82	0.48	0.83
Guzelyurt	0.69	0.80	0.53	0.83	0.84	0.84	0.69	0.81	0.53	0.83
Gaziveren	0.66	0.77	0.43	0.82	0.83	0.83	0.65	0.77	0.44	0.82
Lefke	0.69	0.78	0.36	0.78	0.80	0.80	0.70	0.78	0.38	0.78
Zumrutkoy	0.68	0.80	0.44	0.77	0.81	0.81	0.66	0.80	0.44	0.81
Ercan	0.63	0.76	0.42	0.79	0.79	0.80	0.63	0.76	0.40	0.79
Serdarli	0.62	0.74	0.43	0.79	0.79	0.79	0.63	0.74	0.43	0.80
Degirmenlik	0.68	0.79	0.51	0.83	0.83	0.84	0.68	0.79	0.52	0.83
Alevkaya	0.68	0.76	0.38	0.79	0.79	0.79	0.68	0.76	0.39	0.79
Alaykoy	0.64	0.76	0.34	0.79	0.80	0.80	0.65	0.76	0.38	0.79
Lefkosa	0.61	0.68	0.37	0.77	0.78	0.79	0.61	0.69	0.39	0.77
Margo	0.61	0.73	0.37	0.77	0.78	0.77	0.61	0.74	0.36	0.78
Average	0.67	0.77	0.42	**0.81**	**0.82**	**0.82**	0.67	0.77	0.43	**0.81**

Table 5.3 c) Average correlation coefficient at higher time step in all stations

Stations	SPI 9	SPI 12	SPI Wm	SPI Rm	RDDI 3	RDDI 6	RDDI 9	RDDI 12	RDDI Wm	RDDI Rm
Lapta	0.85	0.85	0.75	0.82	0.42	0.83	0.84	0.84	0.73	0.82
Girne	0.84	0.84	0.75	0.81	0.44	0.83	0.83	0.83	0.74	0.80
Beylerbeyi	0.82	0.82	0.71	0.79	0.39	0.82	0.81	0.82	0.69	0.77
Bogaz	0.83	0.83	0.71	0.80	0.44	0.76	0.76	0.76	0.67	0.73
Esentepe	0.84	0.83	0.66	0.80	0.49	0.82	0.83	0.83	0.63	0.79
Gecitkale	0.83	0.82	0.72	0.80	0.47	0.80	0.82	0.81	0.72	0.77
Vadili	0.83	0.83	0.70	0.76	0.44	0.81	0.83	0.82	0.68	0.76
Beyarmudu	0.83	0.83	0.71	0.78	0.41	0.82	0.82	0.82	0.70	0.78
Gazimagusa	0.83	0.82	0.70	0.78	0.43	0.78	0.80	0.79	0.67	0.77
Salamis	0.83	0.83	0.73	0.80	0.39	0.80	0.80	0.81	0.70	0.77
Dortyol	0.82	0.83	0.68	0.78	0.45	0.82	0.82	0.82	0.67	0.77
Gonendere	0.79	0.78	0.68	0.76	0.30	0.79	0.78	0.78	0.68	0.75
Iskele	0.81	0.82	0.67	0.77	0.43	0.80	0.80	0.81	0.68	0.76
Cayirova	0.80	0.80	0.61	0.75	0.32	0.76	0.78	0.78	0.58	0.72
Mehmetcik	0.81	0.81	0.61	0.76	0.38	0.79	0.80	0.81	0.59	0.74
Ziyamet	0.79	0.79	0.59	0.73	0.36	0.76	0.77	0.77	0.58	0.70
Dipkarpaz	0.82	0.83	0.71	0.78	0.40	0.80	0.81	0.81	0.68	0.75
Yenierenkoy	0.79	0.80	0.63	0.74	0.32	0.77	0.78	0.78	0.58	0.72
Tatlisu	0.87	0.87	0.74	0.84	0.62	0.86	0.86	0.87	0.74	0.83
Kantara	0.80	0.80	0.62	0.73	0.38	0.78	0.79	0.78	0.59	0.71
Akdeniz	0.84	0.84	0.71	0.81	0.59	0.83	0.84	0.84	0.69	0.81
Camlibel	0.84	0.84	0.72	0.81	0.47	0.81	0.82	0.82	0.66	0.79
Guzelyurt	0.84	0.84	0.69	0.81	0.58	0.81	0.82	0.81	0.65	0.78
Gaziveren	0.82	0.82	0.65	0.77	0.43	0.81	0.82	0.82	0.64	0.75
Lefke	0.80	0.80	0.69	0.78	0.39	0.77	0.80	0.80	0.70	0.78
Zumrutkoy	0.82	0.82	0.67	0.80	0.46	0.78	0.79	0.79	0.62	0.78
Ercan	0.78	0.79	0.63	0.77	0.43	0.78	0.78	0.77	0.64	0.74
Serdarli	0.78	0.78	0.63	0.75	0.45	0.78	0.76	0.76	0.60	0.71
Degirmenlik	0.82	0.82	0.66	0.79	0.52	0.82	0.82	0.82	0.66	0.77
Alevkaya	0.78	0.78	0.69	0.76	0.40	0.77	0.76	0.76	0.66	0.73
Alaykoy	0.80	0.79	0.64	0.76	0.33	0.77	0.78	0.77	0.64	0.74
Lefkosa	0.77	0.78	0.61	0.69	0.36	0.76	0.75	0.76	0.60	0.65
Margo	0.78	0.77	0.61	0.74	0.38	0.76	0.74	0.75	0.61	0.71
Average	**0.82**	**0.82**	0.68	0.78	0.43	0.80	**0.80**	**0.80**	0.66	0.76

At similar time step, all indices gave good correlations in the range of 0.95 to 0.99. At 3-month time step, CZI gave highest correlation 0.97 followed by SPI (0.95) and RDDI (0.95). For 6-month time step, CZI (0.99) gave most highly correlated result followed by SPI (0.98) and RD (0.98). In case of 9-month, 12-month and -Rm, CZI showed highest correlation of 0.99 followed by SPI (0.98) and RD (0.98). In case of -Wm, SPI has highest correlation coefficient (0.99), SPI is followed by CZI and RD with correlation coefficient of 0.98 and 0.97 respectively. So the best overall performance is given by CZI at all the time steps except for -Wm where it gave second best correlation results.

The best overall correlation is given by CZI-Wm and SPI-Wm. The least value of correlation is between ZSI-3 and RDDI-Rm. For 3-months and -Wm time step, all indices show good correlations only at similar time steps. RD-3 gave best correlation with ZSI-3 and gave correlation higher than 0.90 with CZI-3 and SPI-3. RD-6 and RD-9 gave best correlation with ZSI at 6- and 9-months. RD-6 has correlations higher than 0.90 with RD-9, RD-12, ZSI-9, ZSI-12, CZI-6, CZI-9, CZI-12, CZI-Rm, SPI-6, SPI-9, SPI-12, SPI-Rm, RDDI-6 and RDDI-9. RD-9 has correlations higher than 0.90 with RD, ZSI, CZI and SPI at 6-, 9-, 12-, -Rm time steps, and with RDDI at 6-, 9-, 12-month time steps. RD-12 showed correlations greater than 0.90 with RD at 6-, 9- and -Rm, with ZSI at 9-, 12-, -Rm, with CZI at 6-, 9-, 12-, with SPI at 6-, 9-, 12-,-Rm time steps, and with RDDI at 9- and 12-months. RD-Rm apart from good correlations at similar time step, showed good correlations with RD and ZSI at 6-, 9-, 12-, with CZI at 6-, 9-, and with SPI at 6-month. ZSI at -6, 9- and 12- and -Rm has same results as RD in these time steps. CZI-6 and CZI-9 also show same results as RD and ZSI. CZI-12 show correlations greater than 0.90 with RD and ZSI at 6-, 9-, 12-, with CZI and SPI at 6-, 9-, 12, -Rm, and with RDDI at 6-, 9- and 12- steps. In case of CZI-Rm, correlations greater than 0.90 are observed with RD and ZSI at 6-, 9-, -Rm, with CZI at 6-, 9-, 12-, -Rm, with SPI at 6-, 9-, -Rm, and with RDDI at 6-month. SPI-6 also has same results as RD, ZSI and CZI except it didn’t have correlation coefficient greater than 0.90 with RDDI at 12-month time step. SPI-9 observed correlations greater than 0.90 with RD and ZSI at 6-, 9-, 12-, with CZI and SPI at 6-, 9-,12-, -Rm, and with RDDI at 6-,9- and 12-. SPI-12 observed correlations greater than 0.90 with RD, ZSI and CZI at 6-, 9-, 12-, with SPI at 6-, 9-,12-, -Rm, and with RDDI at 9- and 12-month time step. SPI-Rm observed correlations greater than 0.90 with RD, ZSI, CZI and SPI at 6-, 9-, 12-, -Rm, and with RDDI-6. In case of RDDI-6, apart from similar time steps, good correlations greater than 0.90 are seen with RD-9, ZSI-9, CZI-9, CZI-12, SPI-9, SPI-Rm, RDDI-12 and RDDI-Wm. RDDI-9 has good correlations with RD, ZSI, CZI, SPI and RDDI at 6-, 9- and 12-month time steps. RDDI-12 showed greater than 0.90 correlations with all indices at 9-month time step. RDDI-Rm has correlations more than 0.90 only with ZSI-6 apart from similar time steps.

5.1.2 Comparison of Drought Indices Based on Drought Severity

Drought severity is the cumulative deficiency below the defined critical level. Since five drought indices are used for the evaluation of drought severity, hence, for their inter comparison they are given seven categories of severity namely "*Extremely Dry*", "*Severely Dry*", "*Moderately Dry*", "*Normal*", "*Moderately Wet*", "*Severely Wet*", and "*Extremely Wet*". The range of values falling into these categories is given in previous Chapter. Pearson correlation coefficient "r" is calculated to determine the degree of association between these indices in terms of severity i.e. if the indices values at each time step are giving similar severity categories. The correlation coefficient is calculated for all the stations at all time steps, and correlations are done only between similar time steps of all the indices.

For 1-month time step, the lowest value of correlation coefficient is calculated to be 0.29, 0.30, 0.31, 0.37 and 0.39 at Camlibel, Akdeniz, Gaziveren, Guzelyurt and Gazimagusa respectively. All these weak correlations are observed between RD and SPI. Maximum values of correlation coefficient are observed in Vadili, Lefke, Guzelyurt, Yenierenkoy Akdeniz and Alaykoy, the observed coefficient value in these stations are 0.97, 0.96, 0.95, 0.95, 0.94 and 0.94 respectively. In case of Vadili and Lefke, these strong correlations are observed between CZI and SPI, while, for the rest of these stations it is observed between ZSI and CZI. The Table 5.4 shows the averaged correlation results of severity categories of all indices at 1-month time step in 33 stations. It can be observed from the table that CZI is showing highest average correlation coefficient in all the stations, followed by ZSI and then SPI. RD is showing the lowest average coefficient value. The table for higher time steps are shown in Appendix B.

Table 5.4 Averaged correlation result of severity categories by drought indices at 1-month time step

Stations	RD-1	ZSI-1	CZI-1	SPI-1	RDDI-1
Lapta	0.70	0.79	0.83	0.76	0.76
Girne	0.74	0.82	0.84	0.79	0.79
Beylerbeyi	0.74	0.81	0.85	0.80	0.79
Bogaz	0.74	0.82	0.84	0.81	0.78
Esentepe	0.71	0.80	0.81	0.78	0.77
Gecitkale	0.73	0.80	0.83	0.82	0.78
Vadili	0.75	0.82	0.85	0.85	0.79
Beyarmudu	0.72	0.80	0.82	0.78	0.76
Gazimagusa	0.68	0.77	0.80	0.69	0.75
Salamis	0.71	0.79	0.82	0.76	0.77
Dortyol	0.73	0.81	0.83	0.80	0.78
Gonendere	0.73	0.81	0.83	0.83	0.78
Iskele	0.70	0.77	0.82	0.77	0.76
Cayirova	0.70	0.78	0.82	0.79	0.76
Mehmetcik	0.72	0.80	0.84	0.77	0.79
Ziyamet	0.70	0.77	0.81	0.78	0.76
Dipkarpaz	0.72	0.80	0.83	0.79	0.78
Yenierenkoy	0.69	0.80	0.82	0.69	0.76
Tatlisu	0.73	0.79	0.82	0.80	0.78
Kantara	0.72	0.81	0.84	0.81	0.74
Akdeniz	0.67	0.79	0.81	0.67	0.74
Camlibel	0.66	0.78	0.81	0.66	0.74
Guzelyurt	0.68	0.80	0.82	0.70	0.75
Gaziveren	0.66	0.79	0.81	0.68	0.74
Lefke	0.72	0.79	0.83	0.83	0.73
Zumrutkoy	0.68	0.80	0.82	0.75	0.75
Ercan	0.77	0.82	0.86	0.85	0.82
Serdarli	0.75	0.82	0.85	0.84	0.81
Degirmenlik	0.75	0.82	0.85	0.85	0.80
Alevkaya	0.77	0.83	0.85	0.86	0.81
Alaykoy	0.76	0.84	0.86	0.85	0.81
Lefkosa	0.75	0.81	0.85	0.83	0.80
Margo	0.75	0.79	0.83	0.83	0.80
Average	0.72	0.80	**0.83**	0.78	0.77

At multiple time steps excluding 1-month time step, the minimum correlation coefficient of 0.42 is seen at Dortyol station between ZSI-Wm and RDDI-Wm time step. Bogaz and Alaykoy stations also showed lower coefficient values of 0.56 and

0.59, respectively, when compared to other stations. The correlation coefficient of 0.56 is found between ZSI-12 and RDDI-12, while RD-3 and ZSI-3 gave value of 0.59 at Alaykoy station. At multiple time steps, many stations exhibited strong correlations with ‘r = 1’. Twenty-nine out of 33 stations show such strong correlations between various indices at various time steps. In case of Girne station, strong correlations are seen between CZI and SPI at 6- and 9-month time steps. Beylerbeyi show strong correlations between ZSI-9 and CZI-9, while in Esentepe, CZI-6 with SPI-6, ZSI-9 and ZSI-12 with CZI-9 and CZI-12 show strong association. In Gecitkale, ZSI-9 with CZI-9 show strong correlations. CZI-Wm and SPI-Wm show strong relationship in Vadili and Beyarmudu. In Gazimagusa, CZI at 6-, 12- and -Rm time step show strong correlations with SPI at same time steps. ZSI-12 and CZI-12 show strong correlation at Dortyol and Ercan while, in Gonendere, ZSI 6-, 12- and -Rm show strong correlations with CZI. In Iskele, ZSI-6 with CZI-6 and ZSI-9 with RD-9 show strong results. In Cayirova, ZSI-9 show strong correlations with CZI-6. In case of Mehmetcik, CZI at time step 6- and 9- show strong correlations with SPI. Dipkarpaz shows more results with strong correlations, like CZI-6 with SPI-6, ZSI-9 with CZI-9, RD-12 with SPI-12, and ZSI-12 with CZI-12. In Yenierenkoy, ZSI and CZI show strong correlations at 9- and 12- time steps. In Tatlisu, ZSI-9 with CZI-9 and ZSI-Rm with CZI-Rm show strong results. In Kantara station, ZSI-12 with CZI-12 and ZSI-Rm with CZI-Rm show strong correlations. For Akdeniz, strong correlations are observed between CZI-Wm and SPI-Wm. At Camlibel, strong correlations are observed between CZI and SPI at 3-, 6-, 12- and -Wm, and this is the only station that shows strong correlation of ‘1’ at 3-month time step. Guzelyurt also exhibited strong correlations at different time steps, CZI-6 and CZI-Rm with SPI-6 and SPI-Rm while ZSI-9 with RD-9. In case of Gaziveren, ZSI-6 and ZSI-9 with CZI-6 and CZI-9, and CZI-Rm with RD-Rm show strong correlations. CZI with SPI at 9-, 12- and -Rm show strong correlations in Lefke, while, Zumrutkoy has strong correlations between CZI and SPI at 12-month time step. ZSI and SPI in -Rm show strong correlations in Serdarli, while, in Degirmenlik ZSI at 6-, 12- and -Rm show strong correlations. At Alevkaya station, strong correlation of r = 1 is seen in case of CZI-6 with SPI-6, and CZI-12 with SPI-12. At Alaykoy station, RD, ZSI and CZI show strong correlations at 12-month time step and CZI-Rm also shows strong correlations with SPI at similar time steps. Lefkosa depicted highest number of strong correlations which are observed between ZSI and CZI at 6-, 9-, 12-month time step, RD-12 with ZSI-12 and CZI-Rm and SPI-Rm. At Margo, ZSI-Rm and CZI-Rm sho strong correlations.

If we consider the averaged value of these correlation coefficient, the lowest averaged correlation coefficient is observed for Dortyol which is 0.65 for ZSI-Wm (Figure 5.1). The maximum value is observed for Lefke which is 0.98 at CZI-12 and SPI-12 (Figure 5.2). To observe the overall best result for the entire study area, the average value of correlations coefficient of severity categories indicate that CZI at 12-month time steps shows the most similar severity categories at all time steps. The averaged values are higher for CZI at all time steps except for -Wm time step where SPI shows value of 0.93 compared to 0.92 observed for CZI-Wm. The weakest results are given by RD at 3-month time step. Hence, comparison of the severity categories, of each drought index at all time steps, shows that CZI best depicts the severity of a drought event at 1-month time step as well as at higher time steps, secondly higher time steps are better able to give true severity value of a drought event.

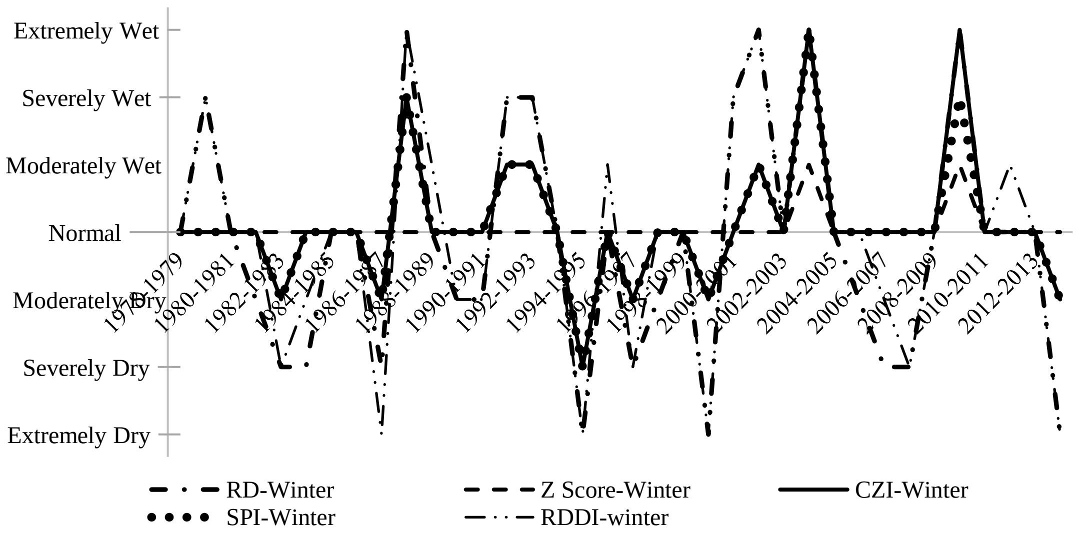


Figure 5.1 Severity observed for five drought indices from 1978-2015 at Dortyol

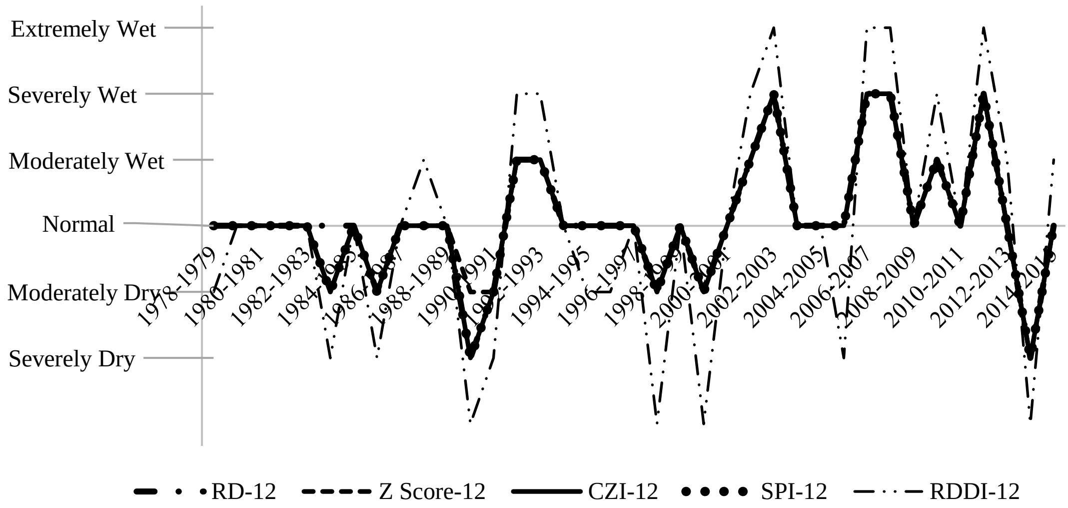


Figure 5.2 Severity observed for five drought indices from 1978-2015 at Lefke

5.1.3 Graphical Representation

To further check which time step can better account for drought conditions, droughts are observed graphically. For this purpose, SPI index is used, since it is a commonly used drought index. The Figures 5.3 -5.7 show graphs for SPI at time steps 6-, 9-, 12- , -Wm and –Rm. Since lower time steps did not give good results in correlation analysis, they are omitted. It is observed that time step 9-month and 12-month give almost same representation. The -Wm step is undermining the severities, in some cases, for dry conditions. However, the -Rm step is able to identify the drought conditions more elaborately and is able to represent the severities better. So it can be concluded that the rain months (November, December, January, February and March) alone can be used to describe annual droughts for North Cyprus. The Appendix C, shows graph for -Rm time step using RD, ZSI and CZI.

5.1.4 Summary

So we conclude that the correlation analysis of indices values and severity categories indicate that CZI performs better than the other indices. It has close association with both SPI and ZSI. While, in case of time steps, 9-, 12- and -Rm time steps behave very similar. So from visual representation of drought indices, -Rm time step is deemed most suitable for identifying drought conditions for North Cyprus.

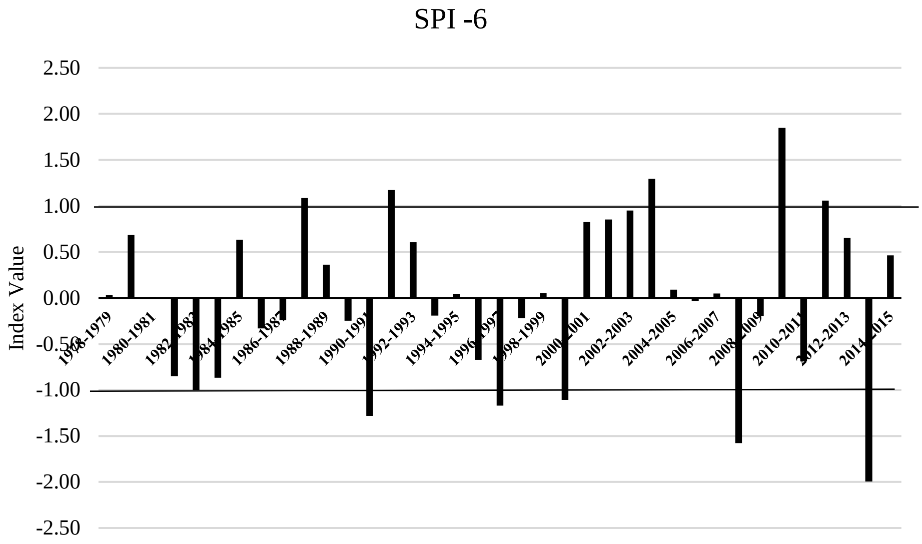


Figure 5.3 Graphical representation of SPI-6

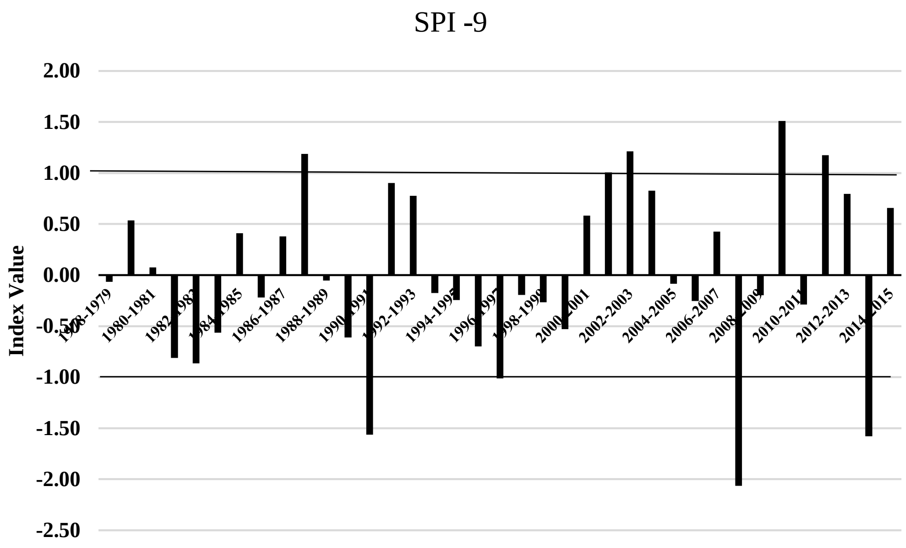


Figure 5.4 Graphical representation of SPI-9

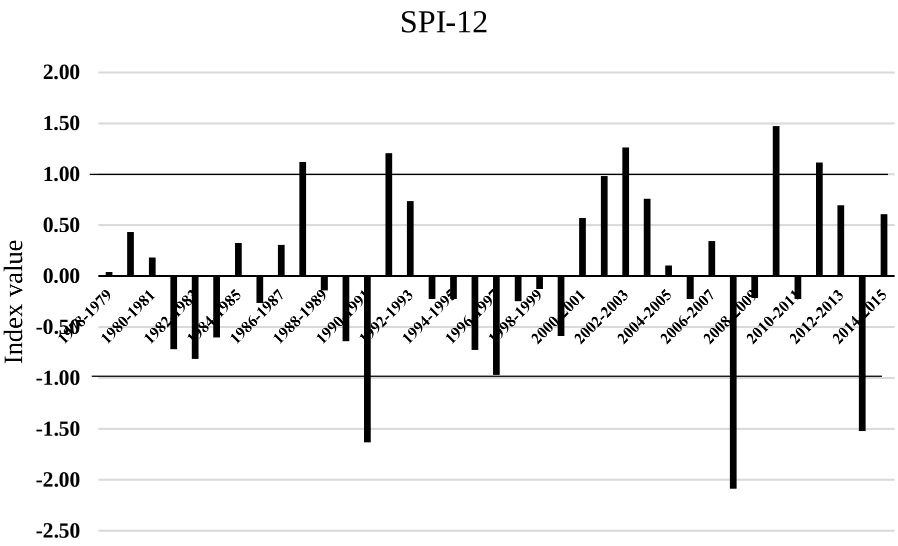


Figure 5.5 Graphical representation of SPI-12

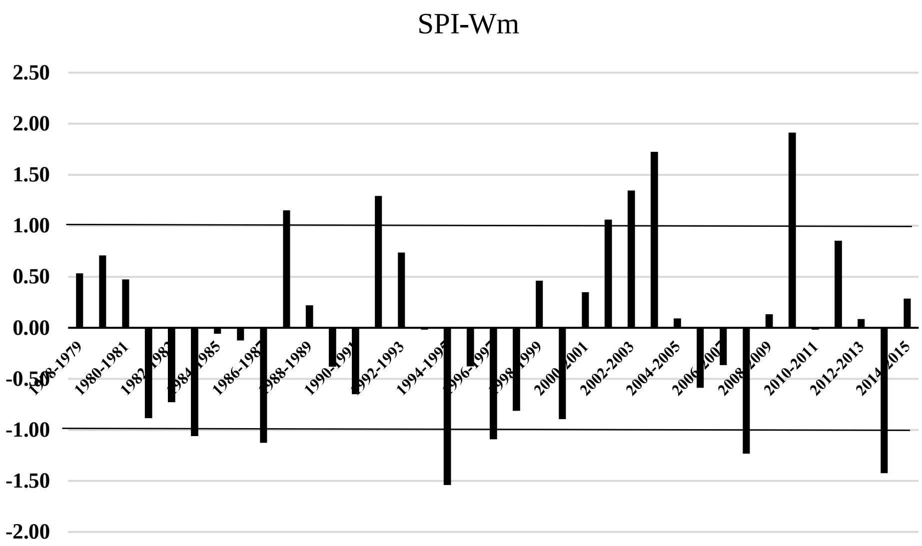


Figure 5.6 Graphical representation of SPI-Wm

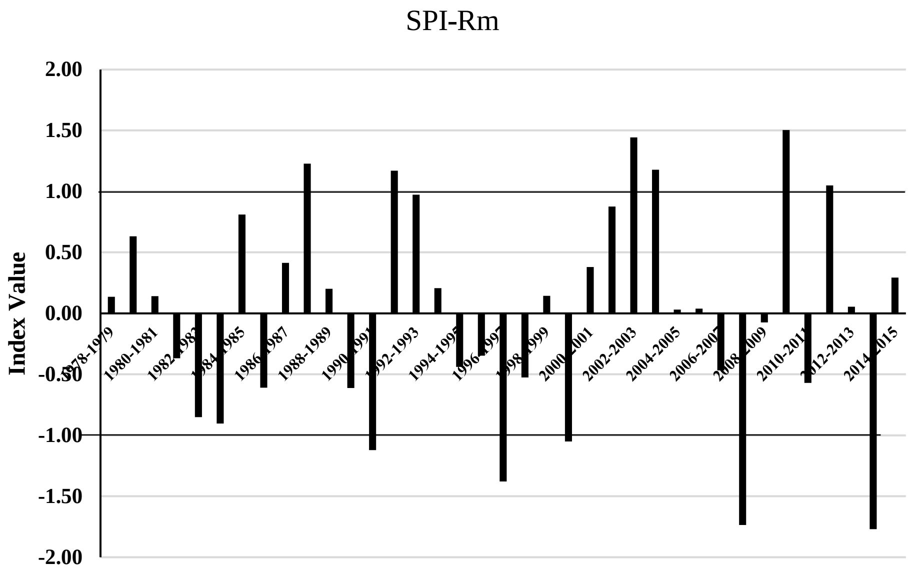


Figure 5.7 Graphical representation of SPI-Rm

5.2. Drought Identification

The droughts are identified based on the calculated values of the five indices namely, RD, ZSI, CZI, SPI and RDDI. For RD, a drought occurred if value is less than -30%. For ZSI, CZI and SPI, a drought occurred if the value is less than -0.99. While in case of RDDI, a drought occurred if value is falling into the lowest three deciles. The drought for time step 1-month are identified for monthly basis, while, for the higher time steps that include *3-month time step* (September – October – November), *6-month time step* (September – October – November – December – January – February), *9-month time step* (September – October – November – December – January – February – March – April – May), *12-month time step* (September – October – November – December – January – February – March – April – May – June – July – August), *Winter months* or -Wm (December – January – February), and *Rain months* or -Rm (November – December – January – February – March), the droughts are identified as an annual drought. In this study, a month and/or year is identified as a drought month and/or year if three out of the five indices identify it so. The sub-sections, 5.2.1 and 5.2.3, will discuss the overall result given by the indices at 33 stations, however, the final identified drought months and years are discussed in sub-section 5.2.3.

5.2.1 Monthly Droughts

The 1-month time step calculated monthly droughts in 37 years. These droughts are calculated using five indices for all 33 stations. For RD index, the highest number of drought months is calculated to be 266 for Girne station. In case of ZSI, highest number is 42 years in Gaziveren and Guzelyurt station. The 58 months in Mehmetcik station and 53 months in Ercan station are the highest number of drought months calculated by CZI and SPI respectively. While, RDDI calculated constant number of drought months at each station which are 132 months. Drought months by RD are mostly high in number in northern coast regions. ZSI drought months are mostly high in west Mesaoria Plains. While, SPI calculated drought months are mostly high in middle Mesaoria Plain.

In every station, RD calculated the highest number of drought months followed by RDDI. ZSI calculated lowest drought months, as compared to other indices, which meant ZSI is not appropriate as an index at 1-month time step as it can undermine a drought condition and will not inform timely about the approaching dry spell. CZI and SPI mostly have similar results. The stations in which SPI showed higher drought months as compared to CZI include Lapta, Girne, Beylerbeyi, Esentepe, Bogaz, Vadili, Dortyol, Gonendere, Dipkarpaz, Akdeniz, Guzelyurt, Lefke, Zumrutkoy, Ercan, Serdarli, Degirmenlik, Alevkaya, and Lefkosa. In Gazimagusa and Iskele, both showed equal number of drought months. In about 22 stations the difference in drought months between CZI and SPI is less than five months, in seven stations the difference is between five and eleven months while only four stations showed difference greater than ten months. These stations are Girne, Beylerbeyi, Beyarmudu, Mehmetcik and Ercan. If overall result of all the indices is considered, then highest number of drought months are shown by Girne, Gazimagusa, Mehmetcik, Ziyamet, Yenierenkoy, Tatlisu, Akdeniz, Guzelyurt, Zumrutkoy, Ercan, Serdarli, Degirmenlik, and Margo. Most of these stations are in peninsula region which shows that this region is more prone to dry conditions. The Table 5.5 shows the number of drought months observed at each station by all indices at 1-month time step.

Table 5.5 Number of droughts at each station at 1-month time step

Stations	RD-1	ZSI-1	CZI-1	SPI-1	RDDI-1
Lapta	258	23	39	40	132
Girne	266	25	32	47	132
Beylerbeyi	256	22	31	41	132
Bogaz	259	21	35	39	132
Esentepe	253	27	38	43	132
Gecitkale	247	20	39	30	132
Vadili	242	25	42	43	132
Beyarmudu	261	22	43	31	132
Gazimagusa	264	27	48	48	132
Salamis	256	22	44	40	132
Dortyol	251	21	30	35	132
Gonendere	256	23	35	44	132
Iskele	261	17	36	36	132
Cayirova	255	20	44	41	132
Mehmeticik	248	35	58	40	132
Ziyamet	255	24	46	43	132
Dipkarpaz	242	29	43	44	132
Yenierenkoy	253	37	44	41	132
Tatlisu	260	20	45	43	132
Kantara	244	37	43	41	132
Akdeniz	246	39	43	45	132
Camlibel	246	35	40	38	132
Guzelyurt	253	42	46	49	132
Gaziveren	247	42	45	44	132
Lefke	232	33	43	44	132
Zumrutkoy	251	32	42	46	132
Ercan	238	24	42	53	132
Serdarli	240	24	43	45	132
Degirmenlik	262	28	39	47	132
Alevkaya	236	33	43	51	132
Alaykoy	241	32	46	43	132
Lefkosa	242	26	39	45	132
Margo	252	24	55	47	132

5.2.2 Annual Droughts

The following paragraphs will give details about the droughts identified at ten stations in different time steps, on annual basis, by the five indices used in this study.

In case of *Lapta*, at 3-month time step, RD identified thirteen, ZSI identified three, CZI and SPI each identified similar five, and RDDI identified eleven drought years. At time step 6-, RD identified eight years, ZSI identified six years, CZI and SPI identified same seven years, and RDDI identified eleven years. Years 1983-1984, 1995-1996, 1996-1997, 1999-2000, 2007-2008 and 2013-2014 are common for all indices in this time step. Time step 9- and 12- show same drought years for RD, ZSI, CZI and SPI, they are seven in number, and each index shows same severity levels in both time steps. RDDI-9 and RDDI-12 have same drought years. For -Wm, RD and RDDI show similar drought years. In the same time step, ZSI, CZI and SPI show same six drought years, the severity for all these years is same in ZSI. In -Rm, year 2006-2007 is observed as drought year in RD but not in ZSI, CZI and SPI, otherwise, the remaining eight years are same for them. RDDI has years 1985-1986 and 2005-2006 as drought years which are also observed by other four indices in this time step. Figure 5.8 displays number of droughts observed by all indices at various time steps in Lapta.

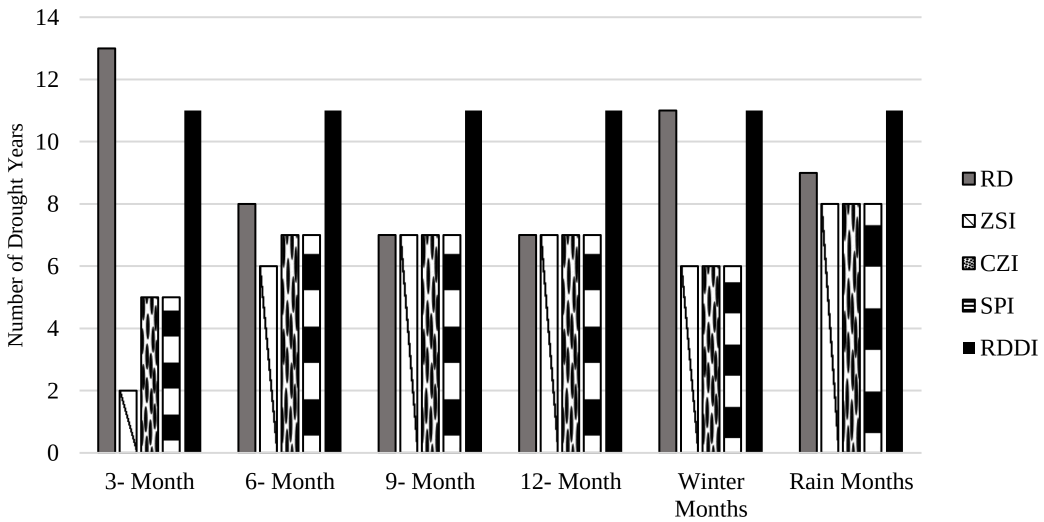


Figure 5.8 Number of drought years observed at different time steps in Lapta station

For 3-month time step at *Girne* station, RD has twelve drought months, the additional drought year as compared to RDDI is 1982-1983. ZSI, CZI and SPI all show same six years of drought, however, in case of ZSI they all have moderate category of severity. In time step 6-, RD has one less drought year as compared to RDDI, this year is

1982-1983. ZSI has seven which are all moderate droughts, CZI and SPI show same eight drought years with slight variation in severities. At 9- time step, RD has six, while ZSI, CZI and SPI show similar drought years. RD has one additional drought year, 2005-2006, as compared to these three indices, the severity category of RD and ZSI is similar, and CZI and SPI show same category of drought for the same years. RDDI-9 again has eleven years. RD-12, ZSI-12, CZI-12 and SPI-12 show same drought years, which are six, the years 1983-1984, 1996-1997, 1997-1998 and 2013-2014 are all classified as moderate severity drought by these four indices. RDDI has years 1989-1990, 1995-1996, 1999-2000, 2005-2006 and 2008-2009 as additional drought years compared to other four indices at time step 12-. In -Wm, RD has high number of drought years, thirteen in number, RDDI shows eleven, ZSI shows five, and CZI and SPI each show similar six drought years. In -Rm, RD has seven, ZSI and CZI show similar five years, SPI show six and RDDI show eleven drought years. The years common in all indices at this time step are, 1983-1984, 1990-1991, 1996-1997, 2007-2008 and 2013-2014.

The *Gecitkale* station at 3-month time step observed thirteen drought years for RD, eight similar drought years for ZSI and CZI, five for SPI and eleven for RDDI. The drought years observed for SPI, 1982-1983, 1990-1991, 2002-2003, 2010-2011 and 2013-2014, are also observed by other indices in this time step. At time step 6-, RD observed eight, while ZSI, CZI and SPI observed same drought years which are four in number, ZSI shows them all to have moderate severity category. RDDI has 1995-1996, 2008-2009 and 2010-2011 as additional drought years as compared to the other indices in this time step. RD-9, ZSI-9 and CZI-9 show seven drought years which are same, ZSI and CZI showesimilar drought categories for each year. SPI-9 did not show 1981-1982 as drought year while rest of the years are same as the other three indices. The years 1986-1987, 1996-1997, 1997-1998 and 2005-2006 are additional drought years which are observed for RDDI-9. RD-12, ZSI-12, CZI-12 and SPI-12 showed similar six drought years with slight difference in drought severities. RDDI-12 has 1981-1982, 1993-1994, 1996-1997, 1997-1998 and 2005-2006 as additional drought years. In -Wm, RD observed thirteen drought years, years 1996-1997 and 2008-2009 are not observed for RDDI, otherwise, all other years are similar. In the same time step, SPI, with the exception of 1999-2000, has same drought years as ZSI and CZI which observed eight drought years in total, while, SPI observed seven. In –Rm, RD observed eight drought years, ZSI, CZI and SPI observed six droughts in same years. The severities are exactly same for ZSI and CZI, while SPI shows 1982-1983 drought as very severe drought and 2013-2014 drought as extremely severe drought compared to moderate 1982-1983 drought and very severe 2013-2014 drought shown by the other two. For RDDI, in the same time step, years 1981-1982, 1996-1997 and 2008-2009 are the additional observed drought years.

In *Iskele* station, RD-3 has thirteen drought years, they are same as RDDI except for three additional drought years in RD which are 1985-1986, 2008-2009 and 2010-2011. ZSI, CZI and SPI show same seven drought years. In time step 6-, year 1986-1987 is extra year observed in RD, rest of the eleven years are same as RDDI. In this step, ZSI, CZI and SPI show same seven drought years, severity only differed in SPI for year 2007-2008. In 9-month time step, RD, ZSI, CZI and SPI showed same six drought years, again severity categories shown by them all for each year is same except by SPI for year 2013-2014. In this time step there are five additional years shown by RDDI. In 12- time step, RD, ZSI and CZI showed similar six drought years, SPI showed three less years which are 1990-1991, 2007-2008 and 2013-2014. Results of RDDI-9 and RDDI-12 are same, only difference is in severity values. In -Wm, RD and RDDI showed same drought years, ZSI, CZI and SPI showed four less but same drought years. The years not shown include 1981-1982, 1982-1983, 1983-1984 and 2008-2009. In -Rm, RD showed nine drought, one year 2008-2009 additional to ZSI, CZI and SPI, while, rest of the years are same. The additional years shown by RDDI in this time step are 2010-2011 and 2012-2013. Figure 5.9 shows the number of drought years observed at Iskele.

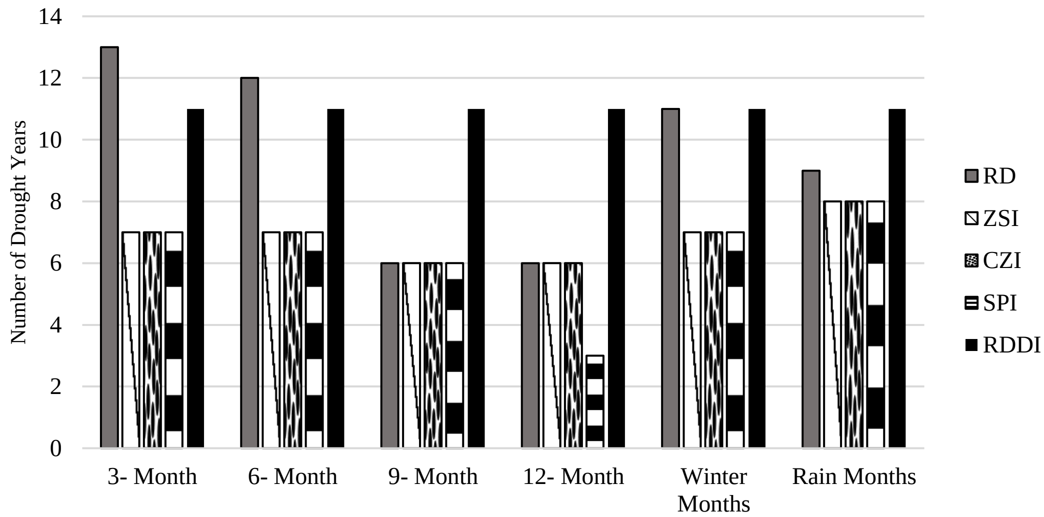


Figure 5.9 Number of drought years observed at different time steps in Iskele station

For 3-month time step at *Dipkarpaz* station, RD showes fifteen drought years, ZSI shows four, CZI shows five while SPI shows three drought years. Years 1982-1983, 2010-2011 and 2013-2014 are common in all five indices at this time step. The eleven drought years of RDDI are also observed in RD. At time step 6-, RD shows seven, while, ZSI, CZI and SPI show similar six drought years. Severity category of moderate drought is different in case of ZSI for year 1995-1996, while, other indices show it to be very severe drought and RDDI showed it as extremely severe drought. In time step 6- and 9-, years 1982-1983, 1983-1984, 1995-1996, 1996-1997, 2010-2011 and 2013-2014 are depicted as drought years by RD, ZSI, CZI and SPI, and severity category is exactly the same for all the four indices in both the time steps. In RDDI-9, year 1996-1997 is observed as drought year, and in RDDI-12 year 1993-1994 is observed as drought year, while, rest of the ten years are same. In -Wm, RD and RDDI show same drought years which are eleven in number, difference in severity is in year 1988-1989 which is shown as moderate drought year in RD and very severe drought year in RDDI. In the same time step, ZSI, CZI and SPI show same drought years, total five in number, severity category only differed in year 1994-1995, which is observed as moderate drought by ZSI and very severe by the other two. In -Rm, RD observed eight, ZSI and CZI observed six, SPI observed five, while RDDI observed eleven drought years. The years 1983-1984, 1995-1996, 1996-1997, 2010-2011 and 2013-2014 are common in all these indices at this time step.

The 3-month time step at *Tatlisu* station (Figure 5.10) shows sixteen drought years for RD, eleven for RDDI and same seven years for ZSI, CZI and SPI. In 6-month time step, RD didn't show year 2010-2011, while rest of the years are same as RDDI. ZSI, CZI and SPI, again, show similar drought years in this time step. In 9-month time step, years 1978-1979, 1981-1982, 1982-1983, 1983-1984, 1990-1991, 2007-2008 and 2013-2014 are common in all five indices, where RDDI shows total eleven, RD shows nine, ZSI shows eight and CZI and SPI show similar seven years. In 12-month time step, RDDI has eleven years and RD shows 1996-1997 additional year, while, rest of the years are same as seven years observed by ZSI, CZI and SPI. In -Wm, year 1995-1996 is an additional year observed by RDDI, while rest of the ten years are same as ten years of RD. ZSI, CZI and SPI have similar eight years, but they are all of moderate nature in case of ZSI. In -Rm, RD didn't show years 1980-1981 and 2010-2011 which are observed for RDDI, but rest of the years are same for both. In the same time step ZSI, CZI and SPI show same six years and severity categories are exactly same for ZSI and CZI.

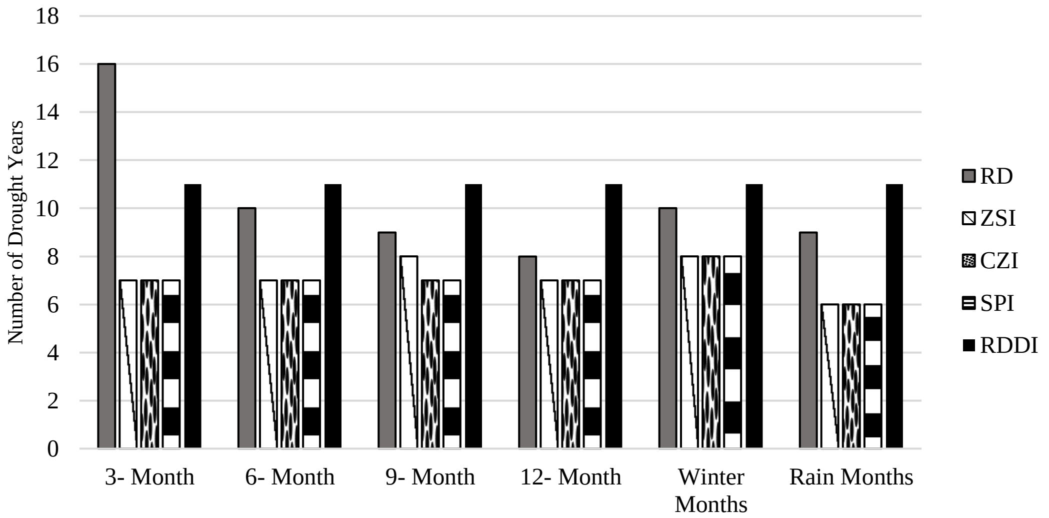


Figure 5.10 Number of drought years observed at different time steps in Tatlisu station

In *Guzelyurt* at time step 3-, the highest number of drought years are identified by RD. RDDI identified eleven drought years which are all same as RD except that RD has two additional years, 1978-1979 and 2001-2002, as drought years. ZSI shows the least number of drought years, only three with moderate severity. CZI and SPI show same years as drought years which are five in number. ZSI and SPI identified droughts to be less severe as compared to other indices. RDDI again identified eleven drought years, which are same as shown by RD but with two additional years as drought years which are 1981-1982 and 2004- 2005. ZSI-6, CZI-6 and SPI-6 identified same six years as drought years, ZSI identified year 2013- 2014 drought as severe drought, while, other two identified it as an extreme drought. At 9-month time step, again RDDI identified eleven drought years which are not same as the previous time step drought years. RD, ZSI, CZI and SPI identified same six years as drought years, however, as compared to previous time step, year 1983-1984 is not identified as drought year rather year 1989-1990 is observed as a drought year. The 12-month time step shows same result for RD, ZSI, CZI and SPI, however, CZI and SPI both show difference of severity in one drought year each. RDDI as compared to previous time step shows only one different drought year. The -Wm time step shows a varying result with years 1983-1984, 1994-1995, 2007-2008 and 2013-2014 identified as common drought years in each of the indices, however, number of drought years shown by RD, ZSI, CZI, SPI and RDDI are 10, 4, 5, 6 and 11 years respectively. RD-Rm gave slightly different drought years as RD-Wm, and identified nine years as drought years. ZSI identified six years, while, CZI and SPI each identified seven years. Again there is slight variation in drought years and in their severities between RDDI-Wm and -Rm. Years 2007-2008 and 2013-2014 are constantly identified as drought year at all time steps for all indices.

In *Lefke* (Figure 5.11), RD and RDDI at 3-month time step identified ten and eleven drought years, respectively, the drought years are same except for 2003-2004 year drought which is observed by RDDI. ZSI-3 and SPI-3 observed same drought years, the very severe droughts in ZSI-3 are extremely severe in SPI-3. CZI shows year 1996-1997 as drought year in addition to those shown by ZSI-3 and SPI-3. In 6-month time step, RD and SPI show nine drought years which are same but the two droughts are shown as severe in RD which are moderate in SPI. ZSI shows seven while CZI shows eight drought events. All events shown by ZSI in this time step are moderate in nature. In time step 9- each of RD, ZSI, CZI and SPI show six drought years, they all have same severity values for these events except for 1989-1990 year drought in which ZSI show the drought to be moderately severe, while, the other the mark it as a very severe drought. RDDI-6 and -9 have difference in two drought events. In time step 12-month , RD has six while ZSI, CZI and SPI show same drought years. In this time step severity of these events is same by CZI and SPI, while, only difference with ZSI is in year 1989-1990 where it shows the events as moderate in nature compared two very severe as shown by the other two. RDDI-9 and RDDI-12 showe exact same results. In -Wm, RD and RDDI showe exact same results with only difference in the severity of events. ZSI, CZI and SPI showe similar drought years in this time step while severity in year 1994-1995 is different in ZSI (moderately severe) as compared to the other two that show it as very severe event. In -Rm, RD didn’t show 1994-1995 year as a drought period, rest of the years are similar to ZSI, CZI and SPI, these three indices even show similar severity of events. RDDI depicts change in only one year between -Wm and -Rm, 1982-1983 year drought is observed for -Rm while 1986-1987 year drought is observed for -Wm.

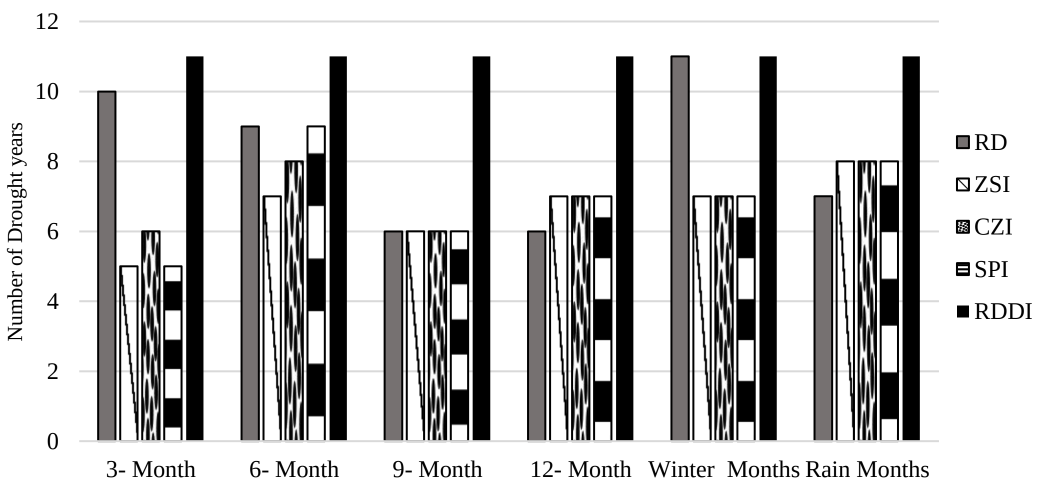


Figure 5.11 Number of drought years observed at different time steps in Lefke station

In *Ercan* station at 3-month time step, drought years for RD are fifteen, for RDDI they are eleven, eight similar years for ZSI and CZI and five years for SPI. In 6-month time step, RD has six drought years, it has one additional year 2010-2011, while rest of the years are same as ZSI, CZI and SPI. Again RDDI has eleven years. At 9-month time step, RD and SPI show same four drought years with similar severity category. Also ZSI and CZI show same six drought years with similar severity category. The eleven drought years in RDDI-9 and RDDI-12 differ in one year, 2005-2006 is drought in case of RDDI-9, while, year 1986-1987 is a drought in case of RDDI-12. RD-12 and SPI-12 show same five drought years, severity of drought only differs in year, 1990-1991. In RD, it is a very severe drought and, in SPI, it is an extremely severe drought. ZSI and CZI show exact same six drought years with similar severity of droughts. In -Wm, RD and RDDI show exact same eleven drought years while, in ZSI, CZI and SPI, years 1981-1982, 1986-1987, 1994-1995, 1999-2000 and 2007-2008 are observed as drought years. In -Rm, RD, ZSI and CZI show same six drought years, SPI didn't show year 1989-1990 but the other years are similar to these three indices. The additional years shown by RDDI in this time step are 1981-1982, 1983-1984, 2008-2009, 2010-2011 and 2013-2014.

Serdarli station shows sixteen drought years for RD-3, eleven for RDDI-3 while five same drought years are shown by ZSI, CZI and SPI, they are all moderately severe drought in case of ZSI. In 6-month time step, RD shows nine, RDDI shows eleven, and ZSI, CZI and SPI show same drought years which are 1981-1982, 1982-1983, 1986-1987, 1990-1991, 1996-1997, 2007-2008 and 2013-2014. In time step 9-, RD and SPI have same six droughts, while, ZSI and CZI showe same seven droughts. RDDI again shows eleven drought years. In 12-month time step, RD, ZSI and CZI show same seven droughts, SPI shows one less drought year than them which is in year 1996-1997. The additional years observed by RDDI are 1986-1987, 1988-1989, 1989-1990 and 1997-1998. In -Wm, RD observed twelve years, RDDI has one less year which is 2013-2014. ZSI, CZI and SPI observed same four years in this time step. In -Rm, RD and CZI observed same seven years, while ZSI and SPI observed same six drought years. The common drought years in all five indices in this time step are 1982-1983, 1985-1986, 1990-1991, 1996-1997, 2007-2008 and 2013-2014. Number of drought years for each index at Serdarli station are shown in Figure 5.12.

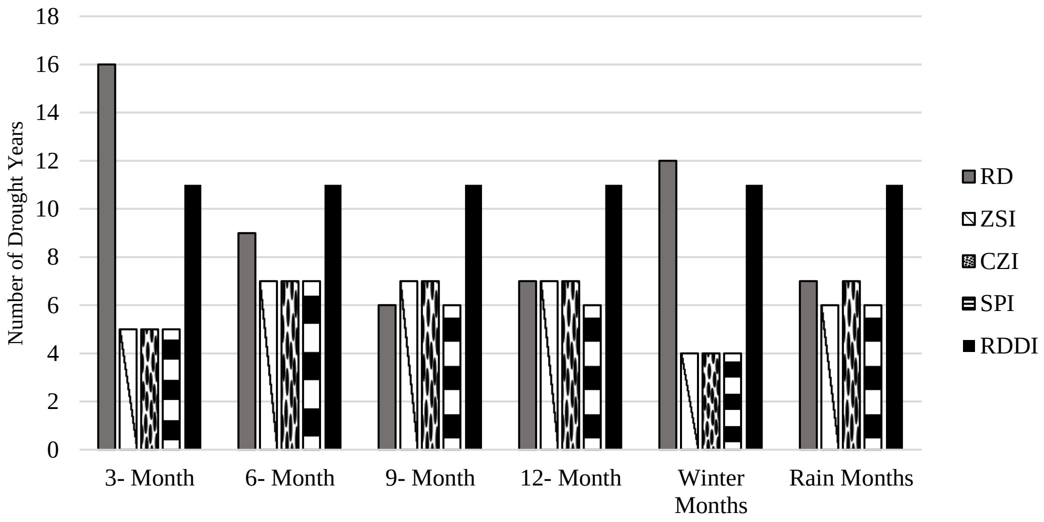


Figure 5.12 Number of drought years observed at different time steps in Serdarli station

The *Lefkosa* station for 3-month time step depicted fifteen drought years for RD which shows four additional drought years as compared to RDDI, these years are 1993-1994, 1998-1999, 2008-2009 and 2010-2011. At the same time step, ZSI shows five, CZI shows six and SPI shows four drought years. At 6- time step, RD shows nine, both ZSI and CZI show same eight years, SPI shows seven, and RDDI shows eleven drought years. SPI didn't show 1982-1983 as drought year which is seen in ZSI and CZI. The time step 9- and 12- show same result for RD, ZSI, CZI and SPI. They show three drought years, 1990-1991, 1995-1996 and 2007-2008, with same severity in all indices at both time steps except for year 1990-1991 which is very severe in RD, while, extremely severe in case of other indices. RDDI-9 differs from RDDI-12 in one drought year, 1994-1995 is drought year in RDDI-9 while, in RDDI-12, year 1988-1989 is a drought year. In -Wm, RD shows exactly same years as RDDI. ZSI and CZI show exact same three years. SPI observed six year as drought years, years 1981-1982, 1986-1987 and 1999-2000 are not observed in ZSI and CZI. In -Rm, RD and ZSI show same four years with same severity categories. Similarly, CZI and SPI show same five years, the extra year shown by them is 2006-2007, however again, the severity category of drought years is same for both. RDDI in -Rm again shows eleven drought years, with slight differences with -Wm's result.

5.2.3 Summary

The overall result of the number of droughts identified at 3-months and higher time steps is given in Table 5.6 (a-b). In case of RDDI, the number of drought years is same i.e. 11 since it tends to divide the time series into ten equal parts so every time step has same number of droughts, however, the years vary. The Table 5.6 (a-b) is only showing results of RDDI for 3-month time step, since, in higher time steps also, it has similar results. The lowest number of drought years are observed in Alaykoy, Lefkosa, Beylerbey, and Bogaz which are present in the middle region of the study area and in Salamis, Gazimagusa and Yenierenkoy. The highest number of drought years are observed for Tatlisu in peninsula region. The Iskele station located nearby has second highest drought years, while Vadili also observed same number of drought years. This shows that eastern side of the study region is experiencing more rainfall variability.

If we observe time steps, RD at 3-month time step tends to give higher number of drought years as compared to ZSI, CZI and SPI. In some stations, even higher than RDDI, only at Lefke station it shows fewer drought years as compared to RDDI. The highest number of droughts shown are 19 in Bogaz station. Even at 6-month time step, RD showed more drought years but the difference in this time step with other indices is not much. The other three indices in this time step show same results in almost all the stations, with a difference of one or two years among them. Only in case of Bogaz station, ZSI showed more difference where it has two years compared to six shown by the other two indices. At 9-month time step, RD gave closer results to ZSI, CZI and SPI which meant this time step gives more realistic picture of droughts in Cyprus and also that RD is more comparable to other indices at higher time steps. In majority of the stations, the results of ZSI, CZI and SPI at 9-, 12-months and -Rm is same, which shows that these three time steps are comparable and give best picture of annual droughts for this region. Two additional time steps used, -Wm and -Rm are very important because the rains are mostly concentrated in these months. RD again showed more difference in drought years compared to other three indices in -Wm, while in -Rm it has similar number of drought years as given by ZSI, CZI and SPI. Since, the results show that drought years by 12-month time step and -Rm are almost similar, hence, rain months alone can give the overall picture of drought conditions in North Cyprus.

Table 5.6 a) Number of drought years observed by each index at various time steps

Stations	RD 3	ZSI 3	CZI 3	SPI 3	RDDI 3	RD 6	ZSI 6	CZI 6	SPI 6	RD 9	ZSI 9	CZI 9	SPI 9
Lapta	13	2	5	5	11	8	6	7	7	7	7	7	7
Girne	12	6	6	6	11	10	7	8	8	6	5	5	5
Beylerbeyi	16	4	5	4	11	9	5	6	6	4	4	4	4
Bogaz	19	1	3	4	11	10	2	6	6	5	3	6	3
Esentepe	15	7	7	7	11	11	6	6	6	6	6	6	5
Gecitkale	13	8	8	5	11	8	4	4	4	7	7	7	6
Vadili	14	5	6	4	11	9	8	8	8	6	6	6	6
Beyarmudu	14	3	6	6	11	9	5	5	5	8	6	3	6
Gazimagusa	16	4	5	5	11	7	4	4	4	4	4	4	5
Salamis	12	8	8	7	11	8	4	4	4	5	5	5	5
Dortyol	13	8	8	6	11	9	6	6	6	7	7	7	6
Gonendere	13	5	5	4	11	9	7	7	7	4	5	5	4
Iskele	13	7	7	7	11	12	7	7	7	6	6	6	6
Cayirova	18	4	7	7	11	6	5	5	5	4	5	5	5
Mehmeticik	17	3	6	6	11	8	4	4	4	7	6	6	6
Ziyamet	13	6	6	6	11	8	7	7	7	4	4	4	5
Dipkarpaz	15	4	5	3	11	7	6	6	6	6	6	6	6
Yenierenkoy	15	5	6	5	11	7	6	7	6	5	5	5	5
Tatlisu	16	7	7	7	11	10	7	7	7	9	8	7	7
Kantara	13	6	6	5	11	6	6	6	6	2	5	5	4
Akdeniz	15	3	3	3	11	8	6	6	6	8	8	8	8
Camlibel	15	3	4	4	11	6	5	5	5	5	4	5	4
Guzelyurt	13	3	5	5	11	9	6	6	6	6	6	6	6
Gaziveren	12	2	5	5	11	8	7	7	8	6	6	6	6
Lefke	10	5	6	5	11	9	7	8	9	6	6	6	6
Zumrutkoy	16	5	5	5	11	7	4	6	6	6	6	6	6
Ercan	15	8	8	5	11	6	5	5	5	4	6	6	4
Serdarli	16	5	5	5	11	9	7	7	7	6	7	7	6
Degirmenlik	15	4	5	6	11	11	6	6	6	5	4	4	3
Alevkaya	17	5	5	4	11	6	5	6	6	2	5	5	3
Alaykoy	14	3	5	4	11	8	7	8	8	6	6	6	6
Lefkosa	15	5	6	4	11	9	8	8	7	3	3	3	3
Margo	16	7	8	8	11	7	6	6	6	4	6	4	6

Table 5.6 b) Number of drought years observed by each index at various time steps

Stations	RD 12	ZSI 12	CZI 12	SPI 12	RD Wm	ZSI Wm	CZI Wm	SPI Wm	RD Rm	ZSI Rm	CZI Rm	SPI Rm
Lapta	7	7	7	7	11	6	6	6	9	8	8	8
Girne	6	6	6	6	13	5	6	6	7	5	5	6
Beylerbeyi	4	4	4	4	9	5	5	5	6	5	5	5
Bogaz	4	3	6	4	12	3	5	5	9	4	6	4
Esentepe	6	6	6	6	12	4	5	6	8	7	7	7
Gecitkale	6	6	6	6	13	8	8	7	8	6	6	6
Vadili	6	6	6	6	13	8	8	8	9	7	7	7
Beyarmudu	8	6	6	6	12	6	7	7	8	6	6	6
Gazimagusa	4	4	4	4	10	5	6	6	5	4	4	4
Salamis	5	5	4	5	11	3	3	5	5	4	4	4
Dortyol	7	7	7	7	9	0	6	6	9	6	6	5
Gonendere	5	6	6	5	12	5	6	7	8	6	6	6
Iskele	6	6	6	3	11	7	7	7	9	8	8	8
Cayirova	5	6	6	6	11	7	8	8	5	5	5	5
Mehmeticik	7	6	7	7	14	3	5	6	10	3	7	7
Ziyamet	3	4	3	5	12	4	6	6	7	6	6	6
Dipkarpaz	6	6	6	6	11	5	5	5	8	6	6	5
Yenierenkoy	5	5	5	5	8	3	4	4	7	3	4	3
Tatlisu	8	7	7	7	10	8	8	8	9	6	6	6
Kantara	2	5	5	4	8	6	6	6	7	7	7	7
Akdeniz	8	8	8	8	10	5	5	5	8	7	7	7
Camlibel	5	5	5	5	10	4	4	4	6	6	6	5
Guzelyurt	6	6	6	6	10	4	5	6	9	6	7	7
Gaziveren	5	6	6	5	10	7	7	7	6	6	6	6
Lefke	6	7	7	7	11	7	7	7	7	8	8	8
Zumrutkoy	6	6	6	6	10	2	4	4	9	6	6	7
Ercan	5	6	6	5	11	5	5	5	6	6	6	5
Serdarli	7	7	7	6	12	4	4	4	7	6	7	6
Degirmenlik	6	4	4	4	13	4	5	5	8	5	5	5
Alevkaya	2	3	3	3	10	4	4	5	3	4	4	4
Alaykoy	5	5	5	5	13	6	7	7	8	7	7	7
Lefkosa	3	3	3	3	11	3	3	6	4	4	5	5
Margo	5	6	4	6	12	5	6	6	7	6	6	6

This means that the droughts observed are due to lack or less amount of rain in these months i.e. November, December, January, February and March. RDDI giving constant eleven drought years in all time steps can help to predict approaching dry conditions in the region. The Figures 5.13-5.19 show the relative frequency of occurrence of drought at different time steps by these five indices, as well as the relative severities of drought events.

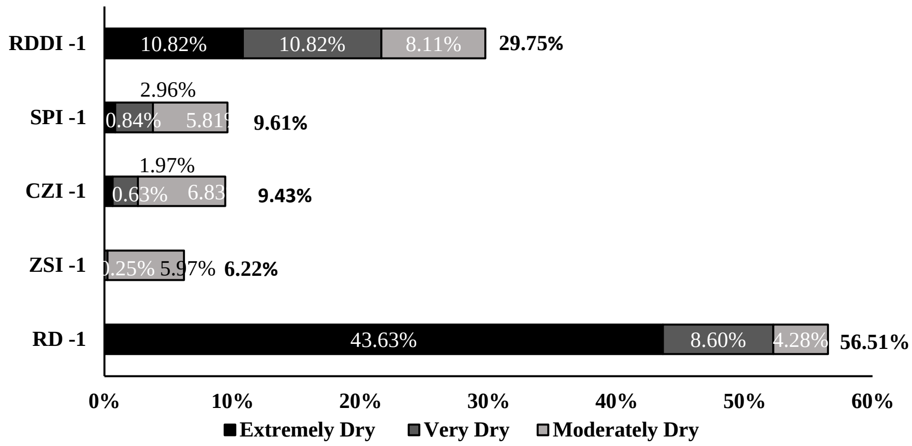


Figure 5.13 Comparison of frequency of occurrence of drought highlighting percentage of severity category at 1-month time step using five indices

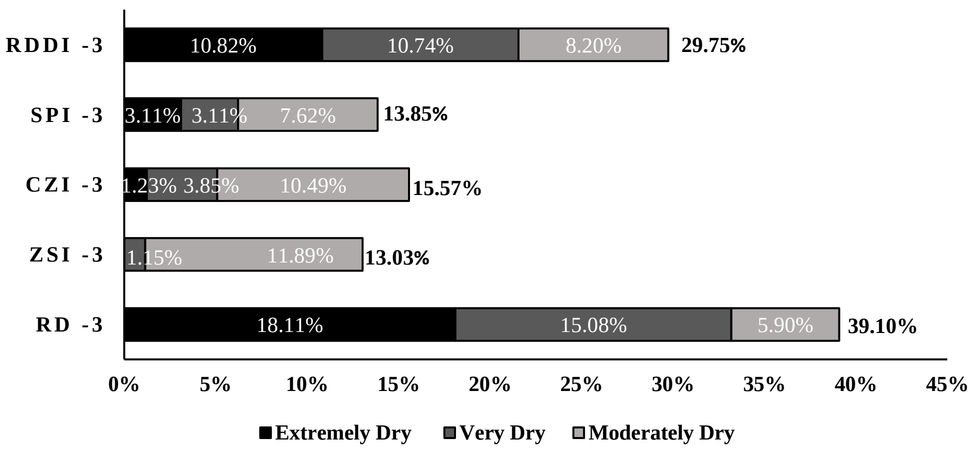


Figure 5.14 Comparison of frequency of occurrence of drought highlighting percentage of severity category at 3-month time step using five indices

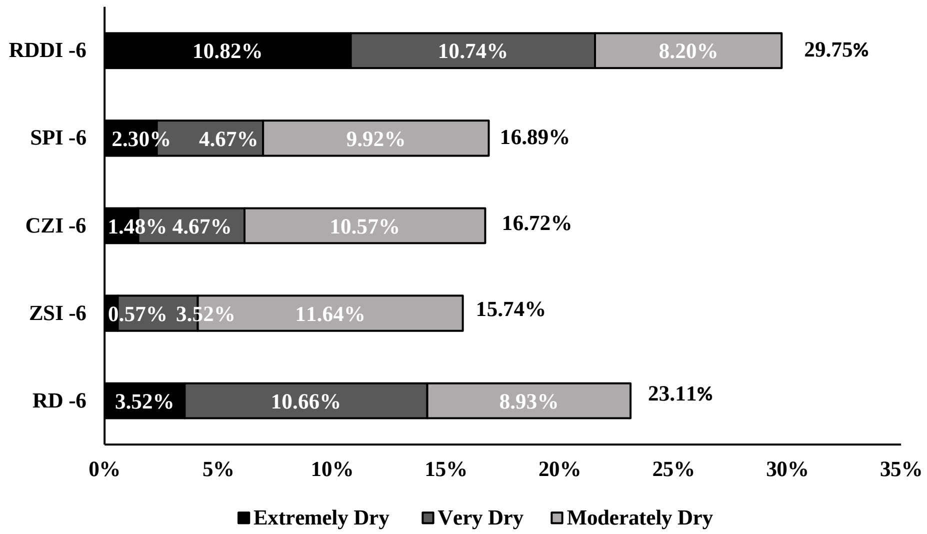


Figure 5.15 Comparison of frequency of occurrence of drought highlighting percentage of severity category at 6-month time step using five indices

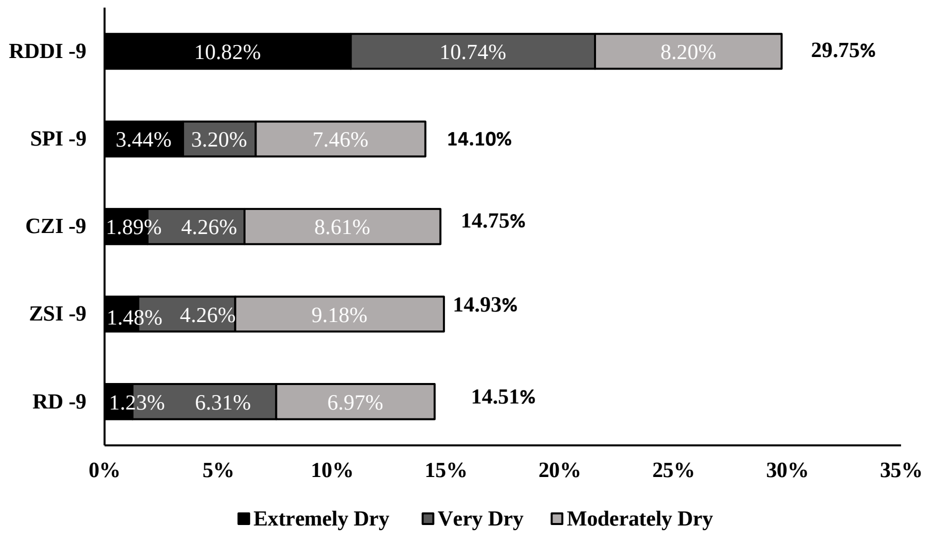


Figure 5.16 Comparison of frequency of occurrence of drought highlighting percentage of severity category at 9-month time step using five indices

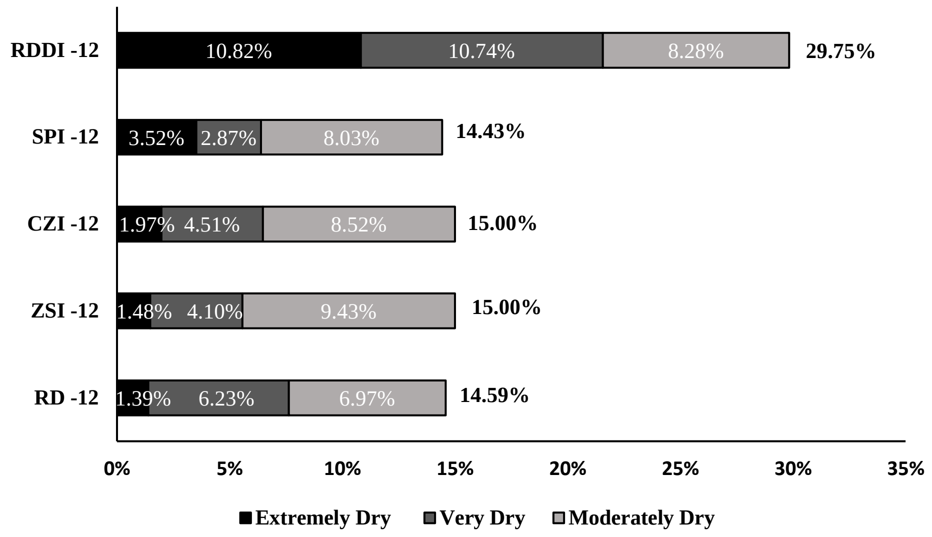


Figure 5.17 Comparison of frequency of occurrence of drought highlighting percentage of severity category at 12-month time step using five indices

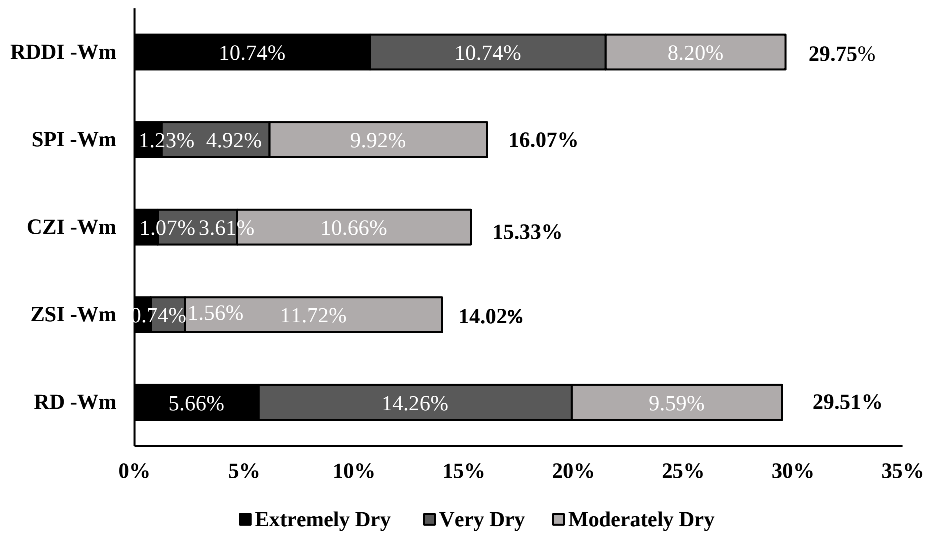


Figure 5.18 Comparison of frequency of occurrence of drought highlighting percentage of severity category at -Wm time step using five indices

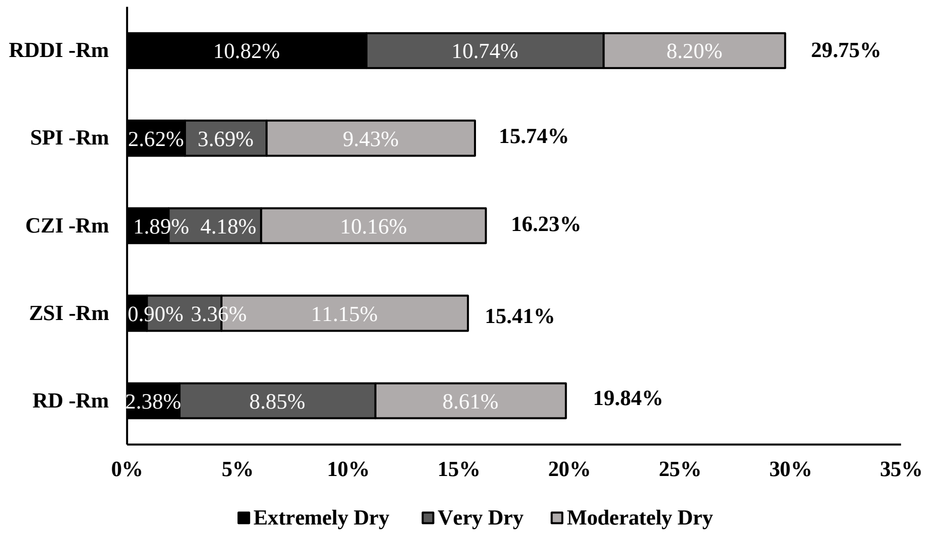


Figure 5.19 Comparison of frequency of occurrence of drought highlighting percentage of severity category at -Rm time step using five indices

It can be observed in the Figures 5.13 and 5.14 that at 1-month and 3-month time steps, ZSI is not showing any extreme drought event. Comparison with other indices show that it is undermining the extreme drought conditions. While RD, on the other hand, is showing extreme events more often which shows that it is exaggerating the drought conditions, especially at 1-month time step. However, at higher time steps, they show almost similar number of drought years as CZI and SPI. So these indices behave more similarly at higher time steps. Out of all the indices, CZI and SPI behave very similar in all time steps showing close association between their methodologies, as both assume the data to follow Pearson type III distribution.

The final historical drought months/ years at each time step for North Cyprus are selected if three out of five indices showed a particular month/ year to be a drought year. The final historical drought months are given in Appendix D. However, this is also done for 3-month and higher time steps to give annual drought years. The final number of drought months at each time step is given in Table 5.7. A total of 30 different drought years are observed in different time steps. These years in order of highest occurrence are 2013-2014, 2007-2008, 1990-1991, 1996-1997, 1983-1984, 1981-1982, 1994-1995, 2010-2011, 1995-1996, 1982-1983, 1999-2000, 1989-1990, 1985-1986, 1986-1987, 1997-1998, 1978-1979, 2008-2009, 2002-2003, 1980-1981, 2003-2004, and 1998-1999. The remaining nine years appeared less than ten times, they are 1998-1999, 2006-2007, 2005-2006, 2004-2005, 1979-1980, 1984-1985, 2014-2015, 2000-2001, and 2012-2013.

Table 5.7 Final Number of drought years at each time step

Stations	3-month	6-month	9-month	12-month	Winter months	Rain months
Lapta	5	7	7	7	6	8
Girne	6	8	5	6	6	6
Beylerbeyi	5	6	4	4	5	5
Bogaz	4	6	5	4	5	4
Esentepe	7	6	6	6	6	7
Gecitkale	8	4	7	6	8	6
Vadili	6	8	8	8	7	7
Beyarmudu	6	5	6	6	7	6
Gazimagusa	5	4	4	4	6	4
Salamis	8	4	5	5	5	4
Dortyol	8	6	7	7	6	6
Gonendere	5	7	5	6	7	6
Iskele	7	7	6	6	7	8
Cayirova	7	5	5	6	8	5
Mehmeticik	6	4	6	7	6	7
Ziyamet	6	7	4	4	6	6
Dipkarpaz	5	6	6	6	5	6
Yenierenkoy	6	7	5	5	4	4
Tatlisu	7	7	8	7	8	6
Kantara	6	6	5	5	6	7
Akdeniz	3	6	8	8	5	7
Camlibel	4	5	5	5	4	6
Guzelyurt	5	6	6	6	6	7
Gaziveren	5	7	6	6	7	6
Lefke	6	9	6	7	7	8
Zumrutkoy	5	6	6	6	4	7
Ercan	8	5	6	6	5	6
Serdarli	5	7	7	7	4	7
Degirmenlik	6	6	4	4	5	5
Alevkaya	5	6	5	3	5	4
Alaykoy	5	8	6	5	7	7
Lefkosa	6	8	3	3	6	5
Margo	8	6	6	6	6	6

The year 2013-2014 appeared in 162 instances, year 2007-2008 appeared in 152 instances, year 1990-1991 in 136 instances and year 1996-1997 in 108 instances. These years are deemed as most drought affected years. The year 2013-2014 appeared as drought year in all time steps of 20 stations, and in five time steps of six stations. It is not observed for any time step in Bogaz and Ercan, for Alaykoy, it is observed only in 3-month time step, for Lefkosa and Margo in two and three time steps respectively. Hence, the middle Mesaoria plains is less impacted in this year. The 2007-2008 drought is observed in all time steps of eight stations and is observed in almost five time steps of 15 stations. The Camlibel and Lefke stations on western Mesaoria plain didn't observe 2007-2008 as a drought year in any time step. It is observed for only 3-month time step in Mehmetcik and Ziyamet present in peninsula region. The 1990-1991 drought is observed in all time steps for four stations, and is not observed in Dipkarpaz station, and in majority of the stations it is not observed in -Wm time step. The 1996-1997 drought years is not observed in all time steps of any station but appeared in atleast five time steps of fourteen stations and is mostly missing in 3-month time step in these stations. The stations that did not show this drought year in any time step include Esentepe, Gecitkale, Ercan, Degirmenlik, Alevkaya, Lefkosa and Margo. This showed that in 1996-1997, the middle Mesaoria plain region is not effected by drought conditions. Interestingly, some drought years are observed only in few stations, like 1988-1989 drought is observed only in Cayirova and Mehmetcik (peninsula region). 2006-2007 drought in Ziyamet, Mehmetcik and Dipkarpaz (peninsula region) as well as in Lefkosa and Zumrutkoy in Mesaoria plain. The 2004-2005 drought year is seen in case of Dipkarpaz and Yenierenkoy station, located in peninsula region. The 2000-2001 drought year is observed in Zumrutkoy only and 1984-1985 in Alevkaya and Margo. The 1985-1986 drought year, observed 24 times in total, is not observed in all the stations, only in -Rm time step in Serdarli, Degirmenlik, Camlibel and Gaziveren, while in more than one time step in Akdeniz, Guzelyurt, Lefke and Zumrutkoy. Most of these stations are in west Mesaoria plain which shows this year affected mostly this region.

In 3-, 9- and 12-month time step, the commonly observed drought year is 1990-1991. In 6-month, 2013-2014 is commonly observed drought year. In -Wm it is 1994-1995 and in -Rm it is 2007-2008. If we divide the 37 years, under consideration, into four decades then about 33% of the drought are observed in second decade from 1988-1989 to 1997-1998. The first decade (1978-1979 to 1987-1988) has 23% droughts, third decade has 25% droughts and, fourth decade (2008-2009 to 2014-2015) has 19% droughts. About 20 stations observed more droughts in second decade as compared to other three decades. Five stations (Vadili, Tatlisu, Serdarli, Degirmenlik and Margo) observed more droughts in first decade, four stations (Salamis, Dortyol, Gonendere and Lefkosa) observed more droughts in third decade. Four stations (Beyarmudu, Gazimagusa, Yenierenkoy and Ercan) observed equal number of drought years in both second and third decade. However, the most common drought, which is observed in 2013-2014, is a part of fourth decade.

5.3. Drought Characteristics

For defining drought characteristics, most suitable drought index together with most suitable time step, that can best describe the drought condition in North Cyprus, is chosen based on the previous results. Although, in our study, CZI gave better results based on higher correlations, followed by ZSI and SPI, but the drought identification showed that SPI and CZI behave very similar. Since, they both assume that rainfall data follows Pearson type III distribution and also they both allow for missing values, therefore, SPI is chosen to determine the drought characteristics. Also, as SPI is the most widely used and accepted index, using SPI to determine drought characteristics will help in inter-comparison with other studies, since, most of the studies all over the world are based on SPI. For selection of time steps, it is observed that RD, ZSI, CZI and SPI, all show more or less same drought years in 9-, 12- and -Rm time steps. Since, drought describes deficiency in precipitation, so -Rm, which includes the rain months in North Cyprus, is chosen to best describe the drought conditions and its properties. However, for frequency analysis, monthly values of SPI are used.

5.3.1 Drought Parameters: Severity, Duration, Magnitude and Intensity

Drought severity defines certain threshold limits which are based on the calculated value of the index used. The drought severity tag is given to each drought year separately rather than to a drought event. To describe a drought event of a particular duration, drought parameters of magnitude and intensity are used. The duration is in years since -Rm is giving singular annual value. The Table 5.8 is showing number of drought years with their severity category identified according to SPI for nine stations, the remaining stations are given in Appendix E.

Most of the drought years observed are mild droughts or near normal years. Highest number of droughts are 22 observed in Yenierenkoy, while lowest are 15 observed in Serdarli. 28 stations showed the drought year ranged between 17-20 years. Highest number of mild droughts (19 in number) are observed by Yenierenkoy, next highest number is 15 mild droughts observed in Camlibel, Degirmenlik, Cayirova, Beylerbeyi, and Bogaz each. The lowest number of mild droughts is nine which is observed in Guzelyurt. Except for Yenierenkoy, number of mild droughts in other stations ranged between 10-15. Highest number of moderate drought is seven observed in Lapta, followed by Lefke, Zumrutkoy and Mehmetcik. Salamis station showed no moderate drought years. 1982-1983 is a moderate drought in eight stations, while 1983-1984 is a moderate drought in nine stations. The year 1990-1991 is the most common year as moderate drought, which is experienced in 13 stations. The year 1999-2000 and 1996-1997 is observed in 11 stations, the years 1982-1983, 1983-1984 and 1994-1995 are observed in 10 stations, and 2013-2014 is experienced in nine, while two years 1989-1990 and 2007-2008 are moderate drought years in eight stations. The remaining nine years which also appeared as moderate drought years are less common. In case of next severity category, nine different years appeared to be very severe drought experienced in various stations, they include 2007-2008 (11), 1983-1984 (2), 1996-1997 (5), 1982-1983 (3), 2013-2014 (7), 1999-2000 (7), 1990-1991 (7), 1985-1986 (2) and 2010-2011 (1). The brackets indicate the number of stations that observed this year as a very severe drought. Four different years appeared as extremely severe droughts, these are 1983-1984, 1996-1997, 2007-2008 and 2013-2014 which are observed in 1, 8, 10 and 13 stations respectively. The year 2013-2014 mostly appeared as an extremely severe drought in peninsula region and western part of country while year 2007-2008 is experienced as an extremely drought mostly in the central part of country. Gazimagusa, Salamis, Dipkarpaz and Yenierenkoy experienced two extreme drought events each in 37 years.

Table 5.8 Severity category of drought years identified at -Rm using SPI

Stations	Mild / near zero drought	Moderate	Very severe	Extreme
Lapta	1980-1981, 1982-1983, 1985-1986, 1988-1989, 1993-1994, 1997-1998, 2000-2001, 2004-2005, 2005-2006, 2006-2007, 2010-2011	1983-1984, 1989-1990, 1990-1991, 1995-1996, 1999-2000, 2007-2008, 2013-2014		1996-1997
Girne	1980-1981, 1981-1982, 1982-1983, 1989-1990, 1994-1995, 1995-1996, 1997-1998, 2005-2006, 2006-2007, 2008-2009, 2010-2011, 2012-2013	1999-2000, 2013-2014	1983-1984, 1990-1991, 1996-1997, 2007-2008	
Beylerbeyi	1980-1981, 1981-1982, 1982-1983, 1985-1986, 1988-1989, 1990-1991, 1994-1995, 1995-1996, 1997-1998, 1999-2000, 2000-2001, 2006-2007, 2008-2009, 2010-2011, 2012-2013	1989-1990, 1996-1997, 2013-2014	1983-1984	2007-2008
Bogaz	1978-1979, 1980-1981, 1981-1982, 1982-1983, 1985-1986, 1989-1990, 1994-1995, 1995-1996, 1997-1998, 1999-2000, 2004-2005, 2005-2006, 2006-2007, 2008-2009 , 2013-2014	1983-1984, 1990-1991, 1996-1997	2007-2008	
Esentepe	1978-1979, 1979-1980, 1981-1982, 1982-1983, 1996-1997, 1997-1998, 1999-2000, 2006-2007, 2008-2009, 2010-2011	1983-1984, 1989-1990, 1990-1991, 1994-1995, 2014-2015	2013-2014	2007-2008
Gecitkale	1981-1982, 1983-1984, 1985-1986, 1986-1987, 1989-1990, 1995-1996, 1996-1997, 1997-1998, 2008-2009, 2010-2011, 2012-2013, 2014-2015	1994-1995, 1999-2000	1982-1983, 1990-1991, 2007-2008	2013-2014
Vadili	1978-1979, 1981-1982, 1983-1984, 1985-1986, 1990-1991, 1995-1996, 1998-1999, 2005-2006, 2006-2007, 2014-2015,	1982-1983, 1997-1998, 1999-2000 2012-2013, 2013-2014	2007-2008	1996-1997
Beyarmudu	1978-1979, 1981-1982, 1983-1984, 1985-1986, 1989-1990, 1990-1991, 1994-1995, 1995-1996, 1998-1999, 2004-2005, 2010-2011,	1982-1983, 1997-1998	1999-2000, 2007-2008, 2013-2014	1996-1997
Gazimagusa	1980-1981, 1981-1982, 1982-1983, 1983-1984, 1985-1986, 1989-1990, 1990-1991, 1993-1994, 1994-1995, 1995-1996, 1997-1998, 1998-1999, 2006-2007, 2008-2009	2007-2008	1999-2000	1996-1997, 2013-2014

In case of the other three parameters: *duration*, *magnitude* and *intensity*, tables are made for each station identifying the drought episode along with their characteristics. Table 5.9 shows characteristics of drought episodes in Lapta, similar calculations are done for all stations (see Appendix F). The highest drought duration observed is eight years during the rain months from 1993-2001. The magnitude of the event is 4.79 while the intensity is 0.60, observed at Yenierenkoy station. Another long duration drought is 1994-2001 drought observed in Cayirova with magnitude of 6.12 and 0.87 intensity, hence, more intense than 1993-2001 drought that is observed in Yenierenkoy station. Gazimagusa also observed a seven year drought in 1993-2000, with intensity of 0.93. Mehmetcik observed same duration drought in similar years with intensity of 0.81. Beyarmudu observed drought in six years (1994-2000) with intensity of 0.94. Tatlisu observed two 6-year duration droughts, one same as Mehmetcik and Beyarmudu but has a lesser intensity of 0.49, but the other drought episode of 1978-1984 is very intense, almost 1. The drought duration of five years is shown by a number of stations which include Camlibel, Alevkaya, Lefke, Iskele, Lefkosa, Bogaz, Kantara, Vadili, Ercan and Margo. Camlibel and Alevkaya stations show this duration for same time period, 1981-1986, and intensity is 0.69 and 0.68, respectively. Lefke and Iskele have period 1993-1998 as drought event with intensity of 0.84 and 0.80, respectively. Lefkosa and Bogaz have drought period during 2004-2009, with intensity of 0.91 and 0.67, respectively. Kantara has a five year drought in 1996-2001 with magnitude of 4.70 and intensity of 0.94. Vadili, Ercan and Margo show 1995-2000 period as a drought, it is most intense in case of Vadili and for Ercan and Margo it is comparable.

Table 5.9 Drought parameters indicating drought characteristics for Lapta station

No of drought episodes	**Drought episode**	**Duration (year)**	**Magnitude (∑DI)**	**Intensity (∑DI/y)**
1	1980-1984	3	2.23	0.74
2	1985-1986	1	0.56	0.56
3	1988-1991	3	2.50	0.83
4	1993-1994	1	0.16	0.16
5	1995-1998	3	3.49	1.16
6	1999-2001	2	1.43	0.72
7	2004-2008	4	3.24	0.81
8	2010-2011	1	0.32	0.32
9	2013-2014	1	1.48	1.48

In this study we are considering intense drought as those events that have an intensity of 1.40 and above. The most intense drought has been observed for year 2013-2014 at Camlibel station with intensity of 3.05. Tatlisu and Gazimagusa experienced almost similar intensity (2.23 and 2.24 respectively), again, for the year 2013-2014. For the same year, intense droughts are observed in Mehmetcik (2.15), Gaziveren (2.05), Lefke (1.96), Cayirova (1.92), Zumrutkoy (1.82), Alaykoy (1.77), Beyarmudu (1.64), and Lapta (1.48). Serdarli experienced an intense drought of magnitude 4.01 and intensity 2.0 in years 2007-2009. Esentepe experienced a drought of 1.55 intensity in 2013-2015. Dipkarpaz station for year 2012-2014 has an intensity of 1.64. For year 2010-2011, Alevkaya has drought intensity of 1.59, and Kantara has 1.44 intensity. Some stations show intense droughts in year 1999-2000, these include Iskele (1.59), Alaykoy (1.52), Lefke (1.47), and Lefkosa (1.42). The year 1985-1986 experienced intense droughts at Lefke and Guzelyurt showing intensity of 1.99 and 1.59, respectively. Other stations that show intensity greater than 1.40 include Ziyamet (1.55 in year 1990-1991), Salamis (1.41 for the period 1996-1991), Beyarmudu (1.56 for the year 2007-2008), Cayirova (1.87 for the year 2004-2005), and Gaziveren (1.53 for the year 1989-1991).

Almost all stations, except for Serdarli, show drought events of 4-year duration and more. The highest number of such events are shown by Girne and Bogaz, three in number for each. Again, all station show drought events greater than and equal to 3-year duration, such events are more common in Lefkosa, Lapta, Beylerbeyi, Yenierenkoy, Degirmenlik, and Vadili. If we take into account all the drought episodes of different durations experienced in all the 33 stations in 37 years, we found total of 272 drought events out of which the distinct unique events (excluding the duplicate events) are 56 in number (shown in Table 5.10). The 2010-2011 drought period is observed in 27 out of the 33 stations, the stations that did not experience this drought are Vadili, Dortyol, Bogaz, Gazimagusa and Margo which are on the eastern part of the region, while in Lefkosa this drought occurred for a longer duration. (Figure 5.20). The other two common drought episodes are 1985-1986 and 1989-1991, both experienced in about 18 stations each. Followed by the 2013-2014 drought episode, this drought is observed in two years (2012-2014) by 11 stations, it is observed in three years (2012-2015) by five stations and observed in three years duration (2010-2013) by one station. The 1981-1984 drought episode of three years duration is observed in 17 stations. The droughts with longer duration are mostly observed during the period 1993-2001, while more intense droughts are mostly observed in the last years, 2012-2013.

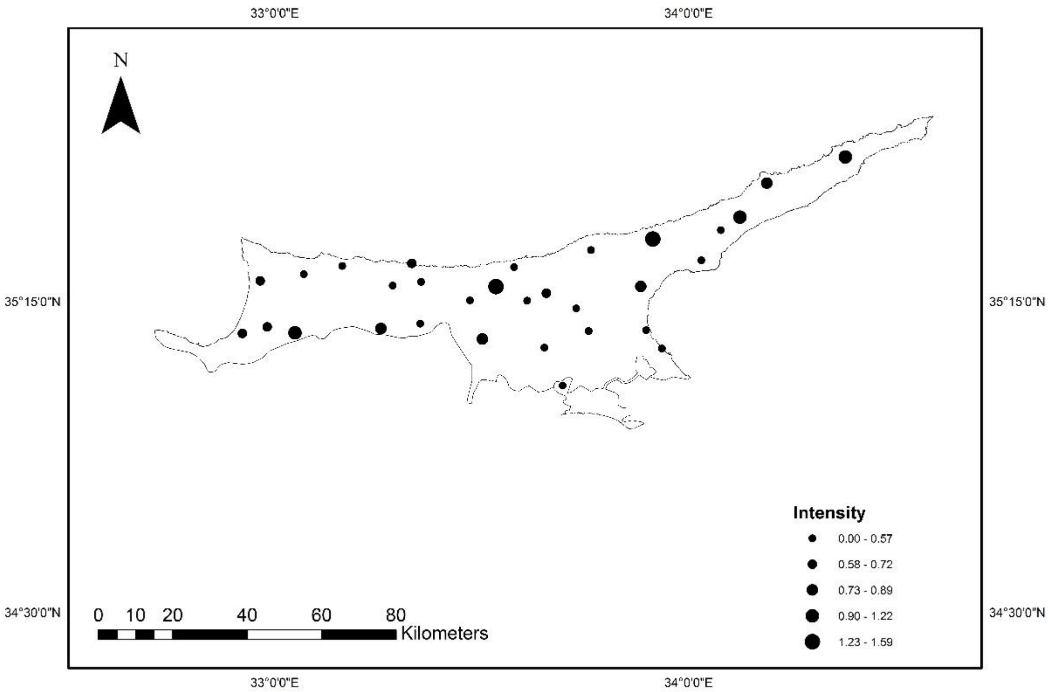


Figure 5.20 Map showing intensity of 2010-2011 drought in different stations

The Figures 5.21 and 5.22 show spatial distribution of 2007-2008 and 2013-2014 droughts in terms of its magnitude and duration. It can be seen that 2007-2008 drought is of larger magnitude and duration in the central and west part of the region, while 2013-2014 drought had larger magnitude and duration on eastern part of the country.

Table 5.10 Distinct unique drought episodes observed in North Cyprus in Rain months during period 1978-2015 (frequency indicates the number of stations experiencing this drought episode)

No. of distinct drought episodes	Drought episode	Frequency	Duration (year)	No. of distinct drought episodes	Drought episode	Frequency	Duration (year)
1	1978-1979	10	1	29	1993-1997	1	4
2	1982-1984	3	2	30	2012-2014	11	2
3	1985-1986	18	1	31	2007-2009	3	2
4	1989-1991	18	1	32	2012-2015	5	3
5	1994-1997	1	3	33	1980-1984	7	4
6	1999-2000	14	1	34	2005-2009	3	4
7	2004-2008	6	4	35	1981-1982	2	1
8	2010-2011	27	1	36	1983-1984	1	1
9	2013-2014	15	1	37	1994-1995	5	1
10	1981-1986	2	5	38	1996-2001	1	5
11	1988-1991	7	3	39	2004-2009	2	5
12	1992-1994	1	2	40	2010-2013	1	3
13	1995-1997	2	2	41	1993-2001	1	8
14	1999-2001	7	2	42	2004-2005	6	1
15	1980-1981	1	1	43	1995-1998	1	3
16	1993-1994	2	1	44	1978-1980	1	2
17	1981-1984	17	3	45	2013-2015	1	2
18	1994-1998	9	4	46	1986-1987	1	1
19	2006-2008	5	2	47	1994-2001	1	7
20	1993-1998	3	5	48	1988-1989	2	1
21	2005-2006	2	1	49	1993-2000	2	7
22	1993-1995	1	2	50	1981-1983	1	2
23	1996-1998	4	2	51	1995-2000	3	5
24	1988-1992	1	4	52	1996-2000	2	4
25	2005-2008	2	3	53	1994-2000	2	6
26	2006-2009	9	3	54	2007-2008	1	1
27	1985-1987	9	2	55	1978-1984	1	6
28	1990-1991	7	1	56	2006-2007	1	1

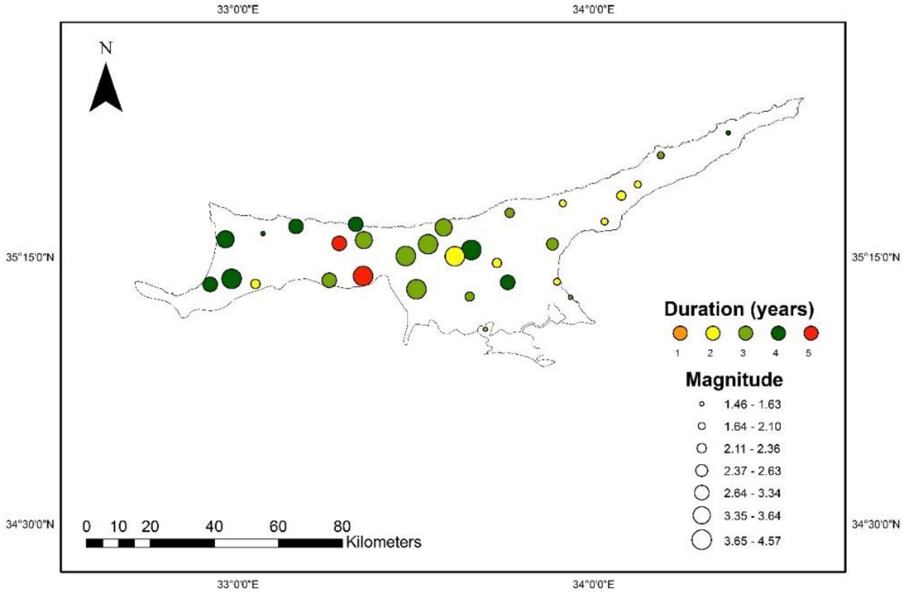


Figure 5.21 Map showing magnitude and duration of 2007-2008 drought in different stations

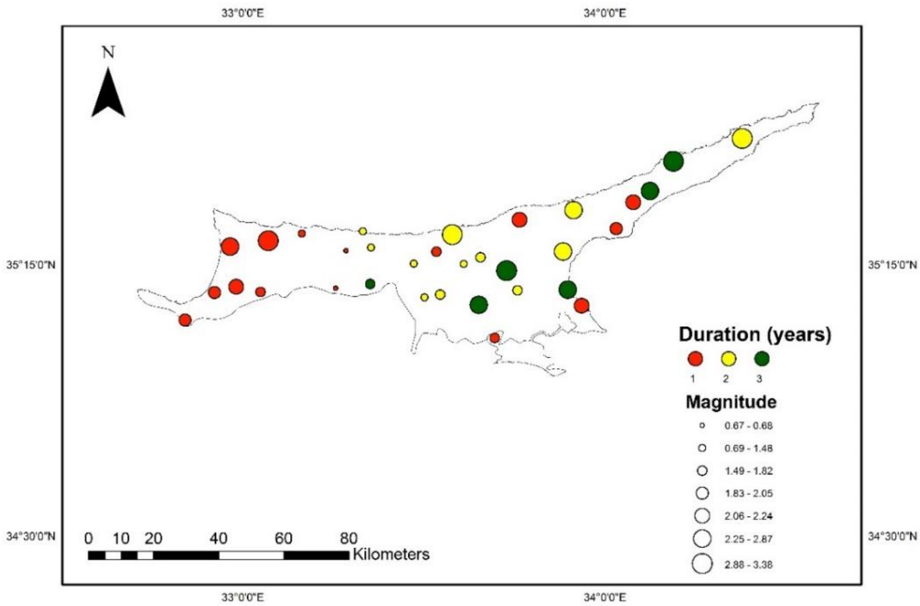


Figure 5.22 Map showing magnitude and duration of 2013-2014 drought in different stations

5.3.2 Drought Parameter: Frequency

The frequency of drought occurrence is defined as the return period of successive month's cumulative negative SPI value. For quantitative analysis of frequency of drought events, its characteristics such as severity (and intensity) and duration are used. The mathematical distribution for estimation of drought events is based on EV1 distribution since it is the commonly used distribution for extreme events in literature. The Chi Square goodness of fit test also supported this where EV1 gave the most reasonable approximation of drought severity values. This is further supported by the Figure 5.23 shows visual representation of four distributions namely: Normal (N), Log-Normal (LN), Log- Pearson type III (LP3) and Gumbel (EV1) distributions. For every station, for 37 years of data, consecutive drought months are identified and the corresponding severities are summed up. For each of these cumulative severities (or magnitude), probability of occurrence and return period are calculated and then the statistical distribution is fitted to the data. This is shown in Table 5.11 for 2-month drought duration taking Zumrutkoy station as an example. The EV1 distribution is fitted to all the stations, the Figures 5.24 and 5.25 show plots for different durations and return periods (2, 5, 10, 20, 25, 50 and 100 years) at Alevkaya and Gonendere stations, respectively, by fitting EV1 distribution.

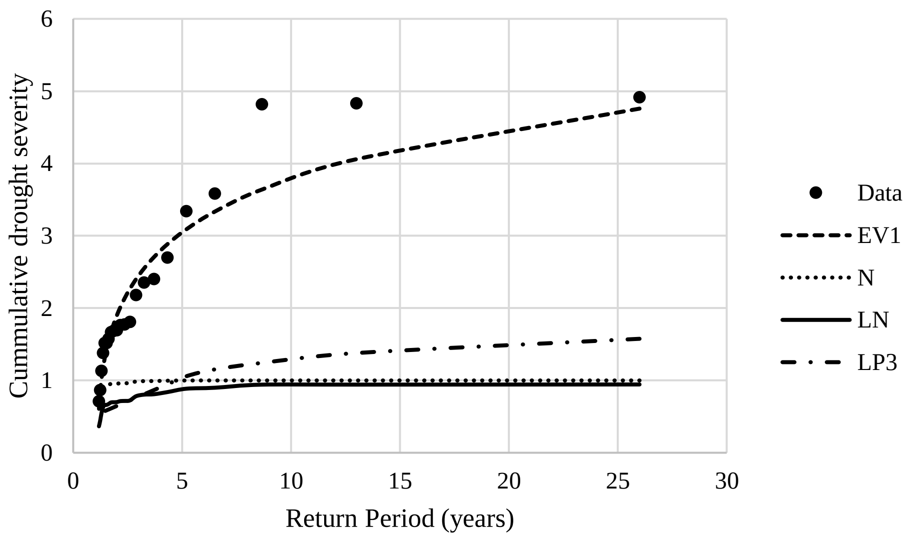


Figure 5.23 Comparison of theoetical fequency distributions

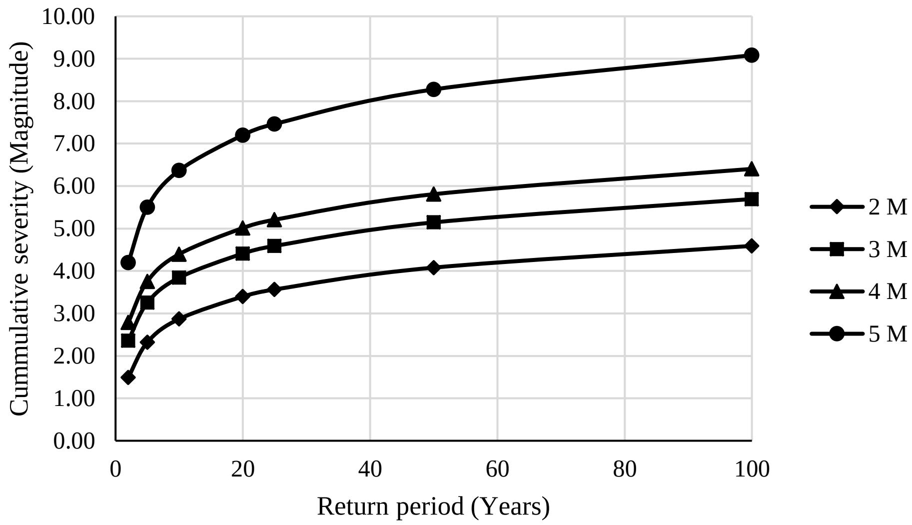


Figure 5.24 Gumbel plot for different durations in month (M) and corresponding return period in years at Alevkaya station

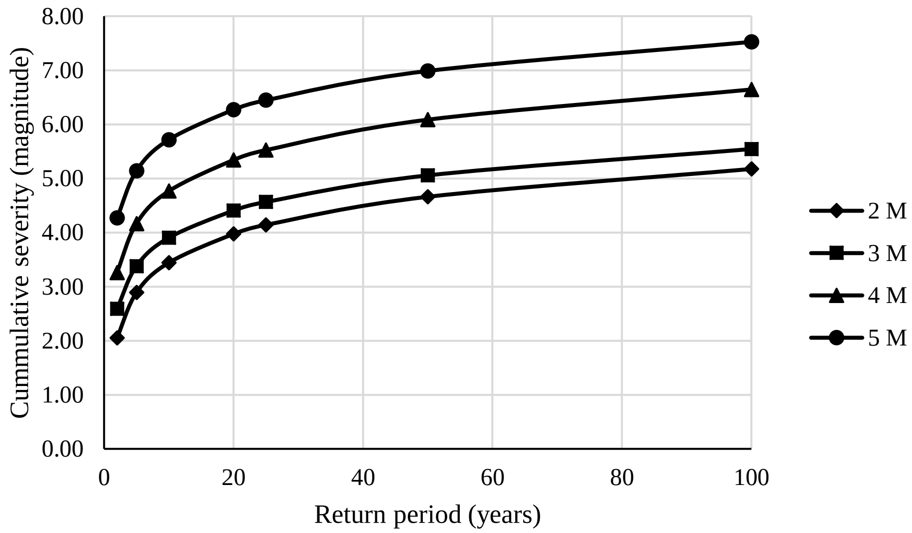


Figure 5.25 Gumbel plot for different durations in month (M) and corresponding return period in years at Gonendere station

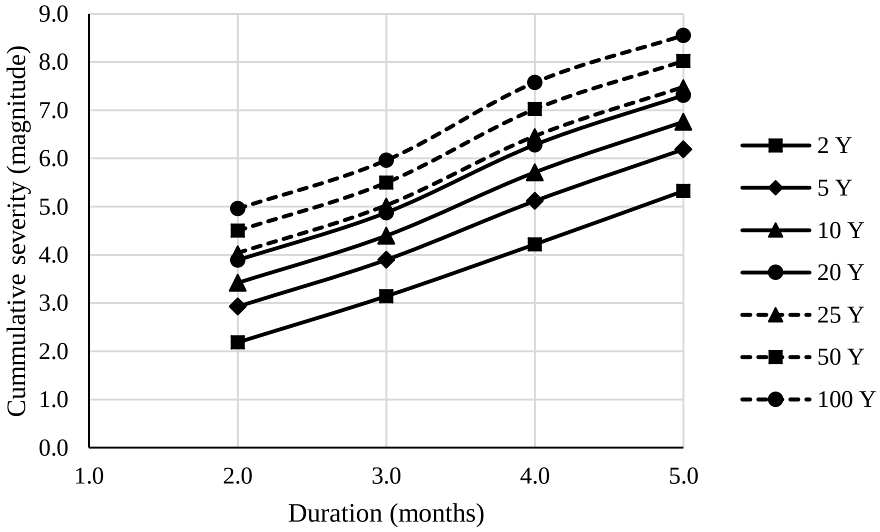
Table 5.11 Frequency table for 2-month drought duration at Zumrutkoy station

Rank	Magnitude	Exceedance probability	Return period (years)	EV1 (Gumbel)
1	3.08	0.03	35.00	3.26
2	2.98	0.06	17.50	2.84
3	2.63	0.09	11.67	2.60
4	2.57	0.11	8.75	2.42
5	2.48	0.14	7.00	2.28
6	2.40	0.17	5.83	2.16
7	2.10	0.20	5.00	2.06
8	2.05	0.23	4.38	1.97
9	2.00	0.26	3.89	1.90
10	1.96	0.29	3.50	1.82
11	1.91	0.31	3.18	1.76
12	1.81	0.34	2.92	1.69
13	1.75	0.37	2.69	1.63
14	1.72	0.40	2.50	1.58
15	1.69	0.43	2.33	1.52
16	1.57	0.46	2.19	1.47
17	1.43	0.49	2.06	1.42
18	1.38	0.51	1.94	1.38
19	1.37	0.54	1.84	1.33
20	1.37	0.57	1.75	1.28
21	1.33	0.60	1.67	1.24
22	1.26	0.63	1.59	1.19
23	1.21	0.66	1.52	1.15
24	1.12	0.69	1.46	1.10
25	1.10	0.71	1.40	1.05
26	0.95	0.74	1.35	1.01
27	0.89	0.77	1.30	0.96
28	0.78	0.80	1.25	0.91
29	0.76	0.83	1.21	0.85
30	0.70	0.86	1.17	0.80
31	0.48	0.89	1.13	0.73
32	0.36	0.91	1.09	0.66
33	0.32	0.94	1.06	0.57
34	0.27	0.97	1.03	0.44
		0.50	2.00	1.40
		0.20	5.00	2.06
	$\bar{x}$ = 1.52	0.10	10.00	2.50
	σ = 0.75	0.05	20.00	2.92
	u = 0.56	0.04	25.00	3.06
	α = 1.19	0.02	50.00	3.47
		0.01	100.00	3.88

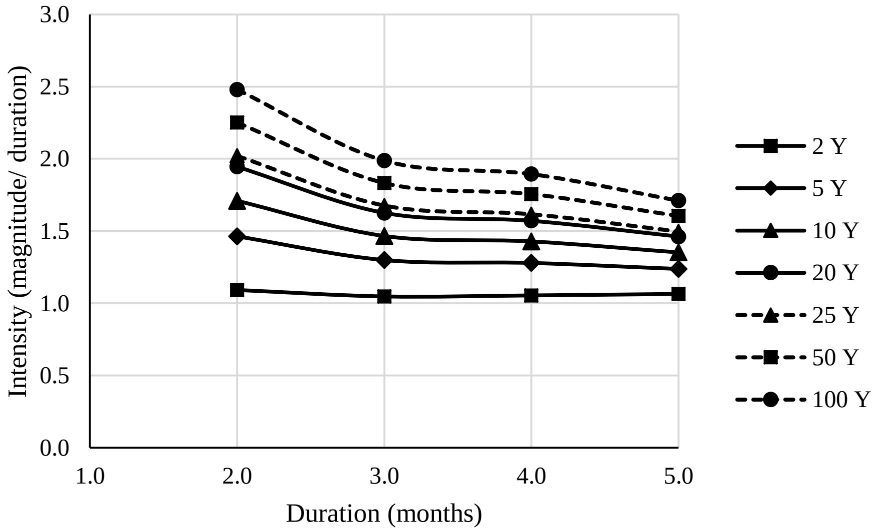
The organization of data shows that 2-month droughts are most common. The maximum number of 2-month drought events is shown by Gazimagusa, 56 in number and lowest number is 29 drought events by Akdeniz. In case of 3-month drought events, maximum number of events is shown by Gecitkale (27) and lowest number is shown by Zumrutkoy (13). The number of 4-month duration events ranged between 5 to 12, where total five events of consecutive 4-month duration drought are shown by Mehmetcik, Kantara, Zumrutkoy and Margo. The 12 events of 4-month duration are observed in Iskele. In case of 5-month drought event, some stations observed only one such event such as Bogaz, Ziyamet and Dipkarpaz, while maximum number of such events is seven which is observed in Degirmenlik. The 6-month drought event is not observed in some of the stations such as Mehmetcik and Kantara. Of the stations in which it is used for frequency analysis the data points are very few, not more than 3-4 data points as in case of Guzelyurt, Gaziveren, Girne, Esentepe, Salamis, Tatlisu, Akdeniz, Ercan, Serdarli, Degirmenlik, Alaykoy and Lefkosa. Remaining stations show single data point. Long duration events of 7-, 8-, 9- and 10-months are uncommon. Very few stations show these long duration droughts, which are singular events except for Akdeniz station that has two 7-month drought events. Other stations that show single 7-month droughts are Lapta, Girne, Bogaz, Esentepe, Salamis, Dipkarpaz, Tatlisu, Camlibel, Ercan, Serdarli, Degirmenlik, Alevkaya, Alaykoy, Lefkosa and Margo. The stations that show 8-months duration droughts include Dipkarpaz, Akdeniz, Ercan, Serdarli, Degirmenlik, Alevkaya and Lefkosa. The 9-month droughts are observed in Ercan, Serdarli, Degirmenlik and Lefkosa, while 10-month long drought is observed only in Lefkosa. The drought events with duration of 8-months and greater are only observed once in 37 years, and these longer durations are more common in central part of the country.

For illustrative purposes, severity-duration-frequency (SDF) curves and intensity- duration-frequency (IDF) curves are plotted for every station. In case of IDF curves, the magnitude of drought period are divided with the duration to get intensity of the event. The results showed that majority of the stations showed 2-, 3-, 4- and 5-month duration drought periods more frequently. The number of 6-months and higher drought events observed is small. It is observed in the SDF and IDF curves that the severity and intensity curves for these durations are converging at 6-months duration. Hence, the results for 6-months duration and higher have large amount of uncertainty and are neglected in SDF and IDF curves. The most reliable SDF and IDF curves are given by smaller durations such as 2-, 3- and 4-months, while 5-months also in case of some stations.

The SDF curves, that relate cumulative severities of drought period to its duration and frequency of occurrence, show a general increasing trend as we move up to the higher return period and move right to increasing durations. The higher return periods are on the top of the proceeding return period. The IDF curves are relating the intensity of the drought event to its duration and frequency of occurrence, these curves are opposite to SDF curves, where it can be seen intensity decreasing with duration, and higher return periods (periods of low frequency) have more intensity than more frequent events (e.g. Figure 5.26). However, this trend is not consistent in case of all the stations, where in some stations (*Lefke, Alaykoy, Gecitkale, Degirmenlik, Ercan, Gazimagusa, Tatlisu and Bogaz*) IDF are mere straight lines (e.g. Figure 5.27), in some stations (*Camlibel, Guzelyurt, Mehmetcik, Yenierenkoy, Iskele, Dortyol, Lefkosa, Alevkaya and Serdarli*) an increasing trend is seen at higher durations (e.g. Figure 5.28), and in some stations (*Akdeniz, Lapta and Kantara*) an irregular pattern is observed (e.g. Figure 5.29), this is mainly due to fewer data points as we move to higher durations.. It can be observed in these figures that SDF curves are following the similar increasing pattern. Hence, SDF curves are better representation of drought frequency than IDF curves.

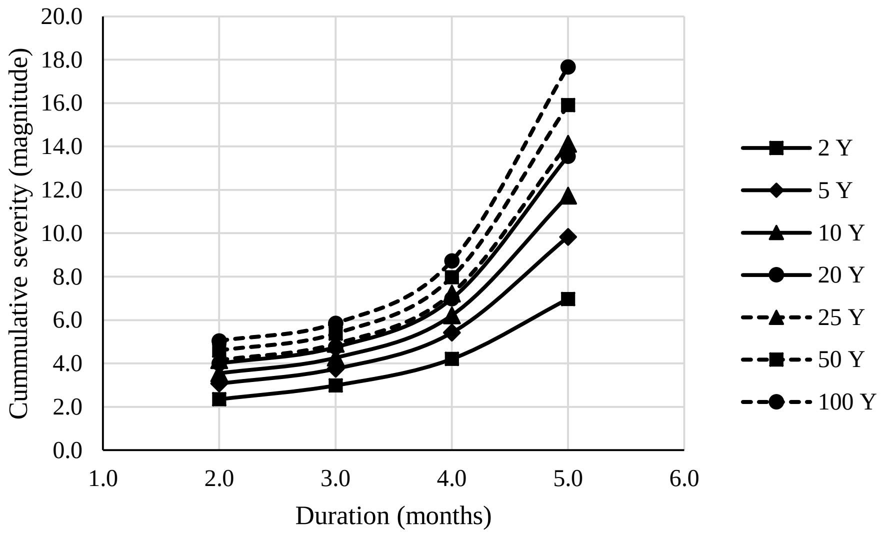


a)



b)

Figure 5.26 Frequency curves at Cayirova station for different return periods in years (Y) a) SDF curves b) IDF curves



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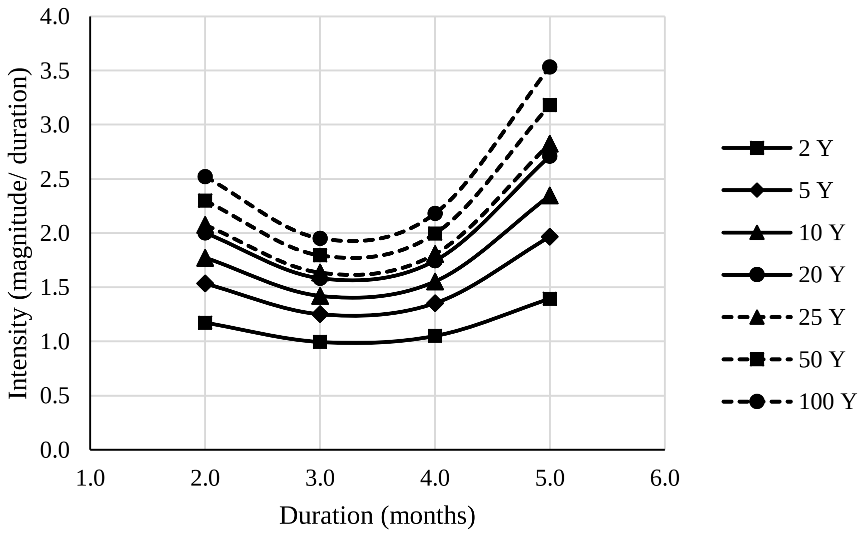
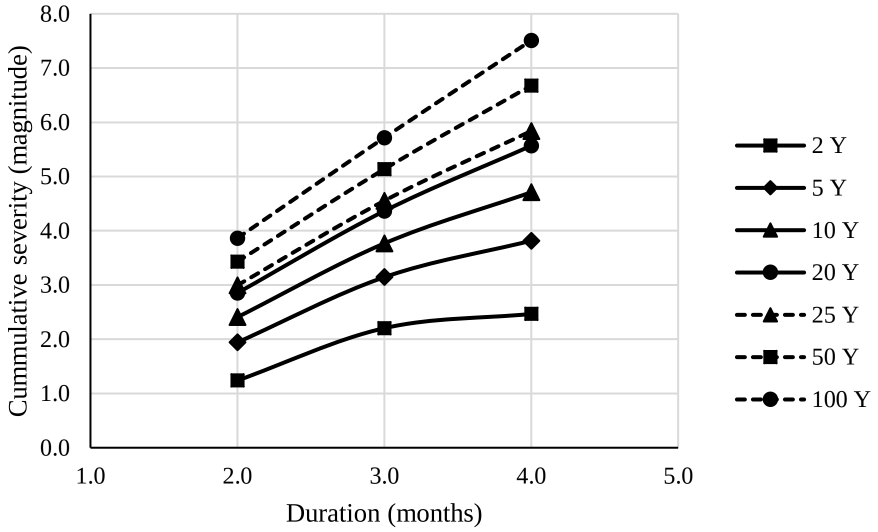
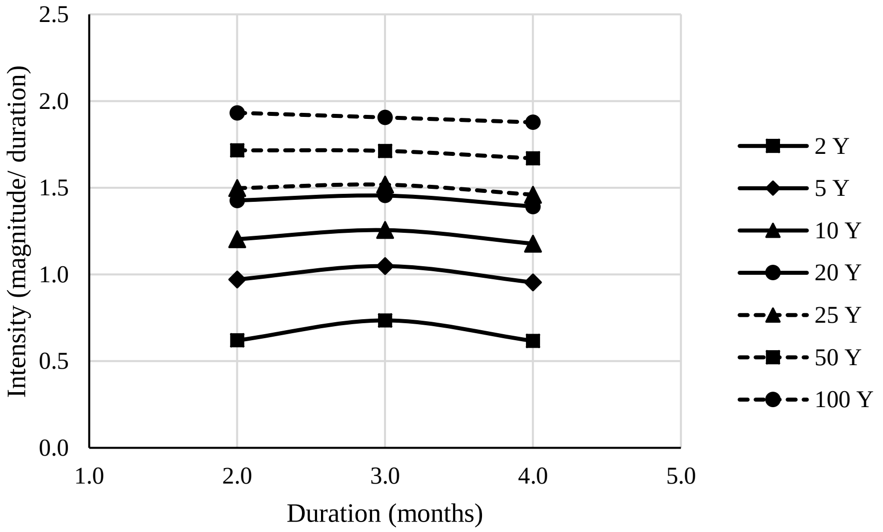


b)

Figure 5.27 Frequency curves at Mehmetcik station for different return periods in years (Y) a) SDF curves b) IDF curves

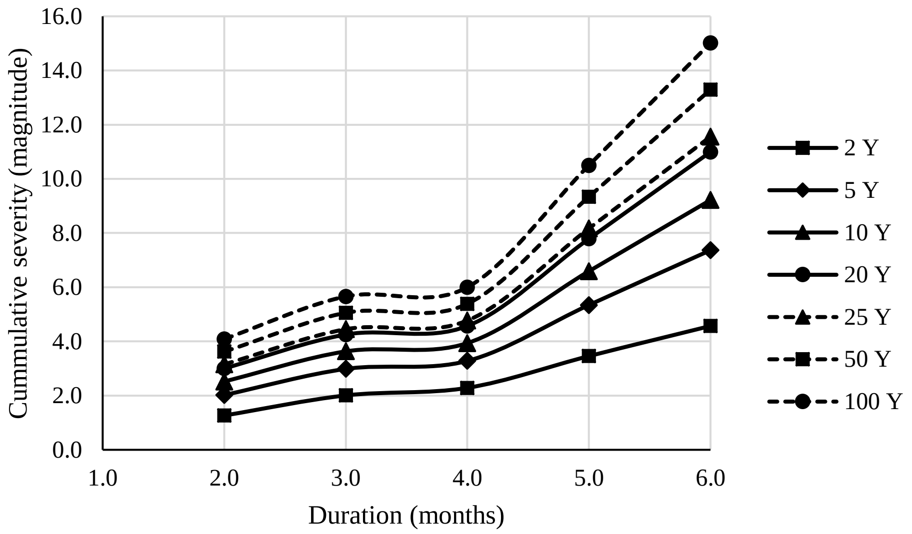


a)

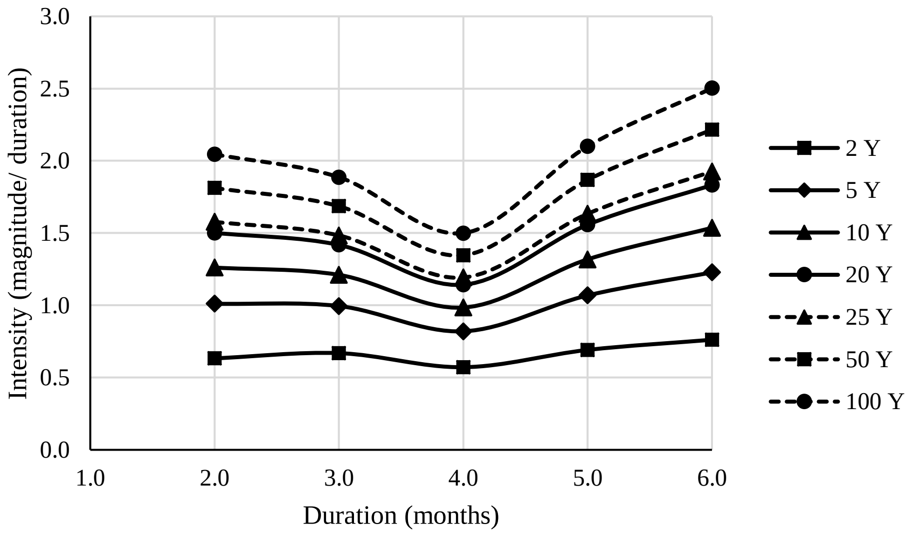


b)

Figure 5.28 Frequency curves at Bogaz station for different return periods in years (Y) a) SDF curves b) IDF curves



a)



b)

Figure 5.29 Frequency curves at Akdeniz station for different return periods in years (Y) a) SDF curves b) IDF curves

In addition, isoseverity maps are also produced for 2-months and 3-months durations for each return period of 5 and 10 years. The reason for choosing these durations is because of more data points in these series, hence, these durations can give better picture of drought durations in North Cyprus. Inverse Weighted Distance (IDW) method is used for interpolation for creating these isoseverity maps for North Cyprus. This deterministic method gives values to unknown regions based on weighted average of known values at known points. They can be seen in the Figures 5.30-5.33. The isoseverity map for 2-month duration and 5 year return period shows that northern coast and north western peninsula part of the country are facing more severe droughts. In case of higher return period, it is observed that the severity values are higher than the lower return period, although the pattern is similar with increasing pattern towards north and north eastern part of the region. In case of 3-month duration droughts, isoseverity maps show increase in severity towards northern coast, north western peninsula, central Mesaoria plain, and eastern part of the country. Again severities are higher in 10 year return period as compared to 5 year return period.

Figure 5.30 Isoseverity map of North Cyprus for 2-months drought duration and 5 year return period using SPI

Figure 5.31 Isoseverity map of North Cyprus for 2-months drought duration and 10 year return period using SPI

Figure 5.32 Isoseverity map of North Cyprus for 3-months drought duration and 5 year return period using SPI

Figure 5.33 Isoseverity map of North Cyprus for 3-months drought duration and 10 year return period using SPI

5.4. Teleconnections with Ocean Atmosphere Circulations

The correlations are performed between drought indices and Ocean Atmosphere indices (ENSO, NAO, WeMO, AO and NCP) using Pearson correlation coefficient and lag times (up to four years). Overall, the strong correlations greater than 0.50 are less common, therefore, any correlation equal to and/or greater than 0.40 are considered noticeable so that any spatial patterns are not missed out.

5.4.1 Teleconnections on Monthly Basis

At monthly time step, the correlations are very weak with all the climate indices at all time lags. However, they are slightly better in case of NCP at zero lag, but they are not strong since the correlations greater than 0.5 are considered to be strong. The stations that show significant correlations greater than 0.22 with NCP at zero lag include Dipkarpaz (0.24), Kantara (0.25), Cayirova (0.24), Dortyol (0.23), Beyarmudu (0.23), Gazimagusa (0.24), Ziyamet (0.24), and Salamis (0.23). These stations are situated in the eastern part of the country which hints that NCP has impact on these stations. The averaged value of stations also highlight that the stations on eastern part, especially the peninsula region, have greater impact of NCP. Since, for a semi-arid country like North Cyprus where precipitation is concentrated in winter months, the monthly drought indices will not be able to show strong correlations with these large scale climate variabilities.

5.4.2 Teleconnections on Annual Basis

In *Lapta*, at 3-month time step, WeMO has correlation > -0.40 with all indices, however, it is significant only for RDDI. Time step 6- gave better correlations at lag-3, correlations greater than > 0.40 are found with ENSO, however, insignificant. All oscillation indices gave better results in this time lag. ENSO again at higher time steps, 9-, 12-, -Wm, and -Rm, gave coefficient > 0.40. Results are significant mostly with RDDI, however at 12- time step, correlations of 0.46 is found to be significant with RD. In *Girne* station, positive correlation of greater than > 0.40 is observed for 9-, 12-, and -Wm time steps, again it is found with ENSO at lag-3, the results are only significant in case of RDDI. *Beylerbeyi* station, also at lag-3 gave > 0.40 correlation with ENSO at 6-, 9-, 12-, -Wm and -Rm, but this time good correlations between 0.50-0.51 are observed at -Wm with CZI, SPI and RDDI. In this station, also, results are only significant with RDDI. The *Bogaz* station as compared to the previous stations gave very good correlations greater than > 0.50 with ENSO at lag-3 at all the time steps except 3-month time step. The maximum correlation is 0.62 in -Wm. The results are significant with RD-12 (r = 0.53) and CZI-12 (r = 0.61), and with RDDI at all time steps. This station even has > 0.40 correlation with NAO at lag-1 in -Wm and -Rm. These correlations are only with RD, ZSI, CZI and SPI, but all are insignificant. In -Wm, NCP has 0.44 correlation with RD and ZSI, 0.43 with CZI, and 0.41 with SPI which is significant. While NCP in lag-2 for 3-month has negative correlation of 0.40 with RD and ZSI which are not significant. The *Esentepe* station did not show any good correlation greater than and equal to 0.40.

For *Gecitkale* station, ENSO gave negative correlation with RD-3 (-0.40), ZSI-3 (-0.40), CZI-3 (-0.40) and SPI-3 (-0.49) at lag-2. At lag-4 NAO gave negative correlations with all indices, good ones are -0.42 with RD-9, ZSI-9, CZI-9 and SPI-9, -0.41 with RD-12, and significant -0.44 correlation with RDDI-9. NCP at lag-1 gave

0.42 correlation with RD-3 and ZSI-3, and 0.40 with CZI-3. All are insignificant. At lag-2 it gave -0.44 correlation with all indices at -Wm, significant only with RDDI. For *Vadili* station, correlation greater than 0.40 is observed only with NCP with RDDI at lag-1, which is also significant, correlation with CZI-3 is observed as 0.40. In *Beyarmudu* station, ENSO at lag-3 gave correlation of 0.40 with RD-6, ZSI-6 and RDDI-6 (significant). At higher time steps, 9-, 12-, -Wm, -Rm, it gave correlation coefficient in the range 0.40-0.48 with all indices expect SPI-Rm for which it is 0.39. The result with RD-12 and RDDI is significant. In *Gazimagusa* station, at lag-3 ENSO at 6-month step has correlations in the range 0.43-0.48 with all indices, significant with RDDI. A very good correlation of 0.51 is found with RD-9 and ZSI-9. It has 0.47 correlation with SPI-9 and CZI-9, 0.48 with RDDI-9, RD-12, ZSI-12 and RDDI-Wm, 0.45 with SPI-12, 0.44 with CZI-12, 0.43 with RDDI-12, 0.46 with RDDI-Rm, and 0.42 with RD, ZSI, CZI, SPI in -Wm, and with RD and ZSI in -Rm. The result is significant with RD-12 and RDDI in all steps. In *Salamis*, no correlation coefficient greater than 0.40 is found with any oscillation. In *Dortyol* station, ENSO at lag-2 of 3-month time step has negative, nonsignificant correlation with RD, ZSI, CZI and SPI in range 0.40-0.44. In *Gonendere* station, at 3-month step, ENSO at lag-2 gave a very good correlation of -0.50 with RD and ZSI and -0.54 with CZI and SPI. At 9-month step, ENSO at lag-3 gave 0.41 correlation with RD, ZSI, CZI and RDDI (significant). At 12-month step, it has 0.40 correlation with RD, ZSI, and CZI. In -Wm correlations are between 0.42-0.44 with all indices. In -Rm, correlation with RD and ZSI is 0.41, while with CZI it is 0.40. In case of *Iskele* station, ENSO at lag-3 show correlation greater than 0.40 with all indices at 9- and 12- time step. In -Wm, 0.40 correlation is found with SPI and RD. In -Rm, correlation coefficient of 0.40 with RD and ZSI, and 0.41 with RDDI. All results with RDDI are significant. In this station, NCP at lag-1 of 3-month gave correlation -0.42 with RD and ZSI, -0.41 with CZI and significant -0.40 and -0.45 with SPI and RDDI respectively.

The *Cayirova* station, at lag-3 gave only noticeable correlation of 0.40 of ENSO with RD and ZSI at -Rm, and also at lag-1 of NCP with RDDI-Wm which is significant. In *Mehmetcik* station, ENSO at lag-3 shows 0.44 correlation coefficient with RD, ZSI and RDDI (significant). In 9-, 12-, -Wm and -Rm, it shows correlation with all indices in the range of 0.40-0.47. *Ziyamet* is another station that did not show any noticeable teleconnections. The *Dipkarpaz* station gave a different result, in which correlation of 0.40-0.41 is found with NAO at lag-3 in -Wm rather than with ENSO which shows weaker correlations in this station. At lag-1, it gave significant 0.43 correlation between NCP and RDDI-Wm. The correlations are insignificant with CZI, SPI and significant with RDDI. In case of *Yenierenkoy* station, correlation coefficient of -0.40 is observed with WeMO at zero lag of 3-month step. Three indices gave this correlation, RD, ZSI and CZI. At zero lag, ENSO gave same correlation with same indices at 12-month time step. At lag-3 of -Wm, NAO gave 0.44 and 0.41 correlation with CZI and SPI respectively, and ENSO gave significant 0.40 correlation with RDDI. In *Tatlisu* station, a noticeable significant correlation (0.40) is observed at lag-3 for ENSO with RDDI in -Wm. NCP in lag-2 showed negative correlations at -Wm and -Rm. The correlation coefficient ranged 0.40-0.44 in -Wm and in -Rm it is -0.41 and it is not observed for RDDI. The result is significant with RDDI-Wm and SPI-Rm. At *Kantara* station, ENSO at lag-3 gave correlations with RD-6 (0.41), ZSI-6 (0.41), RDDI-6 (0.46), RDDI-9 (0.44) and RDDI-12 (0.46), results are significant with RDDI. At zero lag, NCP at 9-month time step gave correlations in the range 0.46-0.48, which are significant in the case of SPI and RDDI. In 12- step correlations in the range of 0.42-0.47 with RD, ZSI, CZI and SPI (significant) are observed. NCP also has correlations in -Rm with all indices in range 0.42-0.43 and it is significant in case of SPI and RDDI.

The *Akdeniz* station, at 3-month WeMO gave -0.41 correlation with CZI and SPI, and -0.43 with RDDI which is significant. In -Wm, it has correlations of 0.41, 0.41, 0.40 and 0.45 (significant) with RD, ZSI, CZI and RDDI respectively. NCP at lag-4 has correlation of -0.41 with four indices except with RDDI, the correlation with SPI is significant at -Wm. The *Camlibel* station, has high correlations with WeMO at 3-month step, -0.52 with RD, -0.52 with ZSI, -0.55 with CZI, -0.53 with SPI and -0.64 (significant) with RDDI. In this station, at lag-1 for 6-, 9- and 12- time step, ENSO shows good correlation of 0.50 with RD-6 and ZSI-6, while with other indices in other time steps it ranged between 0.40-0.46, but RDDI-6, RDDI-9 and SPI-12 have lower correlations. At lag-3, ENSO gave 0.42 and 0.41 with RDDI-6 and 9-, both of which are significant, and coefficient value between 0.45-0.52 with indices at -Wm. The 0.52 correlation with RDDI is significant. At lag-4 WeMO gave -0.40 correlation with

RD-9 which is significant and -0.40 with ZSI which is insignificant. Also NCP at lag-4 has correlation of -0.41 with CZI and SPI, and -0.40 with RDDI at -Wm, it is significant with SPI and RDDI. No good teleconnection is observed in *Guzelyurt* with any oscillation. In case of *Gaziveren* station, 0.42 correlation is found between RD-3 (significant) and ZSI-3 with WeMO and 0.40 with SPI-3 at lag-2. In -Wm, ENSO at lag-3 gave correlation coefficient in the range of 0.42-0.45, only significant result with RDDI. NCP at 3-month step gave high negative correlation in the range of 0.44-0.57 in lag-1 and positive correlation of 0.49-0.53 in lag-2, the correlations are significant with SPI and RDDI in both lags. For *Lefke* station, AO gave correlation coefficient in the range 0.41-0.45 with all indices, significant only with RDDI, at lag-1 of 3-month time step. At lag-3 ENSO with all indices have correlation coefficient in the range of 0.51-0.53 at 6- step, 0.42-0.43 at 9- step, 0.42-0.46 at -Wm, and 0.45-0.48 with -Rm, significant only with RDDI at all time steps. At zero lag, NCP has 0.40 correlation with RD-9, ZSI-9 and SPI-12 (significant), 0.45 with RD-12, ZSI-12, 0.49 with RD-Wm and ZSI-Wm, 0.43 with CZI-Wm, and significant 0.42 correlation with SPI-Wm. At lag-1 of 3-month, NCP has coefficient in the range of 0.46-0.50, the 0.50 correlation with SPI and 0.49 with RDDI is significant. In lag-2, the correlations are negative in the range 0.43-0.46, the correlation with SPI (-0.44) and RDDI (-0.43) is significant. In *Zumrutkoy* station unlike Lefke station, AO at lag-2 of 3-month time step gave negative correlation coefficient in the range of 0.42-0.45 with all indices, significant only with RDDI. ENSO at lag-3 gave significant 0.41 correlation with RDDI-6, in range of 0.40-0.44 with indices at 9- step, same range correlations are also seen in 12-month step but observed only for CZI, SPI and RDDI, and for -Wm the range is 0.41-0.43. All results only significant with RDDI.

Ercan station at lag-1 gave significant 0.42 correlation between AO and RDDI-3. At lag-3, ENSO has 0.42 correlation with RDDI-6 and with all indices at 9- step. At 12- step it is 0.41 with RD, ZSI and CZI, 0.40 with SPI and 0.46 with RDDI. In -Wm step it is in range 0.48-0.49. The results are significant with RDDI. At lag-4, NAO gave negative correlation of -0.41 with RD-9, ZSI-9, CZI-9 and RD-12. At lag-1, NCP gave 0.42 correlation with RD-3 and ZSI-3, 0.47 with CZI and SPI and 0.48 with RDDI. Results are significant with SPI and RDDI. In *Serdarli* station, at lag-2 of 3-month time step, WeMO gave 0.40 correlation coefficient with SPI, ENSO gave

-0.44 with SPI, and AO gave -0.43 with CZI, -0.46 with SPI and -0.48 with RDDI (significant). At lag-3 ENSO gave 0.44 with RDDI-6, at step -Wm it gave correlation in range 0.47-0.48 with all indices, and in -Rm range is 0.42-0.43 and is not seen with SPI. Results are significant with RDDI only. At lag-4 it observed negative correlation of NAO with RD, ZSI, CZI and RDDI (significant) which ranged from 0.40-0.44. In *Degirmenlik* station, at lag-1 of 3-month step, AO gave correlations in range of 0.40 to 0.44 with all indices. At lag-4, negative correlations are observed for WeMO with RD-6 (-0.40), ZSI-6 (-0.40), and RDDI-6 (-0.41 significant). In *Alevkaya* station, at lag-3, ENSO gave noticeable correlations with all indices at 6-, 9- , 12-, -Wm and -Rm steps which ranged between 0.41-0.56. Good correlations are observed with RD-9 (0.51), ZSI-9 (0.51), CZI-9 (0.51), RDDI-9 (0.56), RDDI-12 (0.53) and RDDI-Wm (0.52), the results are significant with RDDI. For *Alaykoy* station, at 3-month time step, a significant correlation of 0.41 is observed between AO and RDDI at lag-1, and significant correlation of -0.40 is observed between ENSO and RDDI at lag-3. NCP at lag-1 of 3- time step has significant 0.40 and 0.45 correlations with SPI and RDDI, respectively. NCP at lag-2 has correlation of -0.42 with RD, ZSI and SPI at 3- step and -0.40 with RDDI. At 6- step -0.44 with RD, ZSI, CZI and SPI. At 9- step, -0.52 with RD and ZSI, -0.53 with CZI and SPI, -0.56 with RDDI. At 12- step, a correlation coefficient of -0.49 with RD and ZSI, -0.47 with CZI, -0.48 with SPI, and -0.53 with RDDI is observed. In -Rm, it is -0.43 with RD and ZSI, and -0.42 with CZI and SPI. Only the results with SPI and RDDI are significant. In the *Lefkosa* station, a significant 0.40 correlation is observed between AO and RDDI-3 at lag-1, and at lag-2, correlation coefficient in range -0.41 to -0.42 is observed with all indices, RDDI gave a significant result. At lag-3, ENSO gave correlation coefficient in range of 0.42-0.43 with RD, ZSI, CZI and SPI at 9- step, while in -Wm correlation is also observed with RDDI which is significant. At lag-4, NAO also gave correlations in range of -0.41 and -0.44 with all indices. At lag-1, NCP has correlations with all indices except SPI in 3-month step that ranged between 0.41-0.45, while at lag-2 the correlations ranged between -0.41 and -0.49. These correlations are significant with SPI and RDDI. The last station, *Margo***,** observed correlations of 0.41 to 0.42 between ENSO and drought indices at 9-time step at lag-3. Correlation coefficient of 0.40 observed with RD, ZSI and CZI at 12- step. And a correlation coefficient of 0.43

observed with RDDI (significant) and correlation coefficient of 0.44 with RD, ZSI, CZI and SPI at -Wm step. At lag-4, NAO gave coefficient of -0.42 with RDDI-9 (significant). NCP at lag-1 of 3- step gave correlation of 0.40 with RD, ZSI, CZI and RDDI (significant) and 0.43 with SPI (significant).

5.4.3 Summary

To get an overall picture of the impact of these oscillations, the rainfall stations are grouped together into five regions to check if correlations are greater on northern part, western part, middle part, eastern part or eastern peninsula. It is observed that WeMO at zero lag and 3-month time step has more correlations with stations on western part of the country (ranging between -0.34 to -0.38) and northern part (ranging between -0.34 to -0.38). This is followed by eastern peninsula stations. These oscillations are stronger on the western part of the country. The negative phase of WeMO can be linked to lower precipitation due to a central European anticyclone which brings drier conditions, a study by Milošević et al., (2016) found negative WeMO linked to low precipitation in Slovenia. However, further investigation is needed to prove the links.

Looking at the lagged impacts of the climate oscillations helps to monitor drought events for drought planning. Winter climate is very important for Mediterranean region as the rainfall is concentrated in this month, so changes or variability in rainfall has direct implications to experience drought conditions. So correlations at -Wm time step are of most importance for us.

At lag-3, ENSO has good correlations (Figure 5.34), especially at -Wm which is 0.46 with all indices except with CZI it has 0.45 and it is significant with RDDI. It is 0.41 with RD-6 and ZSI-6, and at 9- and 12-month step it is in range 0.41-0.43. It is followed by stations in western part with correlations in range 0.42-0.45 at -Wm and then by middle plain region showing correlations between 0.43-0.44 at -Wm. In eastern part it has 0.40 correlation only with RDDI-Wm and in the eastern peninsula region no correlation greater than 0.40 is observed. Hence, ENSO is affecting climate conditions more in northern and western part of the country and the positive correlation indicates that droughts are generally caused by El Nino year and this is in line with study by Ozger et al., (2009). At the same lag in winter months, it is observed that NAO is also showing some noticeable correlations but not as strong as ENSO. These value are significant for RD (0.32) and RDDI (0.28) in northern stations, as well as in eastern (for RD = 0.31, RDDI = 0.31) and eastern peninsula stations, (for RD = 0.31, RDDI = 0.31), they are less effective in eastern and middle plain regions. This shows that positive phase of NAO at a lag of three years can show drought conditions, this is in agreement with the study by Vicente-Serrano et al., (1970) which stated that NAO at positive phase can lead to drought conditions during winter time in southern Europe. The correlations with AO shows that it has more influence on the central and western stations like Ercan, Serdarli, Degirmenlik, Lefkosa, Lefke and Zumrutkoy. According to the literature, NCP at negative phase is linked to higher temperatures and higher rainfall in the southern parts of Turkey and Greece (Kutiel et al., 2002). Most of the stations that have shown good correlations with NCP are positive correlations, however, two stations showed significant negative correlations also indicating wet conditions. But the overall positive correlations are indicating NCP has contribution to droughts in this region. These correlation results do not prove any significant links between climatic oscillations and drought occurrence in North Cyprus. It is concluded that further study is needed to establish sound relationships between these two parameters, which will help to comprehend impacts of climate change on droughts in this region.

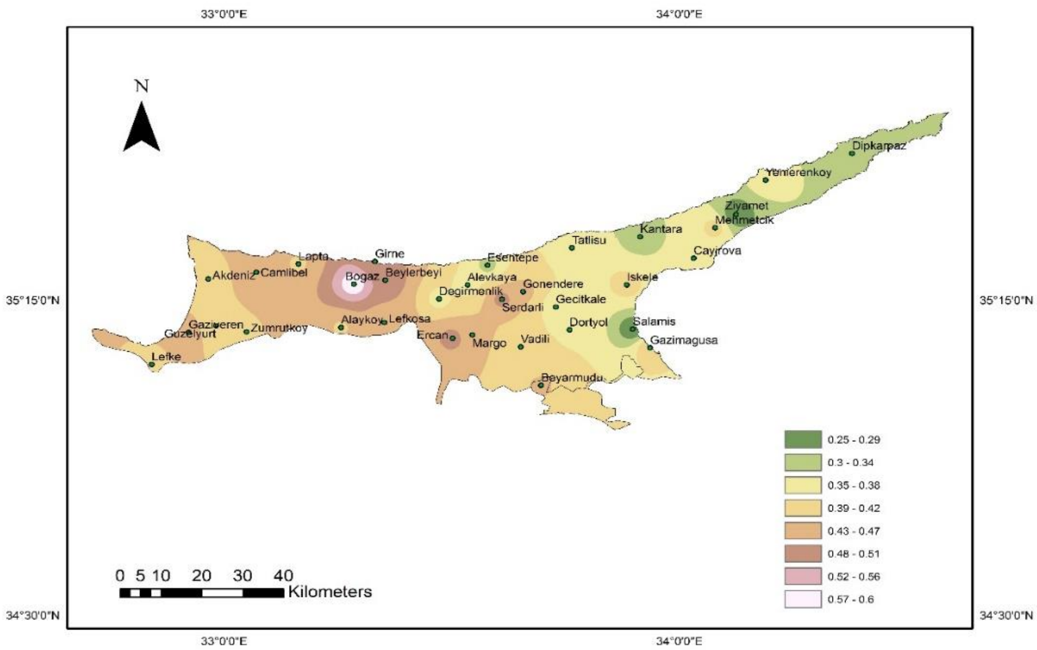


Figure 5.34 Correlations of SPI-Wm with ENSO at lag-3

CHAPTER 6
CONCLUSIONS

In this study, the comparison of drought indices (RD, ZSI, CZI, SPI, and RDDI) revealed that the number of drought years identified by RD are mostly higher in number, when compared with other indices at smaller time steps, 1-month and 3-months, as well as at -Wm. At higher time steps i.e. 9-, 12-, and -Rm, RD gives almost same number of drought years as ZSI, CZI and SPI but tends to exaggerate the severity at smaller time steps, this is in agreement with study by Jain et al., (2015). RDDI tends to show constant number of drought years at all time steps, which suggests that it can sometimes miss out a drought month/year, and/or classify a normal month/year as a drought period. This suggests that RD and RDDI are not suitable for a semi-arid region like North Cyprus in which rainfall is concentered mostly during winter season. ZSI gives fewer drought events at 1-month time step and tends to undermine the drought severity, but mostly in smaller time steps. Hence, ZSI is not suitable at smaller time steps, as it can mistake a very extreme event to a moderate event and therefore fail to detect a serious drought event.

Each of the index has its own calculation method, however, some of them show more similarities with each other. For instance, RD and ZSI behave very similarly which is depicted from the correlation results. Similarities are also observed between CZI and ZSI, and CZI and SPI. However, the index that showed the most similarities with most of the indices is CZI followed by SPI and ZSI. CZI showed slightly better correlation but it is negligible when compared to the other two indices. ZSI and CZI have comparatively easier calculations than SPI and they both also allow for missing data like SPI. Therefore it is concluded that ZSI, CZI and SPI indices are highly comparable and can be interchanged at higher time steps. So for North Cyprus, analysis of drought events can be brought about by any of the index (ZSI, CZI and SPI) depending on ease of calculation desired. Since, at high time steps, the indices behave similarly, this means the time steps of 9-month and 12-month can be used for drought analysis of the region. The similar result with -Rm suggests that the drought analysis of North Cyprus can be brought about by only considering the rain months i.e. November, December, January, February and March.

This study identified various drought years that North Cyprus has experienced during the period 1978-2015 using all indices. Multiple indices are used since each index has its own limitations, hence, the use of multiple indices helped us to derive the real drought months/ years that the country has experienced since 1978. The final drought years, identified based on criteria that at least three indices indicate a particular year as drought year, identified years 1990-1991, 1996-1997, 2007-2008 and 2013-2014 as commonly occurring drought years. The spatial distribution of the drought years also varied, for example, the 2007-2008 year drought is common mainly in the central part of country while 2013-2014 is more common in the western part and peninsula region of the country. Overall, extreme droughts are more common in the eastern part of the country. It is observed that the country experienced more drought in the second decade (1988-1989 to 1997-1998), while one extreme drought year is experienced once every decade (for period 1978-2015). Generally, the second decade experienced longer duration droughts while the last decade experienced more intense droughts. But overall, it is observed that the region mainly experiences droughts of mild nature and short durations. The frequency analysis using SDF and IDF curves indicated that drought frequency is better represented by SDF curves. The isoseverity maps for North Cyprus for duration of 2-month and 3-month with corresponding return periods of 5 and 10 years indicate that severities are increasing at higher recurrence interval, also the northern coast, north western peninsula region, eastern and central part of the country will face more severe droughts.

The teleconnections with Ocean Atmosphere indices did not reveal significant relations to drought occurrence, however, ENSO at lag three is found to have links to drought occurrence mainly in the winter season. However, further investigation is needed to study how these interactions occur. This can be further studied by using drought indices that take additional input parameters such as temperature, evapotranspiration, streamflow, available water content etc. into account, as they might be able to give more information on climate change impacts on drought occurrence. Some examples of the drought indices that can be applied include Keetch- Byram Drought Index (KBDI; Keetch & Byram, 1968) which uses precipitation and temperature as input; Palmer Drought Severity Index (PDSI; Palmer, 1965) which uses precipitation, temperature and available water content as input; Streamflow Drought Index (SDI; Nalbantis & Tsakiris, 2009) which uses streamflow as input parameter but has similar calculations to SPI.

Other future works include using Stochastic time-series model to generate long-term rainfall series to predict frequency of drought events, since the data points for longer duration droughts are fewer in number which makes the results to be less reliable. To get an overall picture of the climate extremes in North Cyprus, a study on wet periods in North Cyprus has to be evaluated.

This thesis will be very beneficial for future studies as it identifies historical drought events for North Cyprus using five indices. This in-depth study of historical droughts, together with their severity, magnitude, duration, intensity, and frequency will aid in the planning of any water related project of hydroclimatic and agroclimatic nature and to take immediate steps for sustainable water management in North Cyprus. The results of this study are also very important to mitigate the impacts of any drought event in future through development of water resource structures. The drought mitigation can be achieved at small scale through awareness in public regarding sustainable use of water. The water use in agriculture can be monitored and efficient planning can help to sustain water resources, since, agriculture is the main water use for North Cyprus.

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APPENDICES

Appendix A: Correlation matrix of all indices at Yenierenkoy station

	RD-1	RD-3	RD-6	RD-9	RD-12	RD-Wm	RD-Rm	ZSI-1	ZSI-3	ZSI-6	ZSI-9	ZSI-12	ZSI-Wm	ZSI-Rm	CZI-1	CZI-3	CZI-6	CZI-9	CZI-12	CZI-Wm	CZI-Rm	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-Wm	SPI-Rm	RDDI-1	RDDI-3	RDDI-6	RDDI-9	RDDI-12	RDDI-Wm	RDDI-Rm
RD-1	1.00	0.14	0.29	0.32	0.36	0.21	0.19	0.78	0.14	0.29	0.32	0.36	0.21	0.19	0.58	0.15	0.29	0.32	0.36	0.23	0.19	0.51	0.17	0.29	0.31	0.35	0.23	0.19	0.60	0.12	0.33	0.35	0.37	0.21	0.24
RD-3	0.14	1.00	0.33	0.34	0.31	-0.26	0.07	0.38	1.00	0.33	0.34	0.31	-0.26	0.07	0.41	0.99	0.35	0.33	0.32	-0.20	0.14	0.43	0.95	0.38	0.38	0.36	-0.22	0.14	0.18	0.96	0.40	0.38	0.35	-0.26	0.14
RD-6	0.29	0.33	1.00	0.97	0.96	0.83	0.92	0.58	0.33	1.00	0.97	0.96	0.83	0.92	0.58	0.33	1.00	0.97	0.96	0.83	0.92	0.59	0.36	0.98	0.95	0.95	0.83	0.92	0.36	0.32	0.96	0.93	0.93	0.75	0.87
RD-9	0.32	0.34	0.97	1.00	1.00	0.79	0.93	0.68	0.34	0.97	1.00	1.00	0.79	0.93	0.70	0.35	0.97	1.00	1.00	0.80	0.94	0.71	0.37	0.96	0.99	0.99	0.80	0.94	0.40	0.34	0.95	0.98	0.98	0.72	0.90
RD-12	0.36	0.31	0.96	1.00	1.00	0.80	0.93	0.72	0.31	0.96	1.00	1.00	0.80	0.93	0.72	0.33	0.97	1.00	1.00	0.81	0.93	0.73	0.36	0.96	0.98	0.99	0.81	0.93	0.43	0.31	0.95	0.98	0.98	0.73	0.90
RD-Wm	0.21	-0.26	0.83	0.79	0.80	1.00	0.90	0.37	-0.26	0.83	0.79	0.80	1.00	0.90	0.35	-0.24	0.81	0.79	0.80	0.97	0.86	0.36	-0.20	0.78	0.75	0.76	0.98	0.86	0.26	-0.24	0.75	0.73	0.74	0.92	0.81
RD-Rm	0.19	0.07	0.92	0.93	0.93	0.90	1.00	0.48	0.07	0.92	0.93	0.93	0.90	1.00	0.48	0.09	0.91	0.93	0.93	0.88	0.98	0.50	0.13	0.89	0.90	0.90	0.89	0.98	0.24	0.08	0.88	0.89	0.89	0.82	0.94
ZSI-1	0.78	0.38	0.58	0.68	0.72	0.37	0.48	1.00	0.38	0.58	0.68	0.72	0.37	0.48	0.93	0.39	0.60	0.68	0.72	0.42	0.51	0.89	0.41	0.61	0.69	0.73	0.41	0.51	0.67	0.36	0.63	0.72	0.74	0.36	0.53
ZSI-3	0.14	1.00	0.33	0.34	0.31	-0.26	0.07	0.38	1.00	0.33	0.34	0.31	-0.26	0.07	0.41	0.99	0.35	0.33	0.32	-0.20	0.14	0.43	0.95	0.38	0.38	0.36	-0.22	0.14	0.18	0.96	0.40	0.38	0.35	-0.26	0.14
ZSI-6	0.29	0.33	1.00	0.97	0.96	0.83	0.92	0.58	0.33	1.00	0.97	0.96	0.83	0.92	0.58	0.33	1.00	0.97	0.96	0.83	0.92	0.59	0.36	0.98	0.95	0.95	0.83	0.92	0.36	0.32	0.96	0.93	0.93	0.75	0.87
ZSI-9	0.32	0.34	0.97	1.00	1.00	0.79	0.93	0.68	0.34	0.97	1.00	1.00	0.79	0.93	0.70	0.35	0.97	1.00	1.00	0.80	0.94	0.71	0.37	0.96	0.99	0.99	0.80	0.94	0.40	0.34	0.95	0.98	0.98	0.72	0.90
ZSI-12	0.36	0.31	0.96	1.00	1.00	0.80	0.93	0.72	0.31	0.96	1.00	1.00	0.80	0.93	0.72	0.33	0.97	1.00	1.00	0.81	0.93	0.73	0.36	0.96	0.98	0.99	0.81	0.93	0.43	0.31	0.95	0.98	0.98	0.73	0.90
ZSI-Wm	0.21	-0.26	0.83	0.79	0.80	1.00	0.90	0.37	-0.26	0.83	0.79	0.80	1.00	0.90	0.35	-0.24	0.81	0.79	0.80	0.97	0.86	0.36	-0.20	0.78	0.75	0.76	0.98	0.86	0.26	-0.24	0.75	0.73	0.74	0.92	0.81
ZSI-Rm	0.19	0.07	0.92	0.93	0.93	0.90	1.00	0.48	0.07	0.92	0.93	0.93	0.90	1.00	0.48	0.09	0.91	0.93	0.93	0.88	0.98	0.50	0.13	0.89	0.90	0.90	0.89	0.98	0.24	0.08	0.88	0.89	0.89	0.82	0.94
CZI-1	0.58	0.41	0.58	0.70	0.72	0.35	0.48	0.93	0.41	0.58	0.70	0.72	0.35	0.48	1.00	0.44	0.61	0.70	0.73	0.45	0.54	0.98	0.49	0.65	0.73	0.76	0.42	0.54	0.67	0.44	0.63	0.72	0.74	0.42	0.54
CZI-3	0.15	0.99	0.33	0.35	0.33	-0.24	0.09	0.39	0.99	0.33	0.35	0.33	-0.24	0.09	0.44	1.00	0.36	0.35	0.33	-0.18	0.16	0.46	0.98	0.40	0.40	0.38	-0.20	0.16	0.20	0.99	0.40	0.38	0.36	-0.23	0.16
CZI-6	0.29	0.35	1.00	0.97	0.97	0.81	0.91	0.60	0.35	1.00	0.97	0.97	0.81	0.91	0.61	0.36	1.00	0.97	0.97	0.83	0.92	0.63	0.39	0.99	0.96	0.96	0.83	0.92	0.37	0.35	0.97	0.94	0.93	0.75	0.87
CZI-9	0.32	0.33	0.97	1.00	1.00	0.79	0.93	0.68	0.33	0.97	1.00	1.00	0.79	0.93	0.70	0.35	0.97	1.00	1.00	0.80	0.94	0.71	0.37	0.96	0.99	0.99	0.80	0.94	0.40	0.34	0.95	0.98	0.98	0.72	0.90
CZI-12	0.36	0.32	0.96	1.00	1.00	0.80	0.93	0.72	0.32	0.96	1.00	1.00	0.80	0.93	0.73	0.33	0.97	1.00	1.00	0.81	0.93	0.73	0.36	0.96	0.99	0.99	0.81	0.93	0.43	0.32	0.95	0.98	0.98	0.73	0.90
CZI-Wm	0.23	-0.20	0.83	0.80	0.81	0.97	0.88	0.42	-0.20	0.83	0.80	0.81	0.97	0.88	0.45	-0.18	0.83	0.80	0.81	1.00	0.88	0.46	-0.11	0.82	0.79	0.80	1.00	0.88	0.31	-0.18	0.77	0.73	0.75	0.96	0.82
CZI-Rm	0.19	0.14	0.92	0.94	0.93	0.86	0.98	0.51	0.14	0.92	0.94	0.93	0.86	0.98	0.54	0.16	0.92	0.94	0.93	0.88	1.00	0.58	0.21	0.92	0.93	0.93	0.88	1.00	0.27	0.15	0.88	0.89	0.89	0.82	0.95

Appendix A: Continued

	RD-1	RD-3	RD-6	RD-9	RD-12	RD-Wm	RD-Rm	ZSI-1	ZSI-3	ZSI-6	ZSI-9	ZSI-12	ZSI-Wm	ZSI-Rm	CZI-1	CZI-3	CZI-6	CZI-9	CZI-12	CZI-Wm	CZI-Rm	SPI-1	SPI-3	SPI-6	SPI-9	SPI-12	SPI-Wm	SPI-Rm	RDDI-1	RDDI-3	RDDI-6	RDDI-9	RDDI-12	RDDI-Wm	RDDI-Rm
SPI-1	0.51	0.43	0.59	0.71	0.73	0.36	0.50	0.89	0.43	0.59	0.71	0.73	0.36	0.50	0.98	0.46	0.63	0.71	0.73	0.46	0.58	1.00	0.50	0.67	0.75	0.77	0.43	0.57	0.63	0.45	0.65	0.73	0.75	0.44	0.57
SPI-3	0.17	0.95	0.36	0.37	0.36	-0.20	0.13	0.41	0.95	0.36	0.37	0.36	-0.20	0.13	0.49	0.98	0.39	0.37	0.36	-0.11	0.21	0.50	1.00	0.44	0.43	0.42	-0.14	0.21	0.20	0.98	0.41	0.39	0.37	-0.17	0.18
SPI-6	0.29	0.38	0.98	0.96	0.96	0.78	0.89	0.61	0.38	0.98	0.96	0.96	0.78	0.89	0.65	0.40	0.99	0.96	0.96	0.82	0.92	0.67	0.44	1.00	0.97	0.97	0.81	0.92	0.38	0.38	0.95	0.92	0.92	0.74	0.86
SPI-9	0.31	0.38	0.95	0.99	0.98	0.75	0.90	0.69	0.38	0.95	0.99	0.98	0.75	0.90	0.73	0.40	0.96	0.99	0.99	0.79	0.93	0.75	0.43	0.97	1.00	1.00	0.78	0.93	0.42	0.38	0.93	0.96	0.96	0.70	0.88
SPI-12	0.35	0.36	0.95	0.99	0.99	0.76	0.90	0.73	0.36	0.95	0.99	0.99	0.76	0.90	0.76	0.38	0.96	0.99	0.99	0.80	0.93	0.77	0.42	0.97	1.00	1.00	0.79	0.93	0.44	0.36	0.93	0.96	0.96	0.71	0.88
SPI-Wm	0.23	-0.22	0.83	0.80	0.81	0.98	0.89	0.41	-0.22	0.83	0.80	0.81	0.98	0.89	0.42	-0.20	0.83	0.80	0.81	1.00	0.88	0.43	-0.14	0.81	0.78	0.79	1.00	0.88	0.30	-0.21	0.77	0.74	0.75	0.96	0.82
SPI-Rm	0.19	0.14	0.92	0.94	0.93	0.86	0.98	0.51	0.14	0.92	0.94	0.93	0.86	0.98	0.54	0.16	0.92	0.94	0.93	0.88	1.00	0.57	0.21	0.92	0.93	0.93	0.88	1.00	0.27	0.15	0.88	0.89	0.89	0.82	0.95
RDDI-1	0.60	0.18	0.36	0.40	0.43	0.26	0.24	0.67	0.18	0.36	0.40	0.43	0.26	0.24	0.67	0.20	0.37	0.40	0.43	0.31	0.27	0.63	0.20	0.38	0.42	0.44	0.30	0.27	1.00	0.17	0.38	0.42	0.45	0.32	0.29
RDDI-3	0.12	0.96	0.32	0.34	0.31	-0.24	0.08	0.36	0.96	0.32	0.34	0.31	-0.24	0.08	0.44	0.99	0.35	0.34	0.32	-0.18	0.15	0.45	0.98	0.38	0.38	0.36	-0.21	0.15	0.17	1.00	0.38	0.37	0.34	-0.24	0.13
RDDI-6	0.33	0.40	0.96	0.95	0.95	0.75	0.88	0.63	0.40	0.96	0.95	0.95	0.75	0.88	0.63	0.40	0.97	0.95	0.95	0.77	0.88	0.65	0.41	0.95	0.93	0.93	0.77	0.88	0.38	0.38	1.00	0.96	0.95	0.72	0.89
RDDI-9	0.35	0.38	0.93	0.98	0.98	0.73	0.89	0.72	0.38	0.93	0.98	0.98	0.73	0.89	0.72	0.38	0.94	0.98	0.98	0.73	0.89	0.73	0.39	0.92	0.96	0.96	0.74	0.89	0.42	0.37	0.96	1.00	1.00	0.67	0.90
RDDI-12	0.37	0.35	0.93	0.98	0.98	0.74	0.89	0.74	0.35	0.93	0.98	0.98	0.74	0.89	0.74	0.36	0.93	0.98	0.98	0.75	0.89	0.75	0.37	0.92	0.96	0.96	0.75	0.89	0.45	0.34	0.95	1.00	1.00	0.69	0.90
RDDI-Wm	0.21	-0.26	0.75	0.72	0.73	0.92	0.82	0.36	-0.26	0.75	0.72	0.73	0.92	0.82	0.42	-0.23	0.75	0.72	0.73	0.96	0.82	0.44	-0.17	0.74	0.70	0.71	0.96	0.82	0.32	-0.24	0.72	0.67	0.69	1.00	0.82
RDDI-Rm	0.24	0.14	0.87	0.90	0.90	0.81	0.94	0.53	0.14	0.87	0.90	0.90	0.81	0.94	0.54	0.16	0.87	0.90	0.90	0.82	0.95	0.57	0.18	0.86	0.88	0.88	0.82	0.95	0.29	0.13	0.89	0.90	0.90	0.82	1.00
Average	0.32	0.31	0.78	0.79	0.80	0.61	0.72	0.59	0.31	0.78	0.79	0.80	0.61	0.72	0.61	0.33	0.78	0.79	0.80	0.63	0.74	0.61	0.35	0.78	0.79	0.80	0.63	0.74	0.38	0.32	0.77	0.78	0.78	0.58	0.72

Appendix B: Table for severity correlation results by drought indices at 33 stations at higher time steps

Stations	RD 3	ZSI 3	CZI 3	SPI 3	RDDI 3	RD 6	ZSI 6	CZI 6	SPI 6	RDDI 6
Lapta	0.86	0.84	0.91	0.89	0.87	0.96	0.94	0.96	0.95	0.93
Girne	0.90	0.92	0.94	0.88	0.93	0.96	0.94	0.96	0.96	0.91
Beylerbeyi	0.81	0.83	0.88	0.83	0.87	0.94	0.93	0.94	0.93	0.89
Bogaz	0.83	0.83	0.87	0.88	0.81	0.89	0.80	0.88	0.90	0.83
Esentepe	0.91	0.92	0.94	0.90	0.92	0.93	0.93	0.93	0.93	0.89
Gecitkale	0.85	0.90	0.91	0.81	0.90	0.95	0.94	0.94	0.93	0.89
Vadili	0.85	0.87	0.90	0.86	0.88	0.95	0.95	0.95	0.95	0.94
Beyarmudu	0.80	0.83	0.88	0.87	0.86	0.94	0.93	0.94	0.94	0.90
Gazimagusa	0.83	0.87	0.89	0.89	0.88	0.93	0.94	0.93	0.93	0.86
Salamis	0.88	0.91	0.93	0.90	0.92	0.95	0.94	0.94	0.93	0.88
Dortyol	0.86	0.89	0.90	0.87	0.90	0.96	0.96	0.96	0.96	0.93
Gonendere	0.78	0.80	0.85	0.81	0.79	0.95	0.95	0.95	0.94	0.92
Iskele	0.83	0.88	0.90	0.85	0.88	0.95	0.96	0.96	0.93	0.93
Cayirova	0.82	0.82	0.90	0.89	0.87	0.95	0.94	0.94	0.94	0.90
Mehmetcik	0.79	0.83	0.88	0.88	0.86	0.93	0.92	0.93	0.93	0.84
Ziyamet	0.87	0.91	0.92	0.91	0.91	0.94	0.95	0.95	0.95	0.90
Dipkarpaz	0.83	0.88	0.89	0.85	0.86	0.95	0.94	0.94	0.94	0.88
Yenierenkoy	0.81	0.89	0.90	0.88	0.89	0.95	0.96	0.96	0.96	0.89
Tatlisu	0.92	0.94	0.95	0.92	0.94	0.94	0.94	0.95	0.94	0.91
Kantara	0.88	0.92	0.92	0.85	0.92	0.96	0.95	0.96	0.95	0.88
Akdeniz	0.81	0.82	0.87	0.86	0.82	0.94	0.95	0.94	0.95	0.89
Camlibel	0.86	0.89	0.90	0.90	0.84	0.94	0.94	0.94	0.94	0.87
Guzelyurt	0.84	0.82	0.86	0.89	0.85	0.93	0.93	0.94	0.94	0.86
Gaziveren	0.84	0.81	0.87	0.86	0.83	0.97	0.97	0.97	0.97	0.93
Lefke	0.90	0.92	0.93	0.91	0.89	0.96	0.92	0.95	0.96	0.91
Zumrutkoy	0.82	0.86	0.87	0.88	0.85	0.95	0.92	0.94	0.94	0.85
Ercan	0.82	0.90	0.90	0.85	0.87	0.95	0.94	0.94	0.94	0.88
Serdarli	0.84	0.88	0.90	0.88	0.88	0.94	0.95	0.95	0.95	0.89
Degirmenlik	0.81	0.83	0.88	0.90	0.89	0.95	0.95	0.95	0.94	0.92
Alevkaya	0.86	0.91	0.92	0.84	0.90	0.95	0.92	0.94	0.94	0.87
Alaykoy	0.78	0.78	0.82	0.80	0.81	0.96	0.93	0.96	0.96	0.92
Lefkosa	0.84	0.87	0.90	0.83	0.89	0.95	0.96	0.96	0.94	0.90
Margo	0.82	0.88	0.90	0.90	0.89	0.95	0.94	0.95	0.95	0.89
Average	0.84	0.87	0.90	0.87	0.87	0.95	0.94	0.95	0.94	0.89

Appendix B: Continued

Stations	RD 9	ZSI 9	CZI 9	SPI 9	RDDI 9	RD 12	ZSI 12	CZI 12	SPI 12	RDDI 12
Lapta	0.96	0.95	0.97	0.96	0.92	0.96	0.96	0.97	0.95	0.92
Girne	0.95	0.95	0.95	0.95	0.89	0.95	0.95	0.95	0.95	0.88
Beylerbeyi	0.96	0.96	0.96	0.95	0.88	0.94	0.95	0.94	0.94	0.83
Bogaz	0.91	0.84	0.87	0.89	0.79	0.91	0.81	0.90	0.90	0.79
Esentepe	0.95	0.95	0.95	0.95	0.88	0.96	0.96	0.96	0.96	0.89
Gecitkale	0.95	0.95	0.95	0.92	0.88	0.95	0.95	0.94	0.95	0.87
Vadili	0.97	0.97	0.97	0.96	0.92	0.96	0.95	0.96	0.95	0.91
Beyarmudu	0.94	0.93	0.91	0.94	0.90	0.95	0.95	0.96	0.95	0.91
Gazimagusa	0.94	0.95	0.95	0.94	0.84	0.94	0.93	0.94	0.94	0.83
Salamis	0.95	0.95	0.95	0.94	0.88	0.96	0.96	0.95	0.95	0.87
Dortyol	0.96	0.96	0.97	0.95	0.93	0.96	0.97	0.97	0.97	0.92
Gonendere	0.94	0.95	0.95	0.93	0.87	0.96	0.96	0.96	0.95	0.88
Iskele	0.96	0.96	0.96	0.95	0.89	0.96	0.96	0.97	0.96	0.90
Cayirova	0.95	0.96	0.96	0.94	0.86	0.95	0.96	0.96	0.95	0.88
Mehmetcik	0.94	0.94	0.94	0.94	0.86	0.96	0.95	0.97	0.97	0.92
Ziyamet	0.93	0.93	0.92	0.93	0.79	0.93	0.94	0.93	0.92	0.81
Dipkarpaz	0.95	0.96	0.96	0.95	0.84	0.94	0.95	0.95	0.94	0.80
Yenierenkoy	0.94	0.95	0.95	0.94	0.85	0.94	0.96	0.96	0.95	0.86
Tatlisu	0.93	0.93	0.93	0.93	0.91	0.95	0.95	0.95	0.93	0.91
Kantara	0.88	0.94	0.94	0.91	0.84	0.89	0.93	0.94	0.93	0.82
Akdeniz	0.96	0.96	0.96	0.95	0.90	0.96	0.96	0.96	0.94	0.90
Camlibel	0.95	0.94	0.95	0.94	0.84	0.96	0.93	0.95	0.95	0.86
Guzelyurt	0.94	0.94	0.94	0.93	0.80	0.94	0.94	0.95	0.95	0.85
Gaziveren	0.93	0.96	0.96	0.95	0.87	0.91	0.95	0.95	0.93	0.87
Lefke	0.97	0.97	0.98	0.98	0.93	0.97	0.97	0.98	0.98	0.94
Zumrutkoy	0.95	0.94	0.94	0.95	0.83	0.95	0.94	0.94	0.94	0.83
Ercan	0.94	0.95	0.95	0.93	0.84	0.94	0.95	0.95	0.91	0.85
Serdarli	0.93	0.94	0.94	0.91	0.88	0.94	0.94	0.94	0.91	0.85
Degirmenlik	0.94	0.94	0.93	0.91	0.83	0.94	0.94	0.94	0.92	0.85
Alevkaya	0.89	0.94	0.94	0.92	0.83	0.92	0.94	0.94	0.93	0.80
Alaykoy	0.95	0.96	0.96	0.95	0.88	0.96	0.96	0.96	0.95	0.87
Lefkosa	0.93	0.94	0.94	0.93	0.79	0.94	0.94	0.94	0.92	0.76
Margo	0.92	0.93	0.91	0.93	0.81	0.94	0.95	0.94	0.92	0.85
Average	0.94	0.94	0.95	0.94	0.86	0.94	0.95	0.95	0.94	0.86

Appendix B: Continued

Stations	RD Wm	ZSI Wm	CZI Wm	SPI Wm	RDDI Wm	RD Rm	ZSI Rm	CZI Rm	SPI Rm	RDDI Rm
Lapta	0.90	0.91	0.93	0.93	0.91	0.95	0.95	0.95	0.95	0.91
Girne	0.90	0.92	0.92	0.93	0.87	0.95	0.94	0.95	0.95	0.89
Beylerbeyi	0.95	0.92	0.95	0.95	0.92	0.95	0.95	0.95	0.95	0.89
Bogaz	0.86	0.83	0.87	0.89	0.84	0.91	0.87	0.91	0.89	0.83
Esentepe	0.91	0.91	0.92	0.93	0.89	0.97	0.96	0.97	0.96	0.94
Gecitkale	0.92	0.93	0.94	0.93	0.94	0.95	0.95	0.95	0.94	0.92
Vadili	0.90	0.92	0.94	0.94	0.92	0.96	0.96	0.96	0.95	0.93
Beyarmudu	0.89	0.90	0.92	0.92	0.88	0.96	0.95	0.95	0.94	0.92
Gazimagusa	0.95	0.94	0.94	0.95	0.89	0.95	0.94	0.94	0.94	0.86
Salamis	0.91	0.89	0.91	0.92	0.88	0.95	0.93	0.95	0.93	0.88
Dortyol	0.82	0.65	0.88	0.87	0.81	0.95	0.95	0.95	0.95	0.94
Gonendere	0.92	0.90	0.92	0.94	0.91	0.95	0.95	0.95	0.93	0.88
Iskele	0.93	0.94	0.94	0.95	0.93	0.95	0.94	0.95	0.94	0.91
Cayirova	0.93	0.93	0.94	0.95	0.92	0.95	0.94	0.95	0.95	0.86
Mehmetcik	0.89	0.87	0.89	0.92	0.89	0.93	0.90	0.93	0.94	0.88
Ziyamet	0.90	0.87	0.89	0.91	0.85	0.95	0.92	0.93	0.95	0.90
Dipkarpaz	0.93	0.91	0.93	0.93	0.90	0.94	0.95	0.95	0.93	0.88
Yenierenkoy	0.93	0.89	0.92	0.94	0.88	0.93	0.93	0.93	0.92	0.84
Tatlisu	0.93	0.92	0.95	0.95	0.92	0.97	0.97	0.97	0.94	0.94
Kantara	0.95	0.95	0.95	0.94	0.92	0.96	0.96	0.96	0.94	0.92
Akdeniz	0.92	0.92	0.92	0.92	0.87	0.96	0.96	0.96	0.96	0.90
Camlibel	0.90	0.93	0.93	0.93	0.88	0.94	0.94	0.94	0.93	0.87
Guzelyurt	0.93	0.91	0.92	0.93	0.86	0.94	0.93	0.94	0.94	0.88
Gaziveren	0.95	0.93	0.95	0.95	0.90	0.96	0.95	0.96	0.96	0.88
Lefke	0.96	0.93	0.96	0.95	0.92	0.95	0.96	0.97	0.97	0.93
Zumrutkoy	0.88	0.82	0.88	0.90	0.82	0.94	0.93	0.93	0.94	0.86
Ercan	0.90	0.90	0.92	0.92	0.86	0.95	0.95	0.94	0.92	0.86
Serdarli	0.87	0.90	0.90	0.90	0.85	0.94	0.95	0.94	0.95	0.86
Degirmenlik	0.88	0.92	0.94	0.92	0.91	0.92	0.93	0.93	0.92	0.87
Alevkaya	0.92	0.91	0.91	0.93	0.85	0.93	0.93	0.94	0.94	0.80
Alaykoy	0.91	0.92	0.93	0.93	0.88	0.95	0.94	0.95	0.95	0.88
Lefkosa	0.90	0.89	0.90	0.92	0.86	0.93	0.93	0.94	0.94	0.83
Margo	0.92	0.92	0.94	0.93	0.88	0.94	0.94	0.94	0.93	0.84
Average	0.91	0.90	0.92	0.93	0.88	0.95	0.94	0.95	0.94	0.88

Appendix C: Graphs at -Rm time step using RD, ZSI and CZI

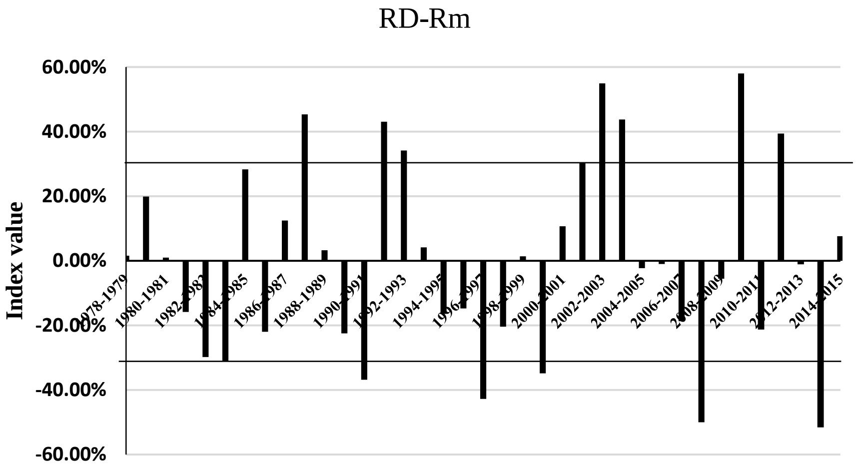

Figure C- 1 Graphical representation of RD-Rm

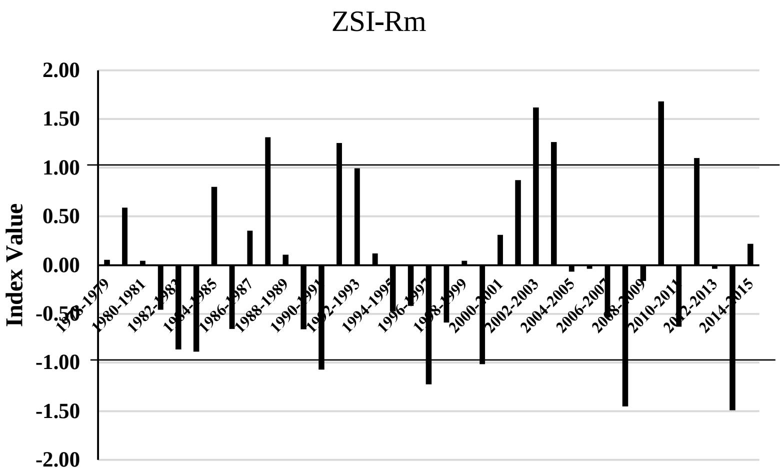

Figure C- 2 Graphical representation of ZSI-Rm

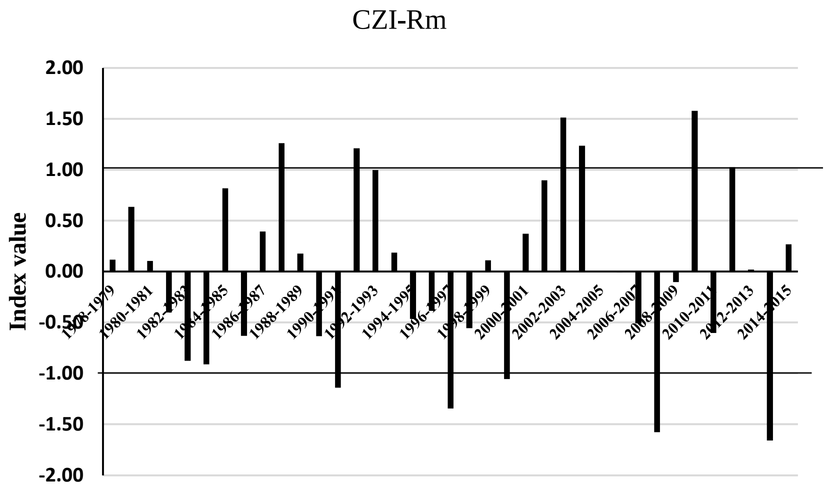

Figure C- 3 Graphical representation of CZI-Rm

Appendix D: Drought months identified using five indices in 37 Years

Nov/78	Jan/97	May/02	May/08	Apr/95
May/79	Feb/98	Oct/02	Oct/10	Apr/01
Nov/80	Oct/98	May/04	Oct/11	Feb/02
Oct/81	May/99	Oct/04	Feb/13	Apr/02
May/82	Oct/99	Oct/05	Apr/88	Nov/07
Oct/82	Mar/01	Feb/08	Nov/89	Apr/10
Feb/84	May/03	Mar/13	Apr/91	May/85
May/84	Mar/04	Apr/79	Apr/92	Apr/80
Oct/84	Nov/04	Oct/80	Mar/02	Apr/07
Apr/85	Dec/05	Dec/82	Feb/05	Apr/09
Dec/85	Dec/06	Dec/87	Jan/07	Apr/14
Mar/86	Oct/07	Mar/89	Dec/07	Jan/01
Feb/87	Jan/08	Apr/98	Dec/10	Jan/84
Apr/87	Mar/08	Dec/99	Mar/12	Jan/85
Feb/89	Apr/08	Nov/00	Feb/82	Nov/14
Apr/89	Nov/08	Feb/79	Jan/93	Mar/05
Dec/89	Mar/10	Jan/82	Oct/95	May/10
Jan/90	Nov/10	Nov/85	Jan/03	May/83
Apr/90	Oct/13	Oct/93	Nov/03	May/06
May/90	Nov/13	Nov/99	Oct/08	Mar/85
Nov/90	Jan/14	Nov/02	Dec/83	Feb/85
Dec/90	Feb/14	Mar/14	Apr/86	May/92
Jan/92	Nov/78	Mar/90	Mar/91	Jan/87
Oct/92	Jan/83	May/80	Apr/96	Oct/78
Apr/93	Jan/86	May/88	Mar/99	Feb/11
Dec/93	Oct/90	May/89	Jan/15	Apr/99
Jan/95	Feb/96	May/91	Feb/15	Feb/00
Feb/95	Feb/97	Mar/92	Mar/84	Apr/81
Mar/95	Apr/04	May/94	Feb/06	Jan/80
Dec/95	Dec/13	Dec/94	Nov/06	Dec/96
May/96	Apr/82	Oct/03	Apr/12	May/05
Nov/96	Nov/98	Apr/06	Oct/91	Dec/80
Jan/00	Oct/94			

Appendix E: Severity category of drought years identified at -Rm using SPI

Stations	Mild/ near zero drought	Moderate	Very severe	Extreme
Salamis	1981-1982, 1982-1983, 1983-1984, 1985-1986, 1986-1987, 1990-1991, 1994-1995, 1997-1998, 1998-1999, 2004-2005, 2008-2009, 2010-2011, 2012-2013, 2014-2015		1999-2000, 2007-2008	1996-1997, 2013-2014
Dortyol	1978-1979, 1981-1982, 1983-1984, 1985-1986, 1986-1987, 1989-1990, 1990-1991, 1994-1995, 1997-1998, 1998-1999, 2005-2006, 2006-2007, 2008-2009, 2012-2013	1982-1983, 1999-2000, 2007-2008, 2013-2014	1996-1997	
Gonendere	1981-1982, 1985-1986, 1986-1987, 1989-1990, 1994-1995, 1996-1997, 1997-1998, 2005-2006, 2006-2007, 2008-2009, 2010-2011, 2012-2013,	1983-1984, 1990-1991, 1999-2000, 2013-2014	1982-1983	2007-2008
Iskele	1981-1982, 1983-1984, 1985-1986, 1986-1987, 1988-1989, 1993-1994, 1995-1996, 2006-2007, 2008-2009, 2010-2011, 2012-2013,	1982-1983, 1990-1991, 1994-1995, 1996-1997, 1997-1998	1999-2000, 2007-2008	2013-2014
Cayirova	1980-1981, 1981-1982, 1982-1983, 1983-1984, 1986-1987, 1988-1989, 1989-1990, 1990-1991, 1995-1996, 1997-1998, 1998-1999, 2000-2001, 2004-2005, 2006-2007, 2010-2011,	1994-1995, 1999-2000	2007-2008, 2013-2014	1996-1997
Mehmetcik	1981-1982, 1982-1983, 1983-1984, 1985-1986, 1988-1989, 1989-1990, 1990-1991, 1993-1994, 1995-1996, 1998-1999, 2010-2011	1994-1995, 1996-1997, 1997-1998, 1999-2000, 2006-2007, 2007-2008		2013-2014
Ziyamet	1981-1982, 1982-1983, 1983-1984, 1985-1986, 1988-1989, 1993-1994, 1995-1996, 1997-1998, 1999-2000, 2000-2001, 2004-2005, 2007-2008, 2012-2013, 2014-2015,	1994-1995, 1996-1997, 2006-2007, 2010-2011	1990-1991, 2013-2014	

Appendix E: Continued

Stations	Mild/ near zero drought	Moderate	Very severe	Extreme
Dipkarpaz	1981-1982, 1982-1983, 1985-1986, 1986-1987, 1990-1991, 1993-1994, 1994-1995, 1999-2000, 2000-2001, 2004-2005, 2005-2006, 2006-2007, 2007-2008, 2012-2013	1983-1984, 1995-1996, 2010-2011		1996-1997, 2013-2014
Yenierenkoy	1981-1982, 1982-1983, 1983-1984, 1985-1986, 1986-1987, 1990-1991, 1993-1994, 1994-1995, 1995-1996, 1997-1998, 1998-1999, 1999-2000, 2000-2001, 2004-2005, 2006-2007, 2008-2009, 2010-2011, 2012-2013, 2014-2015	2007-2008		1996-1997, 2013-2014
Tatlisu	1979-1980, 1980-1981, 1981-1982, 1990-1991, 1994-1995, 1995-1996, 1997-1998, 1998-1999, 1999-2000, 2006-2007, 2008-2009,2 010-2011	1978-1979, 1982-1983	1996-1997, 2007-2008	1983-1984, 2013-2014
Kantara	1978-1979, 1981-1982, 1985-1986, 1989-1990, 1990-1991, 1997-1998, 1998-1999, 2000-2001, 2006-2007, 2012-2013	1983-1984,1994-1995, 1999-2000, 2007-2008, 2010-2011	1996-1997	2013-2014
Akdeniz	1978-1979, 1980-1981, 1982-1983, 1989-1990, 1993-1994, 1999-2000, 2000-2001, 2004-2005, 2005-2006, 2006-2007, 2010-2011	1983-1984, 1985-1986, 1990-1991, 1995-1996, 1996-1997	2007-2008	2013-2014
Camlibel	1981-1982, 1982-1983, 1984-1985, 1985-1986, 1988-1989, 1989-1990, 1992-1993, 1993-1994, 1999-2000, 2000-2001, 2004-2005, 2005-2006, 2006-2007, 2007-2008, 2010-2011	1983-1984, 1990-1991, 1995-1996, 1996-1997		2013-2014
Guzelyurt	1978-1979, 1982-1983, 1994-1995, 1995-1996, 1999-2000, 2004-2005, 2005-2006, 2006-2007, 2010-2011	1983-1984, 1989-1990, 1990-1991, 1996-1997, 2007-2008	1985-1986	2013-2014
Gaziveren	1978-1979, 1981-1982, 1982-1983, 1983-1984, 1993-1994, 1994-1995, 1997-1998, 1999-2000, 2004-2005, 2005-2006, 2006-2007, 2010-2011	1985-1986, 1989-1990	1990-1991, 1996-1997, 2007,2008	2013-2014

Appendix E: Continued

Stations	Mild/ near zero drought	Moderate	Very severe	Extreme
Lefke	1978-1979, 1981-1982, 1982-1983, 1993-1994, 1995-1996, 1996-1997, 2005-2006, 2010-2011	1983-1984, 1989-1990, 1990-1991, 1994-1995, 1997-1998,1999-2000	1985-1986, 2013-2014	
Zumrutkoy	1978-1979, 1981-1982, 1982-1983, 1983-1984, 1988-1989, 1989-1990, 1995-1996, 1997-1998, 1999-2000, 2000-2001, 2006-2007	1985-1986, 1990-1991, 1994-1995, 1996-1997, 2007-2008, 2010-2011	2013-2014	
Ercan	1981-1982, 1983-1984, 1989-1990, 1995-1996, 1996-1997, 1997-1998, 1998-1999, 2006-2007, 2008-2009, 2010-2011, 2012-2013, 2013-2014	1982-1983, 1985-1986	1990-1991, 1999-2000	2007-2008
Serdarli	1981-1982, 1986-1987, 1989-1990, 1997-1998, 1999-2000, 2005-2006, 2008-2009, 2010-2011, 2012-2013	1982-1983, 1985-1986. 1996-1997, 2013-2014	1990-1991	2007-2008
Degirmenlik	1980-1981, 1981-1982, 1983-1984, 1986-1987, 1988-1989, 1989-1990, 1994-1995, 1995-1996, 1996-1997, 1997-1998, 1999-2000, 2006-2007, 2008-2009, 2010-2011, 2012-2013	1982-1983, 1985-1986, 1990-1991, 2013-2014		2007-2008
Alevkaya	1981-1982, 1983-1984, 1984-1985, 1985-1986, 1990-1991, 1994-1995, 1995-1996, 1996-1997, 1997-1998, 1999-2000, 2006-2007, 2008-2009, 2013-2014	1989-1990	1982-1983, 2010-2011	2007-2008
Alaykoy	1982-1983, 1983-1984, 1985-1986, 1988-1989, 1991-1992, 1995-1996, 1997-1998, 2005-2006, 2006-2007, 2010-2011	1989-1990, 1990-1991, 1994-1995, 1996-1997	1999-2000, 2013-2014	2007-2008
Lefkosa	1981-1982, 1983-1984, 1985-1986, 1989-1990, 1994-1995, 1995-1996, 1996-1997, 1997-1998, 2004-2005, 2005-2006, 2008-2009, 2010-2011, 2011-2012, 2012-2013	1982-1983, 1999-2000, 2006-2007	1990-1991	2007-2008
Margo	1983-1984, 1985-1986, 1989-1990, 1995-1996, 1996-1997, 1997-1998, 1998-1999, 2004-2005, 2006-2007, 2008-2009, 2012-2013	1981-1982, 1982-1983, 1990-1991 2013-2014	1999-2000	2007-2008

Appendix F: Drought parameters indicating drought characteristics for 32 stations

Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)	Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)
Guzelyurt				**Zumrutkoy**			
1978-1979	1.00	0.50	0.50	1978-1979	1.00	0.63	0.63
1982-1984	2.00	1.69	0.84	1981-1984	3.00	2.01	0.67
1985-1986	1.00	1.59	1.59	1985-1986	1.00	1.35	1.35
1989-1991	2.00	2.10	1.05	1988-1991	3.00	2.44	0.81
1994-1997	3.00	1.86	0.62	1994-1998	4.00	2.88	0.72
1999-2000	1.00	0.45	0.45	1999-2001	2.00	0.37	0.19
2004-2008	4.00	3.96	0.99	2006-2008	2.00	2.36	1.18
2010-2011	1.00	0.61	0.61	2010-2011	1.00	1.01	1.01
2013-2014	1.00	2.22	2.22	2013-2014	1.00	1.82	1.82
Camlibel				**Lefke**			
1981-1986	5.00	3.47	0.69	1978-1979	1.00	0.63	0.63
1988-1991	3.00	2.01	0.67	1981-1984	3.00	1.65	0.55
1992-1994	2.00	0.80	0.40	1985-1986	1.00	1.99	1.99
1995-1997	2.00	2.57	1.28	1989-1991	2.00	2.19	1.10
1999-2001	2.00	0.59	0.30	1993-1998	5.00	4.20	0.84
2004-2008	4.00	1.47	0.37	1999-2000	1.00	1.47	1.47
2010-2011	1.00	0.25	0.25	2005-2006	1.00	0.73	0.73
2013-2014	1.00	3.05	3.05	2010-2011	1.00	0.51	0.51
				2013-2014	1.00	1.96	1.96
Akdeniz				**Gaziveren**			
1978-1979	1.00	0.44	0.44	1978-1979	1.00	0.52	0.52
1980-1981	1.00	0.21	0.21	1981-1984	3.00	1.62	0.54
1982-1984	2.00	1.67	0.83	1985-1986	1.00	1.15	1.15
1985-1986	1.00	1.02	1.02	1989-1991	2.00	3.06	1.53
1989-1991	2.00	2.09	1.05	1993-1995	2.00	0.61	0.30
1993-1994	1.00	0.03	0.03	1996-1998	2.00	2.11	1.05
1995-1997	2.00	2.53	1.26	1999-2000	1.00	0.66	0.66
1999-2001	2.00	0.20	0.10	2004-2008	4.00	3.33	0.83
2004-2008	4.00	3.64	0.91	2010-2011	1.00	0.62	0.62
2010-2011	1.00	0.68	0.68	2013-2014	1.00	2.05	2.05
2013-2014	1.00	2.61	2.61				
Gazimagusa				**Tatlisu**			
1980-1984	4.00	2.05	0.51	1978-1984	6.00	6.01	1.00
1985-1986	1.00	0.53	0.53	1990-1991	1.00	0.69	0.69
1989-1991	2.00	0.75	0.38	1994-2000	6.00	2.97	0.49
1993-2000	7.00	6.52	0.93	2006-2009	3.00	2.29	0.76
2006-2009	3.00	1.63	0.54	2010-2011	1.00	0.49	0.49
2013-2014	1.00	2.24	2.24	2013-2014	1.00	2.23	2.23

Appendix F: Continued

Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)	Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)
Alaykoy				**Gecitkale**			
1982-1984	2.00	0.85	0.43	1981-1984	3.00	2.24	0.75
1985-1986	1.00	0.17	0.17	1985-1987	2.00	0.22	0.11
1988-1992	4.00	2.97	0.74	1989-1991	2.00	2.42	1.21
1994-1998	4.00	3.62	0.91	1994-1998	4.00	3.07	0.77
1999-2000	1.00	1.52	1.52	1999-2000	1.00	1.05	1.05
2005-2008	3.00	3.07	1.02	2007-2009	2.00	2.34	1.17
2010-2011	1.00	0.74	0.74	2010-2011	1.00	0.46	0.46
2013-2014	1.00	1.77	1.77	2012-2015	3.00	3.38	1.13
Alevkaya				**Girne**			
1981-1986	5.00	3.39	0.68	1980-1984	4.00	2.88	0.72
1989-1991	2.00	1.71	0.86	1989-1991	2.00	2.50	1.25
1994-1998	4.00	2.14	0.54	1994-1998	4.00	3.72	0.93
1999-2000	1.00	0.80	0.80	1999-2000	1.00	1.00	1.00
2006-2009	3.00	3.94	1.31	2005-2009	4.00	3.04	0.76
2010-2011	1.00	1.59	1.59	2010-2011	1.00	0.72	0.72
2013-2014	1.00	0.67	0.67	2012-2014	2.00	1.34	0.67
Dipkarpaz				**Kantara**			
1981-1984	3.00	1.98	0.66	1978-1979	1.00	0.23	0.23
1985-1987	2.00	0.30	0.15	1981-1982	1.00	0.39	0.39
1990-1991	1.00	0.64	0.64	1983-1984	1.00	1.27	1.27
1993-1997	4.00	4.18	1.05	1985-1986	1.00	0.76	0.76
1999-2001	2.00	0.99	0.49	1989-1991	2.00	0.66	0.33
2004-2008	4.00	1.46	0.36	1994-1995	1.00	1.39	1.39
2010-2011	1.00	1.13	1.13	1996-2001	5.00	4.70	0.94
2012-2014	2.00	3.28	1.64	2006-2008	2.00	1.92	0.96
				2010-2011	1.00	1.44	1.44
				2012-2014	2.00	2.66	1.33
Gonendere				**Esentepe**			
1981-1984	3.00	3.08	1.03	1978-1980	2.00	1.16	0.58
1985-1987	2.00	1.09	0.55	1981-1984	3.00	2.47	0.82
1989-1991	2.00	2.26	1.13	1989-1991	2.00	2.72	1.36
1994-1995	1.00	0.05	0.05	1994-1995	1.00	1.04	1.04
1996-1998	2.00	1.22	0.61	1996-1998	2.00	0.74	0.37
1999-2000	1.00	1.17	1.17	1999-2000	1.00	0.32	0.32
2005-2009	4.00	4.04	1.01	2006-2009	3.00	3.51	1.17
2010-2011	1.00	0.62	0.62	2010-2011	1.00	0.38	0.38
2012-2014	2.00	1.58	0.79	2013-2014	2.00	3.10	1.55

Appendix F: Continued

Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)	Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)
Mehmetcik				**Lefkosa**			
1981-1982	3.00	1.93	0.64	1981-1984	3.00	2.15	0.72
1985-1986	1.00	0.29	0.29	1985-1986	1.00	0.58	0.58
1988-1991	3.00	2.48	0.83	1989-1991	2.00	2.27	1.13
1993-2000	7.00	5.70	0.81	1994-1998	4.00	2.27	0.57
2006-2008	2.00	2.31	1.15	1999-2000	1.00	1.42	1.42
2010-2011	1.00	0.55	0.55	2004-2009	5.00	4.57	0.91
2013-2014	1.00	2.15	2.15	2010-2013	3.00	1.70	0.57
Yenierenkoy				**Bogaz**			
1981-1984	3.00	1.29	0.43	1978-1979	1.00	0.19	0.19
1985-1987	2.00	0.70	0.35	1980-1984	4.00	3.23	0.81
1990-1991	1.00	0.99	0.99	1985-1986	1.00	0.61	0.61
1993-2001	8.00	4.79	0.60	1989-1991	2.00	1.92	0.96
2004-2005	1.00	0.10	0.10	1994-1998	4.00	3.67	0.92
2006-2009	3.00	2.07	0.69	1999-2000	1.00	0.94	0.94
2010-2011	1.00	0.89	0.89	2004-2009	5.00	3.34	0.67
2012-2015	3.00	3.25	1.08	2013-2014	1.00	0.68	0.68
Cayirova				**Beylerbeyi**			
1980-1984	4.00	2.05	0.51	1980-1984	4.00	4.02	1.01
1986-1987	1.00	0.05	0.05	1985-1986	1.00	0.33	0.33
1988-1991	3.00	1.67	0.56	1988-1991	3.00	2.12	0.71
1994-2001	7.00	6.12	0.87	1994-1998	4.00	2.47	0.62
2004-2005	1.00	1.87	1.87	1999-2001	2.00	0.57	0.28
2006-2008	2.00	1.83	0.91	2006-2009	3.00	3.46	1.15
2010-2011	1.00	0.53	0.53	2010-2011	1.00	0.51	0.51
2013-2014	1.00	1.92	1.92	2012-2014	2.00	1.42	0.71
Iskele				**Serdarli**			
1981-1984	3.00	1.45	0.48	1981-1983	2.00	1.91	0.96
1985-1987	2.00	0.46	0.23	1985-1987	2.00	1.57	0.79
1988-1989	1.00	0.04	0.04	1989-1991	2.00	2.56	1.28
1990-1991	1.00	1.16	1.16	1996-1998	2.00	1.66	0.83
1993-1998	5.00	4.02	0.80	1999-2000	1.00	0.80	0.80
1999-2000	1.00	1.59	1.59	2005-2006	1.00	0.12	0.12
2006-2009	3.00	2.63	0.88	2007-2009	2.00	4.01	2.00
2010-2011	1.00	0.86	0.86	2010-2011	1.00	0.49	0.49
2012-2014	2.00	2.64	1.32	2012-2014	2.00	1.45	0.73

Appendix F: Continued

Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)	Drought Episode	Duration (year)	Magnitude (∑DI)	Intensity (∑DI/y)
Degirmenlik				**Dortyol**			
1980-1984	4.00	2.96	0.74	1978-1979	1.00	0.45	0.45
1985-1987	2.00	1.59	0.80	1981-1984	3.00	1.56	0.52
1988-1991	3.00	2.21	0.74	1985-1987	2.00	0.19	0.10
1994-1998	4.00	1.35	0.34	1989-1991	2.00	1.54	0.77
1999-2000	1.00	0.90	0.90	1994-1995	1.00	0.33	0.33
2006-2009	3.00	3.90	1.30	1996-2000	4.00	4.35	1.09
2010-2011	1.00	0.49	0.49	2005-2009	4.00	3.30	0.82
2012-2014	2.00	1.37	0.68	2012-2014	2.00	1.76	0.88
Vadili				**Ercan**			
1978-1979	1.00	0.10	0.10	1981-1984	3.00	2.49	0.83
1981-1984	3.00	2.71	0.90	1985-1986	1.00	1.03	1.03
1985-1986	1.00	0.41	0.41	1989-1991	2.00	2.55	1.28
1990-1991	1.00	0.80	0.80	1995-2000	5.00	2.70	0.54
1995-2000	5.00	5.52	1.10	2006-2009	3.00	4.01	1.34
2005-2008	3.00	2.20	0.73	2010-2011	1.00	0.80	0.80
2012-2015	3.00	2.87	0.96	2012-2014	2.00	1.19	0.60
Beyarmudu				**Salamis**			
1978-1979	1.00	0.20	0.20	1981-1984	3.00	1.79	0.60
1981-1984	3.00	2.50	0.83	1985-1987	2.00	0.42	0.21
1985-1986	1.00	0.97	0.97	1990-1991	1.00	0.39	0.39
1989-1991	2.00	1.54	0.77	1994-1995	1.00	0.46	0.46
1994-2000	6.00	5.67	0.94	1996-2000	4.00	5.63	1.41
2004-2005	1.00	0.30	0.30	2004-2005	1.00	0.10	0.10
2007-2008	1.00	1.56	1.56	2007-2009	2.00	2.10	1.05
2010-2011	1.00	0.52	0.52	2010-2011	1.00	0.50	0.50
2013-2014	1.00	1.64	1.64	2012-2015	3.00	2.77	0.92
Ziyamet				**Margo**			
1981-1984	3.00	1.68	0.56	1981-1984	3.00	-3.09	-1.03
1985-1986	1.00	0.29	0.29	1985-1986	1.00	-0.82	-0.82
1988-1989	1.00	0.07	0.07	1989-1991	2.00	-2.19	-1.09
1990-1991	1.00	1.55	1.55	1995-2000	5.00	-2.59	-0.52
1993-1998	5.00	3.81	0.76	2004-2005	1.00	-0.30	-0.30
1999-2001	2.00	1.03	0.52	2006-2007	3.00	-4.03	-1.34
2004-2005	1.00	0.30	0.30	2012-2014	2.00	-1.61	-0.80
2006-2008	2.00	1.93	0.96				
2010-2011	1.00	1.22	1.22				
2012-2015	3.00	2.82	0.94				

Appendix G: SDF curves for different stations

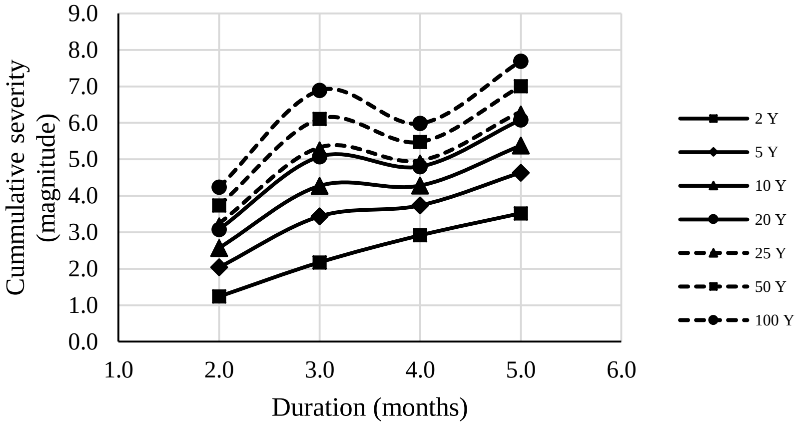

Figure G- 1 SDF curves at Lapta station

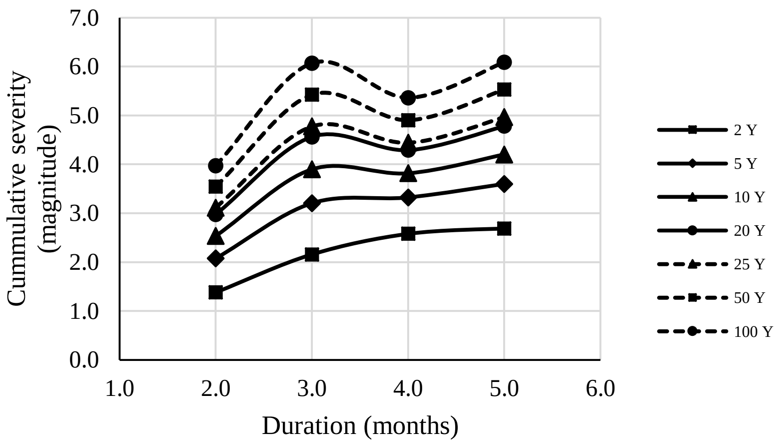

Figure G- 2 SDF curves at Girne station

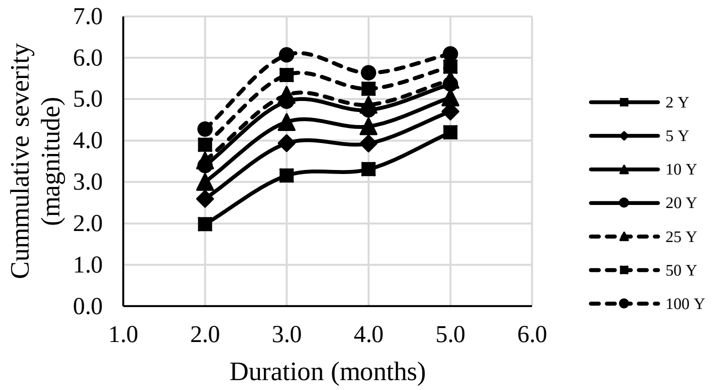

Figure G- 3 SDF curves at Beylerbeyi station

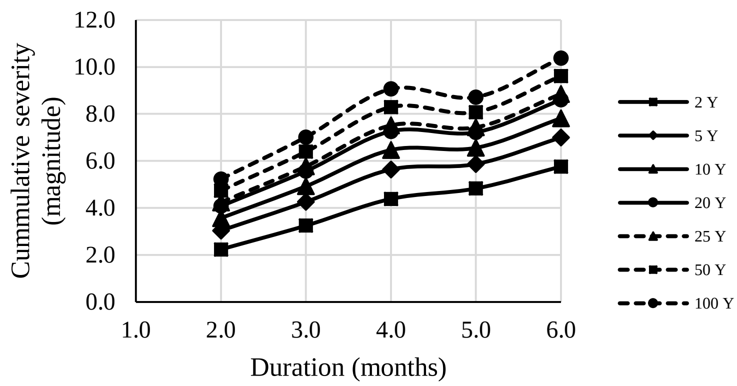

Figure G- 4 SDF curves at Esentepe station

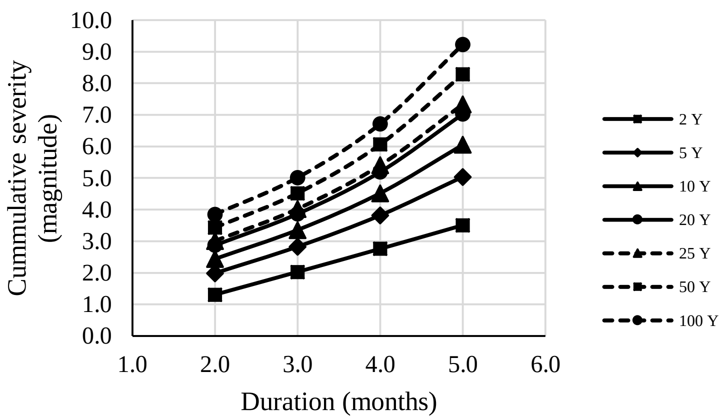

Figure G- 5 SDF curves at Gecitkale station

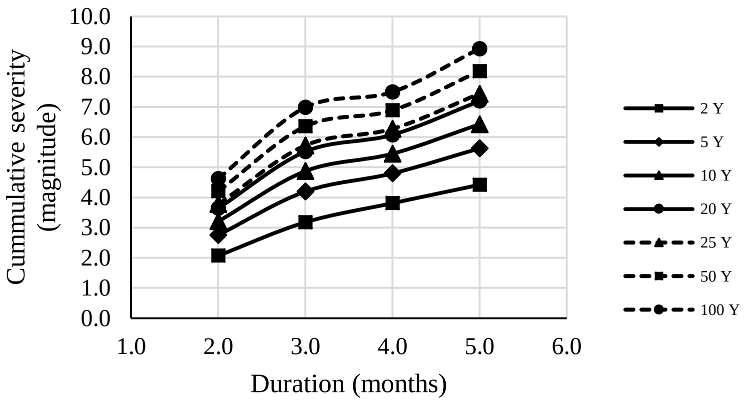

Figure G- 6 SDF curves at Vadili station

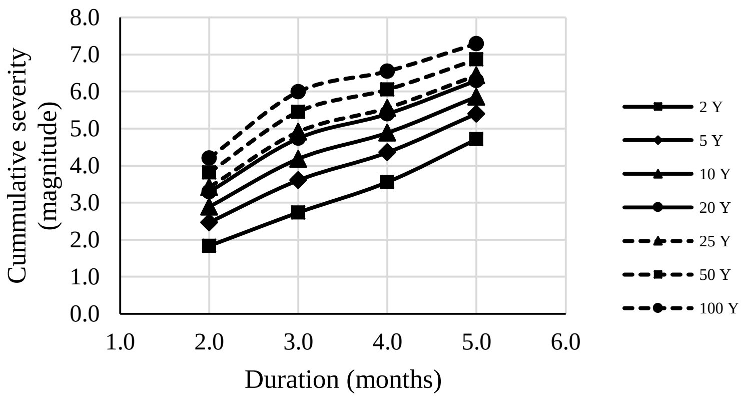

Figure G- 7 SDF curves at Beyarmudu station

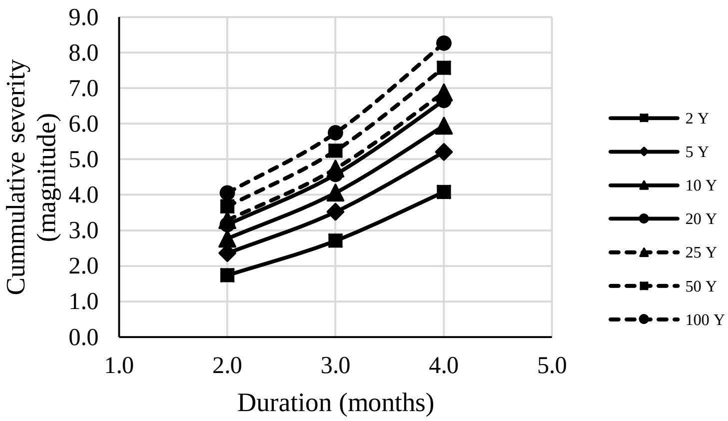

Figure G- 8 SDF curves at Gazimagusa station

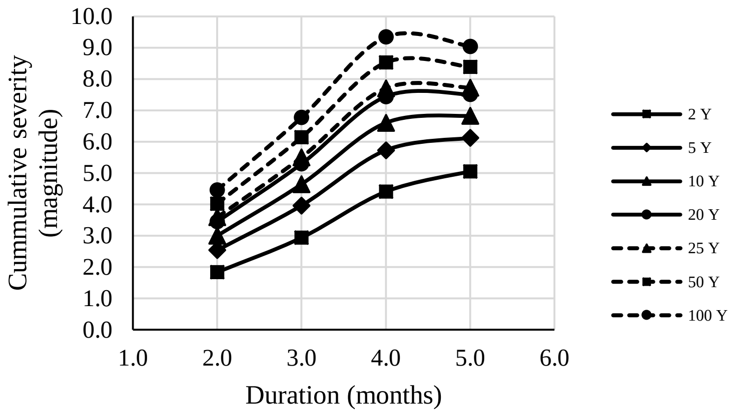

Figure G- 9 SDF curves at Salamis station

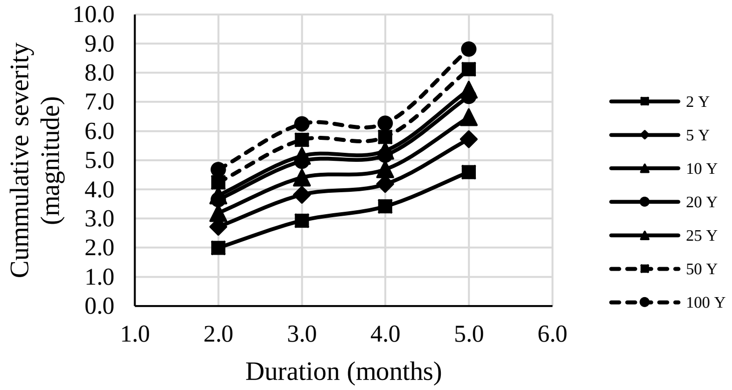

Figure G- 10 SDF curves at Dortyol station

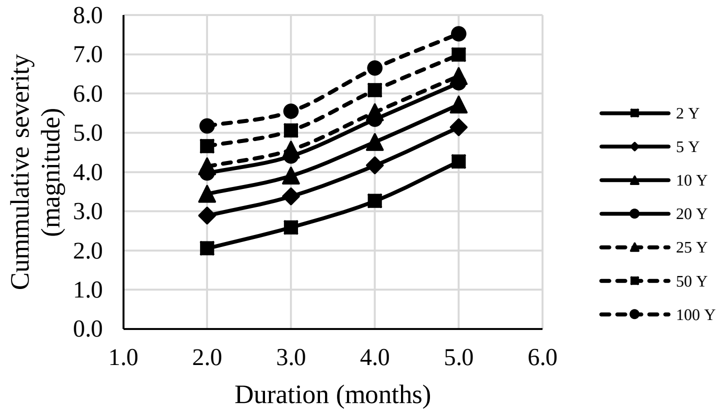

Figure G- 11 SDF curves at Gonendere station

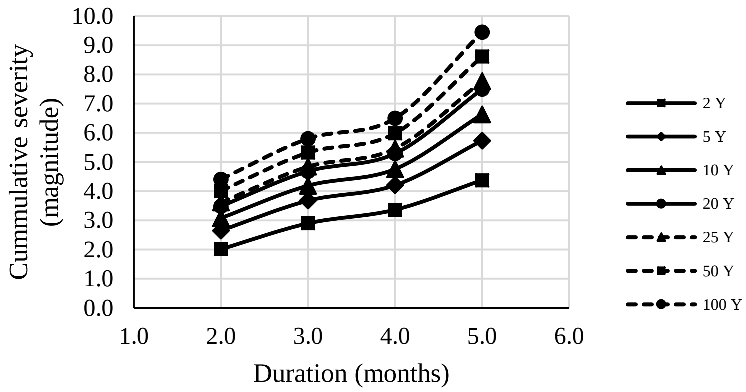

Figure G- 12 SDF curves at Iskele station

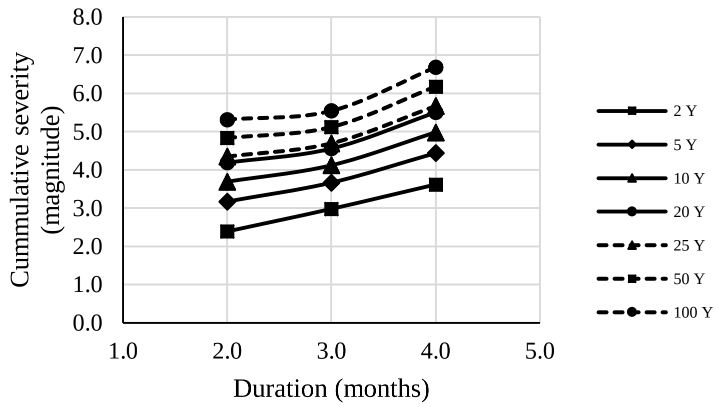

Figure G- 13 SDF curves at Ziyamet station

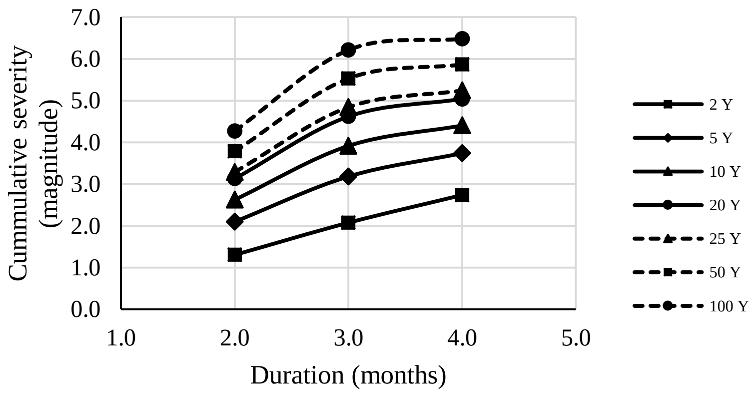

Figure G- 14 SDF curves at Dipkarpaz station

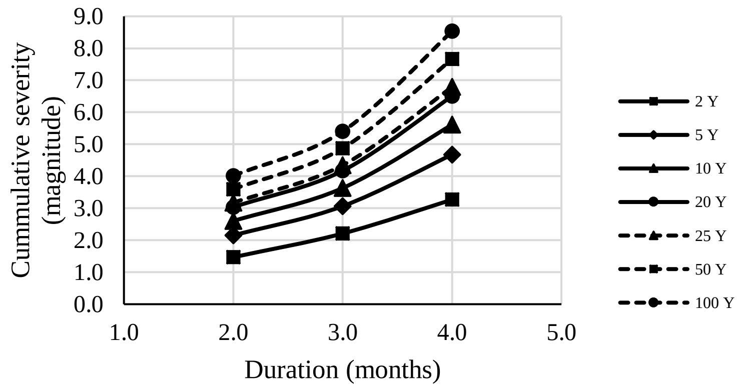

Figure G- 15 SDF curves at Yenierenkoy station

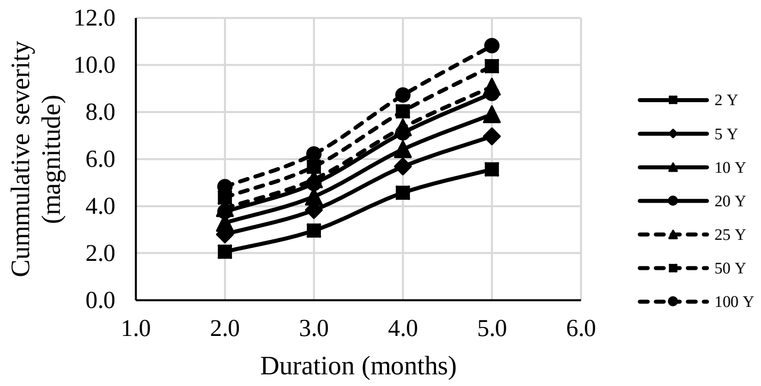

Figure G- 16 SDF curves at Tatlisu station

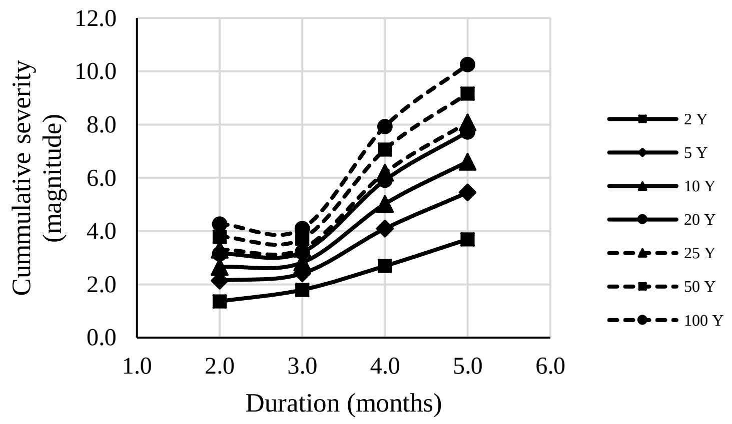

Figure G- 17 SDF curves at Kantara station

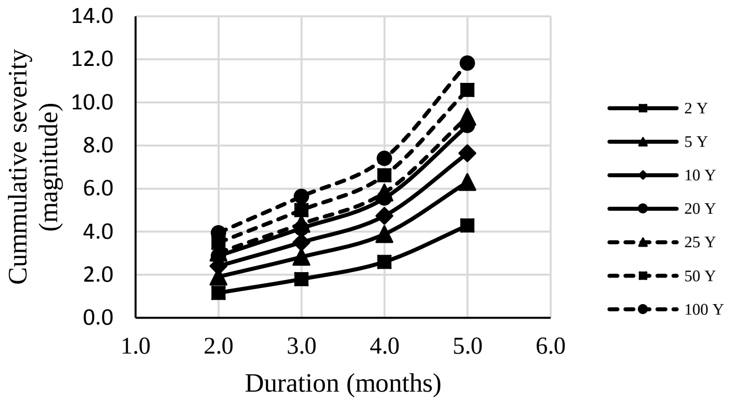

Figure G- 18 SDF curves at Camlibel station

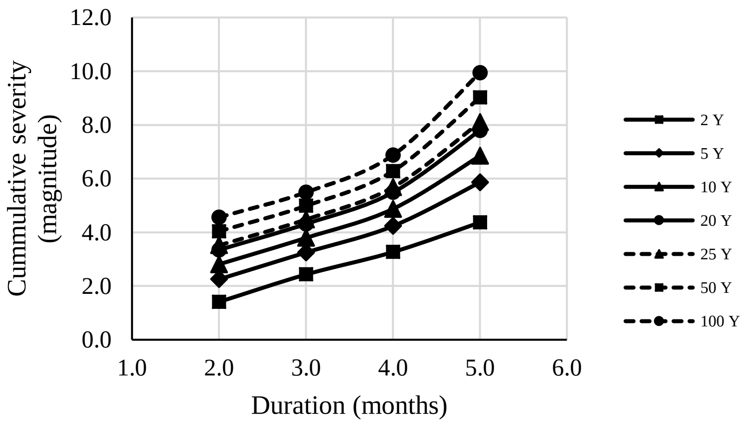

Figure G- 19 SDF curves at Guzelyurt station

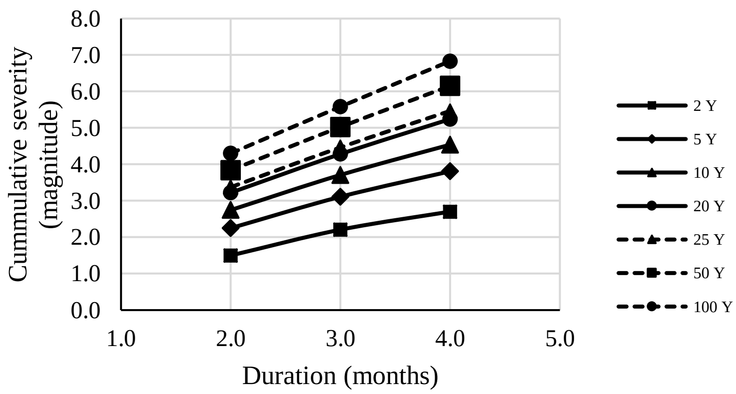

Figure G- 20 SDF curves at Gaziveren station

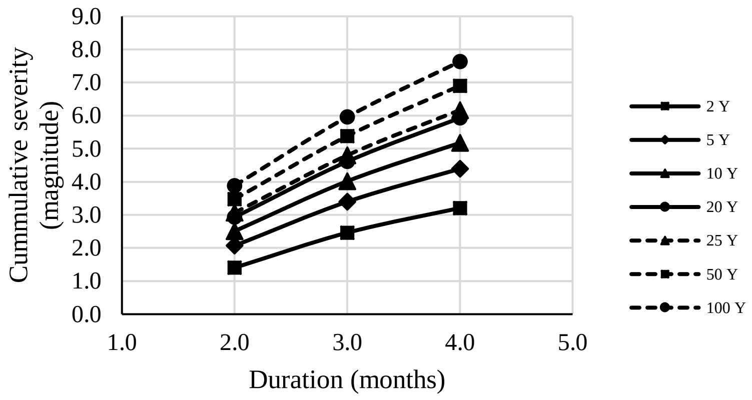

Figure G- 21 SDF curves at Lefke station

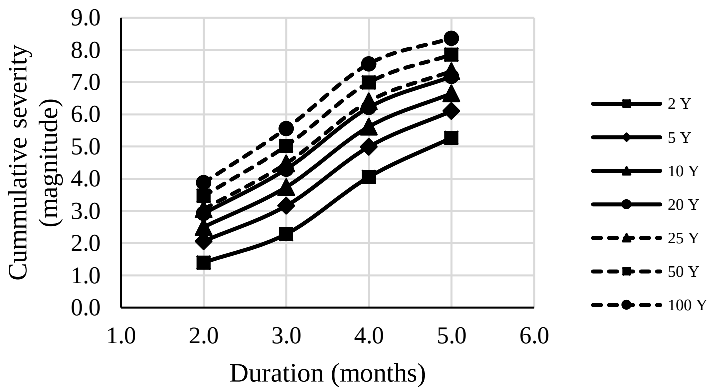

Figure G- 22 SDF curves at Zumrutkoy station

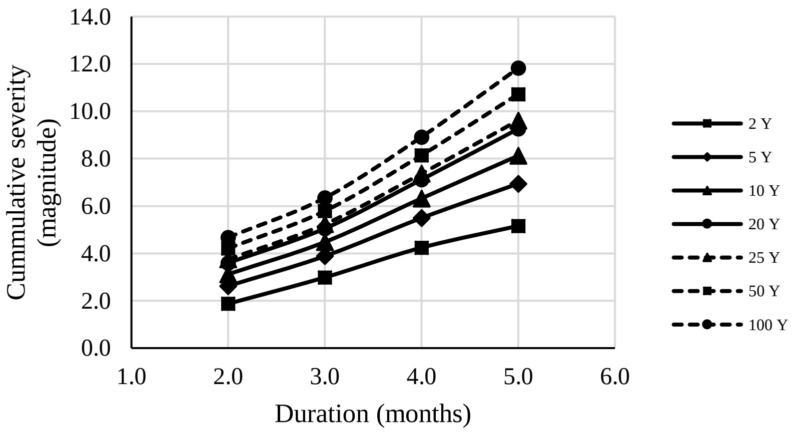

Figure G- 23 SDF curves at Ercan station

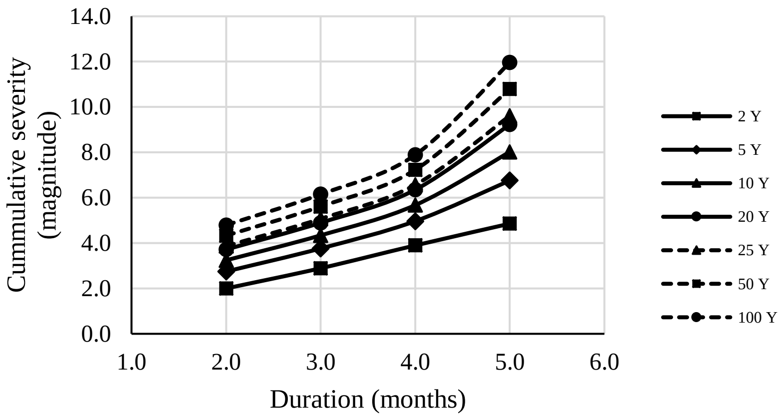

Figure G- 24 SDF curves at Serdarli station

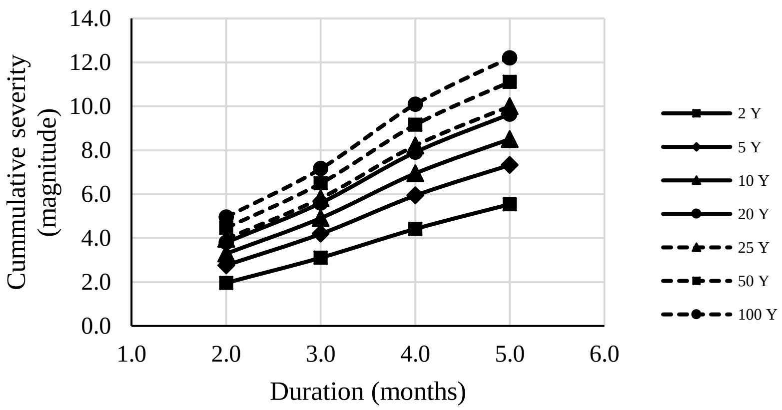

Figure G- 25 SDF curves at Degirmenlik station

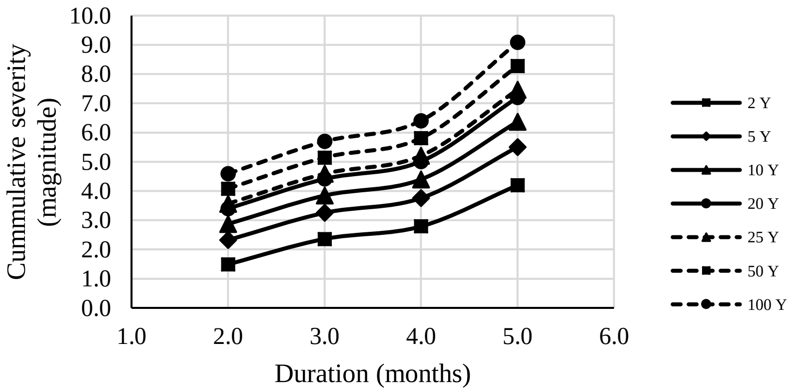

Figure G- 26 SDF curves at Alevkaya station

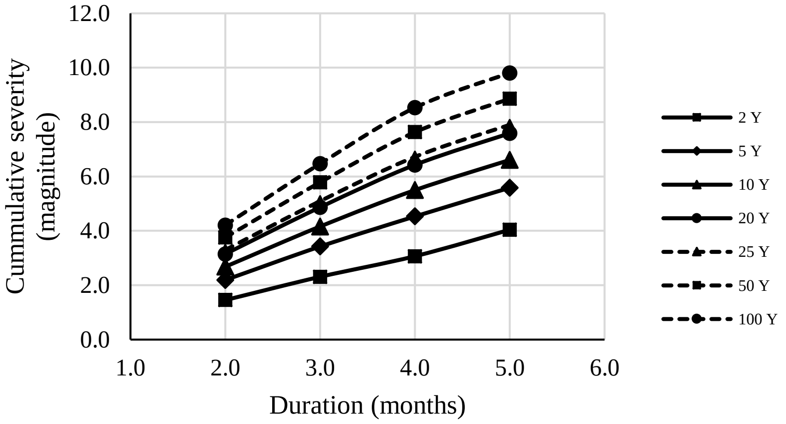

Figure G- 27 SDF curves at Alaykoy station

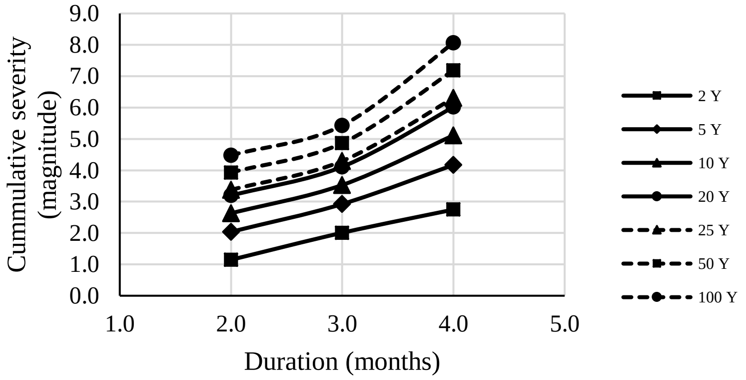

Figure G- 28 SDF curves at Lefkosa station

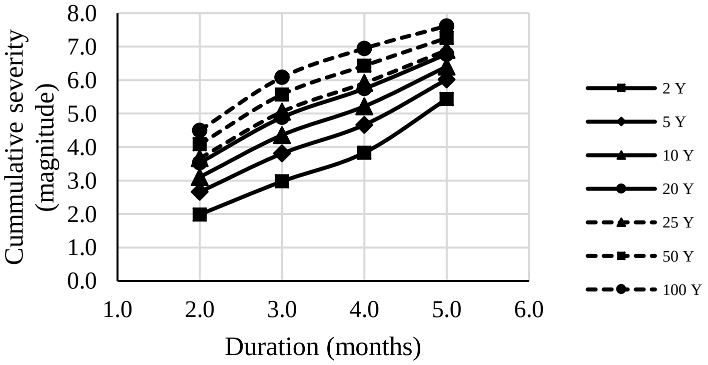

Figure G- 29 SDF curves at Margo station

Appendix H: IDF curves for different stations

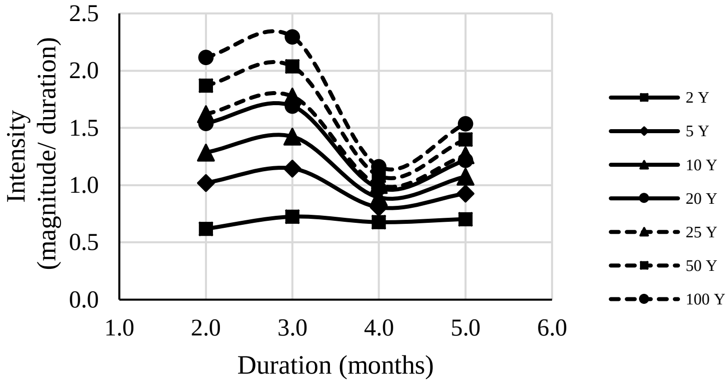

Figure H- 1 IDF curves at Lapta station

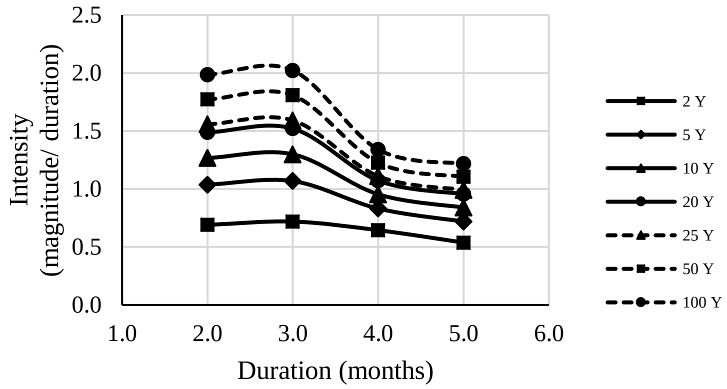

Figure H- 2 IDF curves at Girne station

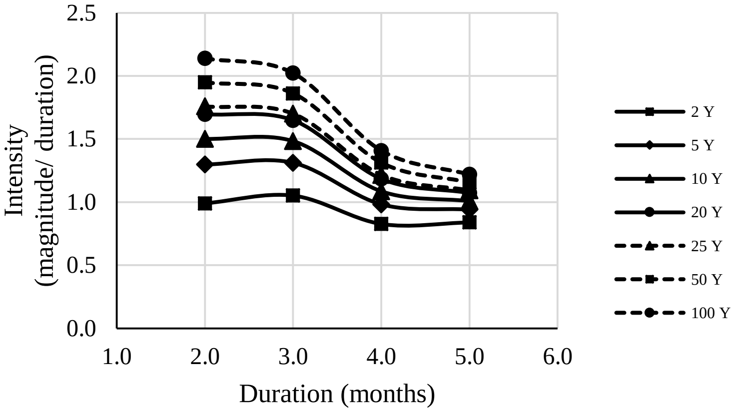

Figure H- 3 IDF curves at Beylerbeyi station

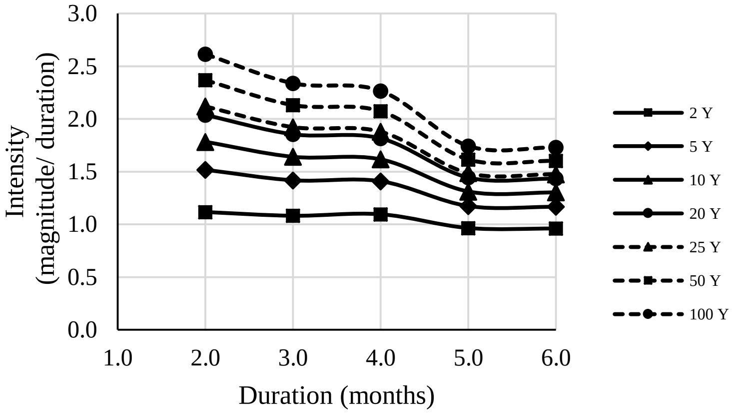

Figure H- 4 IDF curves at Esentepe station

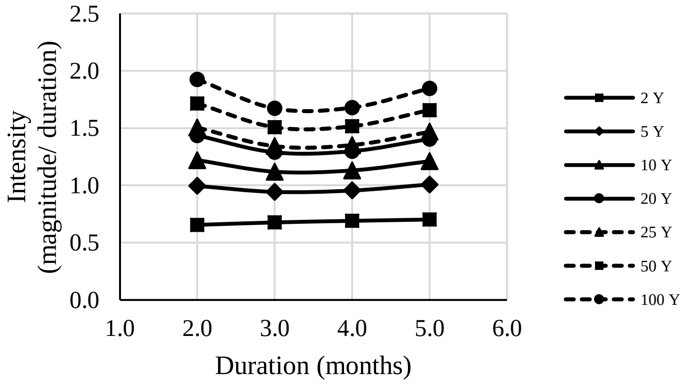

Figure H- 5 IDF curves at Gecitkale station

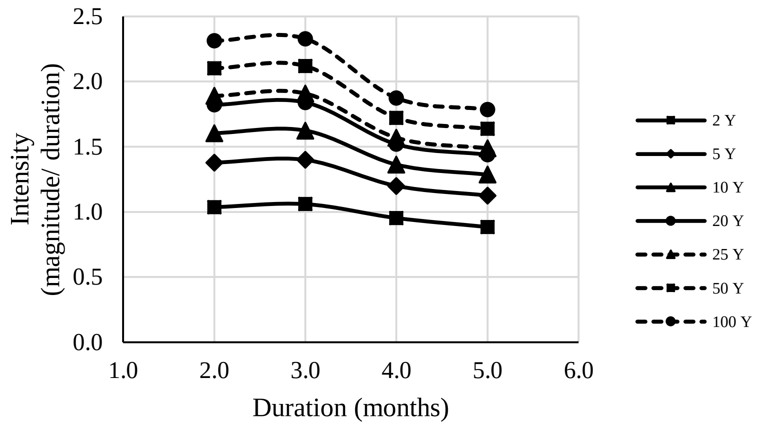

Figure H- 6 IDF curves at Vadili station

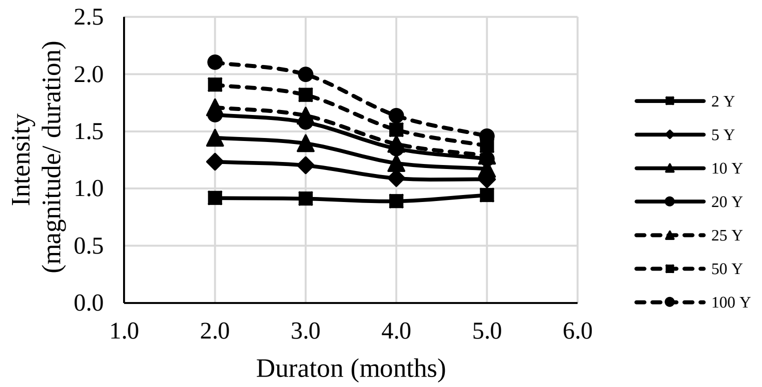

Figure H- 7 IDF curves at Beyarmudu station

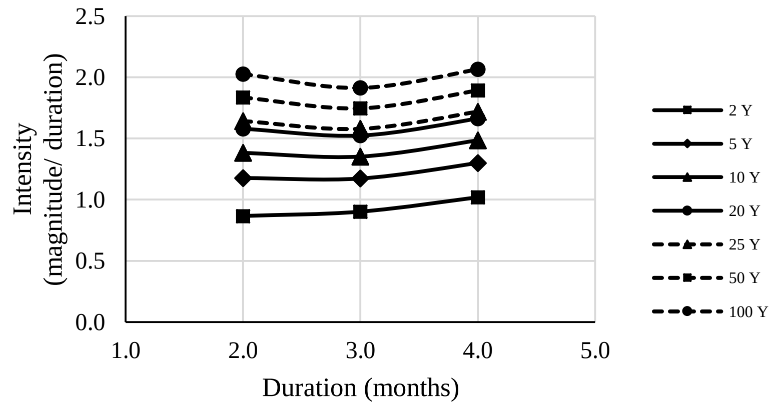

Figure H- 8 IDF curves at Gazimagusa station

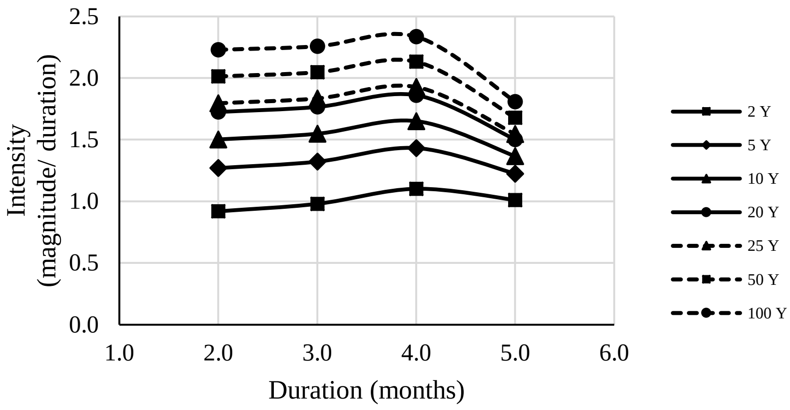

Figure H- 9 IDF curves at Salamis station

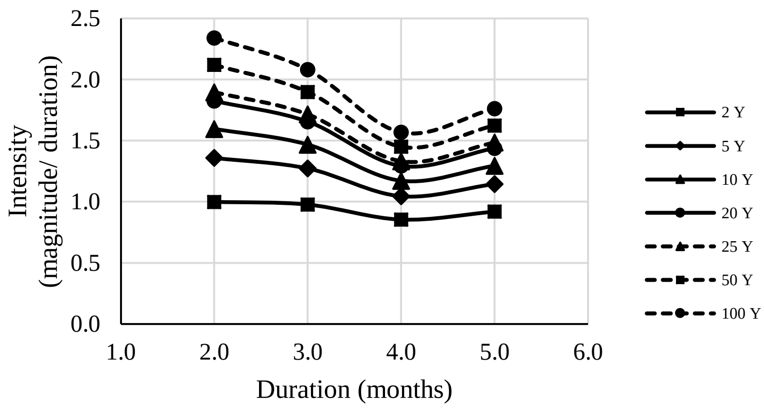

Figure H- 10 IDF curves at Dortyol station

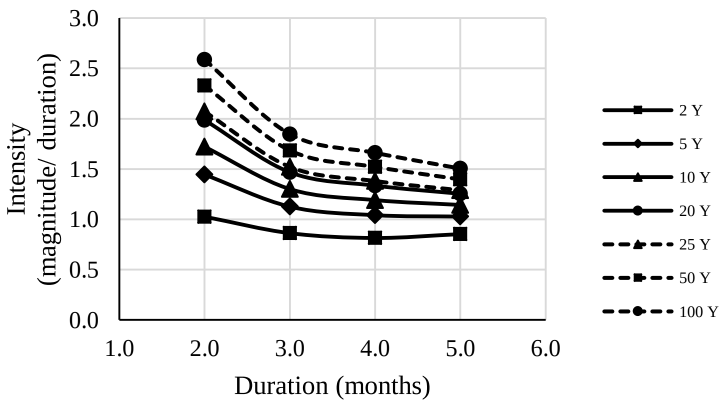

Figure H- 11 IDF curves at Gonendere station

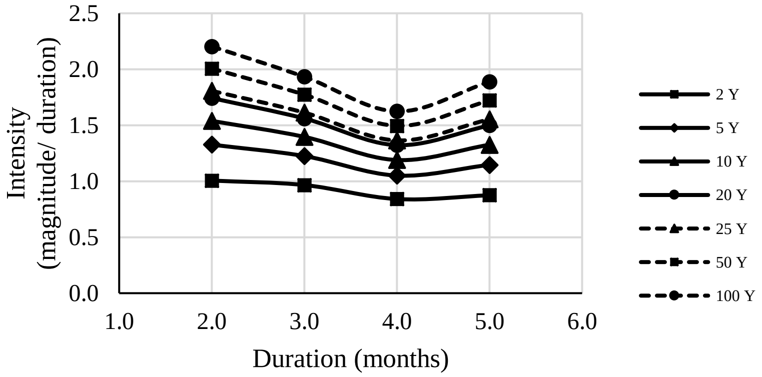

Figure H- 12 IDF curves at Iskele station

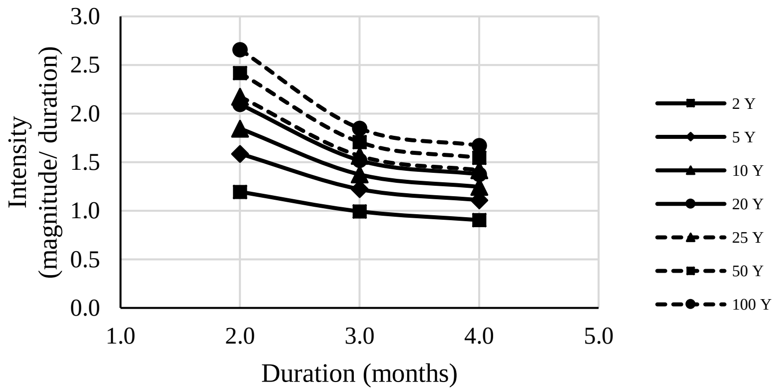

Figure H- 13 IDF curves at Ziyamet station

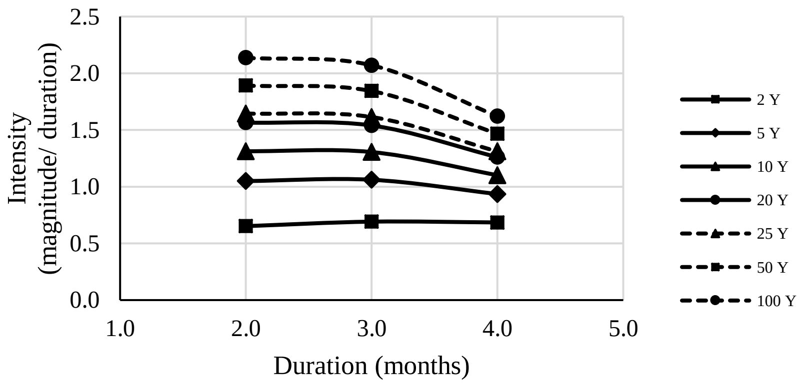

Figure H- 14 IDF curves at Dipkarpaz station

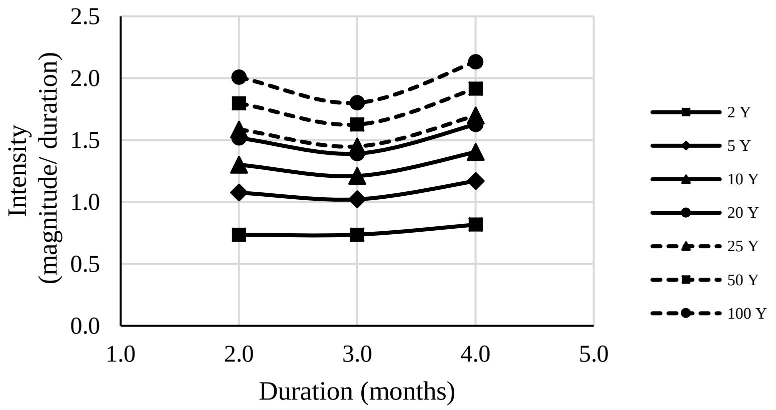

Figure H- 15 IDF curves at Yenierenkoy station

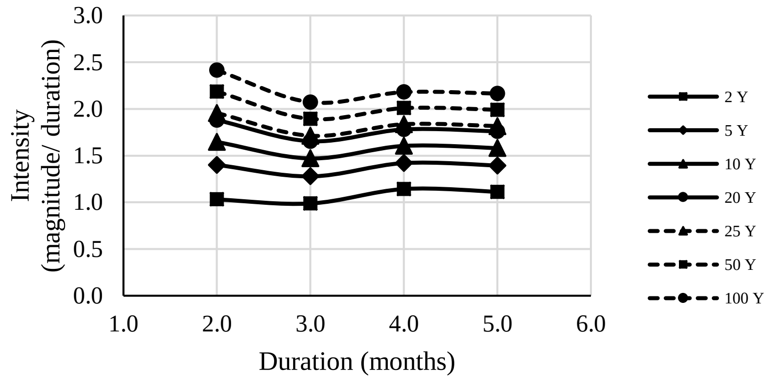

Figure H- 16 IDF curves at Tatlisu station

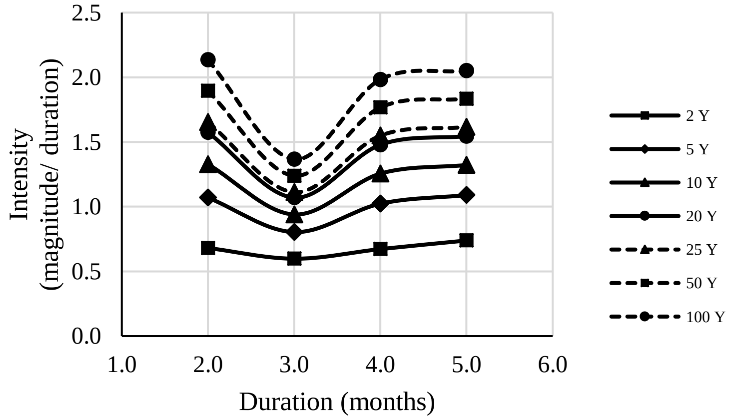

Figure H- 17 IDF curves at Kantara station

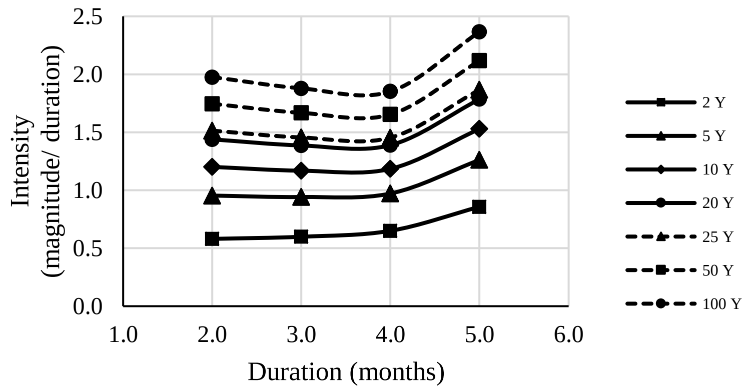

Figure H- 18 IDF curves at Camlibel station

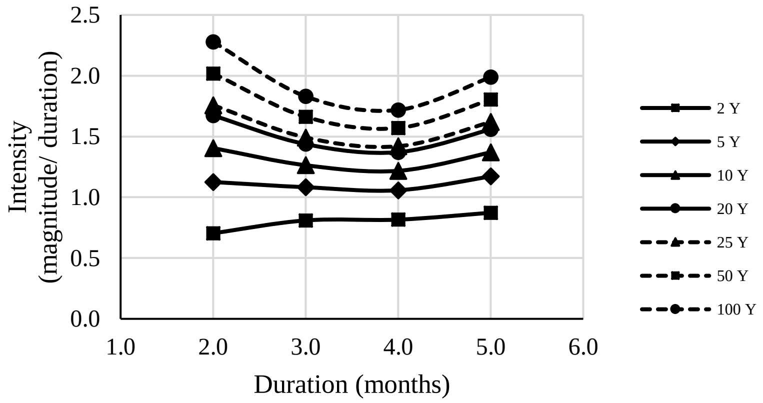

Figure H- 19 IDF curves at Guzelyurt station

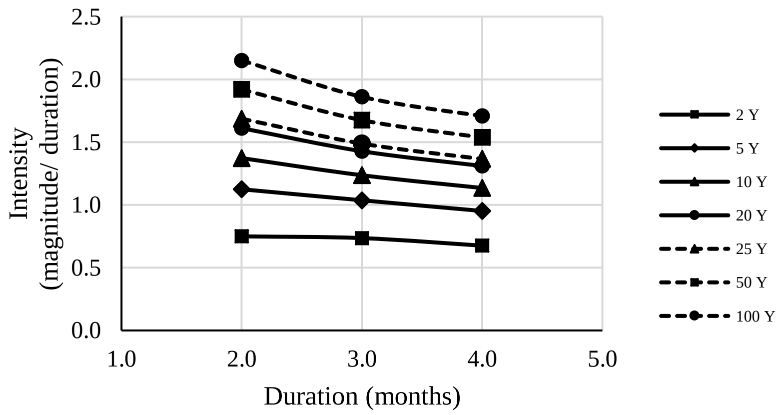

Figure H- 20 IDF curves at Gaziveren station

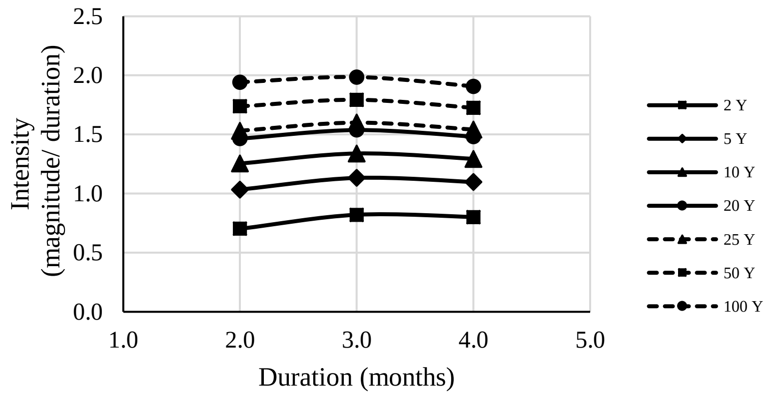

Figure H- 21 IDF curves at Lefke station

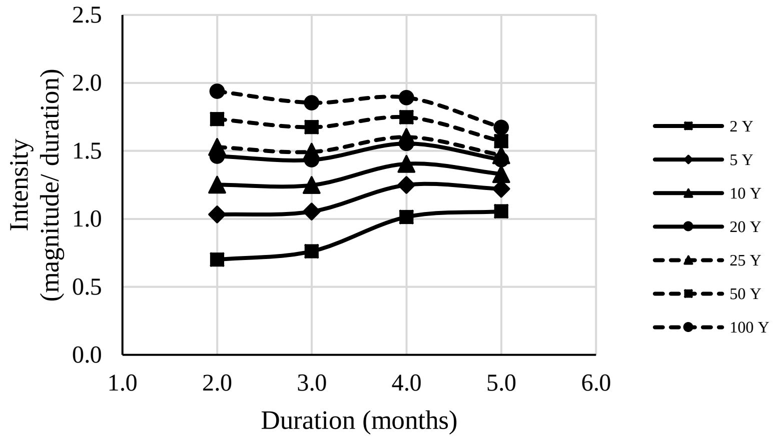

Figure H- 22 IDF curves at Zumrutkoy station

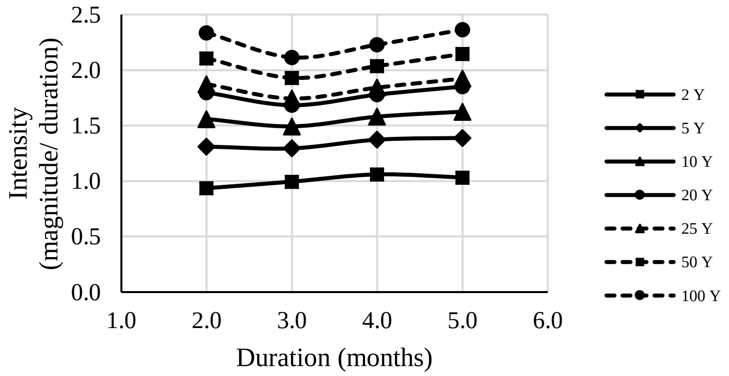

Figure H- 23 IDF curves at Ercan station

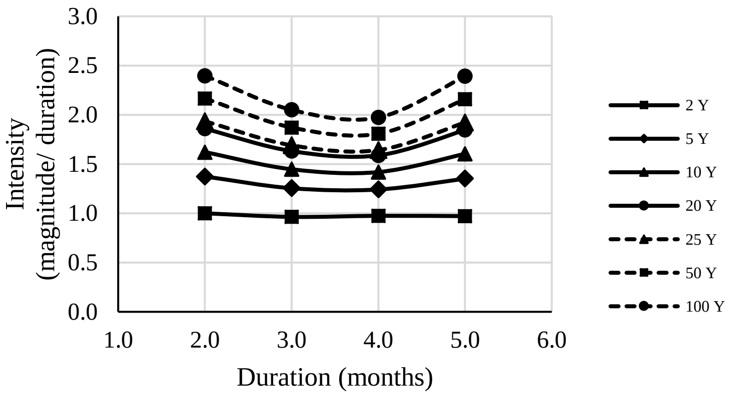

Figure H- 24 IDF curves at Serdarli station

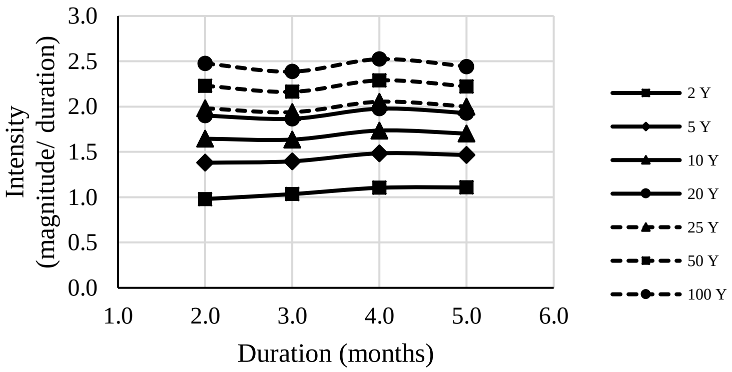

Figure H- 25 IDF curves at Degirmenlik station

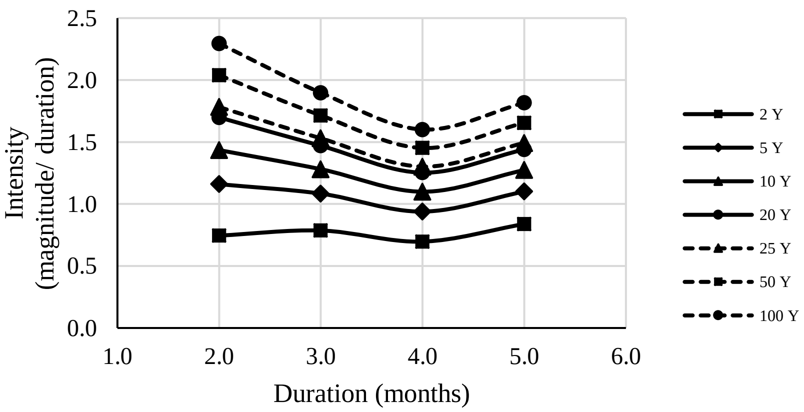

Figure H- 26 IDF curves at Alevkaya station

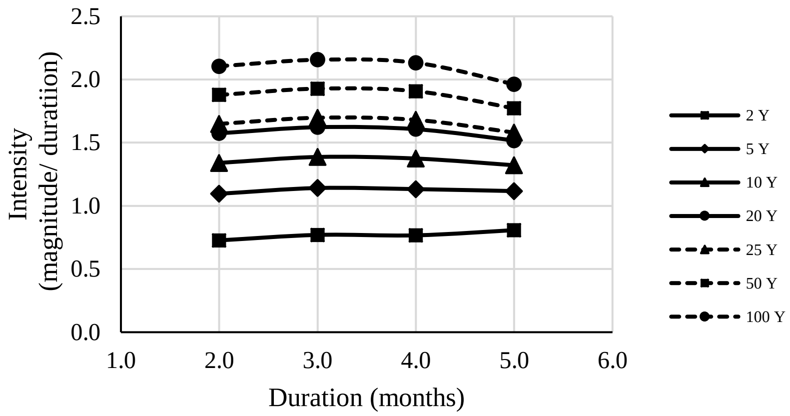

Figure H- 27 IDF curves at Alaykoy station

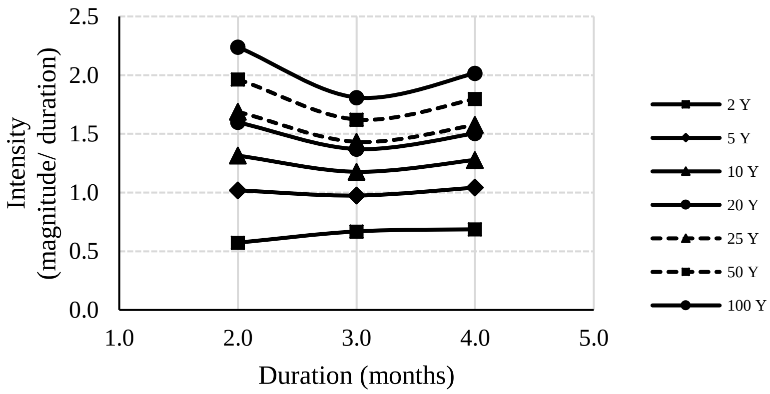

Figure H- 28 IDF curves at Lefkosa station

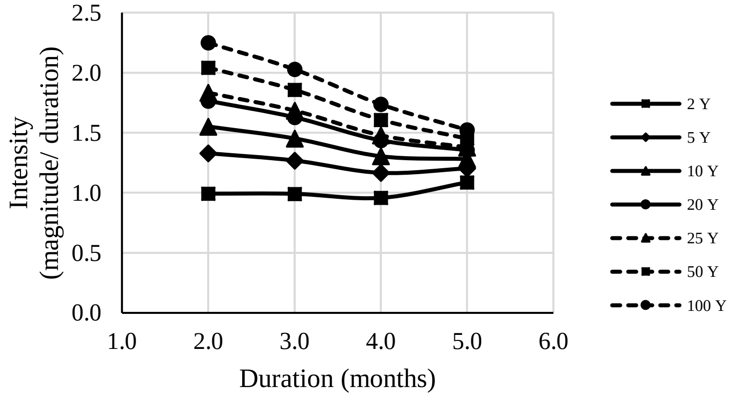

Figure H- 29 IDF curves at Margo station